SD2905 Human Spaceflight:
Space Hotel Red
Human aspect requirements for a Space Hotel in Earth orbit

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Abstract

An analysis into the human aspect requirements for a space hotel is conducted. For eight occupants, it was determined that a partially closed life support cycle is required, including an Oxygen Generator System (OCG), Sabatier Reactor and additional water tanks in case of emergency. A Pressure Control Assembly and sets of fans will allow air conditioning, and a thermal control system is specified. Due to medical concerns, the age of each guest must be older than 30 years. Guest extra-vehicular activities (EVA) will be conducted in a hard shell suit, to avoid any time-consuming preparation. Training will consist of a two-week programme, including training for the EVA and medical evaluations. Other considerations and concerns are also discussed for a successful operation of the hotel.

Contents

1 Introduction

This investigation seeks to analyse and specify the human requirements of a space hotel placed into a low Earth orbit (LEO). Aspects considered includes specifications of a life support, air conditioning and thermal systems, human medical requirements and the constraints that these impose on the mission, conduct of the extra-vehicular activities (EVA), before-flight training and guest activities. Several what-if situations are also considered for emergency planning. Specifications are created for the supply masses, so launch requirement figures may be calculated.

2 Design Specification

The human aspect considerations of a preliminary space hotel design are required by the newly emerged space hotel company, Sky Palace. The space hotel needs to be fully operational by the year 2022, ready to begin welcoming its first guests. The Falcon Heavy may be used, even though it is still in developmental stages, as a rocket launcher. Safety and medical aspects, life support, air conditioning and thermal systems, tourist activities, guest training and preparation all must be specified and justified.

3 Life Support

For a life to be sustained, there is an essential need for a supply of oxygen, water and food. Numerous sources provide quantitative lists of these requirements [1] [2] [3]. Upon review, figures are decided (expressed in per person, per day):

- 1 kg of food, mostly dried, to meet the recommended daily intake (average value depending on several factors, including activity level, height, mass, gender and age).
- 3 kg of potable water, of which 1 kg is required to prepare the food.
- 830 g of oxygen, calculated for a normal level of physical activity.
- Variable quantities of water for personal hygiene, which is typically 10 kg (ignoring any laundry requirements).

Since demand includes provisions for eight people for a period of ten days, the launch requirements would exceed those capable for the mission (approximately 1500 kg). This means that it is necessary to recycle what is on-board the space hotel. This is achieved by implementing a (partially) closed life support cycle.

3.1 Food Cycle

Several studies have been conducted on how to achieve a closed food cycle. However, these methods are only in early stages of development and would consist of plant-based food [1]. Considering the research and development costs, the mass and volume needed for such a system and a desire for palatable food for the guests, this option is not considered. A standard open-loop food cycle is utilised, with food supplies delivered regularly from Earth.

Food consumables must follow precise requirements on both the packaging and food itself:

- Nutritious, providing enough energy and covering the Guideline Daily Intake for the various nutrients, such as carbohydrates, proteins and vitamins.
- Lightweight, since mass is a tight constraint (food should be selected for its energy density).
- Long shelf life.

- Free of contaminants, both in a medical sense to prevent food poisoning or sickness, and in a broader sense to simplify the housekeeping of the station (e.g. no crumbles).
- Palatable for the wealthy guests [2].

In order to fulfil these requirements, several technologies will be implemented. These include:

- Lyophilised food, a process in which the food is flash frozen, placed in a vacuum chamber and then sealed; when rehydrated, the food returns to its normal state, with little to no difference to original item. Beverages will also be lyophilised.
- Thermo-stabilisation, which involves heat processing to eliminate health hazards.
- Dried foods, such as nuts, and food with a low moisture content, such as dried fruit.
- Meat can be treated with ionizing radiation after cooking for sterilisation [4].

Each guest will have the opportunity to choose their own meal prior to launch. Typically, this decision is made several months prior to the flight. Fortunately, given the continuous operation and range of guest appetites, the decision deadline will be made closer to departure.

