AstroCab - A Space Taxi for Two People
Human Aspects - Blue Team

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Fig. 1: Logo

***Abstract*—This paper encapsulates our collaborative efforts toward the development of a Small Space Vehicle tailored for taking two astronauts or tourists to commercial space stations, involving an Overall Coordination Team, a Vehicle Design Team, a team that focuses on Launch and Return, and also our team focusing on Human Aspects of the project. Then, this report in particular outlines human factors and considerations for the construction of this space taxi. Those aspects are crucial to ensure the integrity of passengers inside the capsule. Several points and challenges will be discussed, including the estimation of human basic needs for each flight, a description of all life support needed inside the capsule, a description of all the medical aspects relevant for this type of flight, a complete risk analysis will also be provided with the resolution protocol for one of the off-nominal cases and also the selection and training protocol before the flight will be detailed.**

NOMENCLATURE

ACES	Advanced Crew Escape Suit
ECLSS	Environmental Control and Life Support System
FDS	Fire Detection and Suppression System
ISS	International Space Station
IVA	Intra vehicular
LEO	Low Earth Orbit
MCC	Mission Control Centre
MELISSA	Micro-Ecological Life Support System Alternative
PCS	Pressure Control System
TCS	Thermal Control System

I. INTRODUCTION

THIS project fits into a very special context. Indeed, the cost of the International Space Station represents for the states that fund it a spending of 100 billion dollars for 10 years [19]. In addition, the structural stress on the space station increases with time and will become unbearable in the coming years[20]. That is why, the closure of the ISS is expected for 2030. This closure will launch a new era of commercial space stations financed by private actors. The expansion of this market will request the development of a new kind of space vehicle able to send humans into those space stations at a high frequency while being cost-effective and reliable. This is an important engineering challenge because to meet those requirements, the full reusability of those vehicles should be ensured.

The goal of this project is to study the development of a space vehicle tailored to send two people into orbit and make them come back to Earth in a short-term mission. The development of this vehicle could make it possible to create a kind of cab line between Earth and space stations. However, this vehicle has to represent for space companies a reliable and cost-effective solution to send their employees into space. Moreover, the challenge is also technical because the implementation of all the life support needed in a quite small capsule will make the design difficult, the goal here is to discuss which type of technologies should be available for the vehicle and also which one has to be developed for this special case.

For the realization of this project, some assumptions specific to the human aspect have been made. The stations reached by Astrocab have to be in LEO. In addition, the duration for the outward trip in the worst scenario would be 45 hours. For the return trip, the worst scenario considered for this project is that the Astrocab has to wait 4 full orbits undocked before coming back on the ground, which would represent around 8 hours.In conclusion, for the return in the worst scenario, the capsule will need 8 hours to come back to Earth and then for the whole trip, the life support system and consumables should be prepared for a flight duration flight of 53 hours. In addition, the personnel who are going to travel in Astrocab will not have to be fully trained astronauts, meaning that the vehicle will be fully automated.

II. HUMAN NEEDS

In this section, the basic needs for human survival will be discussed. In addition, the target of the project is not only to send astronauts to space but tourists with no experience of spaceflight too. This difference implies an adaptation in the estimation of these needs. Indeed, to make this project economically viable, the capsule where people will stay during the trip needs to be more comfortable than what astronauts usually get. The main issue here is to find a compromise between the improvement of comfort in the capsule and the feasibility of designing this kind of space vehicle, that's why a mass analysis of these needs should be provided to the vehicle design team.

A. *Food*

The duration of the flight is very short, making the implementation of a food-generating system inside the capsule not relevant. Therefore, all the food has to be prepared and stocked before the launch. In addition, the vehicle's automated nature implies that tourists inside the capsule will not have to perform any actions during the flight, that's why the food has to provide only the nutriments to enable people to survive. However, because of the comfort considerations, it is in the best interest of a business to provide less extreme meals.

The diversity of food that can be offered to tourists is really large because, on a flight of this duration, food conservation is not a concern. According to NASA requirements [5], eight types of food currently exist for space missions but most of them have been created for long-term conservation. Assuming that for this project, the basic meal provided should in majority include natural food or fresh food. This assumption would simplify the appliances needed inside the capsule, as there is nothing to cook. What's more, the amount of water required for cooking can be eliminated from mass analysis. According to [13], an astronaut consumes 0.80kg of food each day to stay in shape, the nutrients provided by food have been calculated before by specialists and the meal has been validated by the astronaut too. However, as explained before, people inside the capsule don't have to work or exercise and they will not stay in the capsule for a long time but for the comfort of passengers nice meal should be prepared. In addition, in the astronaut food consumption given above it's only dry food, however in fresh/packed food the water is still inside the food. That's why an assumption of 1.2kg of food consumption per person and per day has been made for this project.

As a conclusion, 5.3 kg of food should be taken for the whole flight.

B. *Water and Hygiene*

The amount of water required for each flight can be categorized into three distinct categories. The foremost category pertains to drinking water, as outlined in [13]. The water associated with cooking has been assumed before equal to zero. A small amount of water is also needed for the hygiene of people in the capsule. However, regarding the duration of the mission, the quantity of hygiene devices taken for the flight will be limited, it's precisely an example of finding a compromise between comfort and what is really needed. Thus, it's assumed that inside the capsule only toothbrushes and wipes will be taken for hygiene.

Assumptions regarding the water consumption for each trip have been made thanks to this article [13] and will be summarized in Table I. In addition, a short-term trip like this makes the water recycling system not relevant, that's why a water tank should be included in the design of the vehicle. The estimation of the mass of the tank has been based on the Rodnik's tank use in the Russian part of the ISS. According to [6], this tank can stock 210L of water and weigh itself 35.4kg. For the Astrocab, 13.12L of water have to be taken for the flight, a rough estimation given that the mass of the tank needed is assumed equal to 2.9kg

$m_{drinking}$	$m_{cooking}$	$m_{hygiene}$	m_{tank}	m_{food}
12.32kg	0kg	0.88kg	2.9kg	5.3kg

TABLE I: Amount of water needed for each trip

III. LIFE SUPPORT SYSTEM

Our mission demands a lightweight system capable of sustaining a maximum 53-hour journey to a space station in LEO under off-nominal conditions. Emphasizing efficiency and cost-effectiveness, our space taxi model will be meticulously designed with carefully selected technologies and onboard essentials. For the preliminary design of AstroCab important aspects of these systems are the approximate mass, volume, and power consumption of the systems, since it is essential for the Vehicle design and Launch and Return team's work. This information is presented in Table II and the approximation is explained in the corresponding sections.

