accommodating space tourism and related activities

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Preface

The performed research that lies in front of you is done to build a case for the design of a tourist space station as a masters degree graduation project at the Faculty of Architecture of the Delft University of Technology.
A graduation project that took almost two years of time, on a proposed duration of a single year. This reason for the extended time period lies in the nature of the project and the required knowledge of a lot of factors that are otherwise part of the standard body of knowledge of an architecture graduate student, but not in a project that evolves around architecture in outer space, a location that poses so many different problems to creating habitation than on Earth.

While we can see that living in space is possible and has been possible for 50 years already, there has always been a huge amount of attention to the technical feasibility, making things possible, in space tourism the focus should shift towards the experience of the inhabitants meaning larger interior volumes, larger windows, calm environments, all characteristics that are currently very limited in space exploration. Obviously this has to do with the aim of the current exploration, but with a new aim new principles should arise, and this is what this research has aimed for.
This research helped to find the human and design aspects of architecture that where lost by doing a project in space instead of in a project in the normal field of gravity, a project with little to no predecessors especially in the science-fact area of the space tourist exploration.

As there is little known about space exploration for tourists, the whole future of space exploration is quite uncertain in both scenario and requirements. Working with these requirements has been a tough challenge, though the research conclusions on the way architecture should cope with a known user and a new user in this specific environment can be used in any scenario for the future of space habitations. The results can be used by others as a starting point for designing and gives specific guides to spaces in relation to human being and in relation to each other.

During the process, the research and design have long been disconnected on a fundamental level, though the activities provided a basic program, the actual fitting of human beings in a spatial model and drawings has taken quite some time to evolve, finally when they came together both have made a giant leap into finishing both the research and the design.
As architecture is about form, dimensions, spaces and experiences, they require basic principles that go much further than a global program and activity schedule. A principle that only came about whilst working on both the design and research at the same time, in a fashion to combine them and make them communicate. Early design can be seen as spatial research that has further advanced the focussing of the research.

The project is finished under supervision of Robert Nottrot (main mentor), Suzanne Groenewold-Stengs (Building technology mentor) and John Heintz (Research mentor) with earlier support of Nimish Biloria and Huib Plomp, who I all have to thank for their guidance during the entire project.

- Koen Hoofd

Introduction
Fictional space habitation history

Space travel has eluded mankind ever since the first mentioning of travelling to space by Jonathan Swift in his book *Gulliver's travels* (1726), in which he describes a levitating habitat called Laputa. The flying world levitates by magnetic force and has a diameter of 6km. The most notable next step in fictional space exploration and space habitation is in the book *From Earth to the Moon* (1864) by Jules Verne. For the first time he actually wrote about the technical difficulties of space travel in relation to vacuum of space and the absence of gravity. He therefore settled on a lunar fly-by, shot from a canon of the Earth's surface, as this would most notably be the most feasible first step in space travel. Shortly after, in 1869, Edwad Everett Hale describes the first manned space station when he envisioned a 'brick-moon' which would be used as a naval beacon but as it was launched took people with it by accident.

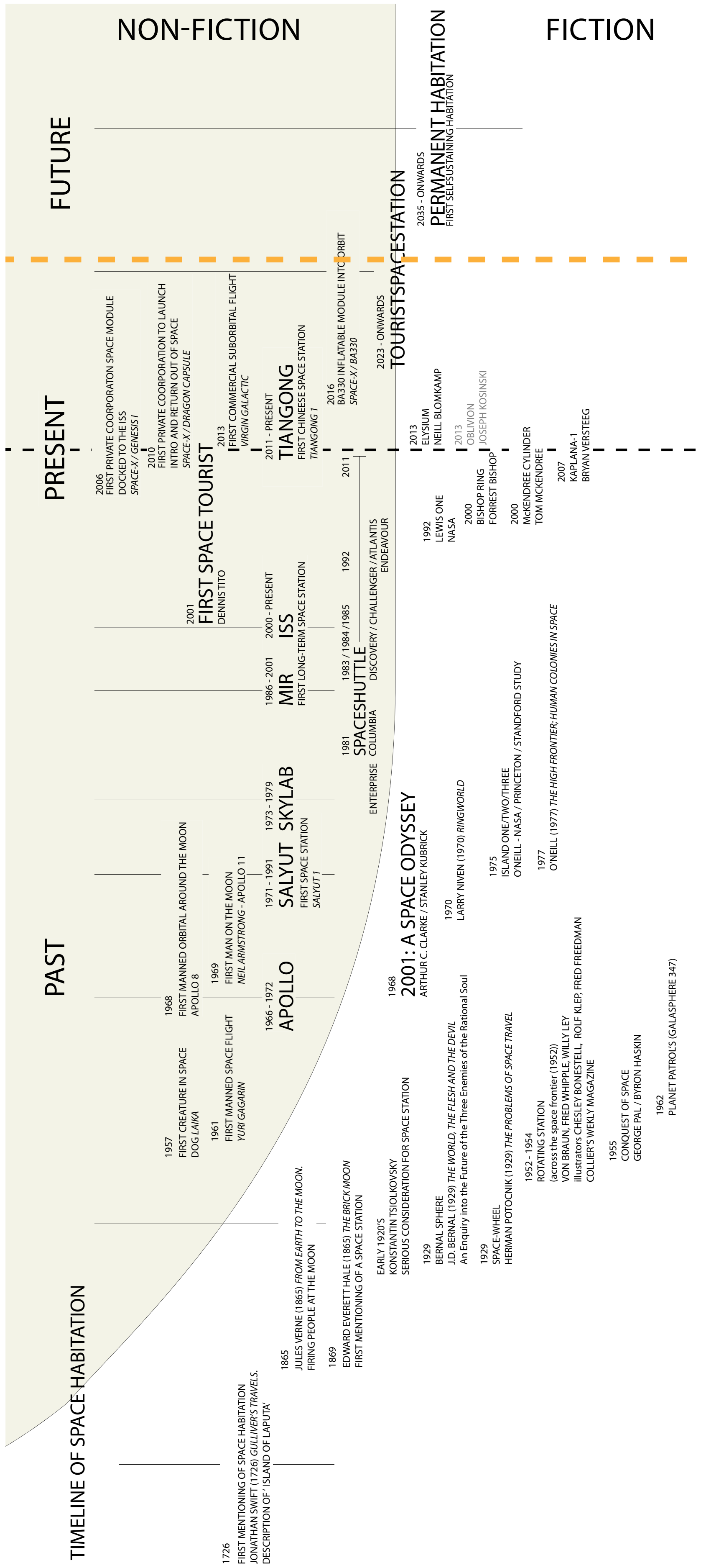
1900
One of the first to seriously consider space habitation was Konstantin Tsiolkovksy, a Russian rocket scientist, who is mostly known for his book *Beyond the Planet Earth* also known as *Outside the Earth* (1920). In his view man would first have to inhabit space just outside of the Earth before going to the moon and Mars. He already envisioned a space station using artificial gravity by a rotational force, a space habitat 30 meters in diameter which he theorised in 1903.
In the end of the 20's John Desmond Bernal writes about a habitable sphere in his version on 'the world, the flesh and the devil'. The sphere with a diameter of 16km and a population of 20 to 30 thousand further evolved human beings, looking down on the world and its humans as if it where a zoo. The sphere would be enclosed and filled with air to create a small internal bioclimate that is completely self sustaining.
In the same year (1929) Herman Potočnik (Noordung) published a design for a 'rotating torus', 'space wheel' or the 'inhabitable wheel', for the first time when he published *The Problem of Space Travel*. The first book that mainly focussed on living in space and space habitations. Potočnik already writes about a lot of problems that are still being worked on today; docking, human body changes due to microgravity and powering a station in space. Alongside Potočnik, Hermann Julius Oberth was investigating the possibilities of space flight on level of rocket propulsion but also investigating the possibilities and dangers of space flight and habitation. Especially in his 1929 published book 'Path to space travel'. A student of Oberth, Willy Ley and Wernher von Braun continued the development of space exploration, mainly through development of rocket engines but also through their research on space habitation. Especially by their publications in Collier's Weekly magazine under the name of "Man will conquer space soon!" (1954) which featured further developments of the space wheel proposed by Potočnik.
A year later the toroidal space habitat made its first film appearance in the movie *Conquest of space,* followed by the TV-series Planet Patrol's in 1962. But most importantly would be starring in the film *2001: A Space Odyssey* (1968), which started the dream for the common man to go into space, and brought a fictive insight in the possibilities of off-world and microgravity living. The 2001 space wheel is almost entirely based on the design by von Braun and Willy.
In the 1970's novel *Ringworld* Larry Niven writes about a much more fictional space habitat encircling a star. The ring has roughly the circumference of the distance of the Earth to the Sun l Astronomical Unit (AU). Princeton physicist Gerard K. O'Neill continues the development of artificial gravity on space habitations with ring shapes in studies made in combination with NASA, Princeton and Stanford in 1975. These studies are referred to as 'Island-One', 'Island-Two' and 'Island-Three', or the 'Stanford-Torus'. Two years later O'Neill finishes his book *The High Frontier; Human Colonies in Space* in which the three types of Islands feature as (1) modified Bernal-Sphere,

(2) Stanford-Torus and (3) two O'Neill Cylinders.
In the early 90's NASA Ames Research Center redesigned the O'Neill cylinder to house 3000 inhabitants, the cylinder, called the Lewis One, with a diameter of 500 m and a length of 325 m would be just enough to overcome problems that occur with pseudo gravity. Smaller cylinders are researched and found to be disorienting as they spin with roughly 3 rpm.
In recent years, with new material developments the radius of possible ring worlds have expanded within the possible range, especially featuring the Bishop-ring. An enlarged O'Neill ring worlds built of Bucky-fibres (carbon nano tubes) to expand the size to a 2000 km diameter. The inner part of this theoretical ring is composed of 200 km of Atmosphere and 1600 km of space before reaching the other side of the ring's atmosphere. All atmosphere is kept in place by the pseudo gravity generated by the rings rotation.
Another design that uses nano-tubes is known as the McKendree Cylinder, the design based on the Island Three model of O'Neill has roughly 20x the length and radius of it's predecessor.

2000
Even now the ideas of spinning space habitats is being seen as the most productive way of settling in space. As referring to the Kaplana-1 (2007) by Bryan Versteeg, based heavily on the Lewis One NASA concept of the early nineties.
The space wheel has made it's into modern science-fiction with an appearance in the recently (2013) produced film Elysium, where the space wheel is habited by the rich and planet Earth by the poor. The off-Earth world is a modern reiteration of the space wheel design by O'Neill and his team in their Island-Two rendition.

DISCUSSION
There seems to be a science-fiction that keeps being fiction without truly being outdated, already for 80 years not much has changed on the design of rotating space wheels, it seems that the first estimates were very optimistic about the year and time of the realisation of such a space habitation. Furthermore, the modern reiterations seem very outdated in perspective to the longevity of the ideas, almost archaic. Should space habitat design be focussed on recreating Earth in microgravity, or should life be adapted to microgravity and weightlessness? The research is focussed on mixing the ideas of science-fiction and reality of space exploration into an exploration of activities and architecture for space tourism in the near future.

SETUP OF THE RESEARCH
First the historical state of government and private based space exploration is reviewed followed by a review of analysis for the future of space tourism. The main analysis of the research focusses on the activities performed by current day astronauts as well as future space tourists with a special look at space sports for further developments in space utilisation and exploration. These activities and the difference from astronaut and tourist requirements form a base for the analysis of the main aspects in space station design based on the human activities, psychology, sociology and experience related to the environment that is an orbital station.



50 years of space exploration

Historical perspective on manned space exploration

During the first 50 years of space exploration there have only been a small amount of changes in rockets that in their turn have changed the possibilities of space habitation. In general there have been three different space launch families that are of most importance to space exploration; the current Soyuz and its ancestors (R-7 booster), the American Saturn rockets and the American variety of Space Shuttles. In general, rocket propulsion has been and still is the main vessel to put our habitations, humans and satellites into space.

R-7 BOOSTER ROCKET (1960 - CURRENT DAY)

The Russian space rockets can be classified within a single branch of rocket technology, with the use of the R-7 booster rockets all of their humanized space exploration missions were launched into space. A rocket initially designed during the cold war to fire heavy bombs and that was later redesigned for the Russian space exploration missions. From the earliest human space flight by Yuri Gagarin on the Vostok-1 rocket and his safe return to Earth, to the current day Soyuz-FG and Soyuz-2, the only active human transport vessel into space and the ISS, they all use a version of the Soyuz booster rocket assembly.

In 1971 a variation of the Soyuz assembly was used to put the first space habitation in orbit by the name of Salyut-1. The rocket in this instance was named Proton-K. The space habitat that continued to exist until 1991 as it grew with the addition of two more modules during its early life time. This was the first time Russian modules docked in space, which did not work in some cases resulting in mission failures. The first successful docking and transferring of astronauts between two modules have been the Soyuz 4 and 5 modules in 1969. The space habitation is the first to accommodate a series of three docked modules in 1978 when the Soyuz 26 and 27 docked to the Salyut 6 station in orbit. Though the space program was titled as a civilian space exploration programme, the Salyut missions mixed with the classified Almaz missions which were military based.

Other assemblies or configurations with the R-7 rocket have been named Sputnik, Vostok, Voskhod, Luna, Manolya, Semyorka, Polyot, Molniya.

EARLY AMERICAN ROCKETS (1960 - 1966)

The earlier American rockets, which are not directly related to putting space habitations into space are however very important to the developments in space explorations future. Especially the 1965 Gemini missions which were powered by the Titan rockets paved the way for space docking, which they successfully achieved in 1966 in the Gemini 8 mission to dock with the Agena target vehicle.

SATURN (1967 - 1981)

The most impressive feat of human space exploration to date is still the 1969 landing on the moon by Buzz Aldrin and Neil Armstrong, which finally succeeded for the first time in the Apollo 11 mission, and later with other astronauts on the Apollo 12, 14, 15, 16 and 17 missions between 1969 and 1972. To escape the gravitational pull and put the weight of the command module and lunar module into space the rocket required had to be immense: the Saturn V. The Saturn V rocket is almost double the length of the previous rockets built by the Americans with a massive length of over 110 meters and a diameter of over 10 meters. Even to this date it is the largest and most powerful rocket that has ever been built by a long stretch, with a possible payload mass to be put into a low Earth orbit [LEO] of 118.000 Kg.

The Saturn V has also been used to put the Skylab space research habitation into orbit in 1973, the last time it has been used. The space habitation had a single interior volume with a diameter never to be built as large in a single volume afterwards. With the internal diameter of 6 meters and a habitable volume of 360 cubic meters. The volume was both relatively impractical for hardcore research and perfect for the experimentation and experience of the habiting astronauts as a free range of motion without physical limitations this space provides offers loads of possibilities. Skylab was taken out of orbit in 1979, only 6 years after launch.

SPACE TRANSPORTATION SYSTEM - SPACE SHUTTLE (1981 - 2011)
The second family of space rocket ships in the history of the American space exploration are the Space Transportation System rocketships, or STS in short. In a mission to reduce costs of space launch the American Space Shuttle provided a solution as part of the launch and space vehicle became reusable. The central module or the actual shuttle is propelled into space by several booster rockets which are expendable, the central module can return to Earth by the use of it's wings and land like a plane.
The different versions of the space shuttles have all had different product names: Enterprise, Columbia, Discovery, Atlantis and Endeavor. Of which Enterprise was the prototype, and Columbia the first officially in use version of the STS.
Earlier shuttle missions were based on experimentation on board its own vessel, and space modules that it brought with it into space in its payload bay. Especially the Spacelab missions. The Hubble telescope has been put into orbit in 1990 on the Discovery Shuttle. The Space shuttles have also brought several crews to the Russian space station Mir during the second half of its existence. The first docking mission to take place in 1995, just a year before the final completion of the space station. The shuttle missions have an impressive records of flights, and have helped in large amounts to construct the International Space Station since 2000.

MIR (1986 - 2001)
During the last years of the Cold War the Russian Mir space habitation start to take shape by flying modular elements into space. As the Berlin war fell and the rivalry between Russia and the United States started to diminish, they actually started to cooperate in the exploration of space. Though it took from 1989 to 1995 for NASA to finally set foot on the Mir space station just before the final module was installed.
A new Space docking system was used to dock the NASA space shuttle to the Mir as the primary versions had a male/female connector which could visualize a domination of one country over the other, the new system called APAS, short for Androgynous Peripheral Attach System, has equal elements connecting to each other, also making it possible to dock any two modules together.
The Mir has been the first large scale modular space station, it in fact offered a pressurized volume of 350 cubic meters in its largest configuration just about the same size as the Skylab space habitat.

INTERNATIONAL SPACE STATION (2001 - 2024/2028)
The final stage of government funded space exploration has been in development since the time Mir was due to be taken out of orbit, the joint venture of 16 countries; the United States (NASA) as front runner, Japan, Brazil, Canada, Russia and the European countries of United Kingdom, The Netherlands, Italy, Belgium, France, Denmark, Switzerland, Sweden, Spain, Germany and Norway, as part of the ESA.
Over time the space station has grown due to its modular technology and has evolved to be the largest pressurized space habitat ever to be constructed. Due to its size and place in history it is also the most complete spacecraft that builds on research and experiences of earlier space exploration missions. Making it besides research driven also pleasant to live in for longer periods of time compared to the earlier space habitations. This is also the reason the first space tourists have ever come into a space habitat as there was ample room and life support to make it a human experience. Up to this day, there have been 10 wealthy civilians traveling up to the ISS for between 20 million and 40 million USD a single round trip, with a trip duration between 8 and 15 days.

LONG MARCH 2F / CHANGZHENG 2F (1999 - CURRENT DAY)
The first Chinese rocket to sent humans into space into their Tiangong-1 space habitation module, the Shenzou rendez-vouz modules have underwent several experimental space trips and have successfully docked to the Tiangong-1 on the 10th trip. (Shenzou 10)

Tiangong (2011 - future)
As China is becoming a more important player in the world economy, and with a population of 1 billion people the time has come to venture into space and its industries. Since 2011 their first habitable space module Tiangong 1 is live and has been inhabited for shorter periods of time. As China is not part of the countries participating in the International Space Station they are building their own future, and not only in the exploration and colonizing in Low Earth Orbit their sights are also set on colonizing the moon. If this is successful other heavenly bodies might follow.

SPACE LAUNCH SYSTEM (2017)
To replace the STS space shuttle program and for the Americans to gain entry to the skies by their own means, the Space Launch System or SLS in short is expected to exist of several configurations of different rockets and modules creating a very flexible platform to launch both people and objects into space. The basic configuration that will be initially be used is able to lift 70 metric tonnes into space, the maximum power configuration will be able to lift 130 metric tonnes into LEO; 10% more then the immense Saturn V rocket.
The system will be used for space exploration beyond LEO, but could be able to supply the ISS if finished before the ISS is taken out of orbit. The plans for the SLS will be more in the direction of travelling to Mars or near-Earth asteroids as NASA plans to investigate these with a possibility to mine them.

India, Iran.
In recent years smaller countries have started their own research for space exploration with mostly unmanned and few manned missions to space. Though the first steps are still to be made they can build on experience of other countries making the catching up for the 50 years they have not participated, as in the case of India. Their aim is to perform a successful manned space exploration mission in the near future.

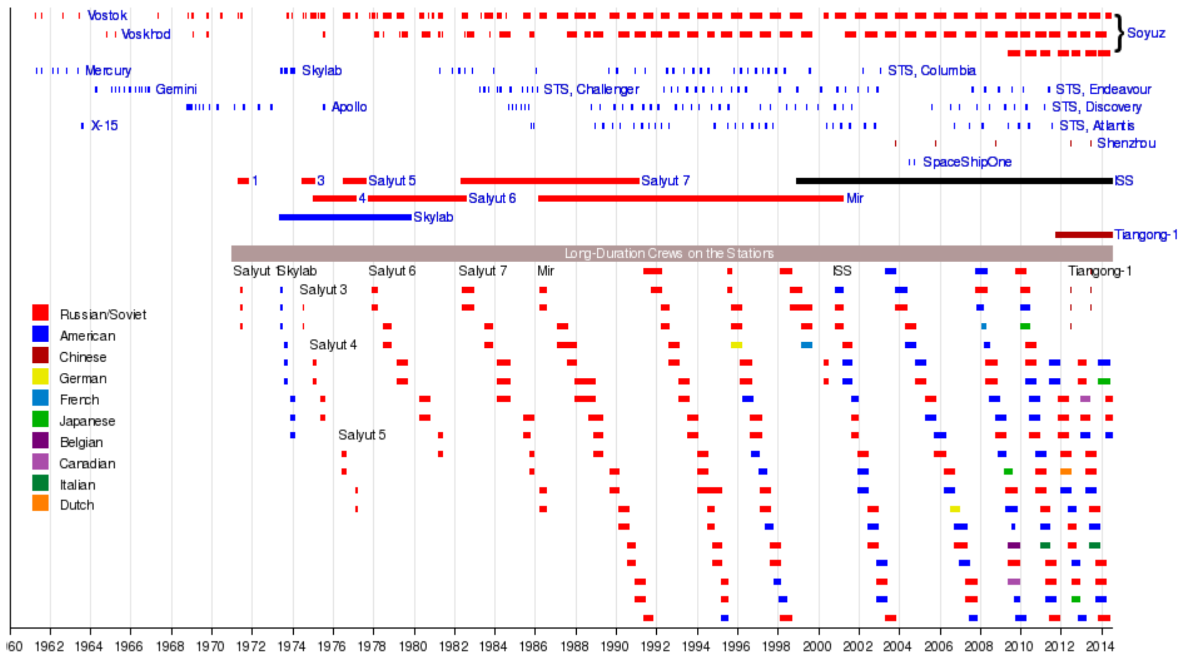
PRIVATE SPACE EXPLORATION
Virgin Galactic
The first step of corporate space tourism adventures should start the end of this year (2014) with the first public flights of the SpaceShipTwo of Virgin Galactic, the second iteration of the suborbital spacecraft (after their SpaceShipOne) by the company of Richard Branson. A spaceship that will bring a group of tourists up to a height of 100km above the Earth at which they will be able to experience the Earth from space and be weightless for 5 minutes before having to strap themselves back in their seats for the return to the planet. Already 200.000 people have shown interesting in the short suborbital trip that will cost around 100.000 per person, showing great perspectives for the future of the company.