3.2 Water Management

Water is a fundamental substance for sucessful operation of the space hotel. The International Space Station has a partially closed water cycle, interacting with the Oxygen Generation System (OGS). This will be discussed further in the next section. While current technologies can recycle nearly 90% of the total water, the potential for innovation is expected to rise in the near future [1]. For the sake of simplicity, it is assumed that a system analogous to that currently on the ISS will be used, scaled in size and with a slightly higher efficiency.

On a spacecraft, all water is recycled for later use. This includes grey water, yellow water and even perspiration and exhalation. The water will pass through coarse filters before entering the Water Management System itself, then 'multi-filtration beds' will remove the remaining impurities, and eventually all potential hazards will be removed through catalytic oxidation [2].

3.3 Oxygen Generator System

On the ISS, the current process used for generating oxygen is by electrolysis which converts water H_2O from a variety of sources into hydrogen H_2 and oxygen O_2. The Oxygen Generator System (OGS) is illustrated in Figure 1. By providing an electrical difference, the chemical reaction

$$2H_2O \longrightarrow O_2 + 2H_2$$

may take place. The oxygen is then vented to the cabin and the excess hydrogen is sent to the carbon dioxide removal cycle [1]. This will be discussed in the next section.

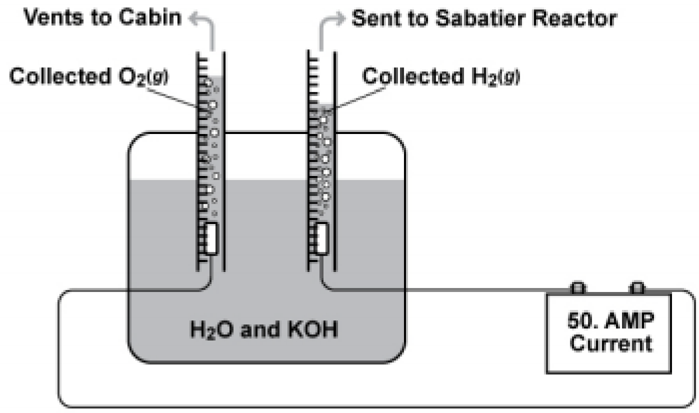

Figure 1: *Illustration of the OGS which allows creation of oxygen by electrolysis.*

3.4 Carbon Dioxide Removal System

The Sabatier reactor is the most advanced system to reduce carbon dioxide concentrations in the air. This reactor is currently used on the ISS, and converts carbon dioxide CO_2 using hydrogen H_2 and heat into water H_2O and methane CH_4. An illustration of the reactor is provided in Figure 2. The chemical reaction is

$$CO_2 + 4H_2 \longrightarrow 2H_2O + CH_4.$$

This process is very advantageous, since the hydrogen produced by the OGS may be removed by this process, and the methane produced can be used in the station's thrusters. As may be seen in Figure 2, cooling is required by the system, and must be considered when developing the thermal control. As all hydrogen produced by the OCG may not be enough for the Sabatier process, external tanks of hydrogen will also be used [1].

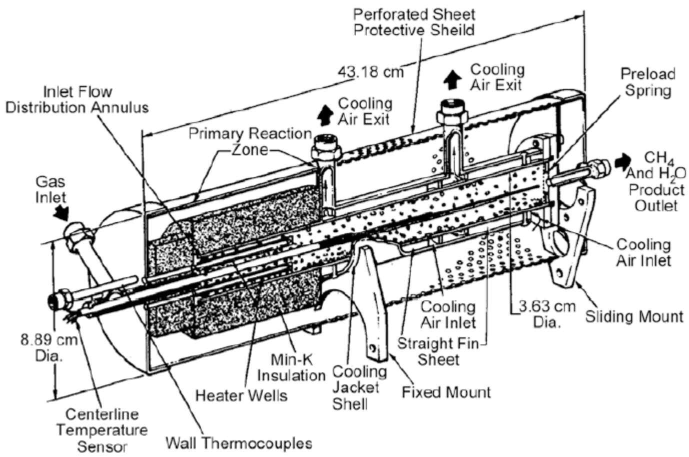

Figure 2: *Illustration of the Sabatier reactor which allows removal of carbon dioxide.*

4 Air Conditioning

It is necessary, for the health and well-being of the crew and guests, that an Earth-like atmosphere is provided on the station. To achieve this, a pressure of approximately 101.3 kPa and a relative humidity of 25 % to 75 % is required. The Pressure Control Assembly (PCA) will be used to maintain this environment. The PCA will allows the capability to vent the cabin atmosphere into space, inject nitrogen and oxygen into the cabin, and monitor the cabin air pressure. There will also be combined sets of fans with either a condensing or non-condensing heat exchanger (the first for air circulation and the second for humidity removal). These sets will be placed in pairs at each end of the station's modules [1].