Type of system	Total mass (kg)	Total volume (m^3)	Power (kW)
Crew need	24.27	0.33	-
Air system	153.80	0.77	0.2038
Waste management	101.65	0.21	0.074
Thermal control	131.00	0.06	0.16
Pressure control	24.50	0.05	0.03
Fire suppression	15	0.01	0.03
Suit	30	0.11	0.02
Seating	30	1.3	-
Crew	160*	5**	-
TOTAL	**670.22**	**7.84**	**0.5178**

TABLE II: Summary of system characteristics * *considering an average mass of a passenger, **While the recommended volume for an 8-day trip is 5 m*^{2} *per person, and scaling down for the mission length would require less volume, the decision was made to opt for a higher volume to enhance the passengers' comfort* [27]

A. *Environmental control - Atmosphere*

To sustain human life within a spacecraft, oxygen is essential for breathing, coupled with the expulsion of water and carbon dioxide. An air management system is imperative to meet the basic life needs of astronauts onboard. Additionally, this system must eliminate trace contaminants present in the closed spacecraft environment, requiring meticulous knowledge for every input and output.

Addressing the human life cycle's fundamental requirements, the accompanying Table III provides a comprehensive overview, prompting the need for strategic design decisions.

nature	mass (kg/day/pers)
O_2	0.84
water (perspiration/respiration)	1.65
CO_2	1
Ammonia (contaminants)	trace
Methyl mercaptan (contaminants)	trace
Pyruvic acid (contaminants)	trace

TABLE III: Humans ins and outs regarding atmosphere supply in ECLSS.

To mitigate fire risks within the spacecraft, the decision was taken to establish a breathable atmosphere containing oxygen and nitrogen, stored in high-pressure gaseous states within stainless steel tanks. Despite cryogenic storage initially being considered, the substantial energy requirements steered the preference toward stainless steel tanks, emphasizing energy conservation over volume, as depicted in Figure 2.

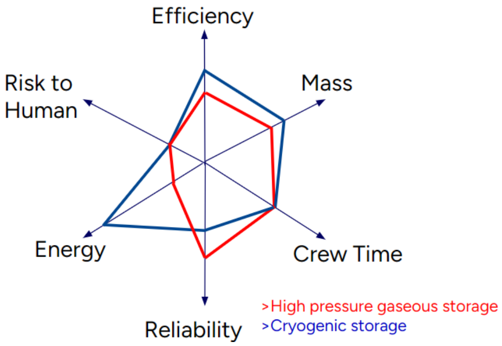


Fig. 2: Comparative choice on oxygen supply based on ALISSE methodology from ESA

Ensuring the spacecraft's oxygen supply involves integrating a device with control valves, thermal control, and composition control. An emergency redundant line, filled with nitrogen in case of depressurization, is incorporated in the IVA suits via the umbilical cord providing oxygen to astronauts.

When managing waste and undesired gases, Table III provides a detailed list. While contaminants like Acetone or Acetaldehyde can be produced in the spacecraft, they won't reach dangerous concentrations within the mission's worst-case scenario of 53 hours [18]. However, they must still be removed to prevent a toxic atmosphere. Drawing from the Shuttle system, methods like activated charcoal, copper sulfate sorbeads, and condensing heat exchangers are effective in tackling these trace contaminants [18]. They integrate into the air filtration system without significantly increasing mass. Particular attention is given to the management of grey water from perspiration and respiration, along with CO_2. The use of LiOH canisters for CO_2 and a condenser within the thermal control system for water removal showcase efficient solutions. The ECLSS operates as an open loop, storing waste onboard due to the potential utility on a space station, aligning with emerging recycling options like the MELISSA system [7]. Detailed discussions on waste management follow. The LiOH canister, in Fig.3 and the condensing heat exchanger are operated in parallel, utilizing a common fan to supply the total flow required for CO_2, humidity and temperature control. Several fans should be provided to meet the operational-fail safe requirement and redundant check valves at each fan outlet prevent back flow through a nonoperating fan and a failed open check valve. All these redundancies increase the mass of the spacecraft but are essential at some point in a manned capsule. However, the only mass needed to tackle CO_2 would only be the canisters of LiOH, hence the interest of such a system. Other ideas, such as chemical desiccant or H2 Depolarized Cell Electrochemical (immobilized electrolyte) were investigated and rejected for mass and energy optimization, in the same manner as in Fig.2. As a matter of fact, CO_2 removal chosen technology does not require additional energy other than the condenser and the ventilation system.

Fig. 3: Canister LiOH, used on space shuttle Discovery. A canister of approximately 0.014 m3 can sustain CO_2 removal for 2 man for 2 days. Our design would include 2 of them.

The accompanying Table IV provides a detailed overview of the mass, wattage, and volume considerations for the air management system within the spacecraft. Notably, the air system incorporates fans crucial for the circulation of air within the cabin. These fans play a pivotal role in extracting air from the cabin, guiding it through pipes and control valves for purification, and subsequently redistributing it to the astronauts. The inclusion of these fans introduces a specific mass component to the overall system. Additionally, the thermal control and condenser aspects are intricately linked to the spacecraft design, necessitating specialized hardware such as space radiators. These radiators are essential for efficiently dissipating heat from the spacecraft, highlighting the interconnected nature of various components in ensuring optimal air quality and temperature regulation for the astronauts. This aspect along with the condenser explanations will be discussed in the following part concerning Thermal Control.

