Hitchhiker - Vehicle Design

Human Spaceflight SD2905 - Team Red

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***Abstract*—The goal of the study is to design a space vehicle that can act as a taxi for two-man crewed launches to orbit and down again, with short refurbishment time, low cost and high reusability. The final design is a space capsule fully reusable and automated without a tank, with a puller abort system and a docking system following the IDSS requirements. To be fully reusable, solar panels and radiators are deployed from the sides of the capsule. Hitchhiker has a final total mass of around 6 tons, which allows it to safely bring astronauts to current and future space stations.**

I. Introduction

The International Space Station has been, since the start of its assembly in 1998, a crucial part of space exploration and research. The orbital station is the reflection of international cooperation and efforts towards scientific advances in many different fields. With the ISS being permanently manned since 2000, several space vehicles were designed and built with the important task of bringing astronauts to the ISS and back, such as Soyuz, Crew dragon or the Space Shuttle.

Now, the ISS is planned on getting deorbited around 2030 for various reasons. This opens up opportunities for private space stations that would serve the same purpose more efficiently and economically. Several private companies already started designing and building these future space stations, such as Axiom, Sierra Space or Blue Origin. With these changes in the landscape of low-earth orbit comes a growing need for cheap, reliable and reusable space transportation vehicles that could carry humans to these different stations, and back. The Hitchhiker's project goal is to provide a state of the art trustable "space taxi" able to bring two passengers to any future space station and back to earth safely, and to perform enough launches to meet the growing demand.

The vehicle design team's role in Hitchhiker's development was mainly to make the proper design decisions to achieve this ambitious goal, by determining the main characteristics and designing the various systems of the space capsule, and collaborate with the other groups of the project to come up with a first functional prototype.

II. Pre-Design phase

A. Mission and requirements

The first step in the design of the space vehicle is to identify and understand the requirements of the mission. Hitchhiker will be a crewed space vehicle, and its role will be that of a "space taxi" : it should be able to rapidly transport astronauts, but also scientists, engineers or potentially space tourists to a space station and reenter earth's atmosphere safely after its journey. The specifications of Hitchhiker's mission lead to a list of main requirements for the space vehicle :

- 2-seats space vehicle
- Able to safely transport humans to LEO and back
- Able to dock with future space stations
- No cargo transport
- Able to transport a broad spectrum of people while minimizing training

B. Goals and main aspects

The main aspects of Hitchhiker's mission provide the main design points that will be chosen as drivers of the development process.

The first and most important design point is safety. There is no doubt that every design decision should revolve around making the spacecraft safe for human utilization. Hitchhiker needs to be able to launch and return humans in acceptable conditions, with the lowest risk of mission failure possible. Redundancies and alternative solutions have been used during the whole design process so that no single fault failure could ever occur during a flight, and the capsule has been designed to accommodate humans comfortably and with the lowest probability of complications possible to achieve.

The second main design point is re-usability. With several space stations planning to be orbited in the next decade, there is no doubt that the launch frequency of space station crews will grow accordingly. To remain profitable and align with the market demand, as well as for sustainability reasons, it was decided very early on that the space vehicle shall be entirely re-usable as far as possible.

Finally, the last important point is automation. In an effort to facilitate access to space and minimize astronaut training to increase research and market opportunities, the whole trip to orbit and back should be entirely automated. Some steps of the trip will be highly affected by this decision, including docking, undocking and the reentry phase.

C. *Type of vehicle*

The first major design decision that had to be taken was deciding which type of space vehicle would be best suited for the purpose of the mission. This decision was taken together with the Launch and Return team, as it would highly impact their side of the development process too. Three types of vehicles were considered for Hitchhiker's design : a space plane, a space capsule landing on water, and a space capsule landing on land. The question was carefully studied, with the following parameters being the drivers of the final decision :

- Cost
- Payload/Weight ratio
- Complexity
- Landing location/Landing operations
- Return phase
- Re-usability
- Safety
- Automation
- Previous technologies
- Ground service time

Even though a space plane would clearly be the best solution regarding ground operations and landing opportunities, such a vehicle would also be more complex and expensive than a space capsule. The payload/weight ratio would probably be lower than with a space capsule because of the lifting surfaces required for the reentry phase, and considering that our payload will not include any cargo. Finally, from a safety point of view, the reentry phase was deemed harder to automate and impossible to overrule for an untrained crew. Therefore, the space plane option was ruled out.