5 Waste Management

In addition to provide resources, it is also necessary to dispose of all waste products on board. Human waste must be collected and stored. Urine is processed to recover the water, which is used in the hotel's operations. Faeces is collected by use of a vacuum, and undergoes little to no processing. Besides microgravity, another important reason for aspiring is to avoid the spread of odours through the station. With a total of eight people, two toilets are sufficient.

Waste produced on-board also includes the packaging for supplies and consumables. In order to conserve volume, the packaging is compacted and placed into cans with other waste. These cans are then expelled [2].

6 Thermal Systems

For guest comfortability, an efficient thermal regulation system is required on the Space Hotel. The temperature will be regulated using a system of radiators and heaters. Each system rejects and generates heat as required for maintaining an appropriate temperature. To achieve an adequate level of comfortability, a temperature range between 18.3°C and 26.6°C should be maintained [3].

For the design of such a system, several values must be estimated. By use of the module Thermica of the Systema software, an estimatation of the solar radiation flux, Earth albedo flux and Earth infra-red flux is found, corresponding to the hotels orbit. Taking the space hotel as a cuboid structure with emissions equivalent to a black body, the rejection capacity P_{RC} on each face of the space hotel may be estimated by

$$P_{RC} = P_{emitted} - P_{abs} \tag{1}$$

where $P_{emitted}$ is the power emitted of a black body and P_{abs} is the absorbed fluxes. The heater power P_{heater} is then

$$P_{heater} = P_{RC} - P_{dis} \tag{2}$$

where P_{dis} is the power dissipated by each subsystem. The radiator area A_{rad} may also be found by

$$A_{rad} = A_{tot} \frac{P_{dis}}{P_{RC}} \tag{3}$$

where A_{tot} is the subsystem total area [2]. The estimated values found are summarised in Table 1. A Cartesian coordinate is applied to each of the faces, where the positive Z-plane faces the Earth. The most dissipative subsystem must be installed on the face corresponding to the highest rejection capacity in order to avoid excessive temperature gradients.

Table 1: *Placement of each subsystem with the corresponding power dissipation, heating power and radiator area.*

Face	**Subsystems**	P_{dis} **(W)**	P_{heater} **(W)**	A_{rad} **(m)**
X-plane	Communication system	400	0	2.978
$-X$-plane	Command & data system	400	1.028	1.450
Y-plane	Propulsion system	100	6.365	0.431
$-Y$-plane	Attitude control system	2900	2.106	8.516
Z-plane	Power system (Batteries)	862	2.047	2.884
$-Z$-plane	Life support system	1960	4.326	6.526

7 Mission Constraints

Since the Space hotel will obviously be located in a hostile environment, it must be ensured that the risks during the guests' flight and stay are kept to a minimum. As a first step towards safety, the launch site, orbits inclination and altitude must be carefully chosen. Aspects of the design must be considered by all design parties, such as a restriction in G-forces not exceeding 5 g's during flight to and from the station [3].

A second constraint to be considered is the altitude and inclination. Restrictions on the design are dependent on the radiation and the total dose that the human body can stand. Radiation effects are caused by energetic particles (less than 10 Mev) in space that can interact with human body cells and increases the risk of cancer. Due to their large velocities, these particles can pass through the human tissues and deposit energy. Highly energetic particles are contained in the inner and outer Van Allen Belts, and are created by solar particles events and galactic cosmic rays. By avoiding areas of high concentration and risk, the radiation dose is set to a minimum. Unfortunately, solar particle events and galactic cosmic rays are difficult to model and predict as these phenomena are very complex [5].