Subsystem	**Total mass (kg)**	**Total volume (m^3)**	**Average power over the mission (kW)**
Expandable O_2 emergency	0.7	-	0
Expandable O_2 gas	2.9	-	0
Tanks Storage oxygen	4.3	0.04	0
Expandable N_2 gas	14.8	-	0
Expandable N_2 emergency	29.6	-	0
Tanks Storage N_2 gas	39.1	0.3	0
Ventilation system and pipes (w/o expandables)*	5*	0.4*	0.0038* [25]
Expandable CO_2 cartridge	15.9	0.03	0
Expand. water for humidity	19.2	-	0.2
Rare gas removal	22.3	-	0
TOTAL	**153.8**	**0.77**	**0.2038**

TABLE IV: System details for the Air supply. *The * are linked to the thermal control system. The others - are not relevant to be counted and may be included in the volume of the storage device.*

In conclusion, the selection of these subsystems proves to be relevant, aligning well with mission requirements. Inspired by systems on Crew Dragon, ISS, or the Soyuz, it represents a sound engineering decision and proved their reliability in operations. Our goal is to achieve a system that is lightweight, compact, and energy-efficient, closely integrated with other systems. Operating within an open-loop system allows for significant savings in storage efficiency, highlighted by low average power in Table IV. However, this comes with trade-offs in recycling capabilities and sustainability considerations.

B. *Thermal and Humidity Control System*

The Thermal and Humidity Control System (TCS) is critical for maintaining a habitable environment within the spacecraft. This system is responsible for regulating the temperature and moisture levels, to be within the range of 20°C to 25°C and humidity of 30–60% inside the cabin [22], ensuring the comfort and health of astronauts and tourists alike. In the vacuum of space, external temperatures can fluctuate drastically, making efficient thermal control vital for protecting both the crew and sensitive onboard equipment. Additionally, managing humidity is essential to prevent condensation, which can damage equipment and create uncomfortable living conditions.

The design of the Thermal and Humidity Control System (TCS) for the space taxi is inspired by the Orion spacecraft's advanced thermal management approach (Figure 4). This system employs two single-phase liquid pumped loops using a 50/50 volumetric mix of Dowfrost™HD (a commercially available propylene glycol solution) and water (PGW). This choice of coolant offers an optimal balance between thermal conductivity and freezing point depression, ensuring the system's operational efficiency across a wide range of temperatures encountered in space.[9]

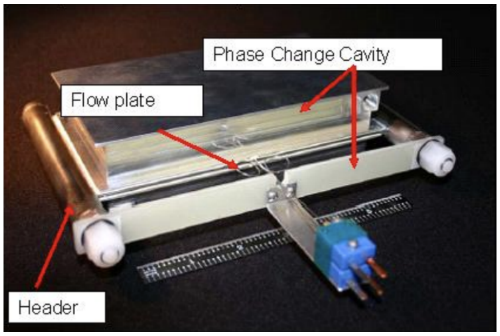


Fig. 4: Phase Change Material Heat Exchanger

Furthermore, the Thermal and Humidity Control System (TCS) is endowed with the capability to adjust humidity levels within the spacecraft, ensuring an equilibrium conducive to human health and the operational integrity of onboard systems. This adjustment is achieved through an integrated network of air revitalization systems and advanced sensors, which meticulously monitor and regulate moisture content in the cabin air. By leveraging a closed-loop system that recycles condensed moisture back into usable water.

C. Pressure Control System

The Pressure Control System (PCS) plays a crucial role in maintaining the spacecraft's internal atmosphere at safe and habitable levels. Utilizing advanced Composite Overwrap Pressure Vessels (COPVs), the PCS is designed to store oxygen (O_2) and nitrogen (N_2) at high pressures, approximately 5000 psia, ensuring a stable supply for atmospheric regulation within the spacecraft. The strategic mixture of O_2 and N_2, maintained at 14.7 psia akin to Earth's atmospheric pressure or adjusted to ≈10.2 psia for lunar missions, emulates conditions conducive to human physiology and the effective operation of onboard systems. [11]

PCS Operational Dynamics – The release of nitrogen and oxygen from the COPVs is meticulously governed by a suite of sensors monitoring total pressure and oxygen partial pressures, ensuring the atmospheric composition remains within optimal limits for crew health and safety. This regulation is pivotal in adapting to the variances in cabin pressure induced by crew activities, system operations, or changes in external environmental conditions.

Adhering to NASA's requirement, the PCS ensures that the pressure to which the crew is exposed remains between 26.2 kPa (3.8 psia) and 103 kPa (15.0 psia) [22], catering to indefinite human exposure without measurable impairments to health or performance.

D. Waste Management System

In the spacecraft design, an open-loop system has been chosen, intending to evacuate all types of waste. In the initial stages of consideration, the option of utilizing space diapers (pampers) for waste management was entertained, particularly given the anticipated short travel time. However, a strategic shift occurred based on commercial considerations and astronaut feedback, leading to the decision to incorporate fully functional toilets in the AstroCab Spacecraft. This choice not only addressed the practical needs of waste management but also prioritized the psychological well-being of astronauts, aligning with their preference for a more Earth-like experience.

Illustrated in Figure 5, the Universal Waste Management System investigated for the Orion capsule promises greater efficiency within a smaller volume. The integration of this innovative system within the spacecraft is depicted in Figure 19 in the appendix. The toilet system boasts reduced mass and volume compared to prior iterations. Standardized designs and the use of UWMS consumables simplify logistics and may lead to the development of low mass/volume fecal canisters [24].

This advanced waste management system efficiently handles grey water, yellow and black water, optimizing both mass and volume. The storage methodology mirrors that of the Crew Dragon capsule and the Orion spacecraft.

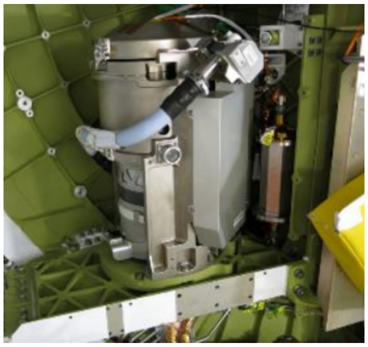


Fig. 5: UWMS, tested for Orion integration

Highlighting efficiency in the AstroCab Spacecraft, the selected waste management system shows promising advancements over its predecessors in the space shuttle and the ISS [21].

