AstroCab - A space taxi for two people Vehicle Design - Blue team

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***Abstract*—In a foreseeable future, space travel is likely to become increasingly common, especially for private and commercial parties. Creating safe and cheap means of travel will be of much interest, to make space travel undergo the same transformation as air travel has in the last century. A concept solution to this is AstroCab, a spaceplane capable of launching atop a conventional rocket, carry a pair of passengers to a LEO space station and safely return with a runway landing, ready to depart again after a two week refurbishment period.**

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I. INTRODUCTION

The task is to design a space taxi system, a 2-person vehicle capable of transporting passengers to any existing or future space station in LEO. To be distinguished from existing space transportation systems, the emphasis lies on reusablilty of the vehicle and low need for passenger training, while having a safety standard matching or exceeding that of current vehicles. The complete system is the combined work of four teams; *Overall coordination*, *Vehicle Design*, *Launch & Return* and *Human Aspects*. The following paper describes the work of the Vehicle Design-team, and will address the overall architecture of the vehicle and the systems it contains, including the thoughts and considerations that went into the design of these.

A. Requirements

AstroCab's vehicle is a cutting-edge spacecraft that redefines space travel with its emphasis on

- Safety
- Reusability
- Automation

Our vehicle is designed to transport and bring back two individuals to space stations situated at an optimal altitude between 350 to 450 kilometers. The vehicle boasts a maximum payload capacity of 260 kilograms, ensuring it can carry essential equipment and supplies.

What sets this spacecraft apart is its remarkable efficiency, completing one-way journeys in less than two days, ideally within a single day. To guarantee the well-being of its occupants, the spacecraft is equipped with a sophisticated life support system, ensuring a safe and secure travel experience.

Automation takes center stage as the vehicle is designed to be fully automated, minimizing the need for human intervention during its mission. This not only enhances operational efficiency but also contributes to the safety of the journey.

A key feature of this spacecraft is its reusability, paving the way for sustainable and cost-effective space exploration. The ability to reuse the vehicle significantly reduces the overall costs associated with space travel, making it a game-changer in the aerospace industry.

Communication is important, and the spacecraft is equipped to facilitate seamless interaction with both the space station and ground control. Furthermore, it can be remotely controlled from the space station, allowing for precise maneuvering and adjustments as needed.

To optimize efficiency and minimize downtime, the spacecraft boasts a quick turnaround time between launches and returns. This ensures that the vehicle can be utilized for multiple missions rapidly, contributing to the overall effectiveness of space exploration endeavors.

A list of requirements was

Requirement ID	Top Level requirement
T 1.0	The vehicle shall transport and bring back **2 people** to space stations at an altitude between **350 - 450 km**.
T 2.0	The vehicle shall have a maximum **payload mass of 260 kg**.
T 3.0	TThe one-way travel duration shall be lower than **2 days, preferably 1 day**.
T 4.0	The vehicle shall have a **life support system**.
T 5.0	The vehicle shall be **fully automated**.
T 6.0	The vehicle shall be **reusable.**
T7.0	The vehicle shall allow **communication** with the **space station** and on the **ground**.
T 8.0	The vehicle shall also be **controlled remotely** from the space station.
T 9.0	TThe vehicle shall have a **quick turnaround** time between launches and returns to optimize efficiency.

B. *Background*

In an era where humanity's reach extends far beyond the confines of Earth, the prospect of commuting to the International Space Station (ISS) has transitioned from science fiction to near reality. It has been more than two decades since humans first set foot on the ISS, and with continuous advancements in space technology from both governmental agencies and private companies, the possibilities for further expansion and exploration are becoming increasingly practical.

One of the most well-known spacecraft is the Soyuz spacecraft manufactured by Russia. The Soyuz spacecraft is a reliable and validated space tool that has played a crucial role in the operation of the International Space Station. Its design structure allows it to carry three astronauts and safely return them to Earth at the end of a mission.