Once it was decided that Hitchhiker would be a space capsule, the choice of the landing location remained. While a space capsule with sea landing would be more simple to build and design, damage to the structure and capsule from the salt water would in turn also increase turnaround time and make it less re-usable. Therefore, it was decided that Hitchhiker would land on land using a combination of parachutes and powered landing. This solution will decrease refurbishment times which is preferable for our case since re-usability is one of the main design points. However, it also highly limits the possible landing areas. While this could complicate operations in the beginning of Hitchhiker's life, the team is confident that improvements to the landing technology could certainly give the capsule a competitive edge in the following decades of space exploration by decreasing the landing radius and allowing it to land in various places with a low turnaround time.

D. *Trunk trade-off*

To be able to reach the goal of having a fully reusable spacecraft there were some decisions that needed to be made about the thermal control and power consumption. Crew Dragon has a trunk with those aspects where half of the trunk is a radiator and the other half is covered in solar panels, as pictured in figure 1. Before reentry does the capsule of Crew Dragon separate from the trunk and the latter is then deorbited. On the way up the trunk also functions as unpressurized cargo storage. [1] Hitchhiker does not need that extra storage of cargo since it's purpose is to act as a taxi. Hence would it be more sustainable to put the radiator and solar panels in hull of the capsule. This would also lead to a mass reduction and a cost reduction if there is no trunk to replace between each flight. This decision makes Hitchhiker to be the first orbital capsule that is fully reusable. It is consequently the main innovation of Hitchhiker.

Fig. 1: Crew Dragon by SpaceX with the trunk

III. Hitchhiker

A. *Abort system*

As launch is the first step of every Hitchhiker's mission, it is a crucial moment where safety must be ensured. As compared with a space plane in the trade-off part, the capsule has the major asset of easily accommodating an abort system, which moves the capsule away from the launcher in case of launch failure. Two general designs exist:

- **Tower - "Puller":** a vertical device added on top of the capsule allows to pull away the capsule from the launcher, used on Apollo, Soyuz and Orion
- **Motor - "Pusher":** thrusters on the sides of the capsule allow to push it away from the launcher, used on Crew Dragon and New Shepard [2]

Since reusability is one of the driving aspect of Hitchhiker, the "Pusher" system has been chosen, as depicted on figure 2 for Crew Dragon. No tower will be jettisoned and the thrusters are used for several purposes. They are the main engines of the capsule which are used for orbit and de-orbit burns. As designed by the Launch & Return team, the landing will be partly propulsive to have a better accuracy and a softer touchdown. The main thrusters will also perform this landing burn. This multipurpose design allows to lower mass and thus cost by reducing the number of engines but also by pooling the amount of propellant. In case of a nominal launch, the abort fuel will be used for the landing burn.

Fig. 2: Crew Dragon abort system

Four thrusters are situated on the fours sides of Hitchhikers, each equipped with its own propellant tanks. Following the escape, parachutes will be deployed for reentry and a propulsive burn will be added if needed, depending on the altitude at which the abort system is activated. The Launch & Return Team has computed the thrust requirements, treating them as constraints to design the thrusters and evaluate the required propellant quantity. This choice of abort system choice ensure both a high level of safety for the crew and full reusability.

B. Docking system

The docking system is crucial to easily enter a space station. Two main procedures exist:

- **Docking:** the capsule directly goes to the docking port, either guided by the pilot or in an automatic way.
- **Berthing:** the capsule approaches ISS until a distance of several meters and then is captured by a robotic arm, which brings the capsule to the docking port to precisely guide it.

In order to design a capsule able to access any space station, docking is selected. As the crew can consist of briefly trained tourists, the docking must be fully automated, like Crew Dragon. [3] It is possible thanks to advanced sensors with laser telemetry to know precisely the distance between the spacecraft and the space station. In case of emergency, control of the spacecraft can be taken from the space station to complete the docking process. It implies that each space station will host at least one trained astronauts, which seems reasonable to ensure the safety of the incoming tourists.

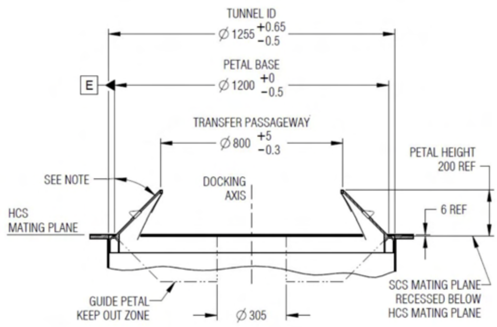

Fig. 3: Dimensions required by the IDSS

Since 2010, there has been an agreement to follow the International Docking System Standards (IDSS). [4] It has been successfully implemented with the ISS adding docking adapters that follow this international agreement. The dimensions are thus specified as depicted in figure 3, especially the inner diameter (80 cm) and the outer diameter (125.5 cm). To be able to dock to future space stations, these requirements are followed for the Hitchhiker docking system.

