HUMAN ASPECTS
FOR A TWO PERSON SPACE TAXI

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***Abstract*—This paper sums up our teamwork on the mission to establish a space taxi to space stations. The work was distributed between several departments including the Overall Coordination Team, Launch and Return, Vehicle design as well as the Human Aspects Team that is ours. The goal of this paper is to study the different human aspects which are present during the spaceflight. Those aspects are crucial as they will ensure the safety of the client. Several points will be discussed : life support systems, safety and medical aspects including physical and mental health as well as crew training and failure events. It offers solutions on how to implement safety and habitability in a capsule designed to be a space taxi.**

Abbreviations – NASA-National Aeronautics and Space Administration, ESA-European Space Agency, LSS-Life Support System, VCD-Vapor Compression Distillation

Fig. 1. Red team and human aspect mission patches

I. INTRODUCTION

A. General background

The closure of the International Space Station (ISS) in 2030 is expected to usher in a new era of commercial space stations, creating a market for the shuttle of individuals to and from these novel orbital platforms. The inception of this market necessitates the development of a new class of space vehicle, one that is cost-effective, reliable, and capable of meeting the unique challenges associated with short-distance space travel. Unlike previous spacecraft, which were primarily designed for large-scale exploration and long-term missions, the ”Space Taxi” is envisioned as a vehicle that prioritizes agility, efficiency, and the capability to operate within the confines of a more localized spatial context. In this regard, the life support system becomes a focal point, not only due to its critical role in ensuring the safety and well-being of the passengers but also because of its potential impact on the overall design, weight, and resource management of the spacecraft.

B. Purpose and motivation

The primary objective of this study is to explore the conceptualization and design of a ”Space Taxi”, specifically tailored for short-duration missions to ferry two astronauts between Earth and the emerging commercial space stations. The motivation behind this endeavor is twofold: firstly, to contribute to the burgeoning field of commercial space travel by providing a viable, cost-effective solution for small-scale astronaut transportation; and secondly, to address the technical and engineering challenges inherent in designing a compact yet robust life support system for such a vehicle. By focusing on these areas, the study aims to not only advance the current understanding and capabilities in spacecraft design but also to pave the way for future innovations in the realm of localized space travel.

C. Limitations and assumptions

This study acknowledges several limitations and assumptions in the design and functionality of a space taxi’s life support system, which is tailored for a two-person crew on short-duration missions. Firstly, the life support system’s design heavily depends on current technology and the understanding of human physiological needs in space, which might evolve with new discoveries. We assume the availability of advanced materials and systems that can efficiently control atmosphere, water, and waste, although such technologies are continually being developed and refined.

Another significant assumption is the constant reliability of life support systems during missions. While modern engineering practices aim for high reliability, the possibility of system failure cannot be entirely dismissed. This assumption extends to emergency scenarios where the life support system must function flawlessly until the astronauts return safely to Earth or another station.

Furthermore, an assumption is that the client base is ESA astronauts. This means that they should have gone through different test before arriving to our company. So less medical and selection test will be provided.

The journey there and back is expected to take less than 6 hours each if the first docking is successful and 2 days each if the docking or returning fails, so the assumption that all necessary supplies for up to four days can be compactly stored and efficiently used within the space taxi might overlook the complexities of human consumption patterns and psychological needs during space travel.

Lastly, the energy requirements for maintaining life support systems are based on the assumption of having access to a reliable power source, which in space, typically involves solar panels. Any failure in power generation or management could lead to catastrophic failures in life support, an aspect that this study assumes will be managed through robust engineering and redundancy.

These limitations and assumptions highlight the necessity for ongoing research and development in space travel technology, as well as the need for rigorous testing of life support systems to ensure they can meet the demands of future space taxi missions.

II. LIFE SUPPORT SYSTEM

A. Human Physiological and Metabolic Needs

The life support system of a space taxi, designed for a two-person crew on up to 4 days mission, must meticulously cater to the physiological and metabolic needs of its occupants. The planned supplies table indicates each astronaut will require 0.84 kg of oxygen per day, leading to a total of 6.72 kg for two people up to four days. A similar allotment is provided for nitrox, which suggests a breathable air mixture that potentially enhances safety and comfort. Cryogenic oxygen is reserved at 0.12 kg daily per person, totaling 0.96 kg for emergency scenarios.

The system anticipates a daily CO_2 emission of 1 kg per person, necessitating an equal mass of LiOH for CO_2 removal over the course of the mission. This balance is crucial to maintaining a safe and habitable environment within the space taxi. Water emissions are expected to be slightly higher at 1.6 kg per day per astronaut, reflecting both metabolic output and potential condensation within the cabin.

For hydration and meal preparation, 1.62 kg of potable water per day is allocated for each crew member, with a total of 12.8 kg needed for the mission duration. In the space taxi's life support system, hygiene water is not included because the mission duration is less than 6 hours each for outward and return, and there seems to be no need for hygiene water for like personal cleanliness in a normal case.

The nutritional aspect is addressed with a dry food mass provision of 1.77 kg per person per day and an integrated water content in food of 0.8 kg, ensuring that the dietary needs are met without excess mass. The management of waste, both liquid (2.7 kg per person per day) and solid (0.1 kg per person per day), is also accounted for, completing the comprehensive life support strategy for the mission. Liquid waste refers to not only hygiene water waste but also the biological waste products such as urine and sweat, projected at 2.7 kg per person per day. Solid waste accounts for fecal matter and food packaging, with an estimation of 0.1 kg per person per day.