Bigelow
In a future space tourism market Bigelow is the largest corporation that focusses on the habitats the tourists will be venturing to. In this time the company, owned by Robert Bigelow, is the first private venture to dock a module to a governmentally funded space craft, in this case the International Space Station, their genesis module is an inflatable module that will not be inhabitable and will be purely used for tests on the effectiveness of their inflatable skin construction, and is used as a first time docking test to a satellite body.
As their future scenario envisions large amounts of tourists going into space, their research and development of larger single volume modules is advancing with a steady pace, first with their BA330 modules (330 m3) also known as Nautilus and their current development of their main space

module for the future; the BA2100 (2100 m3) also known as Olympus. A group of three BA2100 modules could house a group of up to 50 tourists/astronauts, which could be considered a space hotel.

SpaceX

The private corporation of Elon Musk has a most realistic approach into large scale space exploration; after the retirement of the US space shuttle program the only space crafts capable of bringing people up to the ISS (in low earth orbit) are the Russian Soyuz rockets, SpaceX focusses on being able to put humans into space with a cheaper alternative, as a single Soyuz seat costs 71 million dollars. Their Falcon9 rockets have already made successful flights to the International Space Station, successfully docking their Dragon module to the station, a first for a private space corporation. But SpaceX's future relies on the developments of their Reusable Launch Vehicles or RLV, which could cut launch costs from a single orbit and return trip to the amount of fuel used, the relative small amount of 200.000 USD for a two way trip.
Future developments planned for SpaceX also include the development of their Falcon Heavy space rocket and future possibilities for Falcon X, Falcon X Heavy and Falcon XX, which would be able to carry larger and heavier modules into orbit speeding up the space settling process for larger groups of people. The Falcon XX would have the same ability as the 1966 Saturn V rockets to put over 120.000 Kg's into a low Earth orbit in a single flight.



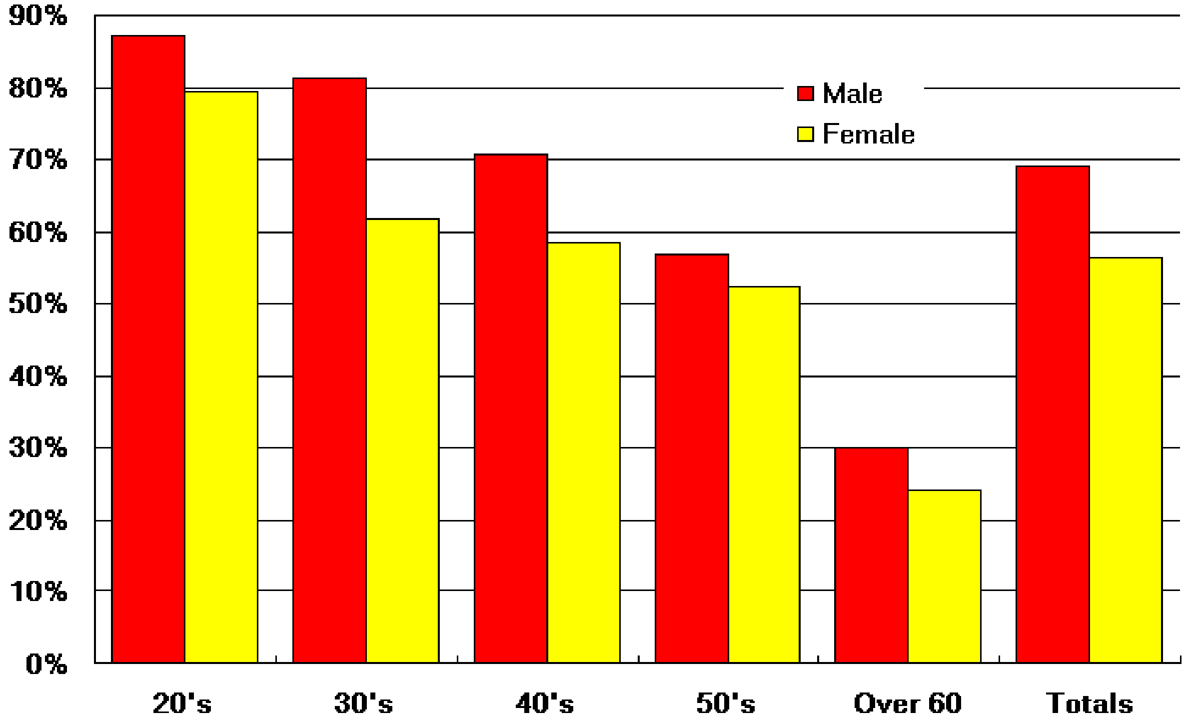
History of human space exploration missions. (http://en.wikipedia.org/wiki/Human_spaceflight)

The future of space exploration and the market for space tourism

As space exploration changes from a government funded act to the world of private investments new ways of funding are required. As we see space exploration companies that aim for tourism are growing worldwide by the specific companies of Virgin Galactic, SpaceX and Bigelow aerospace, the space tourism future looks brighter than ever before. With Virgin aiming to launch their first public sub-orbital flight at the end of 2014, SpaceX performing cargo flights to the Station and are progressing with huge leaps in the development of reusable launch vehicles (RLV's) and Bigelow Aerospace with their inflatable Genesis module docked to the ISS.
The investment models of these corporations are based on initial payments from the countries using their services as they retire their own transportation systems like the US Space Shuttle. As there is no solid future for government funded space exploration after the ISS will be taken out of orbit either in 2020 or 2024, space corporations have to turn to the masses and the open market: space tourism on a large scale.

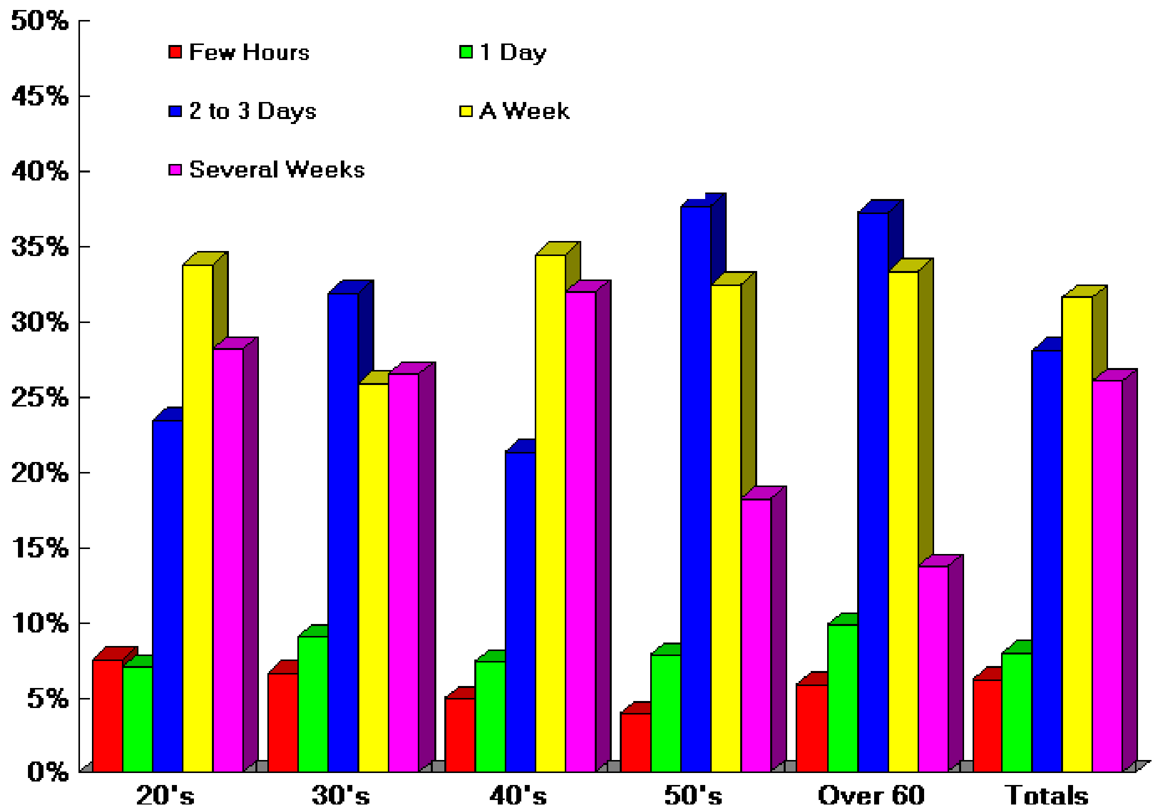
It is known that a large amount of the population would like to visit space, be weightless and look at the stars and the Earth in a new perspective. There are only a few civilians that have ever taken a seat on the Soyuz rockets to the International Space Station (through mediation of Space Adventures company) for around 30 to 52 million a seat. But how many of us would actually pay the price required for a single trip into space and back to Earth?
The first figure (right page) shows a strong correlation between age of respondents and their interest in travelling to space, interestingly there is a difference between the men and women in every age group. Which seems to be typical for the American population as earlier research amongst Japanese people resulted in no significant difference between the male and female respondents. (Collins et al., 1994)
As well as a correlation between age and interest there is also a correlation between age and duration of the space flight. As all of the respondents seemed to prefer a space flight between several days and several weeks, the older people seemed to be more interested in the lower range; several days up to a week. Especially for the over 60 years of age category there is a significant decrease which should with likeliness be accounted for by the degeneration of physical health and a question if they could take the physical stresses of flying into space.

Earlier studies showed a correlation between the age of people and their willingness to pay a certain amount related to their monthly income. Interestingly their research choice options ranged from a single month up to three years, which a small percentage (2,7%) of respondents would offer for the trip. (Stockmans et al., 1995, p. 6) Of course this number has to be related to the amount of people who actually earn enough, or have enough financial means, to pay for a two way trip, which again limits the pool size of people willing and able to go into space.
Eilingsfeld et al. (2002) have made a more detailed estimate of the amount of people and the willingness to go to space for the reasonable price of 100.000 USD for a single trip. It turned out there are 40.000 people on planet Earth physically fit, in the right age, and thus willing to take the space adventure for this price. This price is already quite low compared to the present prices for a trip up to the ISS on board the Soyuz rockets, thus there seems to be a discrepancy between the willingness to pay for a longer journey, which is wished for, and the amount one has to pay for this long stay in space. Shorter trips offered by Virgin Galactic will cost somewhere in the range of the 100.000 USD, but can only provide 5 minutes of actually being in space, and not the several days up to several weeks that have the preference of the test group.



Percentage of (North American) respondents interested in traveling to space. (Stockmans, et al. (1995) pp. 4)

Preferred length of space trip (by North Americans). (Stockmans, et al. (1995). pp 5)



SCENARIO'S

There are several general scenario's for global relations and their developments, each of these scenario outcomes has a result heavily influencing the future of space exploration, both governmental and corporate. The OECD (2004) has thought of three different scenario's for the year 2030; starting with scenario 1 they envision a world that has developed at its best, cooperation between countries are enhanced, trade becomes free is more countries over the planet and economically speaking we thrive. The second scenario is less positive and in general terms neutral to the current world 'state', scenario 3 is a negative scenario to world developments.

Their scenarios are clear but the result for space adventure or space tourism is very vague. They conclude that the space tourism industry will be influenced by all three scenario's and that the space tourism will probably be limited to suborbital and orbital space travel until 2030. A result that is generally accepted as suborbital flights, as provided by Virgin Galactic, are planned to start this year [2014], and orbital tourism has started and seems to have a promising future with multi-billion dollar companies investments. The actual amount of people being able to travel into orbit will almost completely be based on the costs of the trip, the development of the Reusable Launch Vehicle will influence the cost of a single flight drastically.

General microgravity activities and requirements

When designing for space research and tourism the architecture has to be adapted to the specified user, in the case of tourism there are the crew and the tourists and in research there is only crew with their specific needs. There are activities where both user groups have specific requirements, needs and expectations for their habitation, activities that require different performance from the same activity and activities that are unique to each group. Though there are also activities that have overlapping requirements in a lot of their performed activities.

DOCKING AND ARRIVAL
The last part of the travelling up starts when the space station comes into sight, tourists will see the station with their own eyes for the first time. This means all people on board the flight will be getting ready for docking and passing over to the space station from the transport vessel.
Upon arrival at the space station the travellers will have to stay on board the transport vessel for around two more hours as docking and final checks are performed. During this period the newly arriving tourists can already start adapting to weightlessness in the rockets 'transport' bay. After all checks are done and it is safe to enter the space station, the hatch opens and all are invited to pass from the rocket into the space station.

Specifications

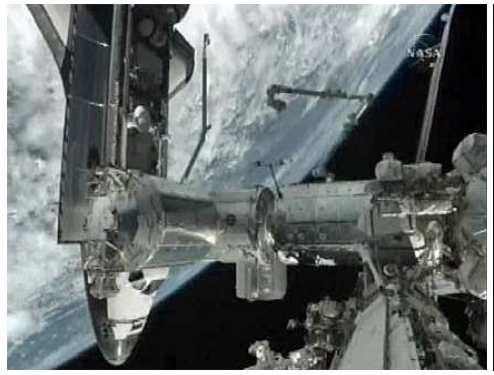
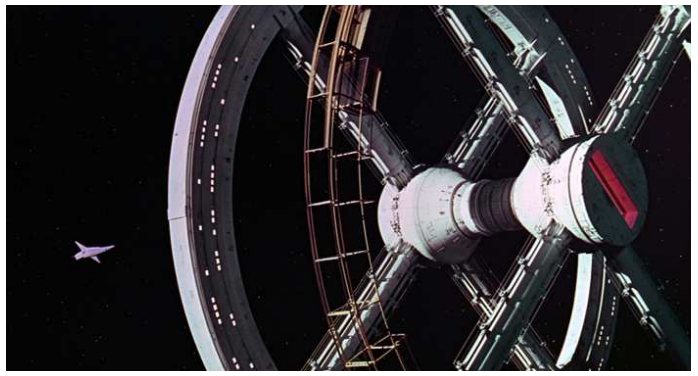
People:	3 man crew, 12 tourists
Time:	2:00h
Entering:	1 person at a time

Science fiction
In the movie *2001: A Space Odyssey* the arriving space craft enters the central element of the spinning space station. The space craft enters the space habitation like a car entering a garage; into the safety of the greater structure protected from exterior hazards. In space these hazards are very large due to the lack of protection from the magnetic field and the atmosphere against meteorites and radiation we have on the Earth's surface. Even though a space craft needs its own protective skin during the journey the feeling of safety inside of the larger station is bigger than in the smaller space craft. This same principle is used on most science fiction movies that involve large scale space colonies like the *Star Wars* movie series and the more recent movie *Oblivion* (2013).

Realised predecessors
In reality the space stations are not large enough to bring in a full space ferry and have to resort to a connection that is outside of the main volume. Other than the limited size difference the technical aspect of connection two space crafts in flight is an enormous task, the first successful space docking attempts where not even designed to move people from one volume to the other. Even today things can go wrong during docking, therefore the docking portals are positioned as far out of hazards way as possible, the extended area's of the station.

Characteristics
Docking itself is an important aspect to the experience of the space station; it is the priming of the individual for what he is about to experience next. It is the first experience the tourists have on interaction with the space station. The approach is also very important, the windows giving view to the approaching habitation for the coming weeks.
The tourists should feel safe during this important stage of the travel and stay even though much could go wrong, the first encounter with the station should be free of stresses not to feel frightened for the rest of their stay feeling something might go horribly wrong.

Requirements
After the initial mating between the space ferry and the habitation have been completed and all checks have been done the hatch door separating the two can be opened. The tourists will then be entering the docking area inside of the space habitation. The docking area is the safety buffer inside of the station might anything go wrong during pressure equalisation.
The high level of technicality put a lot of safety requirements on the docking principle, this is the main reason docking happens on the outside of the space station. Though from an experiential perspective it would be ideal to be able to enter the space habitation with the space transfer in whole.



Docking of the space shuttle Atlantis to the ISS (left) and arrival at the space station in the movie 2001: a space odyssey (right). (http://www.cnet.com/news/shuttle-atlantis-space-station-visible-this-week/)

INSTRUCTIONS
Most of the activities performed by the tourists require explanation from the astronauts as it will be either the first time they will be doing a similar action or the first time they are doing it in an apparent zero-gravity environment. Especially for the group activities these instructions need to meet specific space requirements to ensure every tourist can follow what is explained, visually, acoustically and socially.

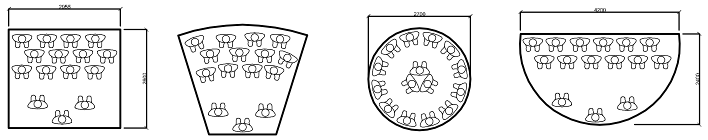
Specifications

People:	3 man crew, 12 tourists
Size:	15 x 2 m^3 = 30 m^3

Requirements
An instruction to all twelve tourists at a single time requires them to face the crew and be informed effectively, therefore an opposition between the two groups of participants is needed. To understand another person the bodies and especially faces should have the same orientation as this personal relationship is best understood this way. Tourists could be easily distracted by the need to control their body positioning all the time, as a counter measure positioning aids are required to keep steady without having to constantly think of the body position.

The instructional area should be in proximity of the location of the activity the instruction is aimed for, as there are possibilities to point at certain aspects of the following activities to explain anything of importance. As an analogy we can look at the experience of diving where a plan of actions is proposed on the side of the water from a higher vantage point getting a clear idea of the proposed activity or route for that time.

To not obstruct vision when forming several lines of trainees by arms and hands touching the ceiling to control positioning, the feet should be fastened to the floor as not to obstruct vision of the people in the rows beyond the first line. In relation to visibility the final row has no viewing line restrictions related to their body positioning because there are no visions to obstruct beyond them.



SPACE WALK

Astronauts

When work needs to be done outside of the pressurized compartment (the safe interior or the space station) astronauts have to exit the station and face the hazards of outer space; micro meteorites, decompression and direct radiation from the sun. These activities are called extra vehicular activities, or EVA's in short, and need to be performed in case of damage on the stations exterior or installation of new external equipment. This is the only time on the International Space Station the astronauts actually wear their space suits, the piece of equipment that keeps them protected and nurtured throughout their EVA. The activity puts the astronauts as far from safety and a home-like feeling as possible. But with this danger also comes the most extreme experience of being in space, connected by a single line to the space station, staring straight into the void of space.
Space walks are usually done tethered, never losing contact with the spacecraft, the outer shell of the spacecraft offers enough grips to hold on to and attach the secured lines. There are two alternatives to this method, using the Astronaut Propulsion Unit [APU] and the use of a robotic arm [Canadam] (ISS).

Tourists

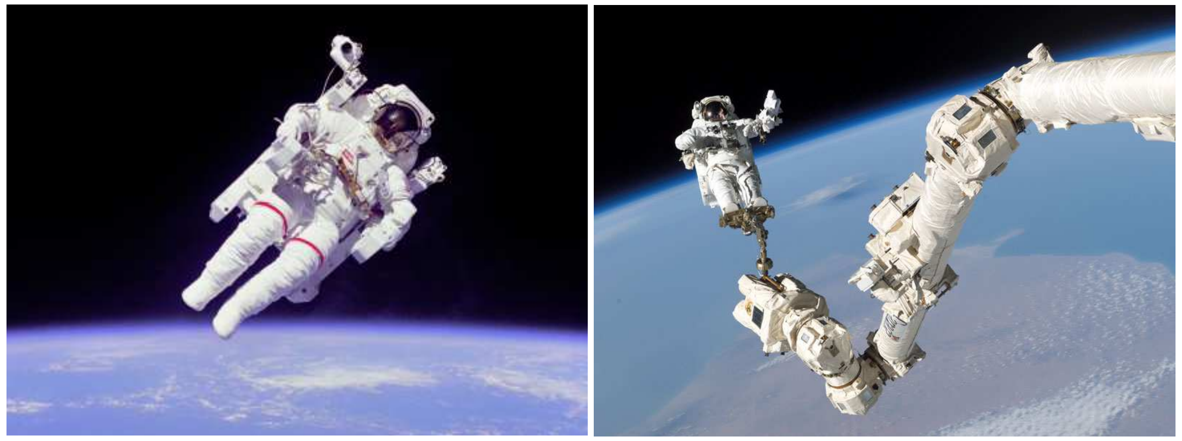
For tourists to enjoy the complete feeling of freedom in combination with excitement also coming from a risk factor, space walks are the pinnacle of space experience. Space walks don't come without risks and are only performed in high levels of need. This has to do with the extreme consequences in case of a failure, but also the preparation required to perform a spacewalk, the regular preparations for a space walk take few hours in pre-breathing, putting on the space suit, getting used to the lower pressure of the suit, and the actual space walk which all combined takes half a day up to a full day of preparation, actual EVA, and the readjustments to interior conditions afterwards. Even with new preparation techniques like the ISLE protocol (In Suit Light Exercise) adaptation to the lower pressure of the spacesuit and the high level of oxygen in the air, the duration of preparations have been drastically reduced from a full day to several hours. Space walks still take a lot of time in preparation and aftermath.
What makes the space walk such a unique experience is that it is the single most real feeling of freedom, distancing yourself from all that you know. At one side there is the planet Earth, which can be viewed unobstructed in all its grandeur, and the other side the dark emptiness of space filled with the shining stars. Although this can be seen from the space station, it does not provide the same experience.

General

To allow maximum mobility and maximum protection from the lack of pressure in space, a space suit is pressurized at 29.6 kPa during a spacewalk, about one third of the pressure experienced by the crew inside the spacecraft. Astronauts also have to breathe in pure oxygen, because the amount of oxygen in air at such a low pressure isn't enough for the body to function properly.
If an astronaut simply donned a space suit in 15 minutes and promptly exited an airlock, he or she would go through decompression sickness, or "the bends", the same thing scuba divers experience if they're exposed to a rapid drop in external pressure by ascending too quickly. The bends is caused by nitrogen in the blood to turn into gas that form bubbles stopping the bloodstream and joint pain, dizziness, cramps, paralysis and even death can follow.

APU

The APU, short for Astronaut Propulsion Unit, has been used in the past to manoeuvre astronauts around the space habitat in case of repairs or installations of equipment on the exterior. The propulsion unit functions as a small space craft propelling the astronaut wearing it by the use of small jets. The use of this kind of equipment has been limited as it has been found to be too risky for astronauts to use as a defect might cause the astronaut to float away into space not to be recovered again. Though this is true, the freedom and feeling of being in space has never been as extreme as at a distance from the space station having nothing of mass within up to 50 meters.
With a highly reliable system that has proven to work without error, a trained astronaut could perform tandem flights with a single tourist.