The docking standard is of an androgynous type, where whichever docking port can dock with a replica of it self. Previously used docking systems had distinct female (ISS) and male (spacecraft) parts such that two parts of the same type cannot dock together. The androgynous docking system allows two Hitchhikers to dock together which can create new mission opportunities.

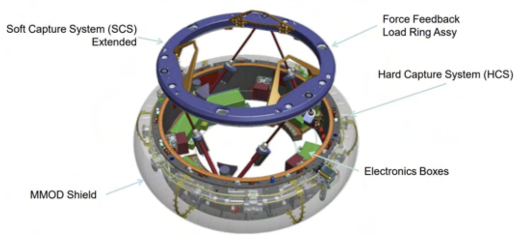

Fig. 4: Androgynous active docking system of NASA

The docking procedure is divided in two parts with first a soft capture and then a hard capture, binding the spacecraft and the space station before opening the hatch. [5] The design of corresponding systems for the Nasa Docking system can be seen in figure 4. The Hitchhiker system will be active with a dynamic Soft Capture System to be able to dock to passive ones. Once docked, power, data, commands, air and communication can be transferred between Hitchhiker and the space station. These docking system characteristics enable Hitchhiker to access all current and future space stations in a fully automatic way.

C. Thermal control system

Having no trunk being one of the major asset of Hitchhiker, it implies to fully integrate the thermal control system and the power generation system within the reusable capsule. It results in high volume and surface constraints and in a need of innovations. The general principle lies on a mechanically pumped loop using water and not ammonia for safety reasons in case of a leakage in the pressurised volume. The coolant collects heat in heat manifolds fixed on the inner hull, is then transported until radiators panel thanks to the pump and then releases heat through radiation as it circulates through the radiators. For redundancy purposes, there are two independent loops per radiator array.

As the outer hull must be cover with a layer of heat protection for reentry protection, radiators cannot be fixed on it as it is done on many capsules as Crew Dragon. Deployable radiators are thus the best solution to meet the volume constraints. Concerning the technology readiness level, deployable radiators are currently used on the ISS, as can be seen on the figure 5. [6]

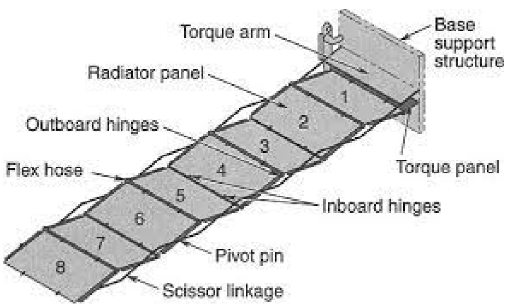

Fig. 5: Deployable radiators on the ISS

The major challenge is to adapted this device to a manned capsule. It has never been made and this represents a major innovation. On the contrary of solar arrays, radiators cannot be flexible since it is solid metallic alloy panels within which a fluid loop enables to transport heat. Scissor linkages enable to deploy the rigid panels in a guided way. A storage compartment houses the folded panels and the release mechanism. Concerning the junctions of the water loop between panels, flexible hoses are used, as it is already used in the ISS system. [7] Considering that the radiators are essential to keep a suitable temperature in the pressurised volume and that it is the first use of such a technology on a capsule, the total needed radiator area will be split in two different arrays on both sides of the capsule. They have been prioritized over solar arrays for the use of two opposite sides of the capsule instead of only one, since it has been judged a more challenging technology. It also enables the radiators panels to have a greater width and thus a smaller number of solid panels per array.

TABLE I: Heat assessment

Heat dissipated by humans	200 W
Heat absorbed from the sun	4 000 W
Heat dissipated by equipment	1 500 W
Margin	20%
Total absorbed heat	**6 900W**
Heat emitted by the outer hull	**4 100 W**
Heat dissipated by the radiators	**2 800 W**

To compute the needed area, an assessment of the heat to be dissipated has been done in table I. The heat released by a human body averages 100 W, and the heat released by the equipment has been assess during maximum use. The hot case has been considered because that is where the constraints are the greatest on the thermal control system. It corresponds to the sun part of the orbit, while half of the outer surface is absorbing sun radiation and all the surface is dissipating. The outer hull is painted in white in order to absorb a small fraction of the incident sun radiation, considered to be equal to 1 370 W/m² in LEO. Considering the absorption coefficient in table II, it leads to 4 000 W absorbed by the capsule from the sun.