B. Air revitalization

1) Open-loop systems vs closed-loop systems: Open-loop systems and closed-loop systems are two different approaches to managing life support in spacecraft. Open-loop systems are simpler, as they do not recycle air or water. Once the supply is used, it must be replenished from Earth or space station. This simplicity makes them lighter and less

TABLE I
PLANNED SUPPLIES AND ESTIMATED EMISSIONS

		Per person per day(kg)	2 person up to 4 days(kg)
Air supply	oxygen	0.84	6.72
	nitrox	0.84	6.72
	cryogenic oxygen	0.12	0.96
Air emission	CO_2 emission	1	8
	Water emission	1.6	12.8
CO_2 removal	LiOH	1	8
Water supply	Potable water	1.62	12.96
Food	Food dry mass	1.77	14.16
	Water in food	0.8	6.4
	All food supply	2.57	20.56
Waste	Liquid waste	2.7	12.8
	Solid Waste	0.1	0.8

expensive, which is ideal for short missions where resupply is feasible.

In contrast, closed-loop systems recycle and purify water and air, allowing for longer missions without resupply. They are more complex and costly, both in terms of financial investment and spacecraft weight, which can be prohibitive for short-duration missions.

For the space taxi, an open-loop system was chosen due to these factors. It provides a balance between the need for life support and the mission's constraints on weight and cost. The short duration of the mission means that carrying enough supplies without the need for recycling is both practical and efficient. This decision was made after careful consideration of the mission requirements and the current state of technology, ensuring that the life support system is reliable yet cost-effective for the space taxi's operational goals.

Modeled after the life support systems like those in the Crew Dragon spacecraft, the space taxi's oxygen and nitrox supply will be a critical aspect of its life support system. The taxi will employ high-pressure tanks to store both oxygen and nitrox—a mixture of nitrogen and oxygen typically used for enriched air diving. Fig. 3 shows those in the Crew dragon. These tanks are designed to be lightweight and durable, crucial for withstanding the rigors of space travel. For the specified two-person crew up to a four-day mission, the system requires 6.72 kg of oxygen and the same amount for nitrox, considering both gases' per person per day usage.

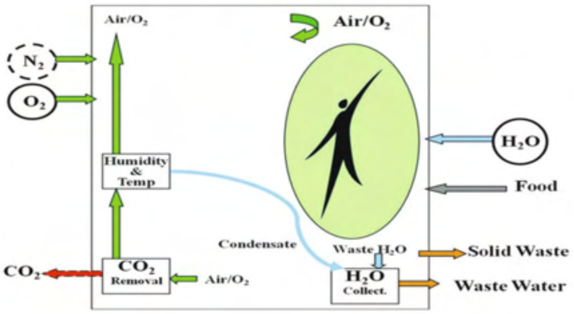

Fig. 2. Open-loop system [1]

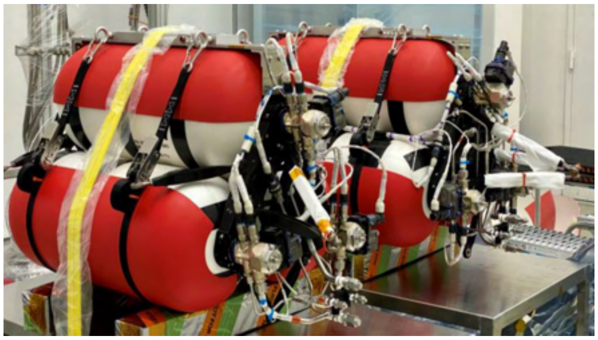

Fig. 3. Oxygen and nitrox bottle packs in the Crew Dragon [2]

The use of nitrox is advantageous in managing decompression sickness risks, especially in emergency descent scenarios. The tanks will be equipped with regulators and monitoring systems to ensure precise control over the cabin atmosphere, vital for both the physiological health of the crew and the operational integrity of the space taxi.

2) Carbon dioxide removal: The carbon dioxide removal system is crucial for maintaining a safe cabin environment by managing CO_2 levels generated by the crew. Lithium Hydroxide (LiOH) cartridges are used due to their effectiveness in binding with CO_2 to form lithium carbonate (Li_2CO_3) and water (H_2O), as represented by the chemical reaction 1

$$2LiOH + CO_2 = Li_2CO_3 + H_2O \tag{1}$$

For the four-day mission, 8 kg of LiOH is estimated to be necessary to ensure the air remains safe for breathing. This method is particularly suitable for short-term missions where resupply is not an option, as it's a single-use system that doesn't require complex machinery or regeneration.

3) Air sanitation, dehumidifier, and air distribution system: Referencing the Crew Dragon's life support systems, the space taxi will include an air sanitation box, dehumidifier box, and distribution system. The air sanitation system is a critical component that ensures the removal of trace contaminants and odors, which is particularly important in the confined space of a space taxi. It includes filters and a catalytic converter to break down volatile organic compounds. The dehumidifier box adjusts the humidity levels, essential for both astronaut comfort and preventing condensation on equipment. The air distribution system ensures that clean, temperature-controlled air circulates effectively throughout the cabin, preventing stale air pockets and maintaining consistent air quality.