Another significant spacecraft is the Crew Dragon spacecraft developed by the American space exploration company SpaceX. This spacecraft is a modern, fully automated vehicle with unique capabilities, capable of carrying up to seven astronauts and safely returning to Earth using parachutes at the end of a mission.

Another notable crewed spacecraft is the Space Shuttle. Developed by NASA in the 1970s, the Space Shuttle, particularly the Space Shuttle program, is one of the most famous crewed spacecraft. The Space Shuttle is a reusable space transportation vehicle used to carry astronauts and cargo into space and return to Earth after completing a mission. They have been used for various tasks, including launching satellites into orbit, repairing space telescopes, and supporting the construction and operation of the International Space Station.

There are also upcoming spacecraft, among them the Dream Chaser, a crewed spacecraft developed by the American company Sierra Nevada Corporation. It is a small, reusable spaceplane capable of traveling between Earth orbit and the International Space Station. Dream Chaser is designed to ferry astronauts and cargo to the space station and has the ability to land on a runway, allowing for horizontal landings similar to airplanes. This makes Dream Chaser a unique and intriguing spacecraft option, offering new possibilities for future space transportation.

Additionally, there's NASA's Orion spacecraft, a multi-purpose crewed spacecraft developed by the NASA. It is designed for transporting astronauts to the Moon, Mars, and other deep space destinations but can also be used for missions to the International Space Station. SpaceX's Starship, currently under development, aims to be a multi-purpose crewed spacecraft for transporting astronauts to the ISS, Moon, and other space destinations. Boeing's CST-100 Starliner, another spacecraft designed for ferrying astronauts to the ISS, can accommodate up to seven crew members.

The development of these space vehicles reflects international cooperation and innovative spirit, enabling the continuous operation of the International Space Station and supporting various scientific research and experiments. Through these space vehicles, astronauts can travel safely and reliably between Earth and the ISS, promoting progress and collaboration in space exploration.

C. Comparison between concept (General Design)

The Dream Chaser and the Crew Dragon, from which we will take inspiration for our project, can both carry crews of up to seven astronauts. In our design project, we intend to carry two people, so it naturally stands to reason that in order to keep manufacturing costs down, we would like to see a vehicle with smaller dimensions. As a reminder, SpaceX's vehicle is 8.1 m high (with the trunk) and has a diameter of 4 m, while Sierra Nevada's space plane is 9 m long and has a wingspan of 7.2 m.

On the other hand, as the crew transport is for tourism and commercial purposes, the training and technical knowledge of the people on board must be kept to a minimum. As few operations as possible should have to be carried out on board, during the various phases of the trip. This is a limiting factor to take into account.

For the selection of solar panels, for example, it was decided not to use deployable solar arrays to avoid the risk of failure during installation. Instead, we opted for a simple opening and closing system based around a pivot link, allowing the solar panels to be mounted on the trunk facing the sun, as on the Crew Dragon. Similarly for the docking system, it was decided that the Astrocab should be able to dock completely autonomously, as is the case with the SpaceX capsule.

Finally, in the ideal scenario, the Astrocab aims to be fully reusable, and the advantages of the space-plane concept can be put to good use. Indeed, if there are no complications, the reentry and landing scenarios are inspired by the Dream Chaser. In the event of a problem, however, abort modes similar to those of the Crew Dragon are used to ensure the crew's safety.

II. System

AstroCab is a spaceplane, in a nominal scenario capable of multiple launches and returns in quick succession, with minimal need for refurbishment. In an off-nominal scenario however, it is capable of using its capsule. like capabilities, by ejecting the passenger compartment as a separate vehicle and return it safely. This separation possibility is intended to ensure passenger safety, without the need for a massive abort system and results in AstroCab looking as rendered in Figure 1, with the split at the yellow circle just in front of the wings. The capsule primarily contains the pressurized section where the passengers are situated, but also all the systems required to ensure passenger survival in the event of separation. The rest of the systems are located in the trunk compartment and are required for mission success after a nominal launch. The hull of the vehicle is continuously made from 9 mm aluminium alloy.