A comprehensive summary of the waste management system's features and efficiency is provided in Table V.

Nail clippings and hair cuttings are not accounted in Table V for our spacecraft missions, as these types of waste, typically encountered on the ISS, are not

Subsystem	Total mass (kg)	Total volume (m^3)	Average power over day (kW)
Grey water	7.1	-	0
Yellow water	7.2	0.02	0
Black water	0.8	-	0
Waste	0.95	-	0
Oral hygiene	-	-	-
UWMS (toilet unit)	85.6	0.19	0.074
Total	**101.7**	**0.21**	**0.074**

TABLE V: Waste management details

relevant. The waste category encompasses typical skin and hair shedding that occurs throughout the day. Addressing this issue, a solid particle filter integrated into the air filtration systems should effectively remove them. Such filters would be replaced after each mission to maintain optimal functionality.

E. Fire Detection and Suppression (FDS) System

The Fire Detection and Suppression (FDS) system is an integral component of the spacecraft's safety protocol, designed to address fire-related emergencies effectively. This system combines the use of Portable Fire Extinguishers (PFE) and sophisticated smoke detection technologies, ensuring prompt detection and suppression of fires.

1) Portable Fire Extinguishers (PFE): Equipped with Portable Fire Extinguishers (PFE), the FDS system provides immediate response capabilities to suppress fires within the spacecraft. There are two primary types of PFEs onboard: a water mist extinguisher, ideal for general applications within the cabin, and a carbon dioxide (CO_2) extinguisher, specifically suited for electrical and equipment fires. An example of a CO_2 PFE is shown in Figure 6.

Fig. 6: CO_2 Portable Fire Extinguisher used in the spacecraft.

2) Smoke Detection System: The spacecraft's smoke detection system incorporates the Crew-Dragon Smoke Detector, featuring an array of sensors capable of detecting the presence of smoke particles through the light scattering effect. Figure 7 displays the smoke detectors.

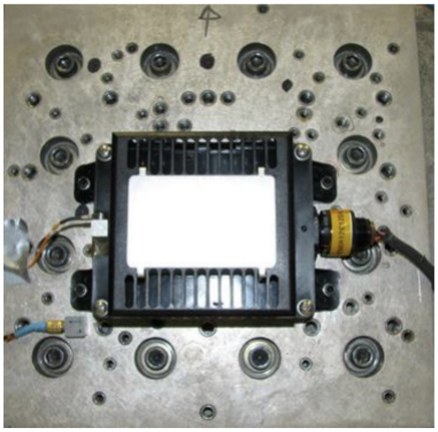


Fig. 7: Crew-Dragon Smoke Detector.

F. Seating and Intravehicular suit system

The primary objective behind the seating and suit system was to ensure cost-effectiveness for accommodating a large number of passengers while keeping the health, safety, and comfort of the crew. Consequently, the design aims to create a seating system adaptable to 95% of the population. Since the spacecraft is a combination of a space plane and capsule the seats should be accustomed to the challenges of different landings. The seats should be highly adjustable and lightweight but sturdy enough to withstand the g forces in every scenario even in the off-nominal cases, like in the pad abort scenario of water landing. The adjustability has to ensure the right position of the torso, secure legs, and the head. For an increased comfort memory foam linen is provided. The design and the estimation of mass are inspired by the characteristics of the Orion's and SpaceShipTwo's chairs. Other seats like Apollo couches and Crew Dragon chairs were examined but excelled as models because of their mass or low adaptability respectively [1].

The IVA suits main purpose is to enable a temporary solution in case of cabin pressure loss, fire, or any problems with the cabin atmosphere when enabling communication. As standard, the suits were worn during the dynamic phases of the flight and they can function as a redundant life support system for a short period of time[23]. Other than functionality the other driving factor was to have a cost-effective solution, which means that the suits would be available in different sizes from S to XL designed in a unisex way with adjustable parts to fit comfortably. As an extra service, the customer can order fully customized suits for a surcharge. To make the suits lighter the systems are connected to the main life support system via a frontal umbilical cord, because the seats are not custom-made for an individual therefore electrical connections and the chord would be harder to mount inside the chairs like in the case of the Dragon capsule couches [1]. The abort scenarios do not include the parachuting of the crew but water landing with the vehicle. In an emergency water evacuation situation, the suit has an inbuilt swim belt similar to the Modified Crew Escape Suit design for the Artemis program [3]. The mass of the suits is based on the ACES system without the survival and parachute system[4]. The estimated masses are presented in Table II.

IV. MEDICAL ASPECTS - ADEL

The space environment has multiple different effects on the human body, from microgravity to radiation, to the dynamic loads of launch and reentry. The first goal was to decide which effects had to be dealt with in the short-term flight of the AstroCab. Table VI summarizes the most important factors for all duration of spaceflight regarding human health and indicates the time frame it is becoming relevant. However, weightlessness has multiple different effects on the human body from bone and muscle loss to difficulties with the balance system adaptation, most of these conditions are expressed in longer space flight. During the few days spent in the AstroCab therefore no exercise device was available for the crew. Additionally, some typical effects and conditions caused by space flight were examined in Table VII. In conclusion, most of them do not need to be considered during the maximum 53 hours spent in the vehicle. On the other hand, some physical challenges of the space environment can be soothed by medicines. From these considerations, the effects studied in detail were: medical issues and unusual conditions that can occur during the flight that can be treated with medicines, effects of radiation, and dynamic loads due to reentry and launch. The solutions to these aspects aim to limit the number of additional mass as much as possible but still maintain a certain level of comfort and medical safety for the crew.