TABLE II: Thermal design parameters

Outer hull absorptivity	0.17
Outer hull emissivity	0.86
Outer hull area	34.5 m²
Wall temperature, sun side	-20°C
Wall temperature, dark side	-80°C
Radiator temperature	25°C
Radiator emissivity	0.78

Emitted heat from the outer hull has been computed considering the Stefan-Boltzmann law and the parameters in table II. By subtracting the emitted heat from the absorbed heat, the heat to be dissipated is 2 800 W which leads to **an active surface of 8 m².**

The radiators have thus been divided in two arrays of 2 m², as both sides of the radiators are active. Each radiator panel is 1m high and 40cm wide in order to optimize the use of the height of the capsule while minimizing the length of the array. The **total mass is 170 kg**. The final configuration is shown in figure 6, and corresponds to:

- **2 arrays of 5 rigid panels:** 1m x 0.4m x 0.04m
- **2 storage compartments:** 1.1m x 0.5m x 0.3m

This innovative thermal control system enables to dissipate the generated heat in order to provide a suitable temperature for the pressurised volume, as specified by the Human Aspects team.

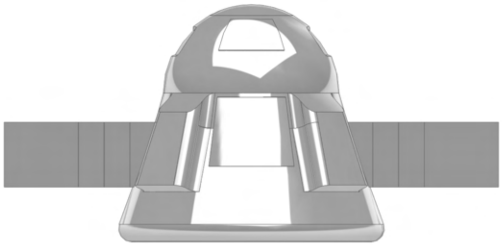

Fig. 6: Deployed radiators on Hitchhiker

D. Solar panels

Similar to the thermal control system, the absence of trunk necessitates innovation to meet the volume constraints within the capsule. After the evaluation of the feasibility of different systems, deployable solar arrays from the sides of the capsule have been chosen. It is a common technology used by different capsules as Cargo Dragon 1, but it has never been used directly on the sides of the manned module. The outer structure needs indeed to be perfectly airtight and to follow the aerodynamics requirements for reentry. A trapdoor system similar to the one of the docking cap has been chosen.

To reduce the volume needed by the stored solar arrays between the inner and outer hulls, rollable arrays have been chosen. The system is based on the Roll Out Solar Arrays (ROSA) used by NASA for the ISS and the DART spacecraft, as shown in figure 7. It is a lightweight and flexible structure but which requires some additional space on the sides of the solar cells for the deployment mechanism. [8] Some improvements concerning the width of this mechanism and his maximal length have been considered for the one on Hitchhiker. As solar arrays are vital to the capsule operation, redundancy has been decided with the total required solar area divided in two different arrays with their own hatch and deployment mechanism. The deployment failure of one array is treated by the off-nominal cases.

Fig. 7: Roll Out Solar Array at the ISS

To asses the required solar area, the needed peak power has been evaluated:

- **385 W per astronaut** required by the Life Support System (data obtain from the Human Aspects team)
- **1 150 W for Hardware:** On board computer (900 W), light (40 W), release mechanisms (120 W), sensors (20 W), engine valves (70 W)

Factors have been considered for an accurate sizing: safety factor of 10%, degradation factor of the solar cells of 5%, efficiency of 90%. On top of that, power is needed to charge the batteries which are used during eclipse time. During the sunlight part of one orbit, the solar arrays can provide 120% of the energy consumed during the eclipse part to ensure a safety margin. Computed data are provided in table III.

TABLE III: Solar arrays sizing

Capsule power with factors	2 500 W
Power to charge batteries	2 100 W
Total power	**4 600 W**
Power to area ratio	250 W/m^2
Power to mass ratio	110 W/m^2
Total area	**19 m^2**
Total mass	**62 kg**

The needed area of 19 m^2 has then been split in two arrays of 9.5 m^2. They are positioned in parallel on the same side of the capsule, as the opposite side is occupied by the astronaut hatch. The dimensions are the following:

- **2 arrays:** 0.68m x 13.5m (width of 0.85 m with the deployment mechanism)
- **2 storage compartments:** 0.9m x 0.45m x 0.45m

The solar arrays in the deployed configuration are sketched in figure 8.

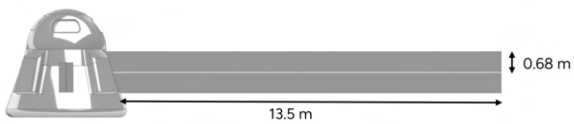

Fig. 8: Hitchhiker with deployed solar arrays

This solar rollable solar array configuration enables to provide Hitchhiker with sufficient power and to ensure redundancy.