C. Water and food supply

1) Tanks for water: The water storage system in a space taxi is designed to accommodate the unique challenges of space travel. The tanks must be robust enough to handle the rigors of launch and space travel while preventing any water contamination. For the two-person crew up to four days, 12.96 kg of potable water is stored, indicating that the system prioritizes the minimization of water mass without compromising the crew's needs for hydration and, food rehydration. The storage tanks are typically made from materials that do not react with water or alter its taste. Additionally, the design ensure that water does not become a free-floating hazard in microgravity, which necessitates a specialized dispensing system. These considerations are critical for maintaining the health and efficiency of the crew aboard the space taxi.

2) Space food: Space food needs to be compact, have a long shelf life, and require minimal preparation. Due to the short duration of the flight, a food production system is not needed and will be a dead-mass for the spaceship. Bringing food and store it is much more efficient for this kind of mission. Therefor, for the space taxi, the food system will provide a balanced diet while considering the limitations of microgravity and storage space. The 14.16 kg of dry food mass and 6.4 kg of water in food for two people up to four days suggest a reliance on dehydrated meals that can be rehydrated with the available water supply. Meals are designed for ease of consumption and to minimize crumbs, which can be a hazard in microgravity. Nutritional content is carefully planned to meet the energy and health requirements of astronauts, including a balance of proteins, carbohydrates, fats, vitamins, and minerals. Packaging is designed to prevent any leakage or spread of food particles in the cabin.

D. Waste management

1) Toilets: The space taxi's waste management system includes a state-of-the-art toilet design, influenced by recent advancements as seen on the International Space Station (ISS) (Fig. 4). This modern toilet, more accommodating for female astronauts, reflects a progression in space sanitation technology, focusing on comfort and functionality. It utilizes airflow to manage waste in microgravity effectively, a significant improvement over previous designs. The choice to have this heavy and expensive system is to give comfort to the astronauts in case the flight is extended up to four days due to off-nominal cases.

Fig. 4. A newly designed space toilet in the International Space Station [3]

2) Tanks for waste: The waste management system in a spacecraft like the space taxi is designed to hygienically collect and store human waste both liquid and solid until it can be recycled or safely disposed of. The system includes tanks specifically engineered to accommodate the microgravity environment of space. These tanks prevent waste from contaminating the spacecraft environment and are equipped with mechanisms for easy and secure waste disposal.

In our case, as an open loop system is used, liquid waste will only be stored in tanks. For solid waste, the tanks are compact, with the ability to compress waste to minimize space usage.

E. *Space suit*

A space suit is an other layer of shielding to protect astronauts from the extreme conditions of space, including vacuum, temperature fluctuations, and harmful radiation. They are used during the whole ascent and descent phases hence the name *ascend suit* or *entry/reentry* suit. They have a complete life support systems such as oxygen, temperature regulation and pressure control that allow astronauts to survive in the hostile environment of space mainly in case of cabin depressurisation.

For the hitchhiker, the chosen suit design has an important impact on the vehicule design and especially on the seats. That's why a custom made version of the SpaceX's suit was created in collaboration with Hitchhiker. SpaceX's space suit is engineered to meet rigorous safety standards while also allowing astronauts to move freely and comfortably during launch, re-entry, and spacewalks. High-tech materials are used to withstand the harsh conditions of space and ensure safety and comfort for the wearer.

Fig. 5. Bob Behnken and Doug Hurley make their way out to the SpaceX Crew Dragon capsule [4]

Then, the main characteristic of this suit is the all-in-one umbilical. This system is specifically adjusted to the Hitchhiker seats and the attachment mechanism fits the design of the seats chosen and presented later. This cable acts as a single connection point for crucial elements of space survival. It supplies cool, breathable air to regulate temperature within the suit. The umbilical also integrates with the spacecraft's communication systems, ensuring astronauts can stay connected with mission control and access navigation and avionics data. Additionally, it delivers pressurization gases, maintaining the suit's internal pressure during the spaceflight. Interestingly, the umbilical connects to a dedicated port near their thigh. This docking mechanism utilizes a quick-release design for emergency situations. Furthermore, the umbilical integrates seamlessly with this custom ”suit-seat” design.

In conclusion, these suits can provide all the LSS required during a human spaceflight and can still help the astronaut after an off-nominal landing in harsh environments.

F. *Monitoring and control system*

These systems are designed to ensure a habitable environment for astronauts by carefully regulating air quality, temperature, humidity, pressure and waste management. The integration of advanced sensors and control mechanisms allows for real-time monitoring and adjustments to maintain optimal conditions. They are maintained by a fully automatized system controlled by the onboard computer.

III. SAFETY AND MEDICAL ASPECTS

A. *Space Environment*

In order to delve into the safety and medical side of the space taxi and examine the potential considerations that we need to make, it is important to analyze the discrepancies of the space environment. Typically

B. *Space Hazards*

C. *Safety Measures*

Radiation : In order to address the issue of radiation - shielding and dosimeters can be used. Shielding involves placing materials between astronauts and sources of radiation to reduce their exposure. The crew will wear dosimeters to monitor their radiation exposure levels in real-time during spaceflight. Another preventive measure that can be taken is to plan trajectories that avoid high radiation areas such as Van Allen radiation belts and solar particle events.