A. Medications on board

To enhance the comfort of the crew few medications were selected from the University of Sidney's study for a trip to Mars [15], based on the medical problems that can occur during the duration of the AstroCab ride. This medication focuses on reducing the symptoms of usual conditions that one can experience on a usual travel such as headaches, and dizziness. Since space motion sickness is known to be experienced during the first few days of the flight and is relatively common, it can take its effect during the inbound trip [17]. These conditions are considered minor conditions. Table VIII summarizes the conditions that can occur and the medicine available on board for that. Since the medical screening process is taken from the aviation screening process, although it is not as comprehensive as in the case of the astronauts most emergencies can be avoided. Conditions such as substance usage, epilepsy, disturbance of consciousness, etc are screened [16]. To provide another layer of safety and because of their low spacial need some medications are available for special cases on board, but they are only used after contact with medical personnel on the ground, and depending on the severity it can abort the mission. Table IX contains the emergencies and the medications used in the case. One should always take into account that in space some medicines might not work the same

factor	time
weightlessness	continous
radiation	continuous
dynamic loads	launch and reentry

TABLE VI: The factors that determine human health during a spaceflight

medical issue	time
Space motion sickness	first 2-3 days in weightlessness [17]
bone and muscle loss	serious effects after months
immune deficiency	weeks
space fever	weeks

TABLE VII: Main medical issues caused by spaceflight and the time frame when they expressed.

Condition	medicine
diarrhoea	loperamide
minor pain	Aspirin, paracetamol, ibuprophene
motion sickness	Benadryl, phenergan

TABLE VIII: Minor conditions that can occur during the flight and medications to ease the symptoms

Condition	medicine
allergic reaction	Epinephrine
seizures	diazepam

TABLE IX: Emergencies that can occur during the flight and medications to ease the symptoms.

as they on Earth, therefore the selected medications are all commonly used well trusted substances. Personal intolerances or needs can also be addressed before flight.

B. Radiation

The radiation field from the surface of the Earth to the LEO orbit is complex multiple different factors determine it from atmosphere to sun activity. The cosmic radiation particles can originate from the Sun, outside the solar system, or can be trapped by the Earth's magnetic field and vary in type (proton, electron, etc..) and their energy can vary from a few keV to GeV [23]. During a journey to low Earth orbit, the traveler is protected by the space vehicle and the Earth's magnetic field. The actual dose of radiation that a passenger can get is highly dependent on the space weather conditions, the vehicle's shielding properties, and the travel trajectory [23]. Another important aspect in evaluating the expected dose of one personnel is the time of the exposure. Based on literature data the following comparisons can be made shown in Table X. In conclusion, the expected effective dose during one flight is the same order of magnitude as the average personnel gets for 1 year on Earth. The long-term effects are hard to determine but the maximum amount of dose one personnel could get should be determined lower than carrier astronauts.

Scenario	Expected effective dose mSv
Average annual natural background	3
Triple-phase liver CT	15
suborbital flight worst case*	11.39
6 months in ISS	80-160

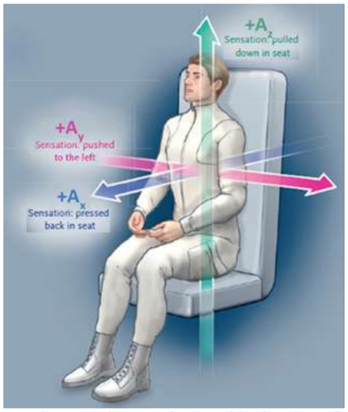
TABLE X: Expected doses of radiation in different scenarios [10]. * *maximum exposure (which includes launching at the magnetic poles and maintaining peak altitudes for the entirety of the flight) in most cases it is an overestimation*

To have an accurate understanding of how effective dose a personnel got during the flight two small devices should be placed on board of the spacecraft. One space-qualified active device can be based on semiconductor technology which provides quick feedback and a passive device for example solid-state nuclear track detector (SSNTD) or Thermo Luminescent detector (TLD) to cross-validate the measurements. Having these monitoring devices also complies well with ICPR regulation [14]. One can find such a device that can fit into the pockets of the suits or clothes worn by the passengers or mount some parts of the seats. Figure 8. presents some example devices.

Fig. 8: Example devices that can be used on board, The example for the active device is European Crew Personal Active Dosimeter [12] and for a typical TL detector [2]

C. Dynamic loads and Seating configurations

Dynamic loads can be a great challenge to the human body. The tolerance of the human body is dependent on the direction facing the load due to physiological differences. Figure 9 shows the different directions. The most tolerant direction is the A_x direction therefore the seats at launch have to accommodate the passenger to experience the most load from that way. The tolerances in this direction according to NASA standards are presented in the Appendix Figure 18. In a nominal case, the g load should not exceed 4 g since this is the most common tolerance of an average human body [22]. The training for the flight includes a centrifuge to give a feeling about the sensations and discover the contingent conflict of the passenger before the flight. In off-nominal scenarios, the maximum expected g load is 9 g for 2s [8] which is in a tolerable range even for a deconditioned crew [22]. The crew is considered deconditioned since the time spent on the



Source: Space Medicine in the Era of Civilian Spaceflight

Fig. 9: Common XYZ Coordinate Frame for Translational Acceleration [22]

space station is unknown and it can exceed 30 days which is the limit of deconditioning[22].

V. NOMINAL FLIGHT PROCEDURES

The flight will be fully automated, which means that the crew doesn't have to use or perform any checklist during the flight. The ground control centre will be in charge of monitoring data and steering the shuttle if necessary.

A constant communication will be established between the capsule and the ground control centre. A satellite communication via S and KU-bands will be more robust than direct communication between the MCC and the space taxi (see figure 10).

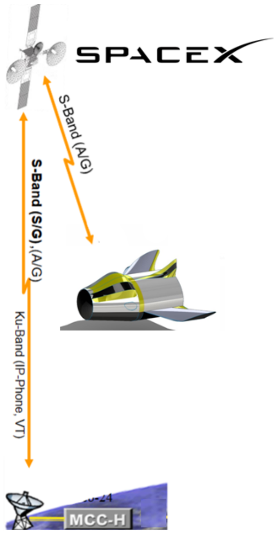


Fig. 10: Communication principle

The Starlink constellation of satellites could be used for such communications, providing extensive in-orbit communications coverage. If communication is lost for a given period of time, this will be considered as a life-threatening situation for the crew, and an abort sequence will therefore be initiated. During the flight, two screens will be displaying entertainment videos and some very basic flight states for the crew, as shown in figure 11.