Astronauts in space during EVA: astronaut Bruce McCandless flying freely with the use of an APU (left), and astronaut Steven K. Robinson being moved through space on the end of the Canadarm2 (right). (http://www.collectspace.com/ubb/Forum9/HTML/002456.html) (http://en.wikipedia.org/wiki/Mobile_Servicing_System)

Canadarm

The Canadarm1 and Canadarm2 have both been installed on the International Space Station of which the second is a larger version of its predecessor. The arm is mainly used to capture and guide new modules towards their docking ports of the ISS, but can also be used for space walks. The astronaut is connected to the end of the robotic arm by his legs, as another astronaut can control the arm from inside the space station, positioning the astronaut on the end of the Canadarm to the desired location.
This robotic arm could speed up tourist displacement from the exit out of the spacecraft to a desired location on the outside of the space craft. An astronaut/crew member should fasten one or two tourists at a time to the end of the arm, and move them to the location of the second astronaut where the tourists can be released.
The arm is also a much safer way to bring people far away from the mass of the space station without loosing contact with it.

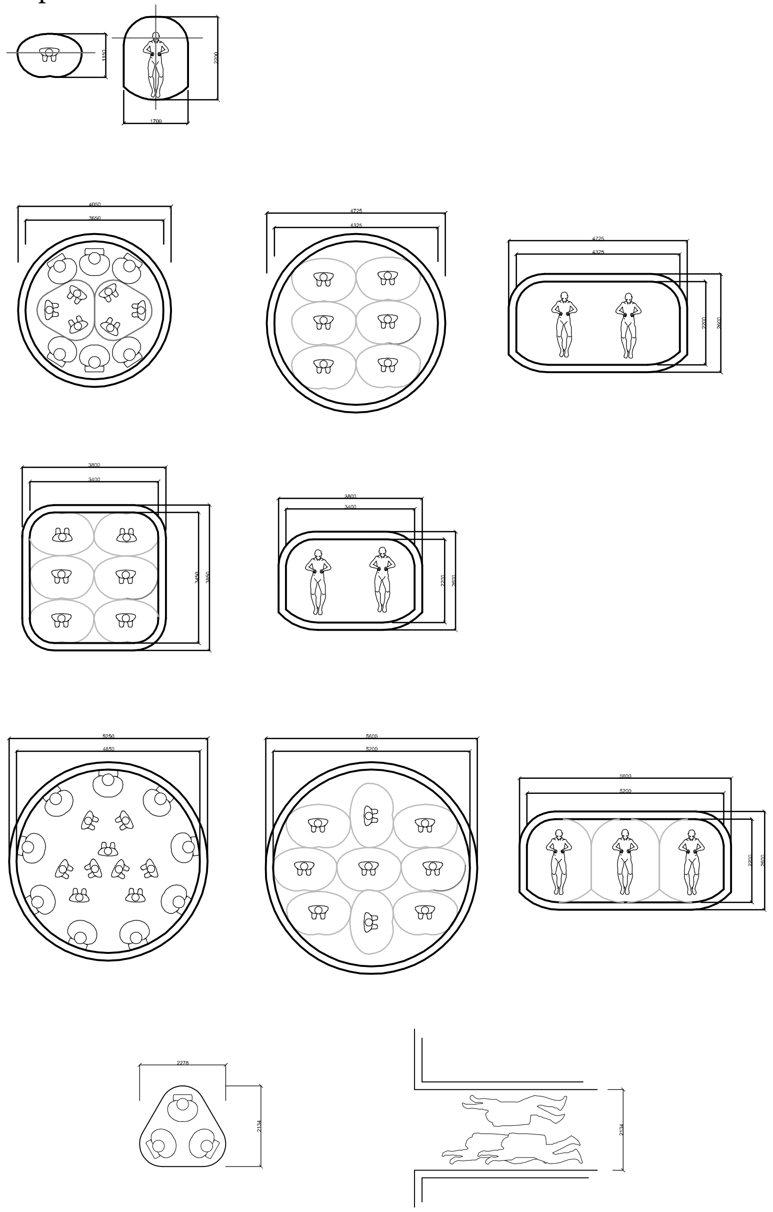
Requirements

The area to don the space suit needs enough space to get into the EVA-suit without any problems, usually the suit is put on with help of another astronaut. The area itself can also be used as the decompression chamber and thus the final chamber before going out into open space. This also requires a separate pressure vessel for the decompression room outside of the normal pressurized volume of the station. The room needs two hatch doors; one towards the station and the other to exit into space.
Each person requires roughly 4 m^3 to have the required freedom to put on a space suit. When three groups of two tourists with their supervising astronauts enter the decompression chamber they will require a minimum of 36 m^3 (9 * 4 m^3) to be able to don their space suits all at the same time.
On the outside of the space station there should be a lot of grips and secure elements to connect the

tether to. Movement along the outer perimeter of the spacecraft ladder-like constructions should make it possible to tourists to move around the station on the outside.

To get to the feeling of flying in space without a real connection to the space craft the APU provides an option, though this piece of equipment takes a load of training before it could be used with safety. And even then something might go wrong, and if it does there is a high risk of death. For safety an 'invisible' safety net could be installed, a space within the tourists can float freely without having the physical safety of the tether reminding them they are not completely free in space.

Procedure
During the spacewalk the tourists are guided by an astronaut by the pair, the astronaut can keep them together and be keeping an eye on both of them, checking their physical and mental state as they go from entering the decompression chamber, going through the preparations and during the outside part of the space walk.
First all participants put on their space suit, after which the hatch towards the other part of the space station is closed and the air is sucked out of the decompression chamber. At the point of equal pressure inside and outside the hatch door can be opened and all of the suited people can go through into outer space.



Minimum space requirements for donning a space suit and exit the internals of the space station.

EATING
The joy of being weightless is also present in the general activities that have to be performed on Earth and in space. Floating food and blobs of beverages are be a fun way to take in the calories and building blocks that the body needs to survive. But next to a very fun experience of weightlessness the social component of eating in space should not be underestimated.
During the day the tourists and personnel will eat together three times a day, breakfast – lunch – diner. Meals in the beginning will consist of two hour sessions; this might seem long but remember that eating in space is a much different experience from eating with effects of gravity. After a few days meal time will be decreased to roughly an hour per meal.

Most foods that are consumed in space nowadays are dehydrated for conservation, they should be rehydrated before use and could be heated if preferred for the specific type of food. Each astronaut can bring his own food package into space as there are many different preferences to people and astronauts around the world. Though there are some limitation to the possibilities as some foods might pose health risks when consumed in space, such as crumbling foods. The crumbs will go everywhere without being able to contain them, posing the risk of choking the tourists and astronauts after inhaling the food. Particles that do escape should be extracted from the air as soon as possible, though eventually they will be collected at an air extraction point. Foods that work in space consist of either liquids or fluids and more solid and cohesive characteristics, such as sauces, meat and beans.

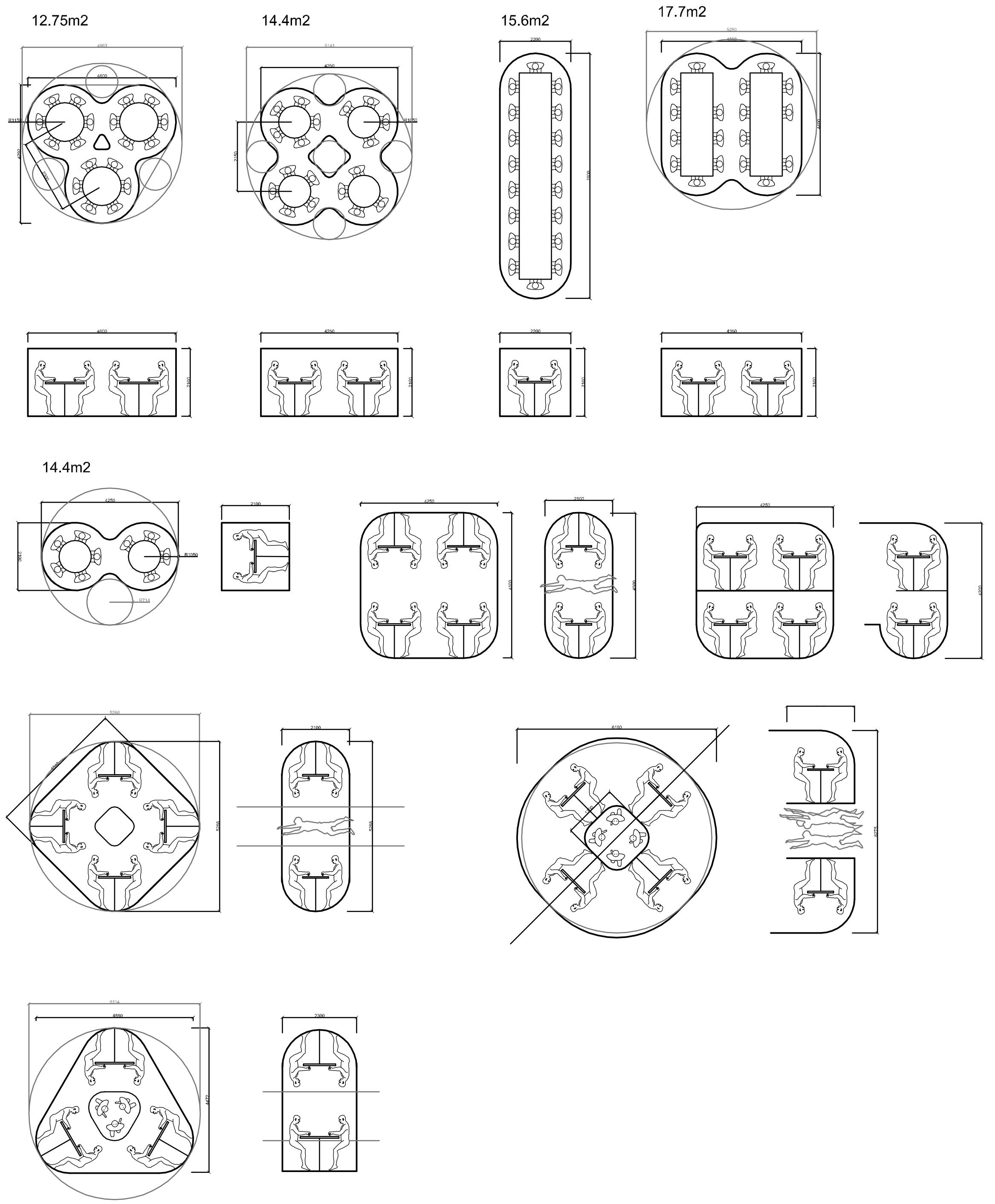
Requirements
The space required to eat together is defined by the amount of space each person requires, as eating is a very social affair all tourists should dine together. With several tables either on the same level and orientation or shifted towards each other. The orientation of a single table should be clear so the tourists face each other in a 'normal' fashion, this encourages social interaction and makes people understand one another easier. The different tables can be placed in any orientation in the space, this makes the experience of space dining understandable on a very local scale and interesting and experiential on a larger scale, as people 'sitting' at other tables are seemingly floating overhead whilst also dining and interacting with their own table company.
In western culture getting together to eat is a very social activity and is often specified by the presence of a table, in most cases even a diner table. The diner table is characterised by its specific height, making it comfortable while eating. In the case of weightlessness the food, drinks and cutlery can be secured to the table making it actually useful more then a physical barrier and structure for orientation.

Astronauts playing with their food. (http://www.spaceref.com/news/viewsr.html?pid=14252)

In the most experiential way of eating in space, the tables are not required. The only requirement on the controlling of food are ways to fasten it, either on the outside or inside of a tourists suit or to a close by wall. Floating objects in mid air without moving has proven to be hard as a small force will result in quite far distance of movement over time, resulting in a loss of sight of the object.

When focussing on catching an object or a series of objects they can float through space, this is even required for the experience, but it should be a limited and controlled amount at a single time. The surrounding walls should be repelling any drinks or food spilled on them and should be easily cleaned. The experimentation with flying food might be very interesting, but it is not hard to make a mess. As clothes might also get filthy fast they either require to be liquid repellent or the space foods should be of such a nature that they don't adhere to fabric, solid foods such as nuts for example. Though in most cases these foods are also brittle and crumble easy, a characteristic that is undesirable.

Tables should be able to extend into the space or be retreated inside of the walls to be stored and be out of the way to enhance efficiency of the space by the adaptability of the equipment used.



Minimum space requirements and different configurations of the dining compartment. (scale 1:200)

SLEEPING

In their private chambers the tourists will get nine hours for sleeping purposes, to maintain an Earth-like life rhythm. The sleep cycle is repeated every day during the duration of the stay. This is contrary to the light/dark cycle of the outside of the space station, which completes a full cycle every 90 minutes, dark-light-dark.

People:	private 1 or 2
Time:	9:00h (max)

Sleeping bags

During the practice of space exploration, there has been a single way in which astronauts have slept: using a sleeping bag. The sleeping bag holds the astronaut fixed in place as he is almost completely enclosed by the fabric; the head and the arms are the only body parts that can come out of the sleeping bag. The bag provides some comfort during sleeping as it is soft and insulating the user to maintain body warmth during sleep. The bag needs to keep the astronaut in place not to float away into the interior of the spacecraft, bumping into equipment and waking up in a strange location with a different orientation than he or she went to sleep in. The tightness of the fixation can be adjusted by the astronaut to the preferred security and comfort.

In earlier space missions astronauts fastened their sleeping bags in any space available on the interior, not having a personal space and being unable to turn of lightning on the interior. For this purpose they also wore sleeping masks. Even earplugs would be required against the large amount of background noise from running machines controlling research equipment and life support systems. Later missions supported small personal stations that could be closed towards the rest of the interior limiting light and sound pollution, making it easier to fall asleep. Though the sleeping bag is still present to keep astronauts warm and in place not to float around the small room waking up on touching a wall.

Though sleeping bags have been used throughout space exploration history, the total experiences have been different (which also has to do with the expedition time and space craft size). As Mike Massimino and Don Pettit explain the difference in experience is that on the Discovery space missions it felt much like a slumber party, where as on the International Space Station it felt much more like an expedition, as if going to the Arctic and be stationed on the frontier of living for six months. (InsideISS, 2014 April 9)

In a time where space exploration design is heavily based on reducing costs and maximizing safety/limiting risk and less on comfort and human well-being, sleeping bags are the ultimate solution to solve the simple act of sleeping on a very pragmatic level. Furthermore the astronauts are paid employees who value different standard when it comes to comfort; they accept the situation and are already privileged to go into space in the first place.

Sleeping pods

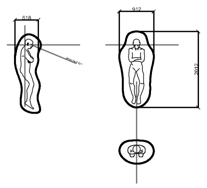
Sleeping pods are the science-fiction equivalents of Earth beds, mostly used to keep the astronauts in a controlled deep sleep, making the transportation and travel over longer distances seem like a night sleep. Two of the most prominent movies that involve these pods are the Alien movie from1979 and Aliens in 1986. Both movies represent individual sleeping modules controlled by a computer on the outside. Both being large enough to support a large human body, they are not large enough to support body movements on the inside suggesting 'hyper sleep' is a non-movement sleep. The small chambers enclose the full body and have a window for the users to be monitored by outside overseers, though the window in the movie 2001: A space odyssey is slightly smaller, it still allows a view inside to inspect the person inside.

The pods actually closely resemble Egyptian sarcophagi, with the same body orientation and internal size; the user is lying as still inside as the dead would in a sarcophagus.

In the 2012 movie *Prometeus* the 'sarcophagus' resembles more of a snow white glass coffin, but with the modern implementation of a see-through touch screen on the top-side.

Though there are developments in the representation of the sleeping pod, the main characteristics

are always the same: the person inside can always be seen through a pane of glass, the controlling and monitoring always happens with the use of a computer with a manual override, the person inside is lying in their underwear suggesting a warm environment inside, and the person inside will not be moving deduced from the size of the chamber.
The only real world representation of the small sleeping chambers is the 9-hours hotel in Tokyo that houses 25 'hotel rooms' on roughly a 25 square meter area. The small rooms share a lot of characteristics with the science fiction pods; their size, clear glass window, and controllability of the private space climate. Though the client can control his own environment from the inside instead of being controlled by an exterior controller.



Minimum personal sleeping space. (Scale 1:200)

Requirements
The sleeping chambers require a high level of privacy for the tourists and astronauts to relax, to create an environment for sleeping purposes it should be calming without distractions, and should thus also be comprehensible; easing the mind. As each person has different requirements during their sleep, especially when it comes to temperature, the interior climate should be controlled by the user creating a local personal climate.
The required size is limited to the body size as it should stay in place during rest. The length, depth and width are the minimum measurements, which results in roughly 2 m^3 (1*1*2) of space for each personal chamber; a total of 36 m^3 for the total crew and tourist group.
To control the natural sleep cycle of the humans on board adaptable lightning should be installed to get the tourists to wake up better and put them to sleep easier. Music might also make it easier for some to catch their sleep, a personal track list could be created or a personal audio player to be connected.

Japanese astronaut Koichi Wakata sleeping in space (left), and a front view of a room/sleeping compartment at the 9 hours capsule hotel in Kyoto, Japan. (http://www.nbcnews.com/id/32179352/ns/technology_and_science-space/t/sleep-no-shower-astronauts: courtesy of NASA) (http://www.uniqhotels.com/9-hours-capsule-hotel)

WINDOW GAZING
Astronauts have often explained the view their location it offers on our planet to be the most intense experience of their stay in space. This either from the view outside of the space station during a space walk, or from the inside through a window. A difference being the fact that during a space walk there is not much time to be enjoy the view because of time pressure and work to be done, especially in case of the astronauts. For tourists however both possibilities provide time to enjoy the view on the planet, but with so much to be seen the space walk does not provide enough time to enjoy the details of the view, something the view through a window does. As there are less

distractions with regular window gazing then when viewing while on a space walk, the view is also more relaxed because of the limited risk involved compared to a space walk.
Through time the view from the inside of a space station has always been through a small sized window providing enough of a view to get a sense of orientation and when close enough to the window provides a good view of the Earth. But with the arrival of the ESA Cupola module in February of 2010 this all changed. The module houses an enormous glass dome in respect to earlier windows and enables astronauts not only to look with a larger viewing field towards the planet but also look 360 degrees around the dome because of the extension and angle of the windows. The panorama is primarily used by the astronauts to monitor planet Earth with their own eyes and at the same time being able to see the exterior of the space station and control the Canadarm with high precision.

Astronaut and Tourist
For the astronauts the Cupola also provides an intense pass time activity and experience, as the astronauts have some time a day for themselves (more now than in the past) they are also able to enjoy the view and their passing over the world for a longer period of time. As can be read in Appendix A on the experience of the astronaut Greg Chamitoff's 90 minutes window gazing there are a lot of different experiences and views in this short time frame, every one of them very intense. Joseph P Allen, an astronaut on the space shuttle missions, has said the following about looking through the window: "It is endlessly fulfilling. You never see quite the same thing as you are orbiting. There is a different ground track every time. The time of day is different; the clouds are different. The cloud patterns show different colors. The oceans are different; the dust over the deserts is different. It doesn't get repetitive." (White, 1998, p. 3)
The tourist experience should be exactly the same as that of an astronaut, but perhaps even more intense.

View at the stars
Not only the view of our planet is of interest to us, but also the view of the stars and planets in our solar system. Because the station is positioned outside of the Earth's atmosphere the view of the stars is not impeded by diffraction of sunlight, the view towards the stars is always present in the sky, not only at night. And at night the stars are also brighter and more sharp than when we would view them from the Earth's surface, even in the darkest night.

The overview effect
The most prominent effect the experience of viewing the planet from space is often described as 'the overview effect', it is the result of the distance one takes to the largest object we know from experience and being able to put its size in perspective. Suddenly it becomes clear to the viewer we have to do something about the results we have as a race on the health of our planet. All of the natural processes are to be seen clearly from a low Earth orbit. White (1998, p. 4) describes the overview effect as "the predicted experience of astronauts and space settlers, who would have a different philosophical point of view as a result of having a different physical perspective."
There is another effect capable of giving man the special feeling of space, something that occurred during the moon flights of the Apollo missions; the feeling of being 'lost in space'. As the Command Module flew around the moon, there were times that there would be no possible contact with the Earth due to the position relative to the Moon and the Earth, and as spacecraft would fly around the dark side of the moon, nothing would be visible but the stars. The moon blocks the view of anything of substance and importance. This feeling of disconnectedness and loneliness can in a way also be experienced visually on the International Space Station as the spaceship turns to the dark side of the planet, there is a spare moment in which al seems black and the eyes need to readjust to the absence of the sun's light. Though this does not implement the absence of contact with the planet, and the distance there already was towards the planet Earth, it still has a strong impact.

When to view
The distance of the space station towards the Earth has an impact on the way the adventure is experienced, as a shorter distance to the Earth creates a highly detailed top view image of a smaller area or a higher orbit providing less detail but showing more of the total picture. The distance of 400km from the Earth's surface is the minimum as getting lower would increase drag significantly, so for a highly elliptical course the perigee would stay at 400km minimum therefore the apogee should increase drastically to give the astronauts and tourist a different view during a single orbit. The higher orbit and elliptical orbits also have a disadvantage in a technical sense because of the energy required to travel further from Earth's surface the price for a trip will be higher and less weight can be taken into this orbit.
Another possible disadvantage of a highly elliptical orbit is the travelling speed, when an orbiting object is travelling at a large distance of its attractor the rotation time is much lower than when the same object is in a lower orbit. In an elliptical course this means the time an object would be close to the attractor is only a fraction of the time spent at a large distance of the planet. The orbital speed at perigee is also much higher in an elliptical path than the same perigee at a stable orbital distance. Creating higher distances from the planet thus come at a high cost.
Every orbital distance has its own characteristic orbital period, though there is not much difference between a low earth orbital path and a medium distance orbit. A distance of 400 km has an orbital period of 90 minutes and a distance of 1600 km a period of 120 minutes, this is a distance factor of 4 while the orbital period is only multiplied by a factor of 1.3. Controlling the orbital period the specific area's that are to be viewed at a specific point in time can also be controlled.