Temperature: In order to regulate the temperature, the spacecraft will be equipped with thermal control systems to regulate internal temperatures and protect crew from temperature extremes, This would be in the form of insulation materials and active thermal management systems to help maintain stable temperatures inside the spacecraft.

D. *Pre-flight testing*

The medical testing and certification prior to space travel must meticulously examine the physiological well-being of the individual to ensure that incapacities due to medical conditions can be avoided. Taking into consideration that this is a short-duration space flight, some medical tests can be avoided. Primarily, each crew member would need to undergo a thorough physical examination and metabolic screening. The physical examination aims at providing a comprehensive assessment of the individual's overall health. During this examination, the medical professional would also be able to identify any abnormalities and screen for potential health risks. To cater for the short-duration flight in particular, the physical examination would entail measuring vital signs - including blood pressure, heart rate, respiratory rate, and temperature, head and neck examination - assessment of the head and neck region as well as the lymph nodes to inspect for any abnormalities. The physical examination would also include a cardiovascular and respiratory examination. Another important step that will be taken before space travel would be metabolic screening. Metabolic screening assesses the body's metabolic function and includes blood tests and countless other tests to evaluate metabolic parameters. As mentioned previously, with the consideration that this space travel should range between 6 hours and a maximum of two days, in rare scenarios, such intensive metabolic screening involving body composition analysis and hormone testing will not be required.

Further, another consideration that will need to be taken is the age and the age-appropriate health screening tests. These would include a colonoscopy, serum prostate-specific antigen testing in men, and mammography in women.

Moreover, the crew would also need to undergo hypobaric and hypoxia exposure training. Hypobaric training involves subjecting individuals or equipment to reduced atmospheric pressure, stimulating conditions experienced at high altitudes or in low-pressure environments, such as those encountered during high-altitude flight or space travel. This can be in the form of altitude chamber testing, which involves placing individuals or equipment inside a sealed chamber and reducing the pressure to stimulate high-altitude conditions. Hypoxia exposure training helps individuals recognize and respond to the symptoms of oxygen deprivation.

E. *In-flight testing*

In-flight testing is another requirement for crew members and it serves several important purposes. It assesses the individual's physiological response to spaceflight and allows medical professionals to monitor crew member's physiological health in the space environment in real-time. Reiterating that this would be a short duration flight, the in-flight testing would primarily focus on vital signs monitoring, motion sickness monitoring as well as psychological assessments. Vital signs monitoring would focus on measuring and monitoring the heart rate, temperature, blood pressure, respiratory rate and oxygen saturation levels. These measurements would be taken through portable medical instruments and sensors, which would collect data and transmit it to ground-based medical teams for analysis. This introduces another element of the medical side of the space taxi, which would entail having a ground-based medical team with medical professionals, who would continually monitor and assess said real-time data for any abnormalitues. The portable medical instruments that would be required for each crew member would be ECG monitors, pulse oximeters, blood pressure monitors and temperature sensors. For motion sickness montoring, we would focus on looking out for symptoms such as nausea, vomiting and disorientation,

F. *Post-flight testing*

Upon completion of space travel, there are a few medical tests that the crew members will need to undergo to ensure that the space environment or travel did not negatively impact their physical health. There will be an immediate post-flight assessment, which would focus on taking vitals and trying to identify any immediate concerns. Additionally, post-flight, another recommended test is orthostatic intolerance testing. Orthostatic intolerance testing refers to the body's inability to maintain blood pressure and circulation when transitioning from a horizontal to a vertical position. This can be caused by spaceflight due to the potential fluid redistribution. Orthostatic intolerance symptons include lightheadedness, dizziness, fainting or feeling faint when standing up, which arises as a result of inadequate blood flow or abnormal cardiovascular responses Another key consideration would be the psychological health of the crew. Noting that this is a short-duration spaceflight, the likelihood of severe psychological effects are quite low, however, it would be ideal to assess the individual's psychological health. Psychological health monitoring could be in the form of looking out for behavioural changes or perhaps physiological indications.

G. Abort system

In order to save the crew at every phase of the flight if something happens, capsules are equipped with abort systems. This system is used differently depending on when the incident appears.

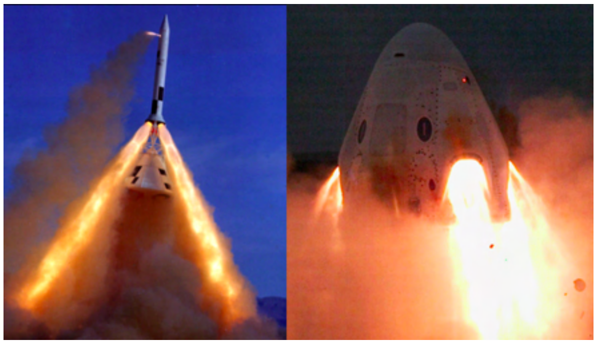

Fig. 6. Apollo and Crew Dragon abort system

In case of emergency on the launch pad or during the early stages of the ascent, the abort system is ignited to propel the capsule away for the main rocket. If a performance anomaly appears during the assent, the abort system can be used to reach an orbit, it may be at a lower altitude or at a different inclination than expected, but it allows the crew to take the decision to continue the mission or come back to Earth. A variant of the previous case is when the abort system put the capsule in a single orbit before initiating re-entry. In some cases, the capsule cannot be put in orbit due to the rocket position when the failure arrives, in that case the system propulse away the capsule to make a ballistic re-entry possible. Abort system can also be used in case of orbit emergencies ass an orbital debris for example. In this situation, the abort system deorbit the capsule to avoid the debris and the capsule go back to Earth. All these different abort scenario are possible due to powerful motors on the side of the capsule. The vehicle is designed to use those engines to land, so there are more powerful than needed for only the abort scenarios.