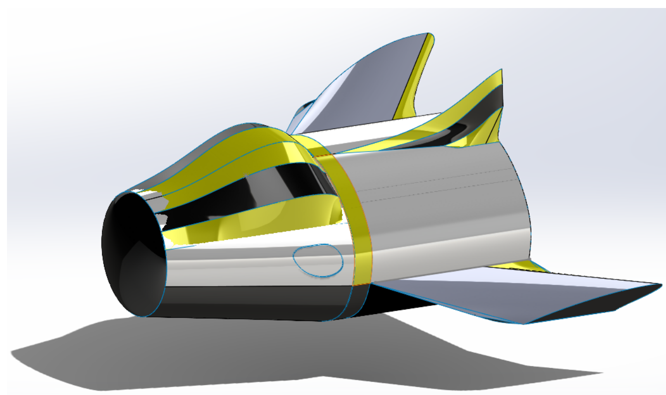

Fig. 1. AstroCab seen in its entirety.

A. Power

As for any space mission, a critical property of the AstroCab's power system is its ability to sustain operations for a mass as low as possible. The first step was to identify the requirements on the vehicle power system. For simplicity, the power consumption was assumed to be constant throughout the mission and was summed to an average power need of just over 2,6 kW, with a breakdown into subsystem consumption found in Appendix A. Over the 72 hours a one way trip would last at the longest, it would total an energy need of 190 kWh. Solar exposure at a typical 400 km altitude LEO is approximately 61% of the 92 minute orbit, or 56 minutes of sunlight followed by a 36 minute eclipse.

Primary Power Source: The primary source of power for the vehicle. Three solutions were considered; chemical batteries, solar cells and hydrogen fuel cells. Nuclear and Radioisotope generators were mentioned but never pursued due to their discrepancy with ESA policies. Typical space graded Li-ion batteries have an energy density of >100 Wh/kg, while hydrogen fuel cells reach 600 Wh/kg [1], resulting in a minimum 1900 and 300 kg primary power source respectively. Assuming a solar cell power efficiency of 430 W/m^2 [2] and full exposure to sunlight during the illuminated part of the orbit, a 10 m^2 array will be sufficient to provide the 4 kWh need of one full orbit.

Secondary Power Source: A secondary source is only needed if the primary source is unable to generate power at all times, as in the case of the primary power source being a solar array. A battery of the same quality as mentioned above, would be required to have a 16 kg mass to provide the 1.6 kWh needed for the 36 minute eclipse. Fuel cells are not considered viable as the electrolysis and H_2 burning processes amounts to around 60% energy losses [3], requiring a significantly larger solar array.

Final power system: Considering the properties of the possible solutions, the choice of final system setup is a primary source solar array with secondary battery storage. The solar array is mounted facing upwards in the bay of the trunk and has a size of 10 m^2, a mass of 3 kg and a peak power output of 4.3 kW. The bay hatches provide protection from the aerodynamic stress during launch and reentry and will be deployed once AstroCab enters orbit, as can be seen in Figure 2. This configuration also allows the solar array to not be oriented completely perpendicular to the Sun and still produce power. As for the battery, being Li-ion, its depth of discharge should not exceed 50% in order to stay healthy. Doubling the mass to a final 31 kg ensures this and provides some 30 minutes of backup power in emergencies by being fully discharged. Additionally, different power modes could be designed and implemented if the need for changes in the consumption arises, such as a power saving mode if one of the bay hatches fail to deploy.

B. Thermal

In LEO, the only major contribution to vehicle mean temperature is the balance between incoming and outgoing radiation, as well as internal heat generation. Assuming no temporal or spatial temperature differentials, meaning all of the vehicle has the same temperature that does not change over time, equation (1) can be used to calculate its temperature balance from where a steady state temperature follows.

