Human Spaceflight SD 2905

Group report

Human Aspects and Life Support Blue Team

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1 Introduction

During the project work of the course "Human Spaceflight" in spring term 2016, the task was to design a Low Earth Orbit Hotel. The class was therefore divided into two teams consisting of different groups that would focus on certain aspects of the design. This report presents the work of the human aspects group of the blue team.

First, the life support system (LSS) including the air revitalization, water management and food supply was to be planned. The main characteristics of the life support system will be described in section 2, the details about the food supply are given in section 3. The second task was to plan the activities that will be offered to the guests on the hotel. In order to offer a unique experience to the guests, the activities should especially take advantage of the living conditions in space, for example weightlessness. The activities will be treated in section 4. The third part consisted of planning the overall schedule for the pre- and post-flight care for the guests. As they are no professional astronauts, a customized training for the guests is needed as well as medical check-ups before and after the spaceflight. These points will be discussed in section 5.

All considerations are based on the team's choice to design a spacehotel which can host up to six guests at a time with three professional astronauts as crew on board. These numbers are mainly based on the decision to use the Dragon capsule, run by the American company SpaceX, for the regular flights to the spacehotel. Further explanations on this subject can be found in the reports of the overall coordination group and the mission control group. Due to the size of the hotel, the life support system could be based on the one currently used on the International Space Station (ISS). The tourist's stay is planned to last seven days, so the number of offered activities is adapted to this time span as well.

Table 1: Human Metabolic Rates,according to [7].

Life Support Unity	Human Need	Per Person (in kg)	Total (in kg)
Atmosphere and Air Revitalization	Oxygen Inspired	0,83	7,47
	CO_2 Expired	1	9
	Water	1,6	14,4
Water Supply	Potable Water	0,7	6,3
	Hygiene Water	23	207
Food	Dry Mass	0,7	6,3
	Water in Food	2,3	20,7
Waste Management	Liquid Waste	1,6	14,4
	Solid Waste	0,1	0,9
	Hygiene Waste water	23	23

2 Life Support System

The Life Support System (LSS) has a simple but very important function: make human life possible in space. A LSS has to provide a breathable atmosphere, water, food, and waste removal. In the special case of the Space Hotel, the comfort of the guest is also extremely important.

The LSS was mainly based on the systems of the International Space Station (ISS) and additional information presented in [7]. Before giving a detailed characterization of each part, it is important to have an overview of the requirements for the LSS. These requirements are shown in table 1. Using these values it is possible to design the LSS for the Space Hotel. The individiual life support units (LSU) will be described in detail in the following subsections.

2.1 Atmosphere and Air Revitalization

2.1.1 Pressure, Temperature, Humidity and Circulation Control

In order to maximize the comfort of the guests, the atmospheric characteristics of the hotel were defined to be as close to the ones on Earth as possible. The values of these parameters are shown in Table 2.

The air circulation is performed by in-built fans in each module. The fans blow the air to the Air Contaminant Removal unit (see 2.1.2) and to the temperature and humidity control unit.

The partial pressure of the main constituents of the atmosphere are monitored by a series of sensors located in each module. The pressure control is done by regulators and valves that maintain the correct conditions of the atmosphere. The same system is used in emergency cases to control and prevent fires, leakages or other exceptional cases.

Table 2: Atmosphere Characteristics, based on [7].

Parameter	Mean Value
Total Pressure (kPa)	101
Total Pressure (kPa)	21
Diluent Gas	N_2
Temperature (°C)	21
Relative Humidity (%)	25-70

The humidity and temperature control is performed using a condensing heat exchanger in combination with a water separator. [7]

2.1.2 Air Contaminant Removal Unit

The Air Contaminant Removal Unit (ACRU) is divided in two parts: the trace gases removal and the CO_2 removal.

The trace gases removal consists of a combination of particulate filters, active charcoal and a catalytic burner. The active charcoal is separated from all other removal units. This separation permits a regenerative operation by exposing the charcoal to vacuum.