H. Limitations of the human body

Due to its composition, a human body can only tolerate a finite acceleration for a finite time, or temperature before suffering with critical damages. During different phases of the flight, astronauts are subjected to acceleration between 4 and 6 Gs, due to the main engine burn or during the reentry. This vertical acceleration is already enough to cause a variety of physiological effects, including dizziness, nausea, blackouts and faint outs (after 6 Gs). During the landing phase, if the acceleration is higher than 5 Gs, astronauts can be hurt and if the acceleration is too close to 10 Gs or more, critical injuries like spinal fracture can occur.

Concerning the rotation speed; 30 rad/s is the maximum rate at which an astronaut's head can rotate before experiencing dizziness or disorientation. With training, this limit can be push back.

The human body is also very sensitive to temperatures. In space, they can go from almost the absolute zero to thousand of degrees due to the friction between the spacecraft and different molecules during re-entry. This peak, can reach 2000 °C, so spacecrafts are equipped with heat shields to protect humans and the structure of the vessel. The heat shield blocks the gradient of temperature in order to have a suitable temperature inside the capsule while having almost 1500 °C at the surface of the shield. As a backup, astronauts where another thermal protection, the suit. This suit is equipped with thermal systems to make sure that inside the temperature is below 41 °C, to avoid serious health problems

I. Seat design

An important aspect of human spaceflight is the design of the seats to make sure that the forces are distributed evenly across the body of a passenger. In case of high exposure to g-forces, which not only may appear in an abort mission, but also usually happens during the re-entry phase, the seats need to be designed in a manner that minimizes the risks of injuries related to the high g-forces.

The conceptual design of the seats that is implemented in the space taxi is inspired by the paper ”Design of a Recumbent Seating System”, from

NASA, [8] The preliminary design of the seats follows the layout depicted in figure 7, in which the passengers lay down with their legs supported. Using these measurements, NASA assures that the seats are suitable to the 5th percentile civil woman, to the 95th percentile civil male. From a business perspective, this will give the space taxi company a broader range of potential clients.

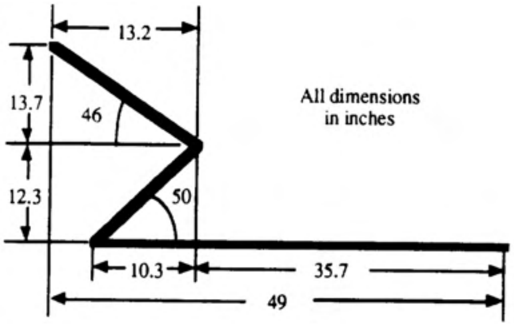

Fig. 7. Conceptual design of the seats [8]

Moreover, the paper compares different types of seat dampeners, that could be used, implemented underneath the seats. Some examples are crushable materials, magnetic dampening and spring dampening. The pros and cons of every alternative is well presented in the paper by NASA and will not be presented here. However, the spring dampening system is chosen for the seats aboard on the space taxi. Using these spring dampeners, the seats can oscillate, leading to providing the highest possible damping out of the alternatives presented [8].

Furthermore, usually the seats aboard of a manned rocket is perfectly molded to the astronauts body to maximize the even force distribution. From a business perspective, this is not feasible. A technology that would mimic this idea is memory foam. This technology originally stems from NASA and was used in the seats aboard on the space shuttle, and is now used world wide in all kinds of different applications [9]. The memory foam is the first layer of contact between the seats and the passengers, ensuring not only a more comfortable flight, but also, as stated previously, a more equal spread of forces.

J. Communication system

Spacecraft communication systems are crucial for transmitting data to Earth, receiving commands from Earth, and relaying information between spacecraft. Communication systems include ground segments (stations on Earth) and space segments (spacecraft and their communication equipment). The three main functions are uplink (commands from Earth), down link (data transmission to Earth), and cross-link (communication between spacecraft) and for each one a different system can be used.
For uplink and down link, radio frequency are most commonly used nowadays, but NASA is developing and other system more performant, the FSO (free space optical) which use laser to send signal faster. Concerning the radio frequency, two bands are mainly used KU (Kurz-unten) from $12\ Ghz$ to $18\ Ghz$ (fig. 8), to communicates between satellites, spacecrafts, ISS and Earth and S band from $2\ Ghz$ to $4\ Ghz$, to communicate with the ISS and previously with space shuttles. The communication between spacecraft as for example between the ISS and some astronauts in EVA (Extra Vehicular Activity) is using UHF from $300\ MHz$ to $3000\ MHz$. Different frequencies are used for different use because on higher frequencies, more information can be sent in a set time but the hardware (transceivers like radios, amplifiers and antennas) must be more powerful and so consume more power.