E. Batteries

Batteries are vital for Hitchhiker, both during nominal phases as eclipse time and launch and reentry (folded solar panels) and during off-nominal cases to provide backup power.

The batteries are designed to provide the nominal capsule power with an efficiency of 90% **during 9.3 hours.** It is enough time to cover the nominal phases without solar energy and to initiate the off-nominal procedures if needed. Moreover, it corresponds to 16 eclipse periods that are encountered in 1 day. Thus the system can supply the nominal power during one full day in case of only one working solar array, as it is discussed in the off-nominal cases section. Lithium-ion batteries have been selected, as they are now the most effective and widely-used technology, even if lithium-polymers could be available soon with better characteristics.

TABLE IV: Batteries sizing

Energy	**22 kWh**
Energy density	200 Wh/L
Specific energy	120 Wh/kg
Total volume	**110 L**
Total mass	**185 kg**

The Lithium-ion technology characteristics result in a total volume of 110 L and a total mass of 185 kg, as depicted in table IV.

This result can be compared to the design of a spacecraft relying only on batteries without solar panels. In such a scenario, all the energy required for the entire mission must be contained within the batteries prior to launch. The nominal mission duration is 4 days, which is more than 10 times longer than the 9.3 hours required with solar panels. Consequently, this leads to a volume and a mass more than ten times greater, amounting to 1 900 kg instead of 247 kg for the solution involving solar panels. Therefore, the use of solar arrays is required for this mission.

F. Off nominal cases

After having designed the radiators, the solar panels and the batteries, logical questions arise when considering failures of these systems. Off nominal cases have been thought considering these aspects to enable Hitchhiker and the astronauts to survive. The cases where only one or two panels/radiators fail have been considering regarding a nominal consumption and a power saving mode. This power saving mode has been designed by the Human Aspect team keeping the minimal electric consumption to gain battery time while allowing bearable life support systems. Using this mode, the power consumption is approximately divided by 2.

In the event of a radiator failure, the power saving mode must be activated in order to minimise the heat generated by the use of the numerous electrical devices. If one radiator fails to deploy or to work, the temperature of the pressurised volume will rise by a maximum of 15°C during the sun exposure period. It is still a bearable temperature for the astronauts even if it is not a optimal one. If two radiators fail, the astronauts will be obliged to use the thermal regulation of their spacesuit because the temperature fluctuation during the orbits will be too important to be suitable for the astronauts. An emergency procedure must be undertaken.

Considering one solar panel and two solar panels failure, the operating times are depicted in table V.

TABLE V: Solar panels off nominal cases

	Nominal consumption	Power saving mode
1 panel failure	1 day	2 days
2 panels failure	9h20min	19h

As explained during the batteries sizing, they have been designed to provide nominal power for 16 eclipses which corresponds to one day in orbit. In fact, the capsule power consumption is roughly equal to the power needed to charge the batteries. In the event of a one solar panel failure, the power produced by the functional panel will satisfy the nominal consumption but batteries will not be charged at all. Batteries will thus be used during eclipses. In case of a two solar panels failure, all the needed power will be provided by the batteries. The spacecraft can consequently survive 9h20min with nominal consumption and around 19h in power saving mode.

In both solar panel and radiator failures, some time is available to analyse the situation and take a decision to end the mission safely. The new technology of deployable radiators and solar panels requires to inspect the hatches of these systems. If the hatches are damaged, the aerodynamic profile is not suitable anymore for a atmospheric reentry. Hitchhiker needs to reach quickly a space station in order to ensure the safety of the astronauts. If the hatches are not damaged, reentry is possible. Depending on the situation, a choice must be made between continuing the mission, reaching a space station or doing a reentry.

The study of these off nominal cases allows to guarantee the safety of the crew by giving them enough time to take a decision regarding the procedures.

G. On board computer

The on-board computer (OBC) orchestrates all the different devices in order to complete the nominal mission. He plays a fundamental role in:

- Guidance, Navigation and Control (GNC)
- Telecommunication actions
- Monitoring the Thermal Control System
- Monitoring the Power supply (solar panels and batteries)
- Monitoring Life Support System
- Data management, processing and display

To transport low-trained people as space-tourists, the on board computer must allow a high level of automation, especially concerning GNC. The on board computer is designed to be able to process sensors values to follow the planned trajectory. Complex (GNC) algorithms will be processed by the on board computer to allow a fully automated flight. Crucial processing units will be doubled or tripled to be two-fault tolerant, which is a requirement to ensure the safety of the astronauts. The OBC must be able to operate between -30°C and + 70°C and survive Single-Event-Effects even if it is located inside the pressurised volume. The precise architecture of the on board computer has not been studied in this early design but the mass budget of 30 kg has been established. It includes GPU, memory cards, graphic cards for display, electric wires and the protective casing.