Requirements
The view on the planet is framed by the windows to the outside of the space station in related to the distance of the viewer. Being closer requires less of a size to see the same a distant person would require to see a certain field of view. To further enlarge the viewing possibilities beyond the flat surface a space with a more rounded view is required, such as the ISS installed Cupola. This immerses the viewer into a world that seems lie beyond the internals of the space station. Much like the overhanging glass box rooms on the Sears towers 103^{th} floor; being able to view all around and still be safe, but create the gut feeling there is a large risk.
To view at the stars the pupils should be as open as possible to catch the most light and see the most in the darkness, at the times the sun is shining right on top of the station this can be hard as the sunlight also shines directly into the viewing area, this should be cancelled out as much as possible. To limit the contrast between the interior and the darkness of the sky, the interior lux levels should also be low.
The view outside should be clear as day to provide the most realistic representation of the planet, as if the window construction is not there at all. This also means limited light refraction to limit distorted views from slight or bigger viewing angles. This is especially present when viewing through the same (small) window with a group of people, as there will only be a few looking straight through and others having to look from angle. Thus larger groups will require more window surface. A group of 15 (12 tourists and 3 crew members) would require a large extended area to encompass all people in an out-of-station feeling and provide a large viewing field.

There is a difference between the smaller windows to give a feeling of orientation and windows that provide a detailed view on the outside world, the difference being the amount of viewing quality the detailed window gives. The smaller windows can be viewed through but should mainly provide a sense of the external with relation to the Earth and the Sun.



Astronaut Chris Cassidy photographing Earth from the ESA Cupola module (left), and Karen L. Nyberg looking out a regular window of the ISS. (http://www.nasa.gov/multimedia/imagegallery/image_feature_2527.html) (http://chasblogspot.blogspot.nl/2008_06_01_archive.html)


Tracy Caldwell Dyson looking out of the Cupola to the Earth that turns below. (http://spaceflight.nasa.gov/gallery/images/station/crew-24/html/iss024e014263.html)

ACROBATICS
The second aspect of being in space that has the biggest impact is the apparent weightlessness, every movement becomes new and interesting having to actively think of what to do to get from A to B. When orientations chance between spaces or even inside of spaces, it requires a lot of the mind to cope with, in the beginning this might already be enough to experience and enjoy microgravity, but as time passes and the human brain adapts to the weightlessness more tricks can be performed such as acrobatics in space, somersaults in every direction and orientation.
(More on space-gymnastics in Space sports)

Requirements
To perform acrobatics in space there are some requirements that have to be met, first being the

size of the space. For a single somersault the space required is not that big, actually not bigger than required for a single person to be in, though a bit more is required in depth. But when performing continuous somersaults you will not stay in the exact place you started, you will probably end up several meters away due to initial impulse.
As more people participate a larger space is required to not bump into each other all the time; movements are quite uncontrolled while experimenting. This size expansion is both useful for larger groups as well as for more advanced acrobatics. The space could be extended in a single direction for a larger group, but could also be enlarged in all directions. The enlargement in height, depth and width creates spaces in which there is no control of movement in the middle but gives an enhanced feeling of freedom as all walls are further away.

HYGIENE
As space exploration trips took longer hygiene became of larger importance than it was in the earlier stages of space travel; specifically for the personal hygiene of the skin. Space designers have tried to build a shower for space in several instances starting with the Russian Salyut missions, the American Skylab missions and the last time on the Russian space station Mir, in which case the shower was early on transformed to be used as steam cabin as the original design didn't function up to expectations, and was dismantled in a later stage to make place for other equipment. (McDonald, 1998, p.19)
In earlier as well as later space exploration missions wet-wipes were used for personal hygiene, as this was at first the easiest way to get the astronauts clean and later on the most effective; on the International Space Station they did not have an on-board shower installation just wet-wipes and rinse-less shampoos.

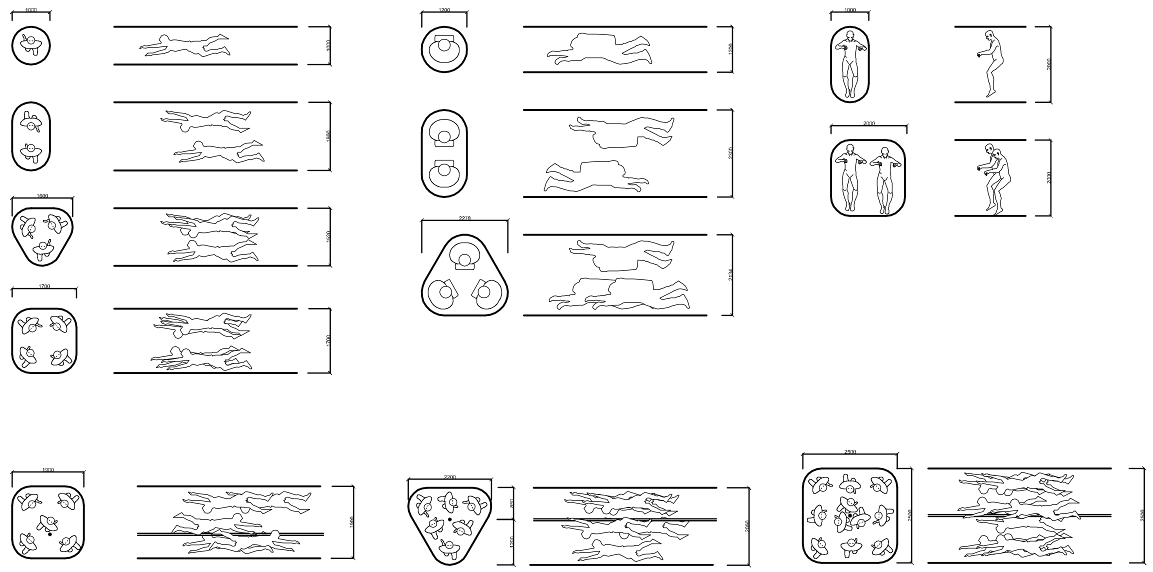
With the future space tourist market more research should be done to improve old or create new designs for the use of personal hygiene, a system that cleans the whole body in a pleasant manner. The emphasis should lay on enjoyment but hazards should not be forgotten because people might drown in badly designed systems. But a nice hot shower makes people feel human in bewildering environments.

Toilet
The space toilet has not changed much since the beginning of space exploration. Unfortunately the inner workings of the space toilet have such a different way than a toilet functioning in gravity, which relies on gravity in all of its functionality. Therefore the way it is used by humans cannot be a replication of the way we use our toilets on Earth. Though cannot be the same, the current toilet is also too strange for instant correct usage as explanations are required. Making this more human might be a large step into the right direction for a more humane space existence for tourists.

Skylab pilot/astronaut Jack Lousma having a shower. (http://www.mcmahanphoto.com/ns589.html)

EXPERIMENTATION
There are also some minor experiments that create better understanding and visualise being in micro-gravity in a simple way like strapping cd-players to a flashlight to stabilize it in mid air, throwing boomerangs, race each other on vacuum cleaners. And some more scientific experiments with water droplets and air bubbles which cannot escape due to the surface tension and lack of gravity.

GETTING AROUND INSIDE IN THE STATION
Movements inside of the station require space for each astronauts and is dependant on the amount of gear he or she is moving, with regular clothes or in EVA suit. In busy area's the interior dimensions require a larger section to make sure multiple individual can travel side by side or in opposite directions. If we look at spaces that expand in all directions at a certain size the distance for a grip at a wall is obstructed by another individual, in this case a new mechanism or grip for control is required. This size is not related to the distance an average human could reach to grab either one side or the other.
To be able to turn around in the space, a larger section is required.

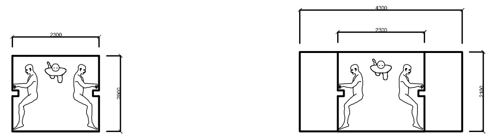


Minimum required sections dimensions for multiple space tourists and/or astronauts to pass through and turn (right). (scale 1:200)

Astronaut specific activities

WORK/ RESEARCH
Throughout the past half a century space exploration has been dominated by making things possible, being completely dedicated to research. As nations have billions of dollars put in the space exploration they have always demanded ultra high efforts from their astronauts resulting in 12 to 14 hours of work per day in the current state of space exploration. This has been even more extreme in the past, when astronauts felt they had to take an unscheduled day off during their mission because they did not agree on the workload. (Häuplik-Meusburger, 2011, p. 250)
Working hours have been scheduled to a controlled maximum, but as explained by Don (Donald) Pettit the work is (almost) never finished within the amount of time provided for the task resulting in having to catch up during scheduled free- or leisure time. (InsideISS, 2014 January 29) The down-time currently scheduled for astronauts is provided during pre-sleep and post-sleep on week days, on Saturdays and Sundays. According to schedule on the ISS the workday starts at 7 AM and continues until 7 PM, which if it is not finished will take until around 8 PM, which results in workdays of about 12 to 13 hours. On Saturdays there are around 6 hours of work scheduled in most cases and some of that work overspills to Sunday. “So if you are lucky there is a single day off during the weekend. It could be multiple weekends in a row without free time.“ (InsideISS, 2014 January 29)

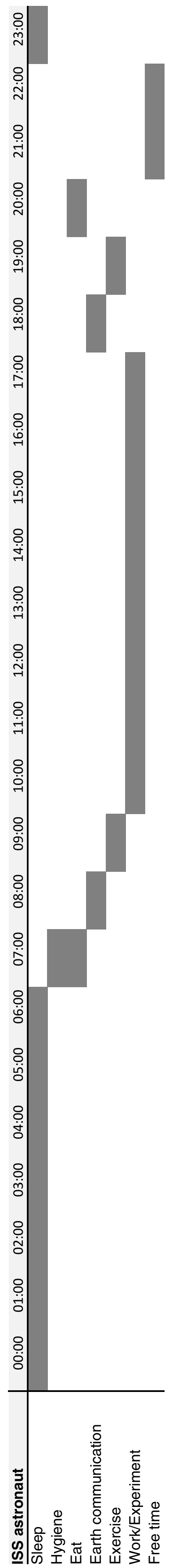
The astronauts role in the case of tourist space adventures will be focused much more on creating the best experience for the tourists than it will be on research. Their role will shift towards guiding and teaching how to function in space to ease the adaptation and better the experience; closely resembling a tour guide.



Section of minimum effective research compartment size. (scale 1:200)

Requirements
All equipment has to be easily understood in a weightless environment and has been oriented in a single direction throughout the history of space exploration, this enhances understanding of different dials, knobs, screens etc.
For efficiency in the use of equipment and setting up experiments the space should be easy to move around in with limited excess space; passage ways large enough to fit through easily but no vast open spaces. The size of hallways used on the International Space Station offers the most efficient way of combining getting around and working on research. The general size with a height of 2.1 meters and a width of 2.3 meters ensures a way of passage even when two people are working on opposite sides of the hallway. The height is big enough to fit even a large person straight up without hitting their head, and small people to still be able to reach the floor and/or ceiling.

The research space should be closed for tourists as in most cases there will be sensitive equipment on board, as tourists do not know how to interact with this the only thing that could happen is an interference with research data. Certain researches could be shown to the tourists but should be taken out of the research area and into the tourist experimental space.



Basic astronaut working schedule during a regular week day. (right)

EXERCISE & YOGA
As part of the regular working day of a long term stay in micro gravity astronauts need to workout two hours a day just to keep fit and maintain bone density and muscle strength, it is still uncertain if it is also beneficial to the immune system. Muscle resistive training (which is the microgravity way of weightlifting) cycling (ergometer) and treadmill running are the common exercising activities at this point in time. The exercises are obligatory but can be adapted to the personal interest of the astronaut, as in the case of Sunita Williams who practiced for a marathon and continued doing this in space.

Requirements
All of the used equipment makes noise when in use and should therefore not be placed close to private chambers which should be enjoyed in peace and silence. The same actually counts for yoga, which should also be performed in silence, therefore the two activities should either be placed in different rooms or never be performed at the same time.

Yoga
Yoga is believed to be also able to counteract the degrading of the body due to the catabolic processes, and instead activate the bodies anabolic processes and relieve stress at the same time. As the experience of going to space and the risks this poses, stress relieve through yoga should be a good way to calm down and enjoy the experience without the high stress levels.
Yoga exercises could performed both in mid air, as well as slightly strapped down. As some of the movements require a position to be held for a longer period of time, floating away with closed eyes will eventually result in bumping into a wall. To counter this walls should be outfitted with simple systems to hold a person in place, either a strap or Velcro of some sorts. Floating away can be preferred but should only be done by more experienced astronauts that have adapted to the amount of movement they initiate.

Space sports

As we can already see interesting experiments develop on zero-gravity parabolic flights and free time activities of astronauts: sports we perform on Earth have their microgravity cousins. There have been several cases in which astronauts have tried performing sports or sports activities in a low gravitational environment, the hitting of golf balls on the moon by Allan Shepard and throwing of a javelin by Edgar Mitchell, but also in microgravity, for example the astronauts on the International Space Station that used vacuum cleaners as rocket propulsion in a man to man mini space-race. Besides this, space soccer, frisbee, mini-golf, baseball and a marathon on treadmill have all been taken a shot at at some point in time on the ISS. (Malik, 2007; 2008; David, 2005; Than, 2006)

As both exploration of the unknown as well as a profound competitiveness is in our genes, space races are a logical step in pushing the boundaries of sports and space enjoyment. But this is only where it can start, there will be much more sports that can be translated or transformed from the Earthly version to the space type. But more importantly; what can be created in space for this specific environment.

THE BASICS
Three-dimensional movements
Without a doubt the new adaptations for sports in space are required due to the displacement from an effective 2,5 dimensional field to the full three dimensions of space. Of course all real-world sports are set in a 3D environment, but we can relate to it as taking place in slightly over two dimensions, going up in the air is in most cases temporary and in almost all cases minor to the base surface. In space there is no dominant plane and is therefore a much more effective in the use of the three dimensional space. As all axis are equal there is no dominance in direction or orientation, until the playing field is introduced. However the direction of movements is still completely free through the three dimensions of space; up, down, left, right, forwards, backwards and any direction in between.

Movement trajectory
Movements in space are similar to displacements in a free fall, after the initial force has been applied to a mass, the person or object will travel in the opposite direction until it meets another object, by interaction the trajectory can be changed. Importantly the vector of the travelling direction cannot be changed in mid air. The only substance with which there is interaction that results in a change of movement is the medium through which the object or person travels in most cases the air. The air creates friction and resistance, but can also change the flight path by the air flow.
On Earth we are bound by the same physics, but as we are only free falling in limited cases the air resistance is in most general movements to be neglected compared to friction from gravity as we are always touching the surface of the Earth. The path we take after we push ourselves away from the planet has the shape of a parabola, where in microgravity it can be described as a straight line away from the object you push yourself away on.
The adaptations have a large impact on the way sports are to be performed in space, both on the aspect of personal movement as well as to props used in specific sports. A ball will not return to the ground surface but will move away from it until it encounters another object to bounce off from.

Launching teammates (tactics)
In team sports squad tactics can help win the game, technique as used in rugby after a throw-in, in which teammates work together to launch a single player as high as possible, would also work in microgravity. Though it would not be the height that is the goal but the speed at which a player will be moving after the launch, since there is no counteractive force restricting the distance.

MOVEMENT BASED
Athletics
Simple space sports are those that do not require any attributes and focus on the body movements of the athletes, what first comes to mind is athletics. Body control and fitness level are the main tools in this range of sports, though the body is in most cases used to pitch a specific object such as a disc, a javelin or ball. Sports that at first glance will not be as interesting as they are in an environment with gravity as the object does not come down to the playing field but continues in a straight trajectory. In this case precision becomes much more important than power, resulting in sports that share more resemblance to darts than athletics.
To maintain the essence of the sports that involve throwing an object such as Javelin throw, disc throw and hammer throw, the specific elements should be replaced by their relatives. In the case of these sports distance is the measured result but the result is a combination of speed and angle, or could be described as precision. Throwing a Javelin in space could be registered as a precision sport that also measures the throwing speed to come to a combined result which is the relative component of distance.

Gymnastics
Extending the realm of space acrobatics gymnastics are a fantastic way to use microgravity to your advantage. Without the limited time to be in the air a routine could go on without interruption. Each of the specialisations have their own microgravity relative. But only the ones involving complex flight elements will apply from a spectacle point of view. Moving from one side of a space to the other performing acrobatics in between, gymnasts will be reviewed on technique and difficulty, similar to competition diving though the speed at which one travels in direction of the final surface can be controlled by the gymnast him or herself instead of a fixed gravitational acceleration.

The size of the space is one of the most important aspects in this sport as the distance from one surface to the next is guiding for the amount of flips a person can perform in relation to the speed of travel. Possibilities for different distances within a single room should be strived for to be able to adapt to different specialisations.

Racing - jumping
As in space a single surface does not provide ample objects to race on as one would run on a track on Earth therefore track racing is more like aeroplane racing on earth. As with all activities in space are like flying. Keeping that in mind, racing in zero gravity is still very much possible but on another level, a track needs several surfaces angled towards each other to be able to create a course. The object of the race would be to end on the final surface starting on the first, perhaps with different ways to get from A to B, the route would be up to the athletes to find the fastest line, in a slalom kind of way.
Moving in the same direction is not as hard in space as there is no obstruction, therefore direction changes need to be required from the sportsmen in order to make it interesting. In micro gravity racing will be much more about agility then pure power and strength.
Longer distances between two surfaces could increase the importance of the powerful push by the legs. As two surfaces would provide a track for a single participants the thought of several athletes battling each other head to head is not so crazy, transforming the racing sport more into a swimming relative combined with the long jump.
In any case the stadium for such sports would require ample size to either complete a full track or have a high enough length to make jumping from one surface onto the next interesting. A length of 25 meters would already require a combination of strength and precision as there is not much control over flight direction after the initial push. One option to enhance flight control is the

addition of a certain type of wings.
Racing in space on the exterior of a space station could be possible, and could be the most extreme experience of space in any sport. Using aeroplane-like rocket ships to manoeuvre through obstacle courses, a type of air race should be possible in the far future. Of course this doesn't come without its hazards, as the results of motor failure could mean drifting away into space or even worse in a trajectory towards the planet resulting in a speedy descent, burning up the ship during the uncontrolled descent into the atmosphere.

CONTACT SPORTS

Wrestling

Could work on parabolic flights as gravity decreases and increases during the parabolas, but during continuous weightlessness the athletes are unable to push each other to the floor; requiring hand grips to secure themselves to the wall, limiting their control by having to give up one arm in the fight, would in most cases mean the other athlete has more power as he or she has the advantage of having both hands free. In a smaller space opposite walls could be used to push against to control the body positioning in space without sacrificing power in the upper body.

Martial arts

General martial arts could work better than wrestling as they rely in impact rather then constant applied force. Though for a punch or kick to inflict a force they require a momentum which require a resistive force, in is most cases the resistance of the fighters feet to the ground surface. The force of a movement based on relative mass differences between an arm and the rest of the body is relatively small compared to the force applied by the resistance of feet to a floor in a 1G situation.
A fight would in most cases end with a choke or submission of which only the relative positions of one person to the other is relevant, but even then some chokes and submissions require the resistance of the floor to pin down an opponent, limiting the amount of possible wins.
The physics between two bodies would become much more important as each pull or strike would result in a momentum in different directions, first the arm or leg in relation to the total body would create a momentum, then the impact of arm or leg on the opponents body would create a momentum on both fighters. This momentum could be used to land the next strike in opposing direction to use the momentum and release its energy to hit the opponent even harder.
Controlling the opponent by moving his body through the open space could position him or her into a vulnerable situation. The required energy to turn the opponent becomes higher the heavier the opponent is, thus requiring the same weight class system as would be required in regular gravity martial arts.
Being able to hold on to each other would make the fight more intense as the impact of a punch or kick would not end in both fighters 'flying' in opposite directions but stay together. The hits can also pack more energy as both the pull and the punch combine their force.
The size of the ring would need to be as small so that fighters don't get stuck in mid air for a long period of time without being able to connect to each other this could and would slow down the fight considerably. A too small arena would make it impossible to float in mid-air without touching walls, a medium format 'ring' would be ideal for most martial arts. The length and width of a boxing ring coupled with the same height would make an arena of 5 x 5 x 5 meters; 125 cubic meters. But as said before the ideal size would be smaller, closer to 3 x 3 x 3 meters, if extruded from a square. A spherical arena with a radius of 1.5 meters would have a same effect on the fight.

BALL SPORTS

As most ball sports could have a relative in space sports, as basketball and soccer/football are passing sports they would work in a similar fashion as on Earth, games like volleyball are harder to copy into space as it relies almost completely on gravity; the passing techniques and the winners on the other teams area.

Billiards / pool / snooker

An interesting close range sports for space is billiards or pool; the small space required offers a sport that can even be done inside a current day space module. The transformation to outer space means two things, a three dimensional playing field, making it much more interesting where to hit the balls and what direction they should be going. The other aspect is the lack of friction, this is both a danger and an aspect that could make it interesting, as the place of the balls will be different through time you might not want to think too long before making your move as alignment might be off if you wait too long. This is also a great danger for the sport, as balls will always be in motion just waiting for a ball to go into the pocket is possible without any adaptations.
As controlling the lengthy cue it would be hard in microgravity it is in the interest of the sport to adapt the body extension equipment to something more controllable in mid-air.
A 'playing field' of only 2 x 2 x 3 meters would suffice to perform this sport. Extra requirements are installations to keep the balls in the pockets after they have been potted, in the case of snooker. Complications would come in personal positioning in relation to the balls within the limits of the playing volume. As in general billiards, pool and snooker the players move on the outside of the playing field to avoid touching any of the balls by accident. Another option is for the players to move on the outside of the playing field, but this would require the containing volume to be able to be opened for the players to reach the ball they wish to play.

Dodge ball - Hand ball

As one of the ball sports that does not require an instrument to handle the ball, and requires high levels of agility it might be one of the main sports to easily adapt to outer space. For this game that is in essence already quite simple the adaptations for space only result in the playing field becoming more three dimensional. The same applies to hand ball as the grip to hold the ball is no different in microgravity than it is on Earth.

Dodge ball is also one of the sports already played/practiced on the Zero-G parabolic flights.