Frequencies need to be chosen wisely as it is interdependent of some design factors including data rate, power consumption, and mass and some requirement as antenna types and coding scheme.

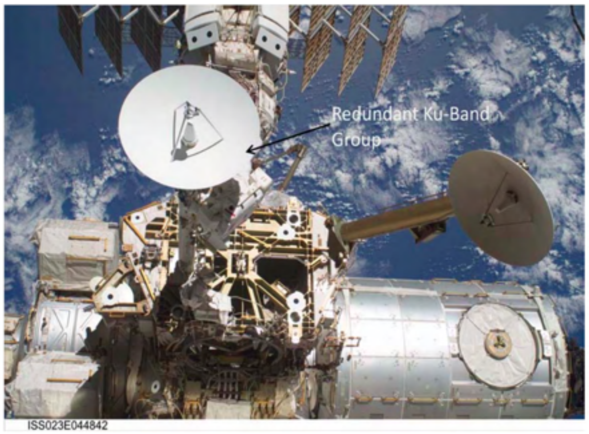

Fig. 8. ISS KU-band antenna

Radio frequency is working well to transmit data as long as we are close to Earth, but for missions further away, as the transmitting time is higher it is important to send more data at the same time. This is the purpose of the FSO. The use of lasers allows larger bandwidth and higher data rates. Other advantages are a narrow beam widths, a low probability of intercept, a resistance to jamming and interference. This way of communicating is promising, but not fully developed yet. To conclude, the space taxi will be equipped with radio communication, as the mission duration is not long and the taxi will only reach low orbits and so stay close to the Earth. For a question of simplicity, to avoid having a lot of mechanism and potential failure and also to gain weight, only one type of antenna is present on hitchhiker and one band of communication is used. The KU-band is selected as it can fulfil all of our requirements regarding the needs of an autonomous space taxi.

K. Ground operations

In the space taxi, ground operations require careful coordination of various personnel. Four technicians assist the astronauts to make sure that their suits function properly and assists with installation of the astronauts into the capsule to ensure their safety.

Before Hitchhiker's launch, four technicians help the astronauts adjust their spacesuits and helmets. Another four-person team assist with the installation of the capsule and ensure their safety before launch. Meanwhile, in the Mission control center, 24 professionals including the flight director, surgeons, engineers and specialist for off-nominal cases and the capsule communicator (CAPCOM). The CAPCOM is usually an astronaut, who is able to communicate more efficiently with the other astronauts. Then, an operating team including two doctors, a boat crew for sea landing or a land landing crew is ready to get the capsule and help the astronaut upon landing.

To sum up, about 50 professionals are needed for the meticulous ground operations assisting the astronauts during each stage of the spaceflight.

IV. CREW TRAINING

A. Pre-training

To make sure that the astronauts can handle the harsh forces and different consequences of the space environment, the astronauts need to endure and complete specific training in order to get the human body and mind strong enough for them to complete their mission and space journey. While the astronauts are in space, the importance of exercise and weight training increases with the duration of their mission. However, this aspect of astronaut training is not considered in this paper, since the goal of this project is to develop a 2-manned taxi to space. The company that provides this taxi service is only concerned about training specific to the traveling back and forth, between Earth and their target.

The spacecraft will be fully autonomous, including the abort system. However, the autonomous system may malfunction. As a consequence of this, a part of the crew training must include a session in which the clients will undergo procedures and training where they learn about how to manage an emergency that hinders the autonomous system to work properly. They will need to know what to do if a fatal error would occur in which the autonomous system would stop working. The FAA states in their checklist for human spaceflight that the crew is required to undergo training regarding abort scenarios and emergency operations (insert source, Human spaceflight checklist). ESA also follows these regulations when it comes to human spaceflight, this is important since ESA is our target client.

Furthermore, the FAA states that crew members need training to withstand the stresses of spaceflight. One clear stress of space flight is the exposure to high G-forces. These forces occur when the rocket would accelerate, which generates a force in the opposite direction of flight. Depending on how fast the rocket accelerates, the forces can grow significantly large. There are different ways one could train getting the body used to these G-forces. One way is with the help of a human centrifuge, as seen in figure 9. In this contraption, high G-force values can be generated as the astronaut spins around in a circular motion, generating a centripetal force. This device would be essential for the training of the clients to make sure they can withstand the high forces while still being able to, for example, undergo the abort scenario procedures. Most likely, the missions that the space taxi company would perform would not result in extreme G-forces. However, if an abort scenario would undergo, there is no guarantee that only low to moderate G-forces would occur. This leads to the having the clients well-prepared if high G-forces would be inevitable. A facility that NASA's astronauts train their resilience to high G-forces is the Air Force Research Laboratory (AFRL). A contract between the space taxi company and a facility like the AFRL but in Europe preferably, where the clients could train, would be essential for the existence of the space taxi company. There are human centrifuges in Europe. An example is the newly opened facility ”RAF Cranwell” in the UK, where the Royal Navy and Royal Air Force undergo their g-force training [11]. Eventually, if this space taxi company would expand and be established, the company could build their own human centrifuge to save money in the long run.