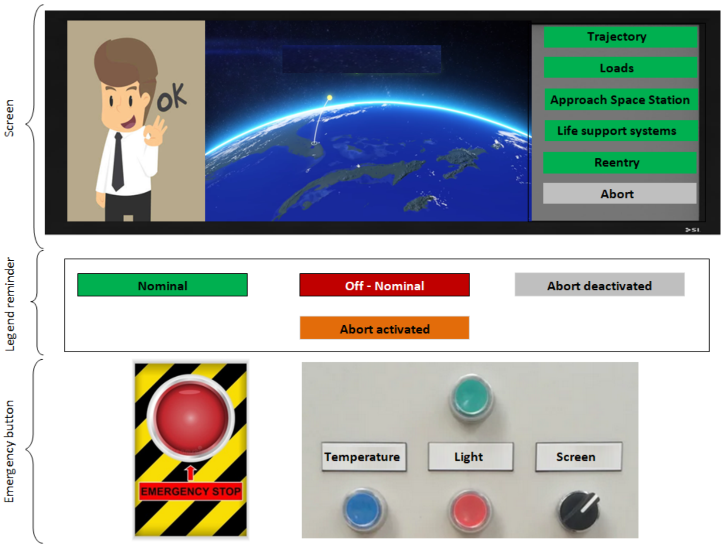


Fig. 11: Screen in the shuttle

The goal of this screen is to reassure the crew in the stressful environment that is a spaceflight, explain what is happening at each phase of the flight, and give them some basic data on essential subsystems of the capsule. They also have access to some knobs for light or temperature inside the cabin, and an emergency button to abort the flight. This abort system will be detailed in section VI.

For docking and undocking sequences, which will be fully automated, the crew has to perform basic visual checks on the hatch (figure 12). A well-trained astronaut will be inside the space station to assist the crew, communicate with them, and make decisions if needed.

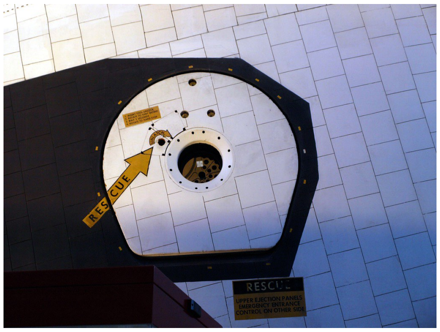


Fig. 12: Hatch of the American space shuttle

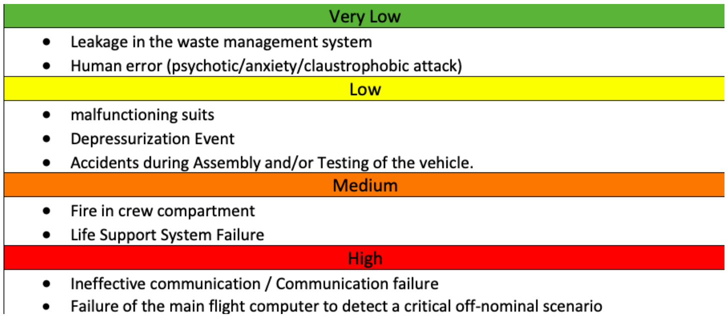
A medical checkup will be done by flight surgeon during the spaceflight and advice for drinking and eating will be sent to the crew, which will have the possibility to unfasten their seat belts and move in the capsule.

VI. OFF-NOMINAL CASES - RISKS ANALYSIS

A. *Risk Analysis*

A short Risk analysis has been performed for this project. The goal was to classify every risk that can compromise the vehicle's integrity and then endanger Astrocab's passengers.

The chosen classification method is the same as the one provided in the overall coordination team report [26]. The specific risks regarding human aspects in the capsule have been summed up in Figure 7.



Very Low
- Leakage in the waste management system
- Human error (psychotic/anxiety/claustrophobic attack)

Low
- malfunctioning suits
- Depressurization Event
- Accidents during Assembly and/or Testing of the vehicle.

Medium
- Fire in crew compartment
- Life Support System Failure

High
- Ineffective communication / Communication failure
- Failure of the main flight computer to detect a critical off-nominal scenario

Fig. 13: Risk Analysis

The vehicle has been assumed fully automated, which is why the passengers inside the capsule have nothing to do in a nominal case and every action should be performed by the team on Earth. It's so much harder to solve problems remotely than with fully trained astronauts who can do actions inside the capsule. Therefore, the likelihood of these risks occurring should be as low as possible and the only way to do this is to have an exemplary preparation for every flight. This involves the conduction of rigorous testing and checks on the life support system, backup life support systems are implemented inside the capsule to address an emergency. For the worst-case scenarios, passengers are trained for emergency procedures. If, despite all the precautions taken an emergency case occurs, the team on Earth must have the power to help address it. Therefore, real-time monitoring and automated fail-safe mechanisms should be implemented inside the capsule. That is why, in case of loss of communication the flight has to be aborted automatically. In the next section, an example of off-nominal scenarios will be described and the emergency resolution process will be detailed.

B. *Off-Nominal Scenario*

One of the risks with the highest magnitude is the failure of the main flight computer to detect a critical off-nominal scenario: an off-nominal trajectory, off-nominal loads during launch, an off-nominal approach speed to the space station, and an off-nominal deorbit burn. In each of these cases, the mission has to be aborted automatically by the flight computer. If the flight computer does not detect such a scenario, the crew must have the possibility to overwrite the main onboard computer and manually abort the flight: this is the purpose of the emergency button (figure 11). Data displayed on the screens (figure 11) will inform the passengers of a life-threatening situation. A backup flight computer will be used to cross-check the overwrite order, the state of the main flight computer, and information given by sensors/measurements as shown in Figure 14. In this way, mistakes made by the crew activating the emergency button in case of nominal flight are avoided. The crew will also be trained for such off-nominal scenarios (more details in section VII).