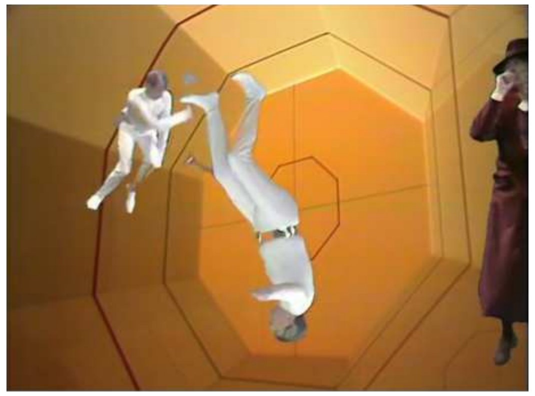
"Passengers have played dodge ball and tag during short periods of weightlessness on the rollercoaster-like parabolic flights of a modified Boeing 727-200 jet operated by the Zero Gravity Corp., the Las Vegas, Nev.-based firm has said in the past."
http://www.space.com/5282-future-space-sports.html

Rugby

Other sports that incorporate hand control such as rugby have issues with the transformation of the scrum, as both teams don't have much to push from against the other team. Furthermore the scrum acts in a two dimensional playing field on top of the ball; imagine a three dimensional form of the scrum, which would require much more players. Perhaps the outer players could connect to the walls in a circle, pushing their teammates forward in a cone-formation.

Space Squash

As first shown in the Doctor Who television series in 1980, the leisure hive shows a science fiction prediction of the way squash could be played in a microgravity (non-gravity) setting. Though the visualisation in the series shows no rules to the game, it represents a playing field that extends in all directions. Compared to regular squash which focuses on a single wall and utilizes four others; all except the ceiling.
In squash one player wins over the other if he hits the ball in a way the other cannot hit it above a certain area on the front wall, or cannot return the ball before it has bounced on the floor for the second time. In space the ball is not 'attracted' to the ground surface making it easier to not let it bounce on the floor surface for a second time. For a reasonable win in non-gravity squash other rules should apply,



Space squash being played in the TV-series Doctor Who, Leisure Hive 2 episode (1980). (Video still taken from http://youtu.be/QiJeas9AeME)

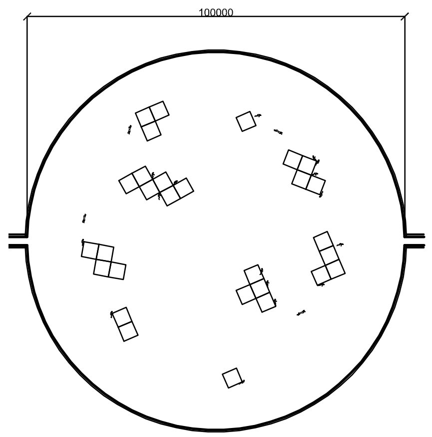
Baseball
Hitting the ball will propel it forward with speed that it will maintain until it is obstructed. This gives a whole new approach to one of the most important aspects of the sport: the home-run. As the ball will never be able to hit the 'ground' beyond a certain point of the playing field.
As we copy the sports basics into a microgravity environment, the 4 bases will be spaced around the internal volume for the hitting team to go from one to the next. The displacement will most likely be done in a straight line which also implements the requirements for a directional push towards the next base, and also makes it possible for the athletes to miss the next base as their angle of propulsion is slightly off. With the defending team on specific bases and places in the hinter-field they can intercept the ball in mid air by jumping into the trajectory.

OUTDOORS AND INDOORS
Certain sports are just easier to adapt to space then others, this is specifically the case on indoor versus outdoor sports. As indoor sports usually take less space and use their immediate surroundings as tools or limitations. In the case of squash it is quite obvious that the sport takes place within the boundaries of the playing field, in which the playing field is used as part of the sport and can be used as strategic element. Instead of creating limitations they provide possibilities.
Any sport tactic that uses its boundaries would probably fit a microgravity environment. The boundaries are most important in the smaller interior sports, but as soon as larger interior spaces are used for sports the less the importance of the outer perimeter becomes.
As will become clear there are some outdoor sports that could benefit from a space large enough to make the sport indoor, a feature that could create new tactics and strategies for the sport to become more attractive to play and watch.

WATER SPORTS
Water sports are a hard one to realise as it is obviously possible to bring large amounts of water into space it is certainly not financially feasible in the near future. This is based on the high specific weight of water and thus the high mass. As in current times the cost of putting mass into space has a cost to weight ratio in the range of 10.000 USD/Kg. A cubic meter of water is 1000 Kg, costing 10 million USD to put into orbit, for only a cubic meter of water. As a general swimming pool on Earth is 25 x 1,5 x 8 meters on average (a volume of 300 cubic meters) will cost 3 billion dollars to launch into a low Earth orbit. This would also take three trips of a future heavy lift launch vehicle to bring the total mass of 300t into space. (An official Olympic swimming pool, sized 50 x 25 x 2, meters has a total water mass of 2500.000 litres or 2500 metric tonnes in weight.)
As water in microgravity forms large bodies in mid air because of its surface tension, people could easily drown when moving through such a volume. Swimming through the blob would mean a combination of flying and diving at the same time.
Due to the lack of a gravitational pull, air inside of the water will not go up, as this direction is created by the differences in density in correlation with the direction of gravitational pull; air is less dense and will rise in water in a normal gravitational setup. In space the air stays inside of the body of water as there is no large gravitational direction. It is even possible to have a mass of water inside of an air pocket in a larger body of water. (dgquintas, 2006)

FUTURE SPORTS
As new possibilities arise sports will develop into new forms, for the later versions of space sports we can only dream in exploration of their possibilities. As reality will in most cases reveal a different version of our ideas, what we can do is imagine the sports and think of their limitations and possibilities in order to make them most feasible.

Ender's Game
In the movie Ender's Game 'space cadets' are challenged to play a game against each other in a microgravity environment testing their tactic, strategic and battle insight qualities. As the squads consist of several students teamwork is critical to win the game.
The aim of the game is to score a goal in the opposing goal, the opposing teams entry to the stadium, by entering the gate in person; effectively bypassing the other team to their defensive gate. To eliminate the other team all players have laser pistols that freeze the opponents suit, limiting them from actively participating in the rest of the game.
The game stage is a sphere with a diameter of 100 meters, inside of this space players are free to move around, using floating objects as devices to either use as cover or use as base to initiate personal movement.
In essence this is a war game, where strategy and tactics will in most cases decide which team wins and which team loses. Much like paint-ball games we play on Earth, a physical war game that involves taking out the opposing team or taking their flag, which could be referred to as their base.



Section of the 100m diameter sphere written about in the 1986 novel by Orson Scott Card, and the 2013 movie recreation. (scale 1:2000)

Movie still taken from the 2013 movie Ender's Game, showing a large spherical stadium with clear view on planet Earth and free floating people, one controlling its position by holding on to a grip on a large octahedron.

Ender's Game movie still, the main character entering the arena slightly lit by the sun rising above the Earth. Obstructions are lit at the hand grips and make them stand out clearly from the open space.

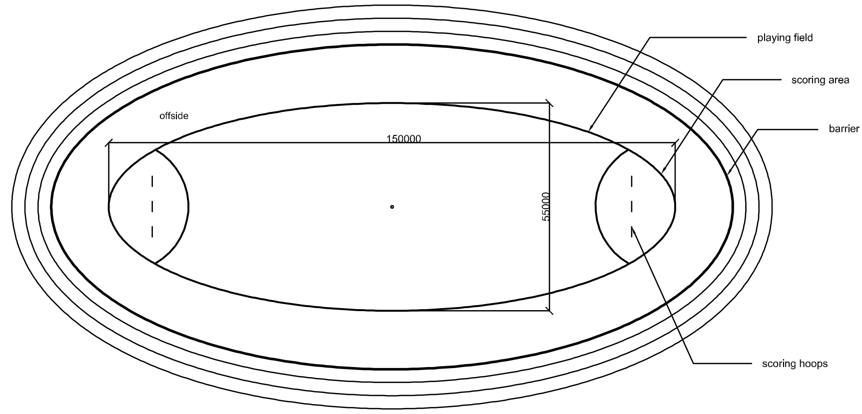
Quidditch

Sports that have only been mentioned in fantasy novels and movies are now coming to the realm of the possible, through absence of gravity. In Quidditch, and the realm of Harry Potter, the broom provides lift and by leaning the body you either move in any given direction. As in space there is no gravity, the broom does not have to provide lift, but it has to has to create the movement in combination with the 'pilot' in a different way. The movement of the 'pilot' and 'broom' could be made by small propulsion jets and steering by angled jets or changing the angle of the body relative to the direction of the forward jet. To use the jets in the most efficient way the sport has to be held inside a pressurized volume.

The game has 4 balls of which one is used to score point in the 'hoops' of the opposing team, these hoops are placed on poles to have them high in the air, in space these could also float in mid air. There are two 'defending' balls that are used to knock opponents of their brooms. The last ball is the smallest and fastest being propelled by its own propulsion, being the hardest to catch; finding this ball will end the game.

The rules in space could be very similar, the balls would not need any changes except for the snitch (the smallest ball)which has to be a small jet propelled object which is both fast, hard to spot and hard to catch. An adaptation the sport would require is the surrounding playing field, the enclosing

walls as opposed to only a floor surface in the original playing field. The freedom of the game will slightly change, but new tactics as bouncing the ball of the walls can be implemented into the game.



Quidditch playing field top view. (scale 1:2000)

The playing field of a regular quidditch match is a staggering 150 meters long and 55 meter wide, not counting the offside area and spectator stages. This obviously is a major challenge to create in space with the current and predicted future possibilities.

The ground surface is not used in the sport as all the activities are performed while in flight. In the fictional game the airspace used is a very large expanse

Possibilities, Limitations, Risks and Requirements

SIZE
As far as sports need space, it can be calculated by engineers and built in space if the funding is there to lift all the materials to space and built the stadium. Though this is heavily dependant on funding from investments which will most likely have to start with space tourism in the most reasonable scenario. The space business is growing but it will still take decades before space travel will become economically feasible for anyone with less capital than the worlds wealthiest. The risk for investments is currently still too large for the masses to participate.
As investments come and space travel becomes a larger part of life, more people go and the trips become less expensive, tournaments and space sports that require large size stadiums will grow in popularity. At first the stadiums will only need to contain the athletes and camera's for the sport to be watched by people all around the planet, though later on complete stadiums with large amounts of seats could be required. In a 3 dimensional way, the spectators can be all around the 'playing volume'.
The size for specific sports arena's are different and a sequence of sports ranging from small playing spaces to large will be a logical series. Though this is also relative to the amount of spectators a sport will draw, and even more the related cash flow that will follow from a space sport. Bigger sports events will probably be pushed into space over smaller sports, because of the relative high wins-to-risk ratio.

"Sports will be more fun the bigger the chamber is in which people play," Collins said, "which will be a stimulus to assemble large structures in orbit, once travel to and from space is much cheaper with reusable passenger vehicles."

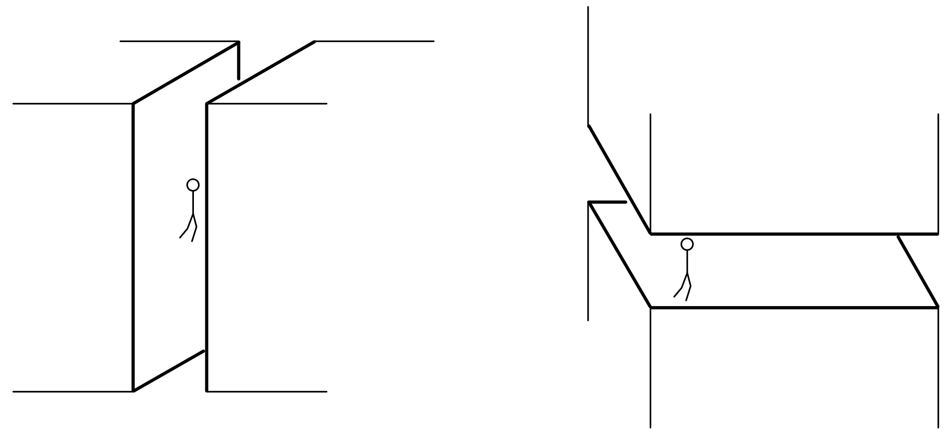
SHAPE
Square or spherical
A different shape has different options for a sports and has different results in use, whether we are talking about trajectories of objects or human movements. In spherical or cylindrical space the radius will provide possibilities to 'run around' the interior surface if the force towards the next step is angled in the right direction the next step will also connect to the surface. Without the surface radius this is impossible, as the body would travel away from the surface with every push. The radius of the Skylab space station allowed such running with a functional interior diameter of roughly 6 meters. Larger diameters will make it harder to run and stay connected to the surface with each step as the incline towards the next footing is lower.

Square spaces are much easier to understand and are therefore also very interesting to manipulate as a small rotation gives a whole new meaning to the orientation and appreciation for the spatial qualities. In spherical spaces the space is already omni-directional an therefore not much changes on personal orientation changes, the only feeling of changes is relative to the other objects and that are also floating in the space. The orientation shifts in a squared off room have a much larger impact on certain angles, close to the 45 degree mark.

Finishing of the interior walls and their connection can be up to the design strategy in this case, soft corners don't necessarily mean a loss of useful space but are able to give more strength to the to the construction. Though sharp corners can calm the mind by limiting a wall visually and explaining where the next wall begins, presumably at a 90 degree angle for understandability.

ORIENTATION
Orientation in space is a problem as we cannot rely on the placement and shape of object to point us in the direction of what is down and thus what is up as well. When we look at the world our brain uses references to what it knows and understands to be right, to construct and understand what is happening around us. When these cues disappear we get disoriented and cannot function properly. We see objects in relation to each other and base conclusions on verticality on these relationships as we know their normal orientation.
The madhouse the Villa Volta in the Dutch theme-park the Efteling uses manipulation of these cues to trick the visitor into thinking the bench on which they sit is turning 360 degrees over head. Though the bench only turns 30 degrees, the room is spinning 360 degrees at the same time as the bench, to further enhance the disorientation the cues on which you think you can rely are manipulated as if working with gravity but actually are not.
There seems to be a strong indication towards an intrinsic orientation in orthogonal structures with 90 degree angles. "Skylab astronaut Ed Gibson reported a sharp transition in the familiarity of the wardroom when rotated approximately 45 degrees from the "normal" vertical attitude in which he had trained." (Hall, 1995) If we can relate this to the fact that at 45 degrees the orientation cues can either stay in the horizontal position or turn into a vertical orientation (in the astronauts brain) going beyond 45 degrees will decrease the angle toward the new vertical.

The specific orientation of a space is directly linked to the spatial cues we know from Earth. These cues can be taken from anything in the space, but most importantly from the distance of two opposing walls relative to the walls in the other main directions (x,y,z), doorway orientation, windows placement and orientation of props used for stationary activities.



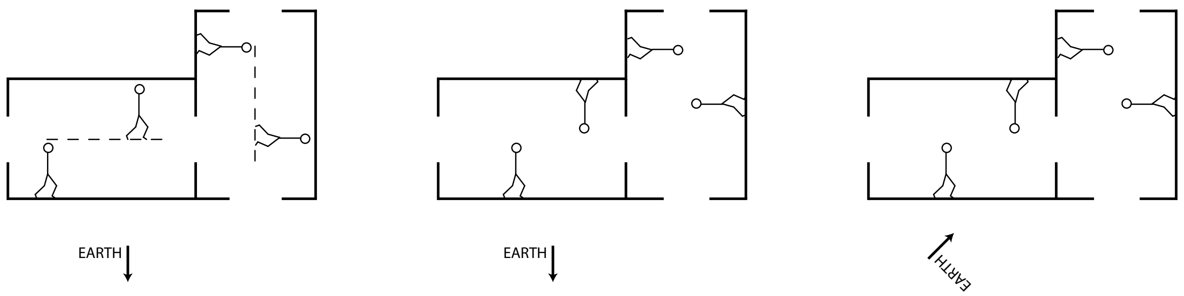
Different perspectives of the same space have a clearly different feeling to them when viewed from the outside.

On the International Space Station the direction of the spaces is not only given form by the fact that all the objects are located in a singular orientation for up and down, but also because of the form-factor of the spaces; they are all hallways, having their length longer than the height and width. The height and width are relatively similar and represent a regular floor level height.

Internal and External reference
Further orientation principles relate to the interior or exterior relationships. The external orientation is the reference to the Earth, Sun and other stars that can be seen from the space station, the stars and Earth are in a single orientation towards the space station providing an understanding of orientation in ever location and internal orientation. While the station is constantly moving in relation to the celestial bodies, the distance to the Earth stays the same with every orbit, this provides a visual orientation with a reference to what is down and thus what is up.

When we disconnect from the orientation of the outside, especially the Earth, orientation principles can be controlled by the interior design. A single room can either have a clear orientation or a combination of relevant directions for the activities performed inside. Each activity has an orientation for the use of equipment or props that is locally defined, having different settings for several activities in the same room can result in a space without clear orientation, the specifics quality of microgravity.

The relative orientation of adjacent spaces and spaces that can be viewed from one room to another is also important for the sense of orientation inside the space that is used. The normal orientation in a gravitational pull with the verticals as main elements can be seen from one space to the next and it will always be the same, this is mostly caused by the limitations put on the use by gravity; angled spaces are problematic to use. In space rooms located next to each other might have completely different orientations, which can also be visible from the used space to the next. These rooms might be very logical internally with a clear orientation, the adjacent room might also have a logical internal orientation but because of their shift in the global orientation the transition between the rooms becomes the defining element for the spatial experience.
Each entry into a space becomes a portal to a new orientation, therefore this doorway should be designed around the specifics of either or both the first or the second room. The entry can already point into the orientation of the room that lies beyond, creating more of a gradual transition than a sudden point of transition.
In general all activities have a certain orientation principle that corresponds to the experience required to either get the most out of the experience or get a high level of efficiency. In relation to the activity and the space designed the internal orientation, orientation in relation to adjacent spaces and the relativity to the Earth can control the way the humans in space will use it and more importantly experience it.

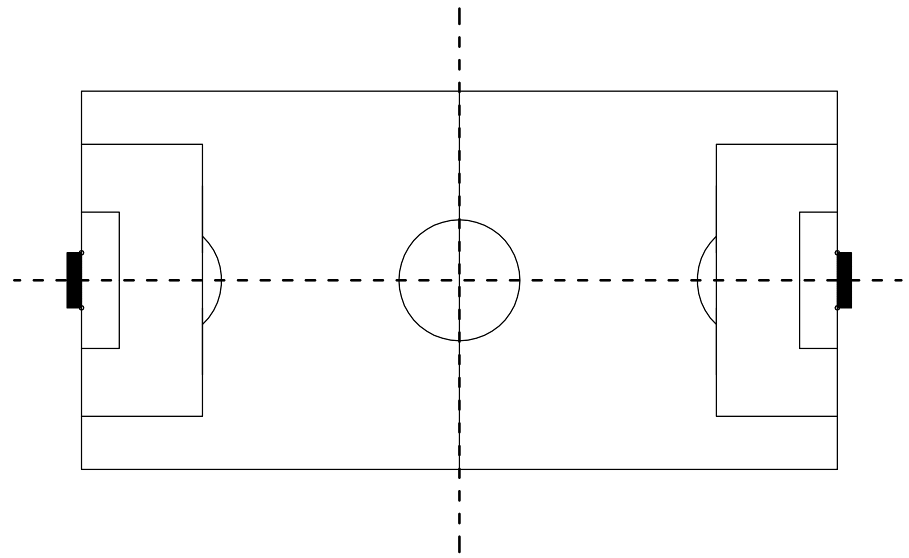


The relation between two activities in the same space, two spaces and their relation towards the Earth.

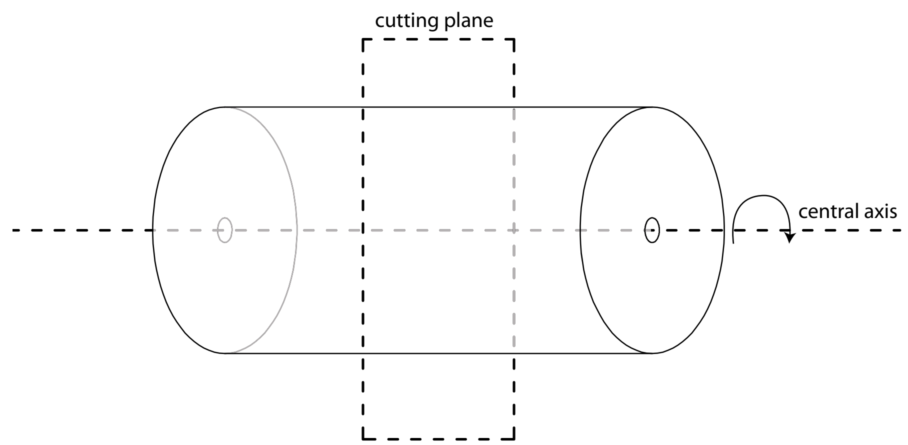
It should not be necessary to always have a view of the Earth to know the global positioning in the space craft, if the interior is clear enough a single glance at the location of the Earth would provide enough knowledge to know the orientation of the space for a longer period of time.
In some cases the view on the Earth will most likely only create problems in orientation as the people will try to hold on to this orientation, making it harder to use the space in any other orientation.

Orientation in Sports
In sports these orientation cues are of importance to winning or losing and can be artificially crafted to point each team in the right direction. Specific points on the edge of the playing field could indicate your location and rotation based on their relative distances and colour. As an example the goals in any ball sport could take the colour of the specific team, so you would always know the orientation of the playing field axis. This should be one of the main orientation cues in any sport with two opposing teams.
Cues that are not intrinsically related to the sport played should not be necessary, as orientation in the direction of the actual up and down related to left and right are only important to maintain an orientation based on what we know from earth.

In most sports the important aspects are opposite goals, either in line or a point form, and most of the playing fields are mirrored on two axis. In space the main axis should be maintained and mirroring around the halfway should also be done, but in space these axis and mirroring should be done in three-dimensional manner. A soccer pitch for instance has a clear structure around two opposing sides with the complete pitch mirrored around two axis.



Soccer pitch with its distinct mirror planes. (scale 1:1000)



A possible translation from a regular Earth sports pitch to the omni-directionality of space. (no scale)

Full-court / Half-court
In certain sports the court is not oriented with opposite goals with defenders, midfielders and strikers but all athletes on an equal basis in changing roles. As in squash the court is half its cousin tennis the turns for hitting the ball are changed every time the ball hits the front wall, as if passing over the tennis net. This also applies for half-court tennis, and also basketball. In basketball in specific the offence and defence change on who has the ball and what position they are in. The goal stays on the same side but cannot be scored in while taking the defensive position. After turning over the ball the new offensive team has to clear the ball, meaning it has to be taken outside over the 3-point line or behind the centre line depending on the specific rules before this team can score points.
Halving the court size has its effect on the amount of space each player has in the game, a regular basketball game is played with 5 against 5, a half-court game is usually played 3-on-3, 2-on-2 or 1-on-1. The biggest advantage for half-court games is the efficiency with which the playing field is used, especially in half-court tennis both players utilize only half of the required space for a regular

game, in basketball 6 players use half of the space required for a full game with 10 people. This difference is not that big, but the game can still go on with only half the required size.