As the inner Van Allen belt starts at about 700 km altitude, the altitude must be set below this height. Due to the magnetic axes of the earth being shifted from its rotational axis, an anomaly is formed. This anomaly is known as the South Atlantic anomaly and is a region over the Earth where the Van Allen belts are very close to the surface. The belt's are known even to reach an altitude of 250 km. This phenomena is known to occur between 35° and 60°, and so the orbital inclination of the space hotel should be below the lower limit of 35° or above the upper limit of 60°. However, above the upper limit of 60°, very energetic particles may also be encountered [1]. Hence, a constraint for the design is an orbital inclination less than 35°. As changing the inclination during launch to the station is expensive, the launch site must be chosen at an appropriate inclination.

Another aspect to consider is the radiation effects on the human body, especially for the space hotel crew as they will be staying longer out in space. The EVA and 'fake-EVA' activities for tourists should take into account these radiation effect. This is why regular radiation measurements must be completed using several fundamental systems. These systems consist of: the Nuclear Particle Detection System (NPDS), Van Allen Belt Dosimeter (VABD), Radiation Survey Meter (RSM) and a personal Radiation Dosimeter for the crew members and tourists [3]. Levels of ultraviolet light from the Sun must also be monitored, with guest exposure to direct sunlight, such as through windows and EVA, is to be regulated. It is decided, based on radiation risks, that each guest must be older than the age of 30. The younger a person is, the more likely they are to be effected by radiation [1].

8 Medical Issues

Several health issues must be considered for any visit to space. Issues to consider include sustainability of high gravitational forces, and adapting to a weightless environment. Guests must be trained and ready to adapt to such environmental extremes. A series of medical examinations and physical ability tests will be conducted to assess each guest's health. The height for each guest must be reasonable, as significant back cramps will develop for tall guests, and issues with equipment size may arise [1].

In order to prepare the guests for the large g-forces experienced during launch, several centrifuge tests will be conducted during the training period. It is also essential that the legs are placed above the head during launch [3].

Adapting to a new environment can be a long process. Each physiological system adapts at its own rate. Symptoms of human body adaptation to the space environment are illustrated in Figure 3. One of the first risks is on the human body's neurovestibular system, which may lead to space motion sickness. The body's sense of orientation is reliant on gravity, and due to the weightless space environment, this system is unnecessary. This condition leads to nausea and vomiting. As this condition cannot be foreseen, medications will be available on-board and tourists will be warned about such a possibility.

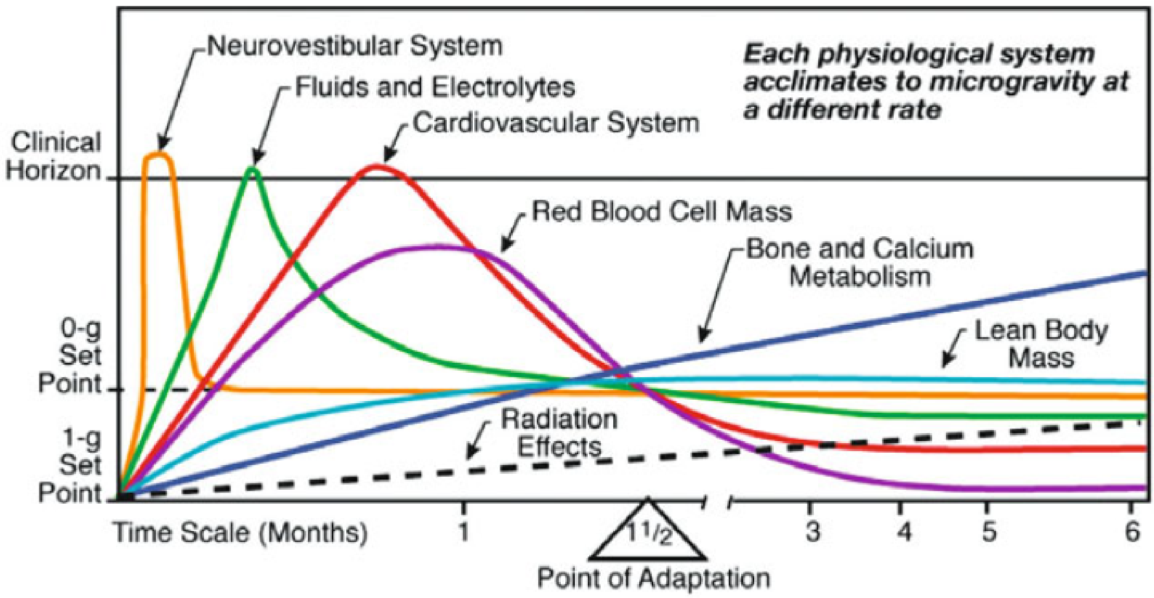

Figure 3: *Illustration of the physiological adaption of the human body to weightlessness as a function of time [1].*