Display and control panels are also very crucial for the mission as they are the human-machine interface. They must be highly intuitive to be adapted for the space tourists. Touch screens inspired from Crew Dragon are the most suitable option, as can bee seen in figure 9. The space suit are designed accordingly by the Human Aspects team with tactile gloves. Specific attention will be paid to graphical display to make it easier to understand the capsule status. Hard buttons for essential features will be still present below the touch screens.

Fig. 9: Control panels of Crew Dragon

H. Heat shield

For the heat shield it was important that it has a high reusability and that would effect the turnover time. The heat shield is attached at the bottom of the capsule. For protection and isolation is a tested and proven technique to use the material $Phenolic - Impregnated\ Carbon\ Ablator\ (PICA)$ on the outside of the backshell, which is a ablative at high temperatures, as in reentry. It was invented by NASA Ames Research Center and SpaceX did an improved version called PICA-X, as shown in figure 10.

Fig. 10: Heat shield of Crew Dragon

PICA is thinly applied in several coats to a thickness of 6 cm. During reentry the outer layer thinner than 1 cm is ablated and char is built from the heat. This char has to be removed and 2 cm of PICA has to be reapplied between each flight. The backshell with the PICA is about 8 cm thick and all of it works as an isolation. The shell has a reusability of 15 flights until it has to be completely replaced. [9]

I. Parachutes

The Hitchhiker's parachute parameters were modelled after the Orion capsule's parachutes system, the specifications were published by NASA.[10] These parameters were controlled to be appropriate with the drag formula using drag coefficient data from research papers on Orion's parachute testing.[11] [12]

$$F_{\mathrm{d}} = \frac{1}{2}\,\rho\,u^2\,c_{\mathrm{d}}\,A \qquad (1)$$

In formula 1 is the density of the atmosphere ρ and it was given from a $MATLAB$ function that calculates it based on altitude. Since Hitchhiker is using powered landing, does it have a lower restriction on the downfall velocity, than if it would have had a splashdown or landed on land as other capsules on the market. The parachute system is using one drogue parachute, two pilot parachutes and two main parachutes. The drogue parachute slows down the capsule to 60 m/s from 150 m/s and stabilizes the capsule. The pilot parachutes are there to pull out the main parachutes and to ensure a smooth deployment. The main parachutes would look as shown in figure 11.

TABLE VI: Parachute characteristics

	Drogue	Pilot	Main
d [m]	7	3.5	35
C_D	0.5	-	0.48
h [m]	7620	2800	-
v [m/s] 60	-	15	

Where d is the diameter of the parachute, C_D is the drag coefficient, h is the deployment height and v is the final velocity.

Fig. 11: Orion's two main parachutes inflated from a test

J. Structure and materials

Hitchhiker's structure is divided into different parts : the main hull, the pressure hull and the internal structure. The main hull provides the capsule's overall external shape and houses non-pressurized elements like engines and maneuvering thrusters. The pressure hull creates a sealed environment pressurized for astronaut habitation. The internal structure within the pressure hull consists of beams, containers, and other components that provide support and house the various systems needed for life support, propulsion, and communication.

The chosen material for the main and pressure hulls is a space-grade aluminum-lithium (Al-Li) alloy. This high-strength, low-density material has been a mainstay in the space industry for decades. At a density of only 1.56 g/cm^3, it offers significant weight savings. However, with a cost of $150 per kilogram, it is also a relatively expensive material. [13] Since Hitchhiker is a small spacecraft, its structural mass will inherently be a large portion of its total mass. Therefore, prioritizing mass reduction over cost was a critical decision. The internal structure was estimated as 30% of the total hull mass and will be made of the same Al-Li alloy.

The internal structure, estimated to comprise 30% of the total hull mass, will also be constructed from the same Al-Li alloy. Finally, heat shielding is another factor to consider when calculating the overall hull mass. To provide thermal protection during reentry, the entire hull will be coated with heat-resistant materials. Additionally, a white exterior paint will be used to minimize absorption and maximize emission of heat. The total mass of the heat shielding material is estimated at 10% of the total hull mass.

Taking capsule geometry into account, this wields a total structural mass of 1 400 kg. The detailed mass distribution of all the different systems and parts of the capsule is provided in part IV.