ARTIFICIAL GRAVITY

In several studies artificial gravity has been proposed to limit negative effects of microgravity on the human body, most prominently muscle loss and osteoporosis or bone loss. But it could also be interesting to be implemented in a sporting environment. Artificial gravity could make it easier for sports to be adapted for outer space, though recreating a 1G environment would also mean the sports don't utilize the specifics of the outer space environment; the apparent weightlessness. The level of gravitation could however be adjusted to create different environments from 0G to 1G for a small to realistic push to the surface, or go beyond 1G creating a heavier than Earth environment to perform in.

The artificial gravity in theoretical studies has always be produced by a centripetal force working on an object; an object inside of a spinning drum. As much as this specific type of artificial gravity has been covered in space exploration history, it lacks essential elements of gravity to be adapted by humans as a logical replacement of real gravity; objects attracting each other because of their mass. The problem with a person being inside of spinning drum is a difference in outwards forces as the revolutions per minute of the drum is static, the distance of the feet of the human to the centre point of the drum is different from the distance of the head to the drum. This creates different outward facing forces on the body, being maximum at the feet and smallest at the head. As long as there is no change in the setup there is no problem, but as the person as much as moves its head he will already feel something is wrong and get motion sick very fast.

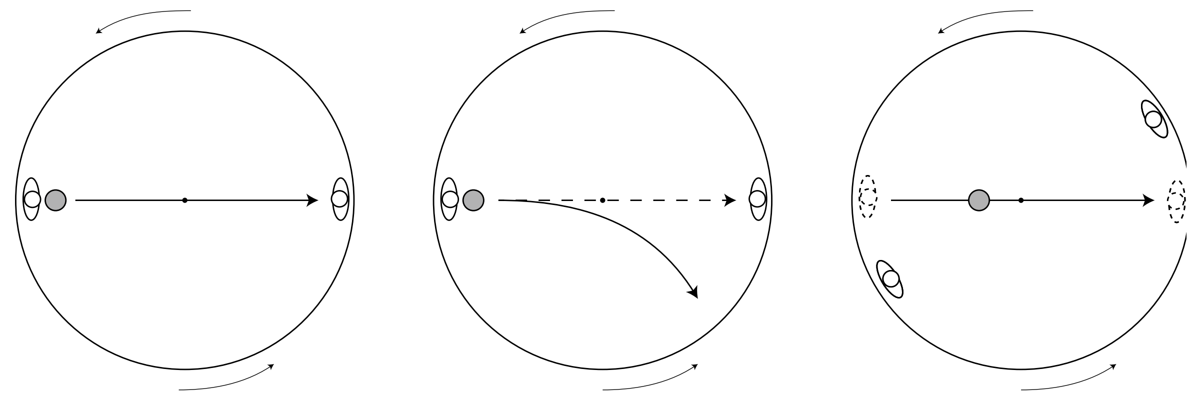
From general literature the dimensions of a station to counteract the effect of Coriolis forces should be about 3 kilometres across; a size that would make the Coriolis forces unnoticeable for humans. This size is directly related to the speed and rotations per minute of the station, it seems that every person can adjust to a certain amount of rotations per minute.

There is however not much research on the minimum size of the a rotating space station in relation to human adaptation to higher rotation speeds. The smaller cylinders would require more rotations per minute (rpm) to create the same level of outward momentum than a larger drum would require to gain the same outward force. The problem with the smaller drum does not lie in the higher rpm count but in the relative difference of the radius from centre of the cylinder to the head of the human and the radius from the centre to the feet; this difference creates an unnatural imbalance when moving. Standing still there is not much of a problem, but even the smallest movements can cause discomfort in disorientation, illusionary self-motion, improper reflexive eye movements and motion sickness. (Hecht et al., 2002, p 151) Hecht et al. (2002) has studied the effects of higher rpm small-radius centrifuge [SRC] on the human body and found proof that however people felt nausea, the effects decreased as they spent more time inside of the SRC. A pointer in the direction of physical adaptation to rotation induced artificial gravity.

The research is done on Earth and is therefore influenced by the Earth's gravitational pull, the next step would be to create a centrifuge in space to perform more realistic research in the environment it is aimed for.

There are some aspects of sports in artificial gravity that have been explored in earlier studies, such as the artificial gravity swimming pool.

An aspect that makes artificial gravity especially interesting for new space sports is the fact that when an object stops its contact with the rotating surface it continues movement in a straight line; but because the world is spinning the trajectory would seem odd from the inside. The only addition to this trajectory is the internal disposition of the initial thrower, who could actually catch his own thrown object if the speed was right. The athlete would have displaced himself during the same time the object was traveling in the straight line.



Relative results of Coriolis force on a spinning environment.

"Experiments with human subjects in centrifuges and rotating rooms have confirmed this. When subjects turn their heads about any axis that is not aligned with the rotation of the environment, they experience vestibular illusions of rotation about a perpendicular axis. The illusions are approximately proportional in magnitude and direction to the vector product of the angular velocities of the environment and the head. The resulting mismatch between the vestibular and visual senses of motion are believed to be a major cause of motion sickness. To minimize these illusions while permitting the normal range of human motion, the angular velocity of the environment should be kept low." (Hall, 1995, p. 297)

"The grammar of architecture for artificial gravity should accommodate this fact. To be meaningful, architecture should have formal properties that are similar to other aspects of the environment. The goal is not to fool people into thinking they're still on Earth, but rather, to help them orient themselves to the realities of their rotating environment." (Hall, 1995, p 290) A statement that is as true for artificial gravity as it is for microgravity.

Artificial gravity swimming pool. (Collins et al., 1995)

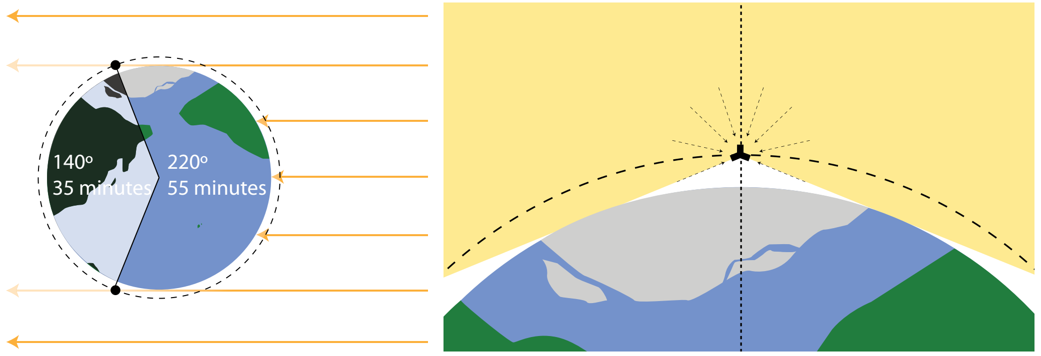
A passionate advocate of space sports, and even an orbiting stadium, is Patrick Collins, Professor of Economics at Azabu University in Japan.

In his research on space sports, Collins and colleagues have speculated about water sports where space tourists can dive through large blobs of water. And why not zero-g versions of existing terrestrial sports, such as table-tennis, badminton, tennis, and even basketball?
http://www.space.com/1855-space-sports-closer-reality.html

LIGHT

As the station makes a complete orbit around the planet every 90 minutes the dark and light elements of the day are not related to the same time frame we have on Earth were a day takes 24 hours and has a single day (light) and night (dark). The duration of the sun lighting the space station per revolution is 55 minutes, the time the station is positioned behind the Earth, compared to the sun is 35 minutes.

As the station is always oriented in the same direction towards the Earth there is a top, bottom, front, aft, starboard and port side. With this distance from the planet the relative area's of the station that will catch the light are located on the sides and top. The sun can come from any direction except the area blocked by the Earth which covers an angle of 120 degrees of the total section. Other light coming in is redirected light reflecting from the Earth's surface, the stars or city lights from large cities.



Duration and incoming angle of the light towards a space station in orbit at a distance of 400 km above the Earth's surface.

Artificial light

Several spaces make use of the possibility to fit the omnidirectional character of space, this means every wall is ceiling floor and separating wall at the same time, this asks for a very specific light plan. As some area's might wish for lights shining from the top, this same light means it will shine onto the bottom of another object or area.
In case of complete omnidirectionality as in the spaces for sports light fittings on all walls enhance the equality of all sides, by changing lighting in some directions prevailing directions can be created to enhance orientation.

In spaces with clear orientation lights can be used to indicate the ceiling of the space, or in case of sleep an orientation in relation to a night light. To light such a compartment evenly without installing light on all walls, lightning should be placed in the corners to light the room without hard shadows from the top. With light coming in at two angles the general space is gradually lit from top to floor without strange dark or light area's depending on orientation.
Because lights could be in the way of a moving person, with lights all around the specific lights should feel cold to the touch. And are ideally integrated into the walls to not have lights sticking out. In ideal cases they are combined with elements of importance so they are easily spotted.

POSITIONING IN SPACE

To not get 'lost in space' in larger volumes without opposing walls at a distance smaller than 2,2 meters apart, extra tools are required to keep control of positioning. A movement through the volume that is stopped by an opposing force might result in being unable to move towards a wall, as there is no object to move away from. An option would be to tether each person to the side of the space with a bungee-cord construction, as the person travels further away from the wall the tension increases and the movement speed is decreased until tension reaches a level where the person is returned to the initial location. A disadvantage in this case is the fact that the person will always return to the original location. Further more there is a high risk of tangling the different tethers making knots in the lines and requiring intervention to return to the original location.
Different lines or ropes could be placed inside of the space to be able to get a grip in any part of the space, structuring these 'grips' also create pathways and a divide in the playing field structuring the game. Removing the tether provides much more freedom for movement.

In more advanced sports for people that have a greater understanding of the physics in space the free positioning in space might be an advantage to counteract an opponents movement, making him unable to participate in the game until a team member gets the person into an active position again.

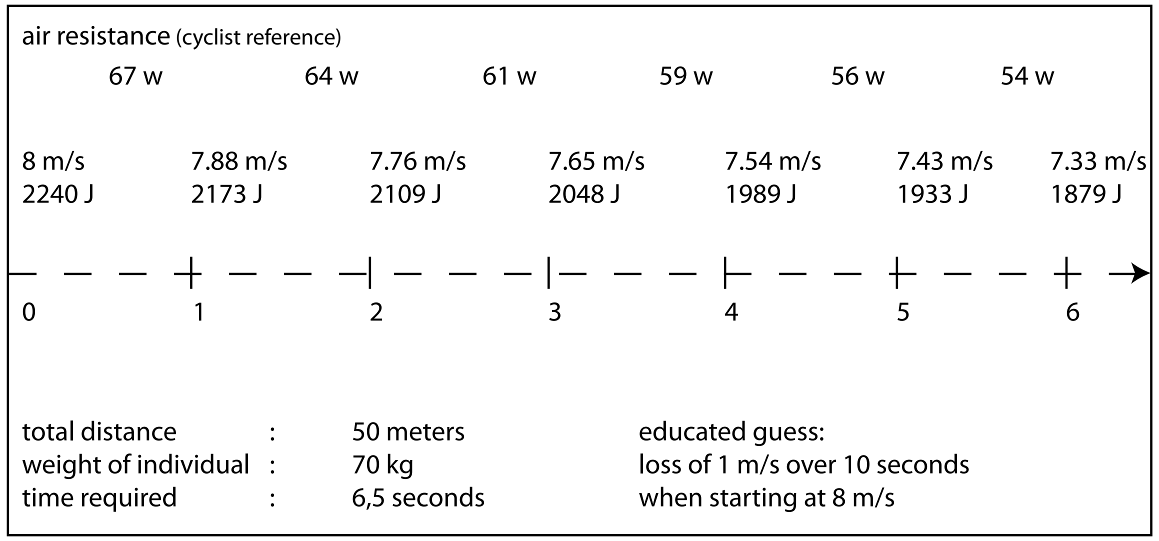
MOVEMENTS, MASS AND FORCE

As Einstein already stated, a force and action are always attended with an equal and opposite reaction. The law of conservation of energy applies very directly in a weightless environment, as can be observed by two colliding or interacting objects. The force is the combination of mass multiplied by acceleration. In the case of mass displacement the total body moves relative to the centre of

gravity, midpoint of the mass.
When moving an object like a racket or bat, the movement of the mass in the object also has an equal and opposite force on the person swinging the bat or racket resulting in both a movement of the object as a movement in the body of the sportsman. As the mass of the interacted object increases the ratio between the human and object decreases and the ratio in movement on interaction changes. With equal mass the objects will gain the same velocity on interaction.
Other than objects, humans can interact with each other in this case the masses are relatively similar, a collision in 'mid-air' with the same velocity would result in both people becoming stationary on impact. Either one of the persons pushing away the other will result in both people moving away from the original location with the same speed in opposite directions.

If an opponent tries to get to the other side of the space by flying through the centre there is a possibility to counter his movement by an opposite force that is equal, if an object with a quarter of the mass but four time the speed is launched at the opponent it is possible to take him out of an active role in the game because this person only has limited options for movement without interaction with an object. An option for his teammates is to intercept this person by flying towards him and giving him some of the own momentum to both reach a stable position in the playing field. In this case watching your teammates becomes crucial to become victorious.

The movement speed in space from a leap pushing away from a wall, the maximum speeds attained by the human body is roughly 8 meters per second, or 29 km/h, for a trained athlete such as an NBA basketball player. Hitting a wall or solid object with this speed injuries are a real threat. At these speeds and with a trajectory in the direction of head to toe the resistance on the air with regular atmospheric pressure is relatively low, resulting in a high maintained speed. In case of a mid-air collision with another athlete impact speeds can reach around 50 km/h!



Speed in relation to body mass and initial pushing speed.

INTERIOR MATERIALS

In each sport the contact surface is different, on Earth sports are played on all kinds of surfaces; grass, dirt, gravel, wood etc. Each of these surfaces have different characteristics with regards to the effects of toughness, traction, forgiveness and so on, therefore each sport is partially characterised by the playing field.
Most of the playing fields could turn out to pose risks to the human health in microgravity creating hazardous sports environments, as small particles of the pitch could come loose in space and float into the airways of the athletes. There are two options to solve this, either by not creating these hazardous environments in the first place or protecting the athletes from inhaling the dust by protecting them locally in form of face masks and goggles.

Softness of surfaces could be required, especially in the initial stages of space sports, forgiving surfaces that don't result in injuries when hit in an unintended matter. Though bouncing of a ball against the wall will work better if the wall has a hard surface.
The speed in which a athlete will hit a wall is calculated by the initial speed the person is given plus the extra momentum acquired along the path of flight. The initial push can in most cases be related to a jump on planet Earth, in which an athletes will reach a maximum height in a vertical jump of 90 centimetres and an average male between 40 and 50 cm. If we look at the speed acquired during a jump we will find that the initial speed in a jump when leaving the surface is roughly 3 m/s or 10.6 km/h: the speed of a fast jogging pace. ($v=a*t$, $a = 9{,}81$ m/s2, $t = 0{,}3$ s (the time to fall from 45 cm to 0))
But to reach the 95th percentile as a male between the age of 20 and 25 you would need to jump 70 cm in a vertical jump, this results in an in space velocity of almost 7,5 meters per second, or 26,8 kilometres and hour. As this is a reasonable jumping height and speed to account for in tourism, and probably even higher for professional athletes collisions could be quite dangerous.
This speed can be increased by putting more energy into the movement while still moving, either by teammates pushing or pushing against solid objects to propel you even faster in the desired direction, each push just adding speed. The only force slowing you down is the drag from the air in the cabin against the your body, though at these speeds the resistance is relatively low compared to the initial velocity.
The resulting speeds could be dangerous, possibly lethal, in case of a head-on collision with another person or a hard surface. To protect the tourists and athletes the surfaces should be forgiving in case of a collision to limit the harm done to the tourists on impact.

As sweat comes with exertion from sports activities interior surfaces need to be able to either repel the moisture or absorb it during the games to be cleaned afterwards. The disadvantage of repelled moisture is in the point where it has the possibility to enter the athletes airways or throat, both will be very unpleasant in their own respect, either getting water down the wind pipe or tasting your own sweat or the sweat of another athlete. On the other hand it might be hard to extract the moisture from an absorbent surface. A surface that would hold moisture until it is wished for the be released would be ideal for space sports, or simply letting the surface dry by ventilation the space with interior air for moisture circulation. Hygiene of the playing field is the next problem. The moisture that is lost by the athletes in mid air and has not reached the borders yet might be an issue that is much harder to tackle. In this case highly absorbent clothing might be a better solution.

Hygiene
In hygienic sense athletes need to clean their body after their sportive efforts, at this moment the hygienic equipment is barely sufficient to clean the body from such efforts. At this point on the International Space Station astronauts use wet wipes and no-rinse body bath to clean themselves. A relaxing shower is currently unavailable in space, something every sportsman or woman enjoys after an athletic endeavour.
But not only in sports, also in general space tourism is this an issue. In the current age there should be a design for a space shower that provides the pleasantness of a warm shower without the problems of installations and health risks. The shower used in the past, that was transformed to a steam bath and later removed, took almost 24 hours to set up. In a setting where time and space efficiency is not as important a shower could be installed permanently.

Sound
Because all areas are enclosed modules sound reflections might become a problem in hard environments as echoes could reverberate for long periods of time. The station could sound like being inside of a tin-can, something that is not a desired experience. The communication between team members is also hindered by excessive noise levels. Problems resulting in requirements for softer materials that dampen and diffuse the sound.

TRAINING FACILITIES
As the athletes would do on Earth, training is their main activity and takes more time than the actual match will. To have interesting matches, with a small amount of mistakes and failures to decide the result of the match, the athletes will have to know what they are doing; this takes time and practice. Taking Earth athletes and making them play their game in a microgravity environment will not make them good at their sport in space right away. Of course they have an advantage in tactics and body control over regular people, but they will have to adapt to the lack of gravity in which some might adapt easily and other might have a hard time.
New space sports are at first likely to be practiced by athletes that have performed a sport as a full time profession on Earth and are ready to take the chance on sports in space.

GRIP
Holding position
As the main propulsion in space will be coming from personal muscle use, this propulsion has a force and should be efficiently applied on an object with mass. To transfer the force the surface should be rough or have a way to hold on to either by hands or feet.
The grid used in the Skylab orbital workshop to position one self provided places for the astronauts to insert the attachments that were fixed under their shoes. They would latch onto the grid with the use of simple form fixtures. The iso-grid integrates the functionality of being able to latch onto a wall and structural rigidity on the inside of the space station with the minimum of weight used to construct it. The triangles that exist inside of the iso-grid provide enough changes in shoe inserts orientation to work in every situation. The feet can be placed in the grid in 6 different directions, each direction shifting 60 degrees compared to the former and next orientation.
As a means to attach oneself to a surface or object in space a pin could be inserted into a material that can hold it. The pressure applied to insert yourself should be quite low, to extract the pin a higher force should be applied, by a means to get away from the hold by jumping or pushing away with the other leg. Pushing with the other leg would only work in case of a non fastening of this leg, a single fixture should also be enough to stay in place while performing other activities.
To keep position with no attachments to the feet, the connecting surface should encompass all the required equipment to make the connection. Thus requiring a contra-form to the feet that needs to be latching on. As all feet are different the 'hole' should be formed to the specific foot on insertion, requiring an adaptive material that can form around anything similar to a human foot. This connection can be very strong and keep the human well in position with a lot of control over the rest of the body movement. But the disadvantage is a fixed position for the foot, making it only possible to use in the specific location and not for fixture half a meter away, this will require a new fixture.
Another option would be to attach yourself to an object or wall with the use of Velcro, walls and objects having the hooks side and people having the rings side. In this case objects cannot be attached to walls, so objects should have both male and female variants of Velcro on them, as a result objects can also easily be attached to each other.
Electro magnets would be a similar solution though with these magnets there is also a possibility to turn them off completely resulting in a free disconnection. An advantage would also be the possible attachment to any metal wall or object.

Regular grips
Like the hand can hold a grip the feet can also use this as a means to hold position. With the grip on top of the foot and the wall below a static position can be achieved. Increasing the resistance on the areas of connection the position in 'horizontal' displacement can be controlled to a higher level.

Providing grip for movement
For a person to move himself forwards he needs a solid object to push against, in the case of a space station the biggest mass is the station itself. Pushing against a wall will make the person

float in the opposite direction. To displace along a wall regular grips could provide ample traction and resistance to put a force on parallel to the wall, but also without grips a parallel movement is possible. If the walls are close together pushing against both at the same time and forwards the resulting vector should be parallel. The pressure put against the walls create enough resistance in friction to push forwards. This positioning is only possible with the proximity of two walls within arms reach.
If the walls are further apart the movement through the space will be a combination of displacement along the axis of head to toe and as well as from side to side, from one wall to the next parallel to the main direction of displacement.

Architectural requirements and design brief

For a general group of tourists a starting amount of twelve seems reasonably small to be manageable in housing, but also interesting enough to go into space with people they don't know. Social interaction is a key feature to make the space journey worth wile as the duration is long as a medium length holiday of roughly two weeks. During the tourists stay a relative crew size of 6 astronauts should suffice, for every two tourists there is one astronaut to guide them.
All goods that are required for the two week stay will be transported with the newly arriving space transport and taking down by the one returning back to the surface of the planet. Each time 12 tourists are taking by a single rocket flown by three astronauts, the other 3 crew members are staying on the space station for a longer period of time as a very experienced crew, the actual up-time is also depending on the research they are running. Some crew members might work in shifts of two weeks on, two weeks off.

PRIVATE SPACE
Description
The private chambers are based on a single tourist or crew member forming their personal space. This space can be modified to the persons needs and wants to make the individual feel at home. The main purpose of this room is to provide a space to sleep, but also supplies room for reading, writing, communicating with family and window gazing.