Also, due to a weightless environment, body fluids will redistribute themselves. Such changes will cause headaches, nasal congestion and temporary body 'disfigurements'. Consumption of large quantities of fluid will counter such effects. Other medical issues include muscle atrophy and bone loss. These effects worsen with prolonged exposure to a weightless environment, as may be seen in Figure 3. To avoid these effects, the guest's length of stay will be restricted to a period of 10 days. Most available medical data are only valid to a short length of stay in space, so it is only justifiable for the guest to stay for a small period [1].

It is also very important to take into account the psychological welfare of the tourists. Separation from home, experiencing weightlessness and being in a confined environment can be very confronting to many people. It is therefore necessary that a full psychological profile be conducted for each tourist before arrival to space. A spacious hotel with full communication with Earth will also reduce the risk of any psychological distress. Appropriate sleeping quarters, good quality food and effective personal hygiene must also be a priority, not only for asssisting pschological issues but for the basic physical health of each guest [3].

A medical kit will also be present on board, containing medication to deal with both physical and psychological issues, including:

- Medical care for headaches, fever and antibiotics.
- Drugs which enhance immunity, bones and muscles.
- Radiation protection.
- Anti-anxiety and anti-depressants.

9 Exercise Requirements

It is necessary for the health of both the crew and guests that numerous exercise machines be installed in the space hotel. This activity is especially essential to the crew to counteract the body's physical decline that takes place in the weightless environment. The bone's, heart and lungs, muscles and organs all degrade significantly with long durations in space. These effects include a loss of calcium in the bone structure, a weakening of the heart's ability to pump blood around the body and muscle atrophy. The provision of exercise equipment will also allow the other physical and psychological benefits that come from regular exercise on Earth [3].

There will be three pieces of equipment present in the hotel, the Cycle Ergometer with Vibration Isolation and Stabilisation System (CEVIS), Combined Operational Load Bearing External Resistance Treadmill (COLBERT) and the Advanced Resistive Exercise Device (ARED). All of these pieces of equipment are the most advanced to date and all are currently in use on the ISS. CEVIS provides aerobic and cardiovascular exercise through cycling exercises [6], COLBERT is used to maintain bone, muscle and cardiovascular condtioning [7], and ARED allows simulation of free-weight exercises in normal gravity which maintains muscle strength and mass [8]. By use of resistive straps, walking may be simulated by COLBERT which creates exercise of the neurophysiological pathways and reflexes, which are necessary for walking on Earth. Each device is designed to minimise the transfer of dynamic forces created by use of the machine to the space hotel.

10 Extra-Vehicular Activity (EVA) Planning

In the space hotel, two types of extra-vehicular activities (EVA) are planned. The first will be scheduled maintenance work, which will be conducted by the crew in the extravehicular mobility unit (EMU). This space suit is in use in the American section of the ISS. As the suit contains an atmosphere unlike that of the Space Hotel, preparations must be made 15 hours prior to commencement of the EVA. Two crew members are part of the EVA at all times, and are involved in a "camp-out" where the body is prepared for a low-pressure environment. This session will take place in the airlock located in the hotel. Three space suits will be provided on station in various sizes [1].

The second EVA conducted is for the hotel guests, where heavy space suits will be used. These suits allow for an atmosphere equivalent to that on Earth, so the preparations discussed previously will not be required. Even though the heavy suit is still only experimental, such research is close to completion [1]. Currently, there is not much demand for such suits, as they are not very flexible, and the practicality of their use in maintenance operations and other EVA exercises is not great.

Fortunately, as the guests will only be performing the EVA for the experience of being free in space, such characteristics are not necessary. For safety reasons, each EVA will be conducted by one guest and crew member at a time, with the guest and crew being tethered to a five metre rope. The hotel will have handrails on its exterior to allow the participants to manoeuvre themselves. Training for this activity are detailed in the next section.