IV. Final design

A. Mass distribution

When considering the final mass distribution, it is clear from section III that there are many aspects that need to be considered to ensure an optimal efficiency, balance and stability. The breakdown of the masses for the various systems can be seen below:

1) Structure: 1420 kg:

The structural mass encompasses the external and internal hulls. The external hull provides the main structural integrity of the capsule and therefore is one of the heaviest components, making up 17% of the total mass (750 kg). The other components that make up the structure are the internal hull (290 kg), internal structure (310 kg) and hull heat protection (70 kg).

2) Propulsion System: 465 kg:

The propulsion system is another vital system required to travel to space, and hence also consists a large portion of the weight. Most of the mass for the propulsive system is from the main engines (440 kg). The manoeuvring thrusters are 25 kg.

3) Life Support Systems: 670 kg:

The life support systems for the Hitchhiker were split up into two main categories, non-pressurised (130 kg) and pressurised life support (400 kg). More details on which life support systems will be used in the capsule will be described in the human aspects report. The mass of the chairs (140 kg) can also be added in that section.

4) Thermal/Heat Management Systems: 460 kg:

The biggest component of the heat management system is the heat shield, which has a mass of 300 kg. In addition to this, the two radiators are used to dissipate heat, each having a mass of 80kg.

5) Electrical Systems: 300 kg:

The main elements of the electrical systems are the batteries (190 kg), power supply (50 kg) and solar panels (30 each).

6) Other Important Components: 1100 kg:

The rest of the mass of the capsule comes from a variety of components that aren't a part of the previous systems. These mainly include the docking system (300 kg), the parachutes (330 kg), the control panel/computer (70 kg). The other important mass that also needs to be taken into account is that of the passengers and cargo, which was given a mass 400 kg.

The dry mass of the capsule is 4400 kg and consists of the sum of all the previously mentioned components without the fuel. When adding the mass for the fuel and oxidizer required for launch (1000 kg), abort and manoeuvring (600 kg), this mass comes out to 6000 kg.

B. Overall Design

Once the team established all the systems and components that needed to fit inside the capsule, the process of designing the shape and layout could be started. The dimensions of the capsule could then be dictated based on volumes of all the parts needing to fit inside.

In terms of the external shape of the capsule, it was partially based on the shape given in a paper by Rajesh Arora and Pradeep Kumar [14]. This report discusses the optimal shape for aerodynamic stability on re-entry into earth's atmosphere. The shape of the capsule consists if a sphere-cone-flare design which will be shown in the the CAD section below. This is a key factor to ensure the capsule does not flip around during re-entry. This shape should also mean that the heat shield and structure are capable of withstanding the temperatures and forces of re-entry.

The position of the main engines was another issue that was addressed. The decision to not use a trunk meant that the engines needed to be built into the capsule. However, due to the heat shield on the bottom of the capsule, the engines would have to be placed on the sides. Therefore, a compartment for each engine was added to the outside of the external hull so the engines could fire to the side of the heat shield. This resulted in the engine being at a slight angle, which needed to be compensated for by adding more fuel.

The internal layout of the Hitchhiker capsule was then discussed, and various key decisions were made. The first design specification for the inside was to have the crew in the center of the capsule to allow them to operate the spacecraft's systems. It was then decided to have the life support systems (LSS) in a compartment below the crew as a large portion of the LSS needed to be pressurised in order to function.
The parts of the capsule that need to be deployed during flight were then introduced into the design. These included the solar arrays, radiators and parachute system. They were each placed into a storage compartment between the internal and external hull in a way that allows them to be extended during the flight.
Another important factor for the design of the Hitchiker was where to put the fuel and oxidiser tanks. It was decided that there would be four tanks of each, to allow a more even weight distribution for the capsule. The four fuel and oxidiser tanks were each placed near one of the main thrusters near the heat shield. This was partly done to have a large portion of the weight near the bottom of the capsule. This again helps to reduce the risk of the capsule flipping around during atmospheric entry.

C. Geometry and volumes

The final geometry of the Hitchhiker capsule was decided upon once we had established the volume required for all the systems and cargo. It was found that a total volume of 27 m^3 was needed, of which 8 m^3 needed to be pressurised for the LSS and crew.

This resulted in a capsule with a maximum diameter of 4.3 m and a height of 3.5 m. These dimensions are allow the capsule to be compatible with launch vehicles such as Ariane 6 and Falcon 9. More information on the launch vehicle used for the Hitchhiker is given in the report by 'Launch and Return'.

The Hitchhikers smaller size compared to other capsules on the market also permits the capsule to be transported via the Antonov aircraft. In the event of an emergency landing, this could help bringing the capsule back to the refurbishing center.