Spatial requirements

People per unit:	1
Amount	18
Total space:	36 m^3
Orientation:	Facing Earth, able to see full space station; multiple or large window
Space relation:	Hygienic, common room

Lighting
As the station turns around the Earth in a 90 minute orbit, the light changes every 35 (darkness) or 55 (light) minutes by approximation. As the station turns behind the Earth there is virtually no light entering the station, as the station turns to the front side of the earth the light that is coming in is very strong as there is no scattering of the sun rays in space. In a sleeping cabin this has to be accounted for as the tourists and astronauts don't want to wake up every orbital period during their sleep time.
Windows are required to be able to see outside from the personal cabins in a private setting, to both have a feeling of direction and get in natural light. The inhabitant of the room needs to be able to control the opening and closing of the blinds him- or herself.
It should also be possible to have directional views out of the space station, as the sun is coming in from an certain angle, this should be possible to be blinded out but still be able to see in the direction of the planet, the stars or any direction other than the position of the sun at that moment.

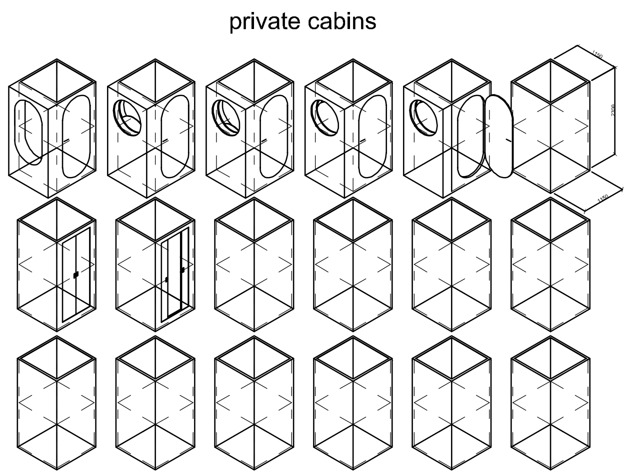
Sleeping
To sleep in the microgravity there are two options to make sure the nights rest is maintained, one is to fasten the body inside of a sleeping bag making it impossible to float away and bump into something resulting in waking up. The other possibility is a soft padding inside the total chamber, which is closed, making it soft to float into a wall.

Communications
For digital contact with family and friends on the surface of the planet the tourists can also retreat to their private quarters connecting with their loved ones through video conversation. The connection only requires a laptop, tablet or other similar device to connect with the home front, being able to inform them on all of the experiences the tourist has gone through during the day(s). The only requirements for this type of activity is a screen to view and a camera and microphone to record, of course a digital connection is required for the instant transfer of data.
Certain product tests can be done by tourists themselves, sent up by their companies, these people require quality connection to converse with their colleagues on the ground to make the most of the time in microgravity.

Entrance
As this is a private area the gateway can be small, only a single person has to be able to come in and out at a single moment. An entrance gate with a diameter of 80 to 90 cm would be large enough to ensure the passing of a person in regular clothing.
In space history the entrance to the sleeping compartment in both reality ans science fiction has been through the upright/long direction of the chamber, this makes it much easier to enter the small chamber without having to bend yourself to fit through the door without hitting the opposing wall. In this case backing out of the small volume has the be in the reverse direction of entry, thus legs first.

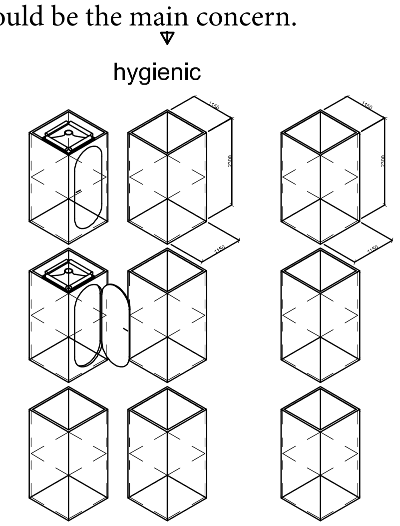
Grip
The space is smaller from itself as it is only meant for a single adult to be inside, this also means there are always walls in close proximity to be reached, even two walls making it possible for a person to propel him- or herself by pushing against both walls at the same time. Extra grips will not be necessary.

Orientation
The private retreat for the tourists should provide a space where tourists can get a sense of their bearing, an orientation that is linked to what they know from experience is up or down to limit brain activity that is trying to make sense of microgravity. Interior orientation should be focussed on creating a clear orientation in the room, but even more important there should be a visual reference to the planet that lies below. Its position is always the same and should therefore be used as the most important orientation visual reference.



18 private cabins. (scale 1:200)

HYGIENIC
The shower is an area where expertise in technical elements is a lot more important than experience, feeling and aesthetics. There have been some showers in space with their iterations and adaptations and none of them functioned as planned or was worth setting up. From an architectural point of view there is a lot to say and to wish fore in the experience.
Ideally the shower should feel like it is on Earth, a calming element in the special space experience, be warm, comfortable and especially soothing. When it comes to orientation, the cabins should face the same direction as the private compartments to be easily found in the morning, this is the same for the toilets which have to be easily found and understood during the night in case someone needs to use it.
In case water is used instead of steam, it should be flowing from the head to the toes adding direction to the space whilst in use. If this is the case, a general lightning system all around the tourist should be possible without having to rely on fixture at the ceiling of the room. Soft lightning from the sides would be more interesting as it hits the water droplets and refracts through them to create a light spectacle in the space.
Soft and warm lighting will set the right mood for a morning shower, or relaxing shower after workout.
Translucent walls and windows will open up the small space visually, as a 1x1x2 space is relatively small. Though privacy is and should be the main concern.



6 shower- and 3 toilet-cabins. (scale 1:200)

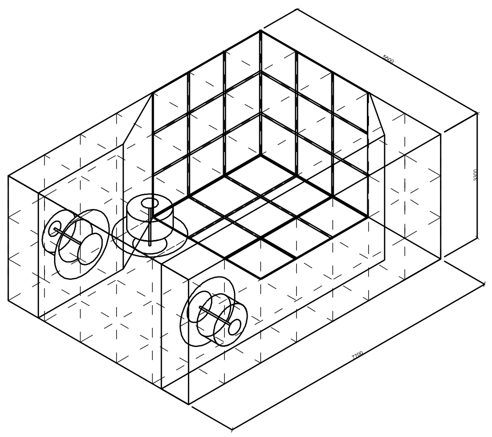
COMMON ROOM
The common room is the space where all users of the space station come together and interact with each other in informal way. The common room is also used for heaving breakfast, lunch and dinner together. The space is also used for instructions and simple experiments that can be done by tourists to get a better understanding of their surrounding by visual results of small tests.

Requirements

People:	18 (12+6)
Space:	40 m^3
Orientation:	Window to Earth and the stars, central position in the space station
Space relation:	Private chambers, toilet, hygiene, fitness, activity / experiment

Grip
As the space has to accommodate a large amount of tourists the volume becomes quite large, up to a point where one might get lost in space. In this specific use there should always be at least one point to hold on to, to position the body in the space. This point could located on any side of the body as feet control is as useful as controlling position by arms and hands, when one point is let go of there

should be another in the vicinity to make sure the tourists and astronauts can control themselves, this results in a maximum distance between two points of contact of around Le Corbusiers modulor 226 maximum height of 2.26 meters between two opposing grips or surfaces.



Orientation varieties in common room setup. (scale 1:200)

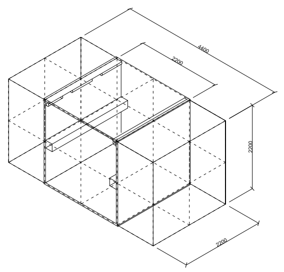
RESEARCH

To continue developments in space exploration the research lab should be installed in future space stations, combining pleasure and work into a feasible research environment. The architecture is very similar to the currently in orbit International Space Station, completely focussed on efficiency and minimal space requirements. Extra experiential elements are not required or wished for to maintain a clear working environment. The spatial orientation, shape and size is already drawn in the activity description.

The space is closed of to tourists in general, though might be open in specific cases to inform the people or invite them for physical body tests, influence of microgravity on the body.

Requirements

People:	6		
Space:	Depending on research setup size		
Orientation:	Internal	-	clear orientation
	External	-	no requirements
Space relations:	control room and installations, restricted access.		



Typical research & control room element. (Scale 1:100)

SPACE EXPERIENCE ROOM

The room where the most interesting aspects of being in space are explored beyond the current possibilities as the space is larger than any space ever created in a microgravity environment. The space suited for acrobatics and free floating, but also to create a primary environment for space sports to start developments.

The space should be adaptable for multiple activities to be performed. For different activities different lightning types are demanded for, this could mean hard light from the sun, soft light through shuttered windows or artificial light during the dark periods when the Earth is positioned between the station and the Sun.

As some activities just require a small space for their activities and more specifically the possibility to control body position at all times, the distance between the walls for these activities should be smaller than in space sports. This requires adaptivity of the space or different environments within the same space.

The large expanse is also very nice for gazing at the Earth and be floating at the same time, the sunlight should not enter the eyes of the tourists directly and diffuse light in the area is only creating less detail in the view; darkness is required around the viewer to increase contrast.

Experimentation and space gym

The space that provides space for large amounts of people in both pleasure sports, workouts and experiments but also for the first stages of professional sports. The space fits beginning space sports but is also a space where tourists and astronauts can invent new space sports while being in the environment the sports will be played.

The main characterising specifications of the space are its size and lack of cues of what is up and what is down. The orientation cues are only aimed at performing the sport and limited to the bare minimum, to keep the experience as essential as it gets in space. Cues that can be thought of in this case are colour or lighting, in the last case the lights could adapt to different colours to be able to change to for different usages.

Sports require a much different approach than purely leisure oriented activities, a professional sport or even with amateurs the way the opponents enter the pitch is important for the players, traditional entry in a full group is desired. The arrival on the pitch should come from either a shared catacomb, or mirrored entries, but before that from a private team dressing room. Sports also require clear environments, especially if played professionally; a regular sports hall has the lines for each sport drawn on the floor in a different colour for each sport, but if we look at professional level basketball, the basketball lines are the only ones drawn. This keeps the rules clear at all times, making it look much more professional at the same time.

Requirements

People:	18 (12+6)		
Space:	>250 m^3		
Orientation:	Internal	-	omni-directional character
	External	-	open view towards Earth
Space relations:	Common room.		
in sports:	Dressing rooms, Catacombs towards the pitch.		

Lighting

Because of the very different uses of the space the lighting plan should be completely adaptable to the activity at hand, a lightning system is required that can be all sorts of colours, have a large range of intensity and could change the orientation input of the space. In case of a lack of natural light the artificial light is the only light, but during the hours the sun shines directly in their effectiveness is drastically reduced. In the case of a sporting event controlling the light is of a much greater importance than in an experiment setup, therefore a high level of controllability of the entering natural light is also very important, in sports.

DRESSING ROOMS

To accommodate the athletes before the game, their dressing rooms are based on the privacy of their team and the traditional entry towards the pitch together with the opposing team. Entering the pitch together with the opposing team creates a moment to get inside the opponents minds. A chance to look the opponent in the eye and gain confidence and fighting spirit. To ensure good communication and understanding between coaches and players the social interaction is important, levelling with each other and having the same orientation is vital, therefore the orientation should be clear internally.

Requirements

People:	8 (6 athletes + coach + physiotherapist)		
Amount:	2		
Space:	64 m³		
Orientation:	Internal	-	clear
	External	-	no common orientation
Space relation:	Catacombs towards playing field, hallway to common room		

DOCKING & DECOMPRESSION

Both the docking adapter and decompression chamber should be placed together as they serve a similar purpose, integration is wished for.
As one of the main experiential activities that is mostly unrelated to its architecture the spacewalk on the outside of the station. The path that leads up to this external experience can be of importance to the way it is experiences. By priming the tourists for their spacewalk excitement can be stimulated and/or anxieties can be reduced.
The optimum location for docking would be inside of the space station for experiential purposes, but as this is not possible a small station, with all the risks involved the docking port should be located on the outer perimeter of the space station minimizing the risk of damaging the station in case of failure.
The space should have one exit towards the experience room for a feeling of the suits in a safe environment, not yet on the outside of the space station. The internals of the larger measured room provide enough wall to wall distance to feel like flying in the outer space in an actual space suit, get the feeling for the equipment, the use and movement limitations. An in-space spacewalk training.

The decompression room is not the same as the spacesuit donning room, but could be. In an experiential way the disconnection of the two activities - getting dressed and going outside - is focussing on the activity at hand in a specific room. The preparations during the first tests in the suit don't have to be connected to the exit point to minimize the feeling of risk and make people enjoy the experience of the moment. Going outside is much more tense experience, priming people for this specific spacewalk experience with the use of a smaller decompression room for just the small group in a tighter space makes it much more intense in anticipation.

The same smaller decompression room is used in docking with a spacecraft, being smaller means less air is required to equalize pressure because of the smaller volume.

Requirements

People:	9 (6 tourists + 3 astronauts)		
Space:	50 m³		
Orientation:	Internal	-	clear orientation
	External	-	no requirements
Space relations:	Placed outwards of the stations mass, the experience room.		

CONTROL ROOM AND INSTALLATIONS

In future space exploration the control room is relatively small, as most of the regular continuation of station management is controlled by the main on board computer. The controls are mainly focussed on keeping the interior climate right, as there is a limited amount of movement required to stay in orbit, and there are no direction changes that need to be controlled by the astronauts. The spaceship is actually very stationary.
The control room should be able to monitor and control the entire conglomeration of space modules for efficient use of space.

The location of the life support systems or general installations is much more important as they should be reachable in case repairs are required. They should be easily accessible for the crew/astronauts but not for anyone else. Either located in a closed off space or in closed cabinets, though for the sake of sound isolation a closed-off space would be referred. In case all of the modules have a local life support system they should also be located in the same place for every module to be easily found to fix a problem. An advantage of the localised systems in multi-module configuration is the possibility to rely on the other systems in case one of them starts to fail and in case of a module relocation.

In both cases the orientation should have a single direction to understand each dial, screen and switch as shifting orientations become very confusing, something that is not wished for in case of precise control. Reference to the outside world is not required.

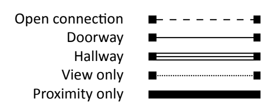
HALLWAYS

There are different forms for hallways to be designed in space depending on the requirements for the rooms they are connecting or passing through. In the case of the researching area the hallway is the work floor, the space is shaped like a hallway to use the space efficiently providing enough space to get through even when people are working on both sides.
The connection between the private cabins and hygienic rooms has to be a hallway or space in between, the hallway that is also connected to the common area creates a transitional zone from the shared to the private. It makes sure no accidents in the hygienic spaces result in problems in the private sphere or the common room at the instant the door is opened. The space between the private and the hygienic creates a direct link making the orientation clear for all the personal cabins and their relation to the hygienic cabins.
In the other areas the integration of passageways into the interior is wished for to enhance the intensity of the space usage. As not all the space is used for a single activity at a time, getting around the active area should always be possible without a dedicated hallway.
As hallways offer a softer transition between public and closed spaces, the entry point for the control room and the research department should be located outside of a room and in a hallway.

PROGRAM PARAMETERS

The resulting relations and space characteristics can be combined in a clear table also relating the spaces to each other.

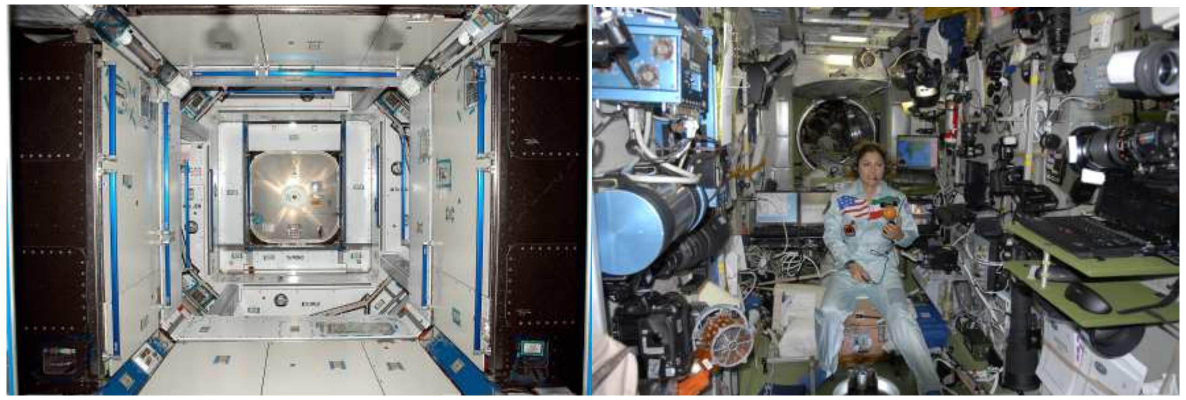
Activity		Space	m3	Orientation	Common orientation	Lighting requirements	Relation
Sleep		Private	60	Clear internally and externally	.1.	Complete control natural and artificial	
Earth-Communications Command / control		controlroom and installations	50	Clear internally	.2.	-	
Eat		Common	130	Activty based		Complete control	
Research		Research	100	Clear internally	.2.	No direct sunlight	
Prepare for game		Dressing room	100	Clear internally		-	
Sport Yoga Acrobatics Windowgaze		Experiment and sports arena	300	Omni-directional		Should allow for any light condition to occur or be planned	
Toilet Shower		Hygienic	30	Clear internally	.1.	-	
Spacewalk Docking		In / out	60	Clear internally		-	



Architectural representation

Astronaut space exploration
As the architecture for astronauts has developed during the past half a century the designs have developed from small enclosures to larger volumes housing the astronauts in space. Although there have been larger volumes providing great freedom for experimentation the later space habitations have shown a simplification and logic inside of the stations that one could relate to an office architecture on Earth. As the internal architecture is as efficient as it gets keeping in mind the body of the astronauts providing the space for controlled movements without getting lost in mid air. The aim is obvious: creating an environment that is as efficient and clear to understand to maximize astronaut productivity.

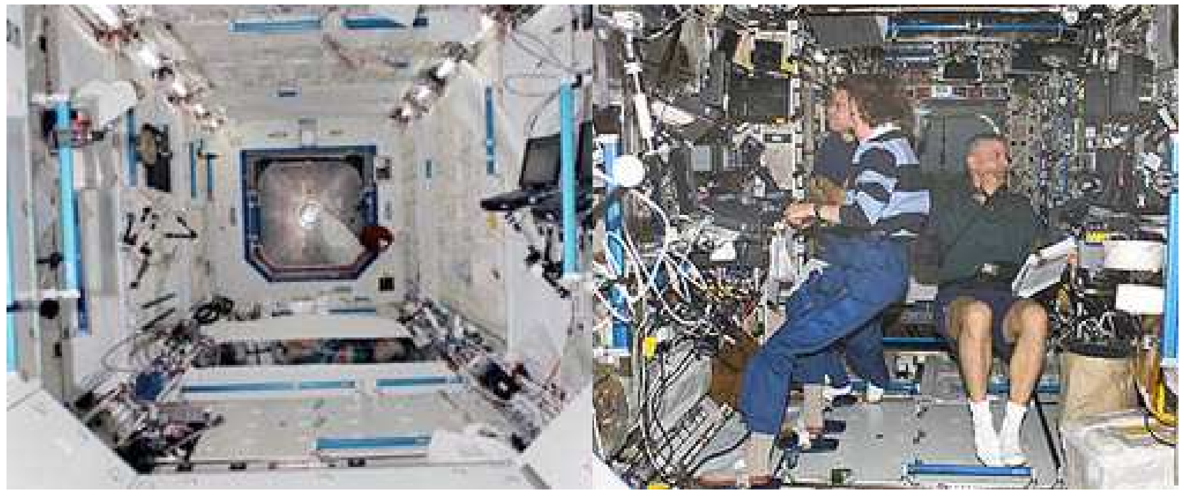
The result is a modular system that has a standardised system of cylindrical modules with rectangular interior spaces. The height and width of the interiors typically have the same measurements, in the International Space Station these measurements are 2.1 meters. This size makes sure most astronauts can fit in up right but will always be able to reach for contact with the walls and the handles mounted on the walls; effectively never resulting in an astronaut stuck in mid-air.
The interior in this case is filled with equipment used for the purpose of research, to keep all the electronics neat and organised they are all oriented in the same way with which the feeling of an upwards direction is suggested. In earlier space habitations colours were used to indicated what should be seen as top and what as bottom, using green paint to indicate the bottom.


The blue color coded grips on the ISS (left) and the green floor in another module (right). (http://www.sts-missionnavettespatiale.net/photo_sts-120_harmony_inter.html) (http://www.spaceadventures.com/experiences/space-station/)

For the movement of the astronauts grips have been created in abundance throughout each module to make sure the astronauts can control their movements in any body position. These grips have tactically been painted blue as to indicate their use, to not let there be any doubt when trying to get a grip on the surrounding and not grab the technical equipment in a mistake as this could ruin a whole experiment.

As far as tourist activities go, we can foresee and predict several matters up to a high level of accuracy based on the activities of astronauts and space tourists, in which the exploration of weightlessness in the 'vomit comet' are also of interest, and can point to ways to enjoy weightlessness.

The activities astronauts have to do are in a small amount also activities compulsory for space tourists as they have to keep healthy by sleeping enough, eat and take care of hygiene; the basic requirements stay the same in space as they are on Earth. But this is until how far their activities will overlap with current astronauts, who have to exercise to keep fit which is not required for a short stay in space because the body will not degenerate that fast in microgravity. The tourists also don't have to work, they are not paid and are paying so they have to expect something for their spending. The time the astronauts use for their work is free for the tourists to act in the way that suits the space experience best, which is about 10 hours a day.


The exact same space module in the same orientation before use and in use. A clear representation of the clutter that comes with the research installations on the ISS missions. (http://www.nasa.gov/mission_pages/station/structure/elements/destiny_prt.htm)

Tourist architecture
The architecture required is a further development from the astronauts environment that is the most functional for its purpose of a working environment, the architecture for tourists should be more focussed on the experience of the key features of the earth orbit: weightlessness and the view on the planet and stars. The spaces should have larger expanses to accommodate more freedom in flight/floating around the interior, and the view on the Earth should be as clear as possible from multiple locations.
The shape of the spaces should also resemble a shape that is more focused on fitting microgravity and its omnidirectional character than the astronauts environment that is based on maximum modular adaptability and effectiveness. The tourist environment should take in account the human vision and ease of adaptation creating a similar environment as if one would be on planet Earth's surface.
The characteristics of microgravity should be utilized to create environments that support the assumptions and possibilities of the interior activities. Architecture that disconnects from orthogonal grids in some area's or even repetitive systematics resulting in a design that fits the specific requirements from an activity point of view to be effective and also show this in the physical form and representation.