Another way that NASA trains their astronauts' resilience to high G-forces is through flight. The astronauts are required to have a certain amount of flight hours per week. This is not only for G-force training, but also for them to be comfortable with steering and controlling an airborne vehicle. In the case of the taxi company, this is not necessary. The clients are only required to get accustomed to the G-forces. Letting them learn to fly is not relevant. Therefore, the human centrifuge is a more realistic approach.

This space taxi company would primarily accept contracts in which the clients are astronauts. However, if the company also were to be able to accept tourist related contracts. More effort needs to be directed towards physical training to make sure that their bodies and health are at an adequate level. ESA, along with NASA has their own training schedule in which the astronauts are required to perform exercises such as push-ups, squats, etc [10]. A training regime similar to what the current astronaut undergo would be mandatory in order for the clients to be cleared to perform the spaceflight. In our primary case, in which we assume our clients are ESA astronauts, ESA is responsible for making sure that the astronauts bodies are prepared for space environment and microgravity and such. What the space taxi company would offer is training regarding the launch and return of the spaceship. Such as the G-force training.

B. Survival training

Another aspect of the crew training is survival training. In case of an off-nominal landing site, which could happen during an abort mission, it may take some time for the ground crew to reach the clients. As a consequence of this, the clients must undergo survival training where they would learn to survive in the wilderness for a certain amount of days, to ensure that they are capable of surviving on their own. It may be the case that the capsule is damaged, and the crew is advised to stay away from the capsule, in case of an explosion or other life-threatening scenarios which could be the result of a damaged capsule. This means that the survival training would be thoroughly conducted, in which the clients would learn to build shelter, look for food, find water amongst other survival endeavors. This is essential for the safety of the client.

Fig. 9. Bob Behnken, NASA astronaut, Nov. 2, 2018 at the Air Force Research Laboratory's centrifuge facility at Wright-Patterson Air Force Base, Ohio. (U.S. Air Force photo by Keith Lewis)

C. Autonomous training

Furthermore, a basic training to inform the clients of how the autonomous system works and what will happen during an abort mission is also provided, making them more comfortable and prepared for an abort scenario. Also, in case of an autonomous system would fail, specific training is offered for the clients to know what to do in this kind of situation. They also need to be able to have a good understanding of the system to follow directions and instructions from the ground crew if this would be necessary. General emergency training is provided as well, for example, fire extinguishing training.

V. OFF-NOMINAL CASE

While extensive measures are taken to design robust life support systems, it is crucial to anticipate and mitigate potential failures, especially in off-nominal situations. Off-nominal cases refer to unexpected scenarios or malfunctions that may compromise the functionality of the life support system and thus endanger the crew. Addressing these challenges requires innovative solutions and contingency plans to safeguard the health and safety of astronauts during their missions. There are different types of potential failures in an open-loop LSS :

Oxygen Depletion: In an open-loop life support system, oxygen is supplied to the crew from stored sources or through chemical processes. A potential failure could involve the depletion of oxygen reserves due to leaks, system malfunctions, or unexpected increases in consumption. This situation could lead to a critical shortage of breathable air for the crew.

Carbon Dioxide Buildup: As astronauts exhale carbon dioxide, it must be effectively removed from the spacecraft's atmosphere to prevent harmful levels of buildup. Failures in the carbon dioxide removal system, such as malfunctioning scrubbers or inadequate ventilation, could result in elevated carbon dioxide levels, leading to respiratory issues and impaired cognitive function.

Autonomous system failure If something goes wrong with the automatic systems, the capsule can be piloted from ground or from the space station (if close enough).

Contamination: Contamination of the life support system components or the spacecraft environment can occur due to various factors, including equipment failures, microbial growth, or chemical leaks. Contaminants could compromise the quality of the air, water, or food supply, posing health risks to the crew.

Temperature Control Failure: Maintaining a stable temperature within the spacecraft is essential for the comfort and well-being of the crew. Malfunctions in the thermal control system, such as failure of heat exchangers or coolant leaks, could result in extreme temperatures that endanger the crew's health and equipment functionality.

Power Supply Interruption: The operation of life support systems relies heavily on electrical power. Any interruption or failure in the power supply, whether due to equipment malfunction, solar panel damage, or battery failure, could jeopardize critical life support functions, including air circulation, water purification, and temperature regulation.

A. Specific case

Considering the new technology of deploy-able solar panel, it can be interesting to focus the impact of a potential loss of electrical power for several hours during the spaceflight. The spaceflight is considered to be either on the day long orbiting before docking or after de-docking before the reentry window is clear.

First scenario:

Cause: Solar panels blocked halfway, half of the solar panels working. Which means that the capsule can only be powered instantaneously and that the batteries can't be charged. In this configuration, the batteries are designed to last 24 hours. They are only used during eclipses.