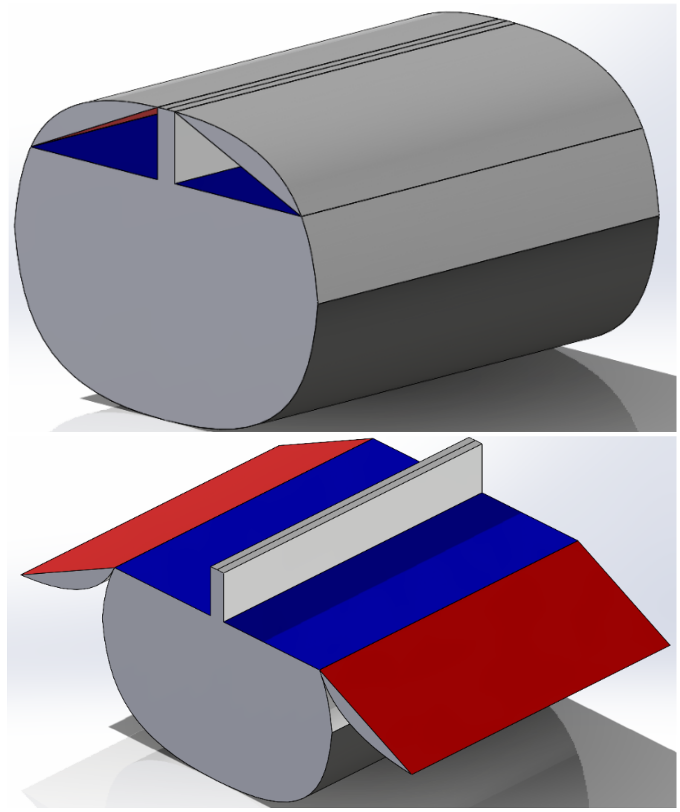

Fig. 2. Trunk hatches in their closed and deployed modes. Solar array is shown in blue and radiators in red.

$$A_{tot}\epsilon_{mean}\sigma T^4 = Q_{internal} + A_{exposed}\alpha_{mean}J_{incident} \quad (1)$$

The left hand side represents emitted radiation, with A_{tot} being exposed surface area of the vehicle, ϵ_{mean} is the average emittance, σ is the Stefan–Boltzmann constant and T is absolute temperature. The right hand side is a combination of internal heat generation from passengers and electronics, $Q_{internal}$ and incoming radiation, where $A_{exposed}$ is area of radiation exposure, α_{mean} is average absorptance and $J_{incident}$ is incoming thermal power. For the temporal invariability to hold, (1) must be considered in both illuminated and eclipsed condition and weighted between the two to correctly describe the thermal balance over one orbit.

For incoming radiation, there are three separate factors to consider: direct sunlight in LEO heating with 1370 W/m^2, sunlight reflected off the Earth at 500 W/m^2) and infrared radiation from the Earth at 250 W/m^2. The former two can be assumed to only matter during the illuminated part of the orbit, while Earth's IR is absorbed at all times. The exposed surface area, $A_{exposed} = 48$ m^2, and its absorptance $\alpha_{mean} = 0.51$ are weighted averages for the full vehicle, for which exact division can be found in Appendix B. The exposed area is half the total surface area, as the radiation is assumed to be illuminating only half the vehicle at any time. This calculation of weighted averages assumes that the vehicle has an equal probability to face any side to the radiation source, which might not be the case in reality when attitude control for solar array orientation is implemented. However, due to the vehicle architecture, this would make the very radiation absorbing thermal tiles face deep space and lead to less absorbed radiation.

Internal heat generation from electronics equals the average power usage in seen in II-A, at 2.6 kW, and from passengers it is assumed to be 350 W, resulting in an internal heat generation of around $Q_{internal} = 3$ kW.

Outgoing radiation is affected by the total vehicle surface area, $A_{tot} = 96$ m^2, unlike only the illuminated area for incoming radiation, and its mean emittance $\epsilon_{mean} = 0.87$, found in Appendix B, but also vehicle mean temperature, T.