Making the familiar strange and the strange familiar
The orientation of space internally and externally has the largest impact on the experience of the space station. Certain activities and spaces should have specific relations to adjacent spaces, but more importantly the activities and the way they are performed should create something different or something known. Certain activities are easily transferred to space, but have a very different feeling. In some cases as sleeping, in the private domain, the feeling of floating and having to go to sleep might be hard in combination. The excitement and strangeness of sleeping in a completely new way requires an environment that is something known and easy to relate to, limiting the strange stimuli on the tourist.

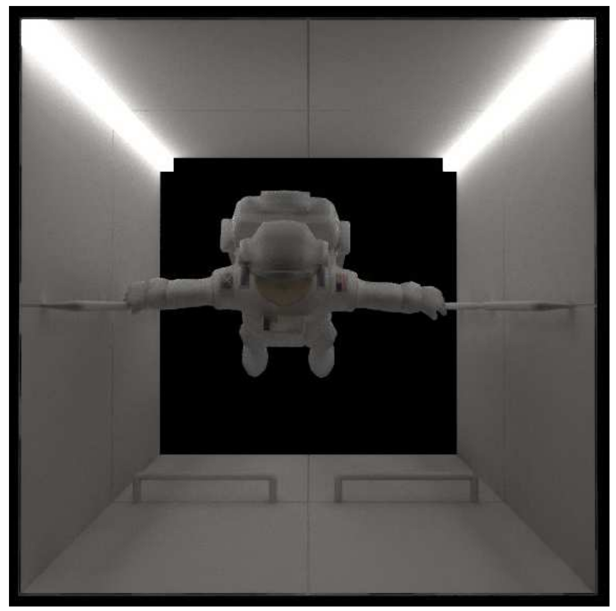
Other activities that are very much like their Earthly cousin should be performed in a space that invites to experiment, and see the activity in a new way. Eating for example is an activity that is performed in similar fashion in both cases, therefore the space relation to the activity can be more exploring the omni-directionality that outer-space invites for.
In a way the hallways between different spaces is the perfect area to experiment with directions other than straight up and small transformations on this, there is only a small amount of spaces that invite for a real strange experience for the abilities in micro-gravity except the experimentation and sports arena.
Other than the change in orientation from one space to the next, most spaces should be working quite logically. Except people won't be walking on the floors, but floating through the middle or along side a wall. This in itself is already very strange!
Direction cues for the movements throughout the interior should correspond to elements of Earth's architecture. Stairways, guide rails, etc. Beware there is no actual up, down, left or right, there is only a movement through space related to the immediate environment, whether this is up or backwards relative to the earth is really not important in reality. Therefore movement is just movement, the direction changes at will and so does the relevant orientation, the only time the orientation changes without directly knowing the angle and the new orientation is on exiting one space and entering another.

Cubic Grid
Integration the different types and rooms into a volume that extends in all directions in the same way, without differences or differentiation between any direction, is required for a design in microgravity. In the designing of a complete tourist space station that has these different functions in a larger volume, a regular grid is an extremely useful design tool. Regular in every direction because the spaces, activities and people can turn in every direction and be no different. A grid that takes the human sizes in account is found in a cubical size of 1.15 x 1.15 x 1.15 meters. A size that fits the width and depth of a person, making the minimum size to fit through, and if stacked create a height of 2.3 meters (2.25 m internally) in which a person can be erected and always touch either ceiling or floor at a single specific time.

Three space typologies

When we look at the different spaces and their requirements we can extract three different typologies in which all of the spaces find their required qualities. Typology 1 consists of the spaces related to the astronauts and their control, thus the control room and researching area. The second type is found in the spaces with the highest privacy level, consisting of the personal and hygienic cabins. Group three consists of the spaces that are for common activities, the Common room, experimentations and the related docking and spacesuit area.

Type 1 - Hallway
The hallway is the type for researching and managing the space station, it consists of spaces that have clear up and down orientation, the distance of the walls with a size of roughly 2 meters ensures a clear passage of astronauts moving from one end to the other whilst not colliding with astronauts working on both sides of the hallway. With a height relatively similar to the width, to ensure constant possibilities for repositioning the body by contacting either top or bottom surface, we can talk about a ceiling and floor as there is a definite orientation inside of the space. The measurements give the space a square section. The length is defined by the required working surface. The sides have the instruments installed and can be opened to access research equipment and the life support system installations.
The orientation of the internals is there to create an interior space that is easy to understand and softly forces people to orient themselves in a similar fashion, to also create a social relation that is understandable from the Earth environment, no adaptations are required.
If length is limited and more space is required for the purpose of research or control, another hallway can be implemented but with a preferred orientation that is similar to the first hall. The relative orientation of different halls on different levels that are directly linked prevents astronauts to having to adapt to another orientation principle when moving from one space to the next.
The lights are located on the connection of top surface and the sides, this is both for orientation reasons as well as a global lightning that creates limited hard shadows, because there will be direct light from either of the directions.

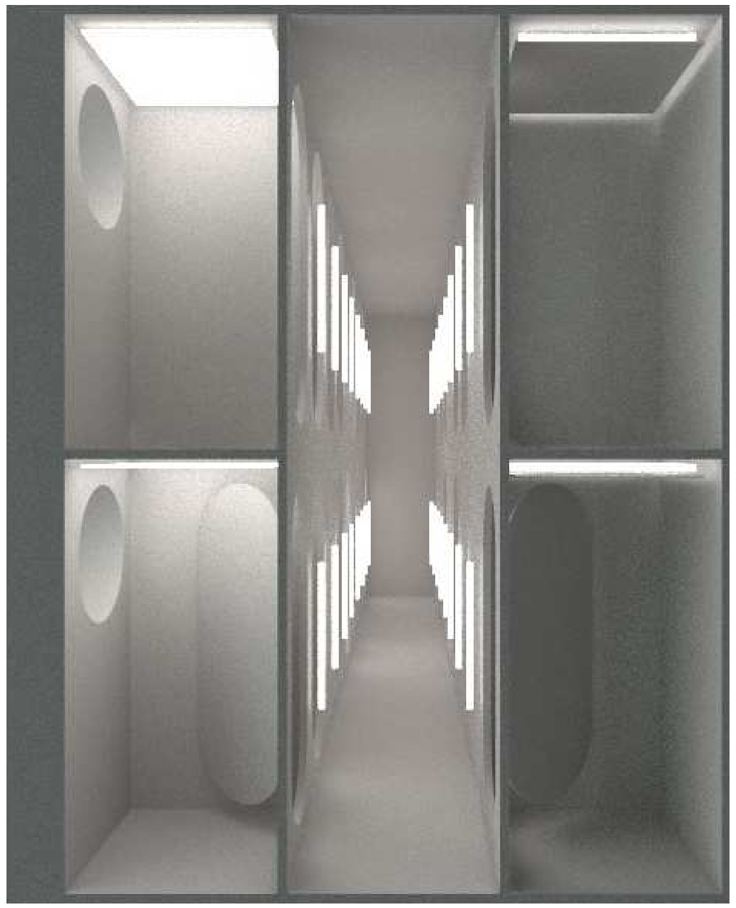


Section of the Research module, depth of two grid dimensions. (2.3 x 2.3 m)

Type 2 - Cabins
When we see the integration of space being used for static activity and movement from A to B in Type 1, Type 2 shows clear separation of both. The smaller cabins create high levels of privacy and the intermediate space creates a clear separation of the cabins. The smaller chambers have the specific functions of sleeping & communication, and hygienic (toilet & shower), and should be closable from the inside to ensure the privacy of the chamber stays in tact.
As none of the private spaces have individual hygienic chambers the relationship between each of the hygienic rooms towards each of the private spaces should be equal. The cabins have a clear orientation towards each other to be able to get from one cabin into the next without having to adapt a new orientation system. This is especially useful case of a midnight toilet visit.

There are a bit more spatial qualities to the second typology than there are in type 1, the orientation inside of the spaces is clear, as is their relative orientation but the space in between can take different forms and is not limited to the two times grid size in height and width. Though one of the two, height of width should not exceed two times the grid size to ensure contact to a wall is always a possibility. It is entirely possible to have a two of the measurements larger than 3 times the grid size, creating a plate-like structure.

The total combination of private, intermediate, and hygienic chambers should be located on the border of the spacecraft, as the private spaces should preferably have a view on the Earth, this also offers limited possibilities for views from the intermediate and hygienic spaces, a result without consequences as the views are no requirement from these specific spaces.

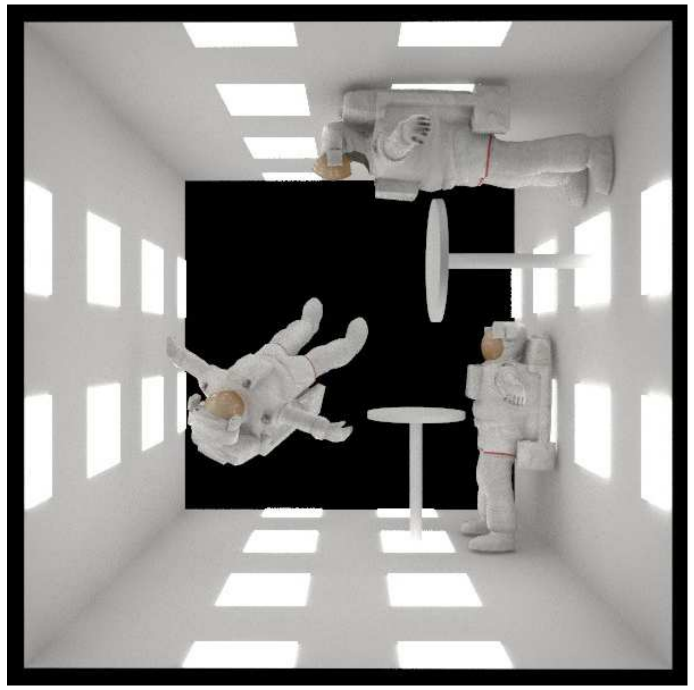


Section of the private cabins (lhs) central corridor and hygienic cabins (rhs) (3.45 x 4.60 m)

Type 3 - Omnidirectional
The other spaces which should be much more effective in providing the special space experience, the spaces in which the omnidirectional character of space is clear in abundance. Orientation is only clear within specific activities, and might have strange orientations in relation to the other activities within the same room. These differences make it apparent that the tourists are in fact in an apperent weightless environment but their social activities on a local schale are still organised and clear.

The distance between the walls is bigger than twice the grid size (larger than 2.2 meters) which has the result of being at a size where a normal person is in some cases unable to touch any of the outer walls, being unable to control his movement for a short moment in time. This is a definite spatial difference from the other two types that always provide options for control to the users.

The orientation cues that are used in the previous typologies, lights for example, to give direction to the space are now used in such a way that works in the opposite manner. Lights from all sides, doorways and windows without relation to a general orientation and distance from a wall create spaces that are unlinked from any logic that would be required for effective functioning on Earth. Each activity can still have its own set of lighting, but this lighting does not have to be logic to the activity that is performed right next to it.



Section of specific space tourism room. (3.45 x 3.45 m)

Conclusions

During the short history of fictional an non-fictional space exploration there have been large discrepancies between the ideas and the actual realisation. This has a lot to do with the requirements put on a space habitation by its environment and the relative ability to fund specific aspects of space exploration make it unrealistic for a lot of our ideas to be realised on a short term. In the specific developments of space exploration for tourism there is a lot to be research as the branch is only just starting, with 10 civilians ever to visit the International Space Station and the suborbital flights of the first tourist space corporations hopeful to start this year or the next. The knowledge of an habitation completely dedicated to tourists is very limited.
Architecture for space exploration is far different from architecture we know on Earth, requiring very high levels of efficiency in weight and size putting high demands on the possibilities for larger than necessary spaces and constructions. But with the rise of the space tourism industries the requirements for much more experientially orientated space stations shift much more towards the maximum possibilities instead of the minimum requirements. The minimum requirements are still required to know what will be the smallest size, and what the advantages are of enlarging a specific space or series of spaces.
There are several aspects that become more important when designed for space tourists, of which one of them is larger spaces used for acrobatics and further space enjoyment. The relative pair of being stationary and in momentum are both controlled by the person him or herself by the use of their bodies in relation to other massive objects. If the space is enlarged to a point where two walls cannot be touched at the same time, people can get lost in space. This might be wished for to be able to experience the full spaciousness, as it also provides a large enough size to perform space acrobatics. In cases where this is unwanted extra handholds have to be provided that run through the parts of the room that are otherwise area's of uncontrolled movement.
The most extreme use of large spaces by tourists can be found in space sports, in which trained athletes can fly though space completing objectives required to give their team an advantage over the other. In early tourist activities these sports are more or less related to a gym like setting, where the sports are performed on a friendly basis to enjoy microgravity, but later stages of space exploration could involve the addition of specific space sports to be played by professional athletes to be broadcasted on Earth for the enjoyment of the masses, or even further to be enjoyed by tourists that are also in space; a space stadium.

In the same manner as movement and control of the human body is important for getting around in space, the orientation of activities and spaces is very important for both the practical as the experiential purpose of going into space. In general we can say that through the ages of space exploration the internal end external orientation have been very clear and controlled to limit sensory input for the astronauts making their jobs easier to be performed. But for space experience the transitions that do happen in space between angled spaces are of high interest, these transitions are the elements that show the omni-directionality of space and should also be used in tourist space adventures to maximize the realisation process.
There are three ways to work with the different directions of space; internal towards external, internal related to internal (different spaces), and within the space itself. These can be seen as different tools to provide either logic or illogical relations between spaces.
To come towards a representation of the different ways to cope with architecture in relation to the requirements of specific activities and the spaces three spatial typologies have been created. The hallway, cabins and intermediate space, and the omni-directional type. Each type is aimed at specific requirements from its activities and spatial use in relation to the human body size and the social

interaction between people.
The hallway for clear orientation, the plate and cabins for privacy and clear orientation, and finally the omnidirectional space in which a combination of similar orientations and differences create a balance to optimize the experience for both social interaction as well as total freedom.
These measurements for all typologies are directly related to the size of the human body, a grid of 1.15 x 1.15 x 1.15 meters works with the human body in all directions. With a height of a double grid an interior height of 2.25 meters is created, and as a minimum width 1.15 meters is enough for a single person to navigate through with ease and still have enough width to feel comfortable..

In relation to the historic approach for spacecraft design the new extension of the experience elements and the movement towards larger spaces has an impact on the spatiality of the total architecture. The more controlled area's however resemble a lot of qualities implemented in current space architecture, though in current times the interior is completely cluttered with equipment. This is just a result of the use, not of its architecture.

Thought for architectural consideration

As the architecture will most likely be utterly different from the architecture we know on Earth as even Konstantin Tsiolkovksy already knew but still did not get through to space design and most science-fiction. (*https://www.sfsite.com/gary/tsio01.htm*) There would be only one reason to keep it similar, which is to ease the adaptation of humans from the planet to apparent weightlessness. But for functionality purposes most elements of architecture will be completely different, adapted to the way they are used in microgravity.
To create easy adaptation to new products and settings elements of known objects can be used to replicate a known environment making adaptation and use easier. This copying of special object aspects or design elements is called skeuomorphism. It carries meaning from a previous medium so the new can be understood from the start, and interacted with instantly.
As Scofidio talks about Skeuomorphism in architecture for space exploration, he questions weather architecture space should resemble architecture in gravity at all. (Lovell, 2014) He worries a future interplanetary outpost might look like an American suburb with a bucky dome to protect it. But to a further extent this also applies to other divisions of space developments; architecture should function for use in space.
The representation of the Earthly elements of architecture in space are on the one hand good for easy adaptation to the weightless environment but also limits the architectural and spatial effectiveness. The new living environment requires a completely new approach to designing as the use is also very different.

In retrospect, skeuomorphic approach to space design has greatly influenced the way the research has been done. Every sport in this research has been designed for a gravity environment, some exceptions, and have been reviewed in a micro-gravity environment. Though this is the approach that could result in the first space sport stadium, the sports that are specifically designed for space will most likely be much more interesting than the adapted Earth sports.
To recite Scofidio "With every new medium we tend to first copy the old one as best as we can. It helps us find the similarities and differences between the new and old." Though the development in space is not really a new 'medium' it is a relatively new field of architecture that has limited relation to its Earth relative. Skeuomorphic aspects in this case are the basic parameters of the design, as the activities are in first instance relatable to the activities on Earth. The medium in this case stays the same, as the software and representation are similar to what we know, but the designed object, the design constraints and the specifications of its surroundings are completely different from what we know.

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Appendix A : Around the world in 90 minutes

Greg Chamitoff's Journal
Date: 08.28.08

Message 3

Suddenly, on the right, I see a spidery orange glow surrounded by pitch blackness. It's a big city with a sprawling glow of light. For a moment I can see two worlds at the same time – **blue sky with clouds on the left and pitch black with city lights on the right. Then the Earth below disappears into total blackness.** The Japanese robotic arm, the frame of the airlock, and the entire port-side truss with massive solar panels is brightly lit. Sunset for us is several minutes later since we are so far above the surface (same thing as sunset in a valley versus mountain top). With the Space Station so brightly lit and no light reaching the Earth's surface from the sun, **we suddenly seem to be isolated and floating in this endless void** (which we are). Then the brightness begins to dim and the solar arrays take on a spectacular flame colored orange. Gradually over about 30 seconds they fade and fade until they too completely disappear. Now the only thing I can see through the window is the reflection of lights from inside.
I had to leave the window for a few minutes to shut off all lights in the JEM, Columbus, and Node 2, dim all the computer screens and try to point them away from the windows. Now back at the window, I clearly see one bright star. A few seconds later I see 5 stars. There's nothing below and there's no way to know that the Earth is there. After another round of blocking internal light from fire-port stickers, displays, etc., I come back to the window and finally see a full sky. **Suddenly it doesn't seem like we're alone in an endless void anymore.** The black sky is completely filled with thousands of stars in every direction – many are distinct, but even more are part of a slightly lit patch, which is clearly comprised of hundreds of dimmer or more distant stars. It's like a clear night sky while camping in the mountains, but you can somehow tell that you are seeing more of the dimmer stars, and every one of them is sharp, with none of the shimmering that you get when looking through the atmosphere.
Suddenly I realize that I can see the Earth again, too. The moon must be out. I checked later on the computer, and sure enough, the moon was up on the starboard side of the Station. So the moon illuminated the ground, and I could begin to make out the shape of clouds. Strangely, though, with the moonlight behind me (out of sight), it did not interfere at all with the visibility of the stars.

The brightest star is near the horizon and it hasn't moved since sunset. It must be Polaris, which makes sense. Once I realized this I checked the horizon in the direction we're going. Sure enough, I could actually see new stars rising quickly. A look toward the aft, and I could see the stars setting. I instantly got hit by a high speed planetarium effect, as if the whole sky was spinning around me (with Polaris straight up). The sky moves quickly for us, since we're going around once in 90 minutes. So, whereas on the ground the motion of the stars is hard to detect visually, up here you can see the whole sky rotating quickly overhead. Of course, it is our revolution rate as we circle the globe that's causing this effect, but at 360 degrees in 90 minutes. That's 4 degrees a minute, which is very noticeable.
Now I see an orange glow ahead on the horizon. It's a city on the coast of some continent. I'm still playing "name that place" and guessing it must be northern Africa or Europe. We're over land now and I see city lights in all directions. Wow, this looks like a scene from a movie - incredibly full sky of stars above and a full display of lights below on the planet. It reminds me of a particular opening scene from one of the Star Wars movies. I see a few flashes outside the Station (on the Station). What could it be? It seems like the flash you'd see looking out the window of an airplane from its own beacon. But we have no beacon. The only possibility is a flash from lightning on the ground. I'm looking for some lightning and suddenly I see a shooting star below. Wow, that's the first one

that I've seen from space. Very cool! It streaked across the sky from north to south below us. The next flash was not easy to explain – it was blinding for a split second. The Japanese robotic arm is parked about 15 feet away from me right out the window. It lit up so brightly for a split second that it startled me. What the heck was that? It was too bright to have anything to do with distant lightning on the ground. I have no idea. My only thought, and it seems like a long shot, is that I saw a tiny micro-meteroid (dust particle) hit the ISS. What else could it be? The only other option I can think of is a cosmic ray hitting my retina. I've been waiting to see the expected flashes from this, but so far haven't seen one. Maybe this was it?

Now I do see lightning on the ground. It's jumping from cloud to cloud over the entire surface that's in view. Presently the solar arrays start to glow. As they take on their orange flame color again, the stars are fading fast. Within seconds I can only see Polaris. Now the Station is in full sunlight and I can't even keep my eyes open it's so bright. After finally adapting to the brightness, the sky and Earth are once again gone. I see only the truss, solar/radiator arrays, robotic arm, and nothing else. The horizon starts to glow with a bluish haze that begins to outline the horizon from north to south. It still seems that there is an endless chasm of nothingness below. The glow is spreading to the north and getting thicker. I can see the surface ahead, but still nothing at all below. It's totally black. Again, I'm wondering where we are? I want to figure it out for myself. The terminator line, which fills maybe 10% of the view straight away from the window, is moving behind us. We're over land, and it seems to be a vast desert with ridge lines of barren mountains. I see snow on a few ridges, but otherwise it looks like dry desert. Minutes go by and we're still flying over this desert – it's huge. Now there are some mountains, and then a vast area of mountains and valleys. In the valleys I see clouds, and it seems to be like morning fog. I've never seen clouds like this before. Now I'm really sorry I don't have the camera here. There are endless branching networks of mountains and valleys in all directions, and the clouds are appearing only in the branches of the valleys. The clouds look like giant snowflakes. It's really amazing. There are patches of snowflakes everywhere, as the clouds are fully and perfectly outlining the shapes of all the detailed recesses of the valleys. I need to get a picture of this some time. I'm afraid this might have been my only chance to see it. I've never seen any pictures of anything like this before either – just incredible.
I'm still wondering where we are, but I figure it must be Russia or China. Now I'm starting to see the coastline approach. I see one isolated volcano-shaped mountain with snow. There's another. OK, now we're over the first one and I see a string of volcanos nicely spaced heading north. We must be around the Kamchatka peninsula. Now we're heading out to sea, and there are a few small islands with nothing else coming for a long time. I think we're headed back down towards Chile all the way across the Pacific from north to south. OK, time to check the computer. Yep, that's right - Hawaii coming up soon on the right side, but I won't be able to see that unless I fly down to the Russian segment where Sergei and Oleg are sleeping. That was my first time all the way around with my head out the window the entire time. What a spectacular show!

From space,
Greg

Appendix B : Two week itinerary