To remove the CO_2 of the atmosphere a Sabatier Process, as presented in equation 1, was chosen:

$$CO_2 + 4\,H_2 \rightarrow CH_4 + 2\,H_2O\,. \tag{1}$$

The hydrogen present in the process is obtained by the electrolysis of the water, a process needed to obtain oxygen. Due to this interconnection between the CO_2 removal and the O_2 production, it is important to determine the mass balance(Appendix A). With this balance it can be seen that to remove all the CO_2 of the atmosphere an excess of approximately 4,5 kg of oxygen is produced. Part of this excess is stored for emergency cases and to replace leakages. A more detailed explanation of the mass balance is presented in the appendix A.

Although the Sabatier process is sufficient to remove all the CO_2 from the atmosphere, the ACRU also has an emergency storage of LiOH that can be used to remove CO_2 (equation 2) in case of any malfunction. According to [7], 1kg of LiOH is enough to remove 1kg of CO_2.

$$2\,LiOH + CO_2 \rightarrow Li_2CO_3 + H_2O\,. \tag{2}$$

2.1.3 Air Supply Unit

The nitrogen that composes the atmosphere is stored in tanks which are refilled regularly to replenish losses due to leakages.

In order to maintain the correct level of oxygen in the atmosphere, the Air Supply Unit (ASU) uses an electrolysis process to break the molecules of water into oxygen and hydrogen, according to equation 3.

$$2\,H_2O \rightarrow 2\,H_2 + O_2\,. \tag{3}$$

According to the balance of mass (see appendixA), the process needs about 14,6 kg of water per day of which 7,4 kg are a result of the Sabatier Process. The remaining amount will come from treated liquid waste.

2.2 Water Supply

Due to the long duration aspect of the mission of the Space Hotel, it is important to have a partially closed loop for the water cycle.

All water and urine is processed to potable water in the same system. The urine is treated through a water vapour compression distillation (VCD) process. After this process, this water is mixed with the rest of the waste water and then reprocessed using a multi filtration process.

According to Norberg [7], "the full closure of the water loop is impractical because there is some water in final waste products, and because the evaporative cooling systems of space suits consume water.". Due to the above-mentioned reasons the reuse of water in the Space Hotel is estimated to be close to 90 %.

2.3 Waste Management

Due to the water loop, urine and faeces collection need to be done separately. The urine is treated as described in 2.2. After the urine treatment "a brine of concentrated waste water products" [7] is collected in tanks and discarded with the faeces on the "back to Earth" flight.

2.4 System Safety

For safety reasons, all modules are equipped with optical sensors, and CO2 reserves to detect and suppress fire. Also for safety reason a special Medical Kit will be on board of the Space Hotel. This medical kit is based on the one present in the ISS [1] and counts about 190 medicaments. The crew members will also get some medical training such as stitching up wounds and giving injections to be prepared for medical emergency cases.

3 Food

The importance of food for people lies not only in the pure nourishment but also in the psychological benefit from a delicious meal. Therefore, the guests will be offered a choice of different meals every day in order to make their stay at the hotel as pleasant as possible. Due to the limited upload mass, this choice can only be realized using a system of ordering in advance. Before the flight, the guests will receive a menu for their whole stay in space where they have to choose for each day between several dishes. As the guests probably want to experience how life on a space station for a professional astronaut looks like, astronaut food will be provided as well as convenient food from Earth.

Due to weightlessness and limited resources in space, it is not possible to prepare fresh meals on board the hotel. The food will be brought up to space together with the guests and then be reheated in an oven. As the food should not get damaged during the flight to the hotel, a customized form of packaging is needed. Especially when thinking about fresh fruit that might be demanded for breakfast by the guests, the forces during the launch have to be considered as fruits bruise easily. The limited cargo space in the capsule is a further boundary condition for the possible dishes. Astronaut food is already made to meet this conditions, however, providing "normal" food is a bigger challenge. In order to meet all those restrictions, it might be a good choice to cooperate with an airline caterer as they are already specialised on preparing meals that are easy to reheat on an aeroplane, do not need additional fresh ingredients and have a good volume to mass ratio.

For drinks, the guests will be offered different kinds of soft drinks, water and coffee as well in the same habit as it is done on the ISS. Unfortunately, it is not possible to offer alcoholic drinks as the escaping ethanol is a threat to the air revitalization system. However, alcohol-free beer or wine could be provided if some guests don't want to abstain from the taste of beer or wine.