The process of designing the vehicle for thermal balance was is performed iteratively, as any changed surface areas and/or coatings, including addition of radiators, affects both incoming and outgoing radiation, just not necessarily equally. By fitting AstroCab with 10 m^2 of radiator surfaces, as seen in Figure 2, the area, acceptance and emittance values as presented above were achieved. The absorbed external heat ended up averaging as 33 kW over one orbit, which together with the internal heat generation of 3 kW required an average emitted heat of 36 kW. Equilibrium was found at a steady state temperature of 23 $^\circ$ C, a reasonable level for keeping passengers alive and vital electronics functional. Since it is an average temperature for the vehicle, it allows for differentials, like keeping the passenger module regulated, if the need would arise in a further design process. The need for electrical heaters is not needed for AstroCab, as the proximity to the Sun and Earth made overheating a more likely concern.

C. Propulsion

Propellant: As aforementioned the design of the AstroCab had reusability, safety and automation in mind. The choice of propellant was required to reflect those priorities, therefore some criteria were created to evaluate the different propellant types. These were: environmental impact, reliability, efficiency and total mass.

Efficiency represents the I_{sp} of the fuel, which is simplified way of comparing the potential efficiency without considering mixture ratios of oxidisers. With further resources an I_{ssp} for the different propulsion systems could be compared to provide even more insight. The reliability is deemed lower for systems with less historic precedent and more moving parts. The total mass is an estimate which includes the entire propulsion system , therefore tank weight is regarded.

By looking at common industry choices today it was narrowed down to a few reasonable options. Mono and bi-propellant hydrazine, methane, RP-1 and HTP.

Fig. 3. Fuel comparison (red, yellow, green equate to poor, average, good respectively)

While other fuels seem overall to be more efficient, the propellant which suited our needs the best was monopropellant hydrazine due to a few main factors. Firstly, it requires no oxidiser which reduces complexity and makes the system more robust. Secondly, it gives the lowest propellant mass for aforementioned reasons and allows us to more easily have separate fuel tanks for capsule and ship.

However, poor efficiency and substantial environmental impacts are a necessary consequence of this fuel. The main environmental concern is during fueling where a potential leak could be harmful for nearby humans as well as the local environment[4].

Thrusters: After the propellant was decided upon some basic calculations were done to estimate the thrust required to perform the transfer burn in a reasonable time. A goal of 1 day travel time was set. With an orbital period of 92 minutes, a value of 5 minutes was assigned as the maximal burn time to enter the transfer orbit. 5 minutes was used as it represented a low enough burn time, to with good approximation be considered an instant burn.

To achieve the necessary ΔV for the transfer maneuver in under five minutes, a thrust of 3000N was required. Since there are no available thrusters of this power on the market, the thrusters were instead modeled with 8 400N Ariane Group monopropellant hydrazine thrusters. By using existing thrusters a more realistic value for I_{sp} and by extension a propellant mass could be calculated. In practice this is inefficient due to excessive piping, therefore if this were to reach production stage three 1000N thrusters would be used instead.

For altitude control 24 20N Ariane Group monopropellant were used to provide full rotational and translational control of the Spacecraft. While maybe more than necessary, redundancy is critical when designing human graded spacecrafts and the mass from each additional thruster is only 650 g [5]. These were placed in clusters of 6, with locations shown in figure 4

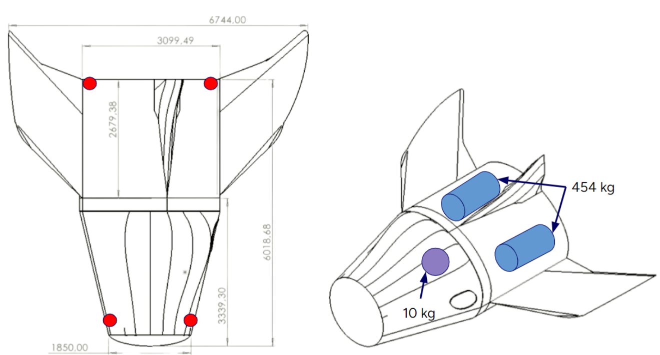

Fig. 4. Control thruster cluster location (left), propellant location and mass (right)

The logic behind using the same fuel for altitude control and main thrusters were to minimize tank mass and in turn reduce structural mass. The allocation of fuel