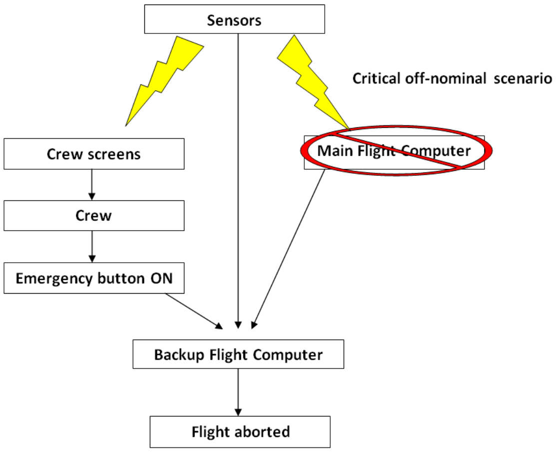


Fig. 14: Decision tree in case of critical off-nominal scenario

We see on figure 14 the importance of the flight sensors. The information they provide has to be reliable. This is the reason why they have to be two-fault tolerant (redundancy).

VII. CREW SELECTION AND TRAINING

From the nominal and off-nominal scenarios, it is possible to write requirements for the crew selection and training. These requirements are :

- Physical and medical conditions

Space is a harsh environment, as well as the spaceflight: G-loads, microgravity, radiation, etc. It is therefore essential to be sure that the passenger will survive such hard conditions.

- Situation awareness and crew interaction

A spaceflight generates a lot of information (sounds, movements, vibrations, etc) that the crew is constantly interpreting (see figure 15). Given the fact that the crew has access to an emergency button (with cross-checks by a flight computer), staying calm is essential for the success of the flight.

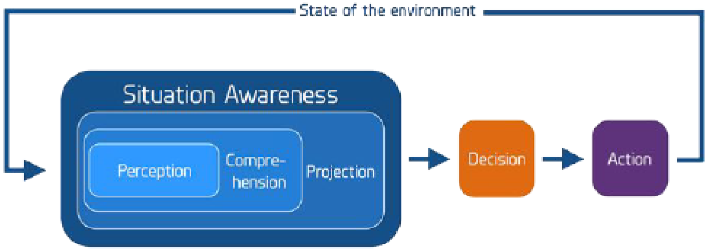


Fig. 15: Situation awareness

- Technical capacities

The technical capacities mainly refer to the basic nominal procedures and visual checks, as well as the off-nominal procedures (evacuation and use of fire extinguishers).

A. *Crew selection*

The crew selection will be composed of two phases :

- An application screening phase

For this application screening phase, the candidate has to pass a medical test issued by an aviation medical examiner. This test is useful to detect the biggest contraindications. The candidate also has to answer a simple questionnaire (2 hours) on his life, job, and activities. This questionnaire could be crippling in case of incoherent answers.

- Selection phase at the company site

This phase is composed of a complete medical test with a flight doctor and an interview with a psychologist to better know the person and his motivations.

B. *Crew training*

Once the crew selection is done, the crew training starts. It is composed of two types of training: technical training and physical training. The technical training is composed of courses on the different phases of the flight, nominal procedures (familiarization with the cabin and the equipment, opening/closing the hatch, visual checks), and off-nominal procedures in case of evacuation or fire. The physical training is composed of a test in a centrifuge, so as to be sure that the candidate can survive high G-loads and demonstrate self-control (figure 16).

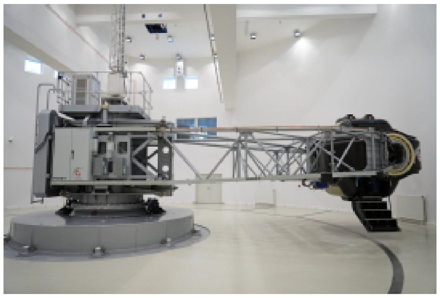


Fig. 16: Centrifuge test

All these courses are mandatory. However, the candidate can still follow non-mandatory courses, so as to train like a real astronaut: scuba training in a pool for the effects of microgravity (adapted to their diving experience), medical aspects of spaceflight, crew strength training and survival training. The client has to pay for these extra courses.

C. *Final test*

The crew training is concluded with a test in a simulator (see figure 17). The purpose of this test is to check that the crew members know how to use the different cabin equipment, know the abort procedure, know how to evacuate in case of emergency, and know how to manipulate the hatch.

Fig. 17: Simulator

The simulator reproduces the flight conditions: acceleration, noise, etc. An off-nominal scenario is programmed by the flight instructor. When the test is running, the passengers have to detect it on the screen and activate the abort mode. An evacuation is then executed. Finally, the passengers have to show that they know how to manipulate the hatch (open/close) and perform the correct visual checks. Candidates must pass this test. If they fail, they must take it again.

D. *Planning*

Finally, the Figure 20. shows that the entire crew selection and training could be done in only a week.

Some courses can be followed remotely, giving clients some flexibility. If the client is only following the mandatory courses, he has to be on-site for only 3 days.

VIII. CONCLUSION

This report aims to provide a solution to the human aspect related to the closure of the International Space Station, and the start of commercial space travel. This report is not technical but a comprehensive response to the challenge of making short-term space missions reliable, accessible, and safe for everyone.

In this research, we deep dive into the category of human needs underlying the life support system. The report represents aspects covering environmental control, waste management, and emergency systems, in order to ensure the habitable environment inside the spacecraft. Moreover, the medical considerations from medication along with the radiation consideration, are described for the crew's safety.