Consequence: There will be partial power shutdown to limit the power drawings from the batteries. The most important systems that rely on power supply have to be preserved. Thus, the system will enter in low power mode at about half the nominal power. In this mode, the power drawings from LSS and navigation systems have to be adjusted. Specifically for the LSS, the power is to be divided by 2 and here are the planned adjustments:

Air revitalization including ventilation is about 0.2 kW and the oxygen-nitrogen tank are high pressured. They are used for backup when a pressure adjustment is needed. This means that ventilation is the LSS with the most power draw. Its consumption can be reduced meaning that the air won't circulate as much as before but the ventilation should still be able to renew it and vacuum the ambient air to push the emitted CO2 to the filter. **Dehumidifier system** needs 0.04 kW/CM: this system can also be restricted to draw only 0.02 kW per crew member. **CO2 removal** is guaranteed by the lithium filter as it requires no power. **Lights** should be lowered to the minimum brightness. **Communication** must be preserved as well and no real power saving can be done. **Onboard computer** should in low power mode. This is the most power drawing system in the capsule, so reducing its consumption in low power mode should be the first thing to try and achieve. This mode implemented by the IT engineers allows to reduce the overall power consumption by a third reaching 30% reduction. **safety detectors** (fire, health, oxygen rate,etc) are still fully powered

In the end as shows table.II, the power savings comes as 50% from the LSS and 35% from the lights and onboard computers, totalising a 40% electricity savings.

Alternative scenario :

LSS	Adjustments
Ventilation	-50%
Dehumidifier	0,04 to 0,02 kW/CM $\rightarrow -50\%$
CO2 removal	No power draw
Light	-50%
Onboard computer	-30%
Total	**-40% power draw**

TABLE II
LOW POWER MODE ADJUSTMENTS

Cause: No power supply from the solar panels. In this configuration, the batteries can't be charged and the instantaneous power is no longer coming from the solar panels. The batteries are designed to last less about 9 hours. Using the low power scenario, this can be improved by 40% meaning the batteries can last 13 hours. In the event that the capsule could not reenter within the 13 hours, the LSS operate as follows.

Consequences on the LSS:

- Astronauts can rely on the air tanks as they are highly pressurised until the pressure starts to decrease. The ventilation however can't work properly, meaning they will quickly have to put on their spacesuits. Thus, they should be ready to use their spacesuits resources at all time and by waiting before the beginning of depressurization. They can thus save some of their suits resources in case of further complications.
- Communication and navigation: an automatic reentry mode powered seperatly can be trigerred by the astronauts. This mode should be trigerred within the 13 hours of battery power.

This alternative scenario is not really conceivable as the capsule should reenter before the power outage. If the reentry can't be triggered, the crew will need a quick rescue, as they only rely on their spacesuits resources.

VI. CONCLUSION

To conclude, this paper presented a complete study about human needs in space regarding a short-duration flight. It also emphasizes which system can be used to accommodate human in space for a 2 seat taxi, from the O2 production to waste management without forgetting water and food supply. Space is a harsh environment even is a space capsule, so one needs to make sure the astronauts are in a good health condition to fly and also that it is still the case after the mission. All those elements were covered in this paper. Some training is necessary to be able to work in concert with ground operation in case of emergencies, or just to be able to behave well in a space station. To finish, to be ready in every situation, some off-nominal cases were explored, in order to make sure our capsule can keep astronauts alive in those extreme situations.

The crew's safety is our priority, and Hitchhiker is perfectly well design to accommodate two astronauts up to four days in space.

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APPENDIX A : DIVISION OF WORK

All members contributed to the paper writing, with the work division presented in the following Table III. More work was done by all the members during the project to provide data to the different groups in red team and answer their questions.

Name	**Main responsibility**
Alex Doulas	Crew training, seats
Zakariya Mahi	Space suits, off-nominal case, ground control
Sudha Shree Mohanarangam	Safety and medical aspects A to F
Julien Oiry	Limitation of the human body, communications, abort system, conclusion, references, appendix
Haruto Tomii	Life support system, introduction and general organisation

TABLE III
DIVISION OF WORK

APPENDIX B: MASS, VOLUME AND COST BREAKDOWN OF ALL DIFFERENT SYSTEMS

System name	**Mass** [kg]	**Volume** [cm^3]	**Cost** [$]
Air revitalization system			
air sanitation box	20	15 000	50 000
dehumidifier box	15	136 000	50 000
air distribution system and fans	30	48 750	100 000
high pressured tank (200bar, 50L)×2	108	100 000	300
LiOH cartridges	1.54	100 000	50 000
Air Supply (2 person up to 4 days)	22.4	0	278
Water and Food storage			
Tank for water	8.6	9 000	115
Storage and package of Food	8	7 000	115
Water Supply (2 person up to 4 days)	28.16	0	26
Food Supply (2 person up to 4 days)	14.16	0	3 618
Waste management			
toilets	45	336 000	2 300 000
tank for liquid waste	8.6	9 000	200
tank for solid waste	4	2000	200
Pressure control			
equalization plug, pipes, fans and valves	30	26 000	1 000 000
Temperature control			
heat exchanger, radiator	70	421 875	1 000 000
Communication system			
radio transmitter and antenna	25	170 250	500 000
Power and Control System			
Control panel	40	100 00	210 000
On board computer	40	50 000	210 000
Vitals monitor	25	154 000	80 000
Electrical Power System	50	100 000	2 000 000
Safety and Emergency Support System			
cryogenic O2 storage	13	16 875	2 000
Cooling system for cryogenic O2	10	125 000	150 000
First aid, fire suppression	12	13 500	5 000
Space suits	30	80 000	3 000 000
Total			
Launch payload	530	1 775 650	37 714 037
Return payload	498	1 775 650	

TABLE IV
DETAILS OF MASS, VOLUME AND COST OF DIFFERENT SYSTEMS