D. CAD

Once the final design was finalised, a CAD model was made with the aforementioned design considerations. The CAD model for the capsule can be seen in figures 12 and 13, where the latter shows the capsule with the radiators and solar arrays deployed.

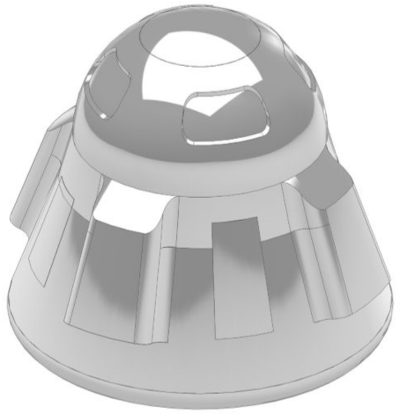

Fig. 12: CAD Model for the Hitchhiker capsule

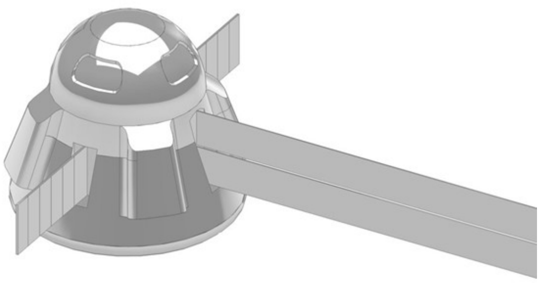

Fig. 13: CAD Model for the Hitchhiker capsule with the radiators and solar arrays deployed

A basic model of the interior of the capsule was also made to show the basic locations of the main components. This can be seen in figure 14 below.

E. Turnaround time

Turnaround time is a key aspect of Hitchhiker's operations, and has to be adapted to launch demand to fit into the business plan. The main aspects limiting turnaround time are :

- Refurbishment
- Transport
- Testing and certifications

Transport time from Algeria to Kourou is approximately 10 days. Since Hitchhiker is a crewed capsule, testing and certification time will be the main limiting factor and should largely exceed refurbishment times, especially in the beginning of operations, before the

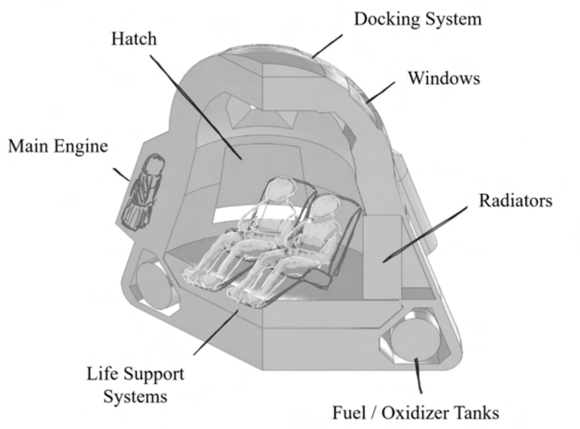

Fig. 14: CAD Model for the Hitchhiker capsule's interior

capsule proves its reliability. However, the turnaround time will decrease over the years as processes get faster, as it is the case with recent reusable rockets. For instance, the turnaround time of Space X's Falcon 9 booster decreased from more than 200 days in 2017 to about 50 days in average in 2023. Of course, the turnaround time will be significantly larger for a human rated space capsule than for a rocket booster, but the team is confident that Hitchhiker's turnaround time could go below 100 days in the span of 5 to 10 years.

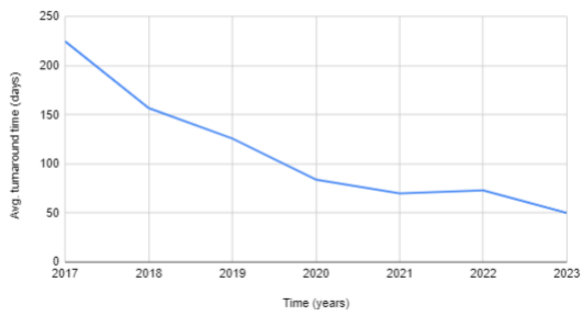

Fig. 15: Average turnaround time of Falcon 9 booster

V. Conclusion

Reaching low Earth orbit safely and efficiently is no small feat. Hitchhiker prioritizes crew safety above all else, employing extensive automation and reusability to ensure frequent, reliable space travel. This innovative design aligns perfectly with the growing demand for low Earth orbit transportation, particularly for crewed missions to space stations. Through meticulous analysis of mission profiles and current market trends, Hitchhiker prioritizes long-term technological advancements to become the leading human-rated vehicle for low Earth orbit within the next 10-15 years.

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