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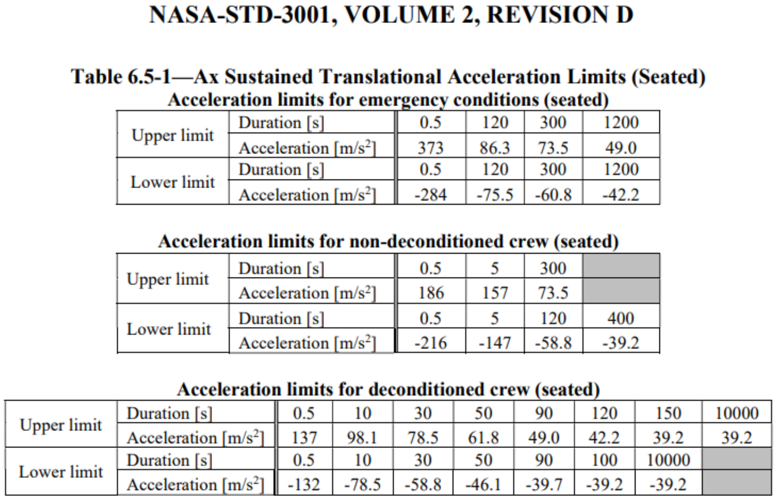
APPENDIX A
LOAD TOLERANCES OF THE HUMAN BODY



NASA-STD-3001, VOLUME 2, REVISION D

Table 6.5-1—Ax Sustained Translational Acceleration Limits (Seated)

Acceleration limits for emergency conditions (seated)

Upper limit	Duration [s]	0.5	120	300	1200
	Acceleration [m/s^2]	373	86.3	73.5	49.0
Lower limit	Duration [s]	0.5	120	300	1200
	Acceleration [m/s^2]	-284	-75.5	-60.8	-42.2

Acceleration limits for non-deconditioned crew (seated)

Upper limit	Duration [s]	0.5	5	300	
	Acceleration [m/s^2]	186	157	73.5	
Lower limit	Duration [s]	0.5	5	120	400
	Acceleration [m/s^2]	-216	-147	-58.8	-39.2

Acceleration limits for deconditioned crew (seated)

Upper limit	Duration [s]	0.5	10	30	50	90	120	150	10000
	Acceleration [m/s^2]	137	98.1	78.5	61.8	49.0	42.2	39.2	39.2
Lower limit	Duration [s]	0.5	10	30	50	90	100	10000	
	Acceleration [m/s^2]	-132	-78.5	-58.8	-46.1	-39.7	-39.2	-39.2	

Fig. 18: Ax directional load tolerances [22]

APPENDIX B
INTEGRATION SYSTEM

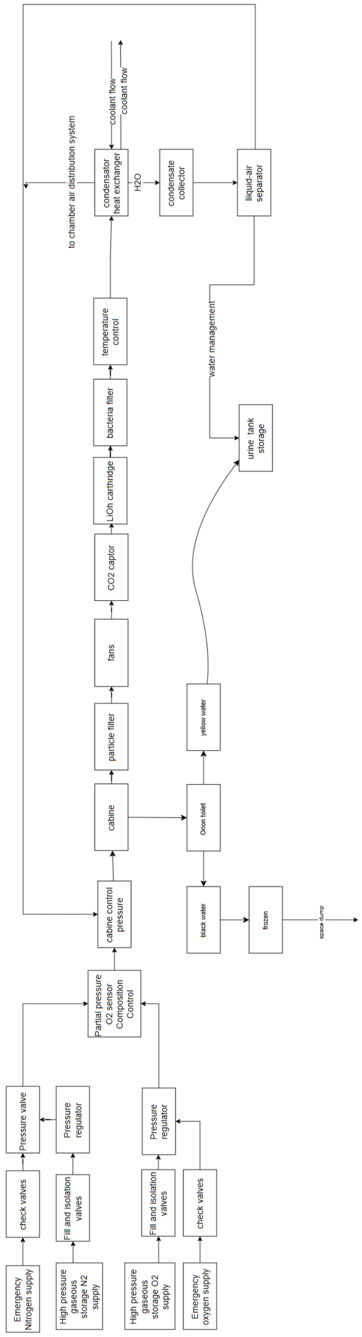
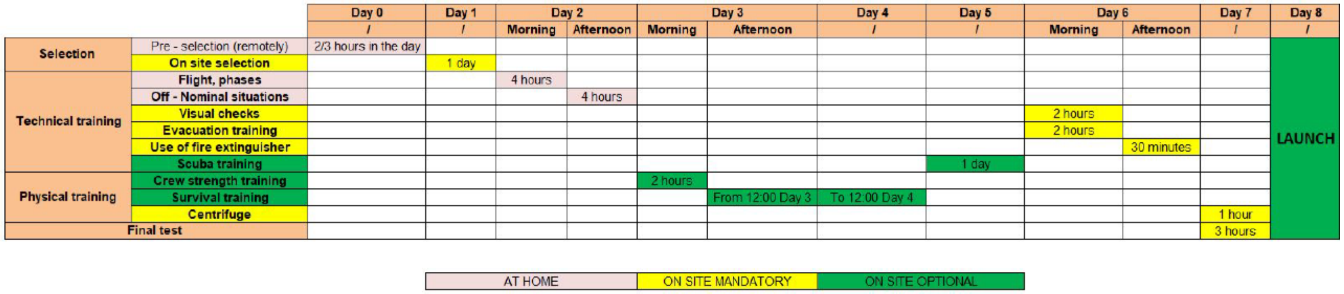


Fig. 19: Open loop integration for ECLSS (air supply and waste management system)

APPENDIX C
SCHEDULE OF ASTRONAUTS



		Day 0	Day 1	Day 2		Day 3		Day 4	Day 5	Day 6		Day 7	Day 8
		/	/	Morning	Afternoon	Morning	Afternoon	/	/	Morning	Afternoon	/	/
Selection	Pre - selection (remotely)	2/3 hours in the day											**LAUNCH**
	On site selection		1 day										
Technical training	**Flight, phases**			4 hours									
	Off - Nominal situations				4 hours								
	Visual checks									2 hours			
	Evacuation training									2 hours			
	Use of fire extinguisher										30 minutes		
	Scuba training								1 day				
Physical training	**Crew strength training**					2 hours							
	Survival training						From 12:00 Day 3	To 12:00 Day 4					
	Centrifuge											1 hour	
Final test												3 hours	

AT HOME	ON SITE MANDATORY	ON SITE OPTIONAL

Fig. 20: Schedule for crew selection and training