The needed amount of food was calculated according to W. Larson's "Human Spaceflight: Mission analysis and design" [3]. According to this, 2,3 kg of food are needed per day and person. This sums up to 145 kg per week when guests are on the hotel. As it is planned to have one week without guests after each week with guests and two crew members will still remain on the station, an additional amount of 32,2 kg food is needed for this week. The crew will mainly eat astronaut food that does not contain as much water as normal food, so the extra food for this week will only weight $\sim$ 25 kg. The cleaning devices for the kitchen and the needed eating supplies like forks and straws will add around 8 kg mass. In total, $\sim$ 180 kg of food related items will have to be transported on each launch.

In order to be prepared for some extraordinary events that would force both the crew and the guests to stay longer than expected at the Space Hotel, there will always be a reserve of astronaut food on board that can feed nine persons for up to two days.

4 Activities

While staying on the Space Hotel, many unique and fascinating activities will be provided to the tourists. During daytime, the tourists will be offered to participate in a schedule of incomparable and extraordinary activities.

Activities not possible to perform on Earth without μG environment will make the tourists have an extraordinary stay on the Space Hotel while they become one of the few people that have experienced weightlessness and get to experience the life of an astronaut.

4.1 Microgravity Games

Space billiard and space tennis will be offered to the tourists to play during their stay. Weightlessness makes it possible to add an extra dimension when playing billiard and similar ball sports so therefore unique variants of these activities will only be able to be played on the Space Hotel. In the module assigned to these activities, minor preparations that are easy to handle will be performed by the crew before an activity is carried out.

4.2 Food Tasting

As the residence is a hotel there will of course always be ordinary food available for the tourists while staying on the Space Hotel. Regular vehicle transfers to and from Earth will make it possible to transfer regular food on a weekly basis. However, trying professional astronaut's food will be a great experience for the tourists and different sorts of these types of food will be available to try in order to experience a professional astronaut's daily meals.

4.3 Space Gym

Space gym machines are necessary to have on the Space Hotel as there will be professional crew astronauts staying there for several weeks. For the tourists who live in weightlessness for less than a week, exercising for medical reasons is not necessary. However, it will serve as a funny and interesting activity for the tourists staying on the Space Hotel and will contribute to their astronaut experience.

Space gymnastics and exercise machines used on the International Space Station will be used for this gym purpose. One of the most common machines that could also be implemented on the hotel is a version of the Advanced Resistive Exercise Device (ARED) that is also used daily on the International Space Station (ISS) [2]. This equipment trains big parts of the body's muscles and optimizes the chances of reducing the negative effects on the muscles. These machines are extensive in dimensions and demand both volume and payload power when being delivered to the Space Hotel. As the rule of thumb is that every kilogram of payload to LEO costs around 10 000 USD, payload is always an economic issue. If the postflight feedback from the guests asks for more exercise machines, the number of machines would be increased over time.

As the stability of the hotel should not be disordered, every movement inside the Space Hotel has to be calculated in order to not disturb the moment forces of the structure. Therefore, the exercising machines must be taken into account when designing the Space Hotel so that there are margins for sudden internal movements. It is as well important to use slow body movements in weightlessness to minimize the risks of space sickness.

4.4 Movie Theatre

On the Space Hotel there will be a small projector providing the possibility of showing movies and pictures on a screen. This will allow the tourists to experience weightlessness-cinema. This cinema demands little preparation and does not require big apparatus volumes. Music will also be available and weightlessness-dancing with one of the crew astronauts acting as a dance instructor.

4.5 Guided Tour over the Earth's Surface

On the Space Hotel, there will be two window cupolas from which the tourists can gaze out into deep space or look right down onto Earth. Binoculars and telescopes will be available, offering the possibility to zoom in onto cities or big natural monuments such as mountains or lakes.

As an orbit around Earth for the Space Hotel will be alike the orbit time for the ISS which is around 90 minutes, a guided tour performed by one of the crew astronauts will be performed during one orbit. Therefore the possibility to zoom in to Earth as the astronaut is giving tips on mountains, pyramides, the Chinese wall and big cities or other interesting places one can see from the Space Hotel by using low-weight equipment, will be offered for the guests.