11 Before-Flight Training

To prepare for arrival at the Space Hotel and the space environment, a two-week training programme is planned. The activities involved are summarised in Table 2. This training programme involves about six day learning periods and one day off each week. The training will involve medical, food and hygiene preparations, flight system training with a centrifuge exercise and simulations, and EVA training with dives in the EVA heavy suit, detailed in the previous section. The training programme will also involve a parabolic flight exercise so weightlessness may be experienced prior to flight to the station. Medical evaluations of the guests will be conducted before the first day of training, and will continue throughout the training period.

Table 2: *Training activities that will be provided during the two week training period. The time required for each activity is included [3] [1].*

Training	**Time**	**Description**
Introduction day and overview of space travel	1 day	Provides an overview of space travel and the environment. A full day will be spent detailing the space environment.
Medical evaluations	2 days	Medical evaluation of each guests medical condition so it may be monitored throughout the trip. Will be conducted during the two weeks.
Onboard food system	4 hrs	Overview of food consumption. Lunch will also be provided with taste testing.
Radiation safety	1 hr	Presentation on radiation risks and safety
Sanitary and hygeine training	3 hrs	Introduction to sanitary and hygiene facilities on board. Includes practical sessions.
First aid overview	4 hrs	Gives an overview of applying first aid, in case of emergency.
Physical training	2 hrs	Information on how to physically train on the station.
Flight systems	1 day	Overiview of flight systems, infrastructure and operations
Flight simulation	1 day	Introduction to flight conditions and simulation of arrival at the space hotel.
Centrifugal exercises	4 hrs	Experience high g-forces before actual flight
Parabolic flight experience	1 day	Allows an experience of weightlessness before arriving in space.
Dives and EVA training	2 days	Practice in the diving pool being in the space suit in a weightless environment. Will also overview necessary requirements of the EVA.
Conclusion	1 day	Review everything that was covered over the two week period.
Total	$\sim$12 days	

12 Guest Activities

During the guests stay in the Space Hotel, numerous activities will be planned for the guests. These will include:

- Participation in an EVA, as discussed previously. One guest will participate each day during their stay.
- A fake EVA room, where guests may spend their leisure time.
- Sporting equipment will be provided on the station, such as frisbees and soccer balls, allowing guests to experience sport in a weightless environment.
- Communication facilities for video conferencing with people on Earth.
- Participation in space science experiments.
- Scheduled interesting Earth events and phenomena, such as the Auroras, weather systems and places of interest.

In addition to these activities, specified times for breakfast, lunch and dinner will be allocated, each consisting of one hour each. Two hours of physical exercise will also be required of each guest, so their physical condition may be maintained. Regular meetings with the crew's medical specialist will also allow for monitoring of each guest's medical condition.

13 What-If Situation

Given the critical nature of these systems, it must be ensured that they are operative at all times. For this reason, the water management system should be realized with two independent units working in parallel. This allows for, in the case of one of the system components malfunctioning, for a level of operability.

It should however be considered that the damage may be more extensive. In this case, water tanks will be provided board. It is also necessary to consider food requirements in the case of an adventure, and these two things should be considered together. Since such unforeseen conditions could delay the the next mission, on-board reserves should have the ability to last until the next available launch. This means providing approximately 120 kg of food and 1200 kg of water. For the food, since the typical shelf-life is 2 years, a 'First-In, First-Out' procedure will be utilised, where the food that arrived first is consumed first to prevent spoilage or waste. The rotation of guests should ensure that it is possible to consume all the food before date of expiry.

14 Conclusion

Human aspect requirements for a space hotel are detailed. A partially closed life support cycle is specified, containing elements sufficient for eight occupants. These include an OCG, Sabatier reactor and external water tanks. A thermal control system and air conditioning system is to ensure a healthy environment for the crew and guests. Medical issues are accounted for, where the length of stay is restricted to ten days and the guests age must be above thirty years. EVAs are planned for both crew and guests with EMU and hard suits respectively. Training will be provided over a two week programme, preparing guests for some of the activities scheduled on board, including physical exercise requirements, food and the EVA. Flight safety and medical issues will also be covered over the two weeks.

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