4.6 Mock Science

The major reason to build the ISS was to make it possible to have experiments carried out for a long time in space. Similar experiments of mock science will be possible for the guests to perform on the Space Hotel, increasing the sense of how the everyday in-space work for a professional astronaut is like. Mock science that includes plants and zero-g experiments will be available for the guests however the apparatus used for these experiments is of course limited by the available volume on the hotel.

There is a Biolab on the Columbus module on ISS which will serve as an inspiration for a similar experimental rack to be delivered to the Space Hotel [9]. Microscopes will offer the chance to have a closer look on plants brought from Earth and a simplified version of the Fluid Science Laboratory that exists on the ISS could be provided. Here, the tourists will be able to study simple aspects of fluid dynamics in μg environment and how weightlessness affects the viscosity and behaviour of fluids.

4.7 Extravehicular Activity (EVA)

The EVA is the most demanding activity available for the tourists on the Space Hotel, both in terms of preparation and safety measurements but as well in experience level. Thanks to upcoming NASA procedures regarding the preparation for space walks, it will be possible to have a very compact and shortened schedule demanding only a few hours of preparation in space before starting the space-walk. The tourist that is going out for a space-walk will always be accompanied by a professional astronaut. There will be no tasks to perform for the tourist and the professional astronaut will always be nearby to guide the tourist's movements and assist in case of emergency. We chose the Russian space suit Orlan as it offers a high flexibility regarding the different sizes. During an EVA, there are several cases of emergencies possible to appear. A tourist might for example panic or a problem with the suit might occur. In this case, the professional astronaut will always be nearby to assist the tourist. The professional astronauts will undergo various training sessions regarding helping their partner during an EVA such as this is done in the NASA astronaut training.

As the EVA demands extra preparation and crew resource on the Space Hotel, there will be additional costs for the guests choosing this alternative. Up to 30 % of extra costs will be charged which will cover the professional astronaut's time on the Space Hotel prioritizing this single guest's activity, additional preparation sessions on Earth before launch as well as expected upcoming additional costs from insurance companies.

5 Preparation and Post-Flight Feedback

After making the decision to visit the space hotel, the tourists have to go through some check-ups and preparations in order to prevent both medical problems and accidents. The tourists will undergo a medical and psychological test, some preparation for the stay on the hotel and a separate extra vehicular activity (EVA) training if they want to do an EVA. After the trainings, they will have some days for private preparation at home. Before the launch, there will be an additional preparation session to memorize the most important things. After coming back from the space hotel, there will be a post-flight check-up, and tourists will have a opportunity to give some feedback on the space hotel.

5.1 Medical and Psychological Test

The space environment is very different from the Earth's environment. Trivial physical problems on Earth can be critical in space. That is why a medical check-up before the flight is needed, as well as a psychological check-up because if someone shows unexpected and dangerous behaviour in the small and closed Space Hotel, this would be very hazardous. The psychological test will as well be used to get to know the applicant closer in order to match people for their stay on the hotel together in a way so that the group will enjoy their stay together. The basic check list for the medical check-up is as follows. First, the applicant's blood pressure must not exceed 140/90 mmHg because there will be a big difference of condition of blood stream on account of the gravity change. Second, in order to move and do activities in space properly, the applicants must have proper reach of their arm and normal joints. Third, they must be free of physical and mental diseases, and any addiction to alcohol, drugs, or cigarette. A more specific check list is attached in the appendix.

5.2 Preparation for the Stay on the Hotel

During the preparation period which will last 5 days, the applicants will be provided a general introduction and training for pre-adaption to space environment. After a welcoming part, the tourists will get general information about the hotel. They will be given an overview of how the space hotel was started, what activities are offered on the hotel, how to execute daily activities like eating and moving in space, and things they should beware of, etc. Then, the applicants will start training. First, there will be team building activities which aim at building up a corporate feeling between the tourists that will stay together on the station. Second, they will do simulation training. In the Space Vehicle Mock-up Facility, there will be a model of the space hotel, and applicants will experience the inside of the space hotel as well as the interior of the space vehicle that will bring them up [5]. They will practice how they move and how they live in there. During a parabolic flight, the tourists will experience zero gravity [6]. Third, there will be centrifuge training [8]. To prevent passing out during acceleration of space shuttle, they will experience high acceleration in NASA Ames Research Center. Lastly, there will be emergency situation training and physical training.

5.3 EVA Training

If The applicants want to do an EVA, the will haveto pay extra money because of the trainings they need to do and the additional assistance they need on board. They will have to learn how an EVA is carried out, so what has to be done in preparation, how to leave the space station, how to behave in space etc. The training will consist of some underwater training in a huge water pool such as the one in the Sonny Carter Training Facility which is is 40 feet deep and 200 feet long [4]. Such a pool provides an environment quite similar to space, so they can learn how to move in space The applicants will practice how to get on the space suit and get important safety instructions as well. As they do not need to carry out a specific task during the EVA, only four days of training will be needed.

5.4 Private Preparation at Home and Launch Preparation

The tourists will be given seven days for private preparation to pack their luggage, relax after the preparation training etc. Then, they come to the launching site and prepare for the launch. their luggage will be checked to make sure that it does not exceed weight limit and that they do not carry dangerous items with them. Finally, we will remind them of the information they got during the preparation days regarding the safety instructions etc.

5.5 Post-Flight Check-up and Feedback

After landing on Earth, the guests will get a health check-up to help them recovering and to prevent aftereffects. They will as well get the opportunity to give feedback on their stay in the Space Hotel.

A Mass Balance for Life Support System

According to Norberg [7], "the mass balance for life support system (...) enables the determination of requirements for resupply of non-regenerative functions and the preliminary sizing". To determine these requirements, table 3 shows the balance of mass for two different cases: producing the minimum of O_2 (and discarding the excess of CO_2), and using the Sabatier Process to remove all the CO_2 (and discarding the excess of O_2). In the table, the first case is represented as balanced by O_2 and the second case is represented as balanced by CO_2.

All values are given in kilograms and present the data of a "full day" with nine people on the hotel. In the same way as the Life support system (LSS) the values are also based on the data presented in [7].

After the analysis of the table, it is clear that the difference of mass that has to be reposed in each case is very small, just six percent. Therefore the decision to use the Sabatier process to remove all the CO_2) of the air is viabl, since the small difference does not justify the creation of an auxiliary CO_2 removal process.

Table 3: Balance of Mass. All values are given in kilograms and are calculated for a total of nine persons during 24 hours.

Human Metabolism		
Parameter	Per Person	Total
O_2	0,90	8,51
CO_2	1,00	9,00
H_2O (ingest)	3,00	27,00
Urine	1,60	14,40
Hygiene Water	23,00	207,00
Solid Waste	0,10	0,90
General Assumptions		
% of H_2O Reused		90
% of O_2 goes to Airlock		5,00
% of O_2 Leaked		8,00
Electrolysis		
Parameter	Balance by CO_2	Balance by O_2
O_2 Produced	12,96	8,51
H_2 Produced	1,62	1,06
H_2O Used	14,58	9,57
Sabatier		
CO_2 Removed	9,00	5,91
H_2 Needed	1,62	1,06
H_2O Produced	7,38	4,84
CH_4 Produced	3,24	2,13
O_2 Excess	4,46	-
CO_2 Remain	-	3,09
Leakings		
O_2 Leaking	5,49	0,68
CO_2 Leaking	0,00	3,09
H_2O Loss	23,40	23,40
Total Mass	28,89	27,17

B Health Check List

According to [7], a medical check-up for people who want to go to space should cover the following aspects:

- General medicine
- ears, nose, throat
- ophthalmology
- pulmonology
- cardiovascular system
- hematology
- abdomen and digestive system
- endocrine and metabolic
- genitourinary
- musculoskeletal and orthopedics
- dermatology
- neurology
- psychiatry and human behavior
- obstetrics and gynecology
- dental
- infectious diseases
- anthropometry
- radiation exposure
- nutrition
- physical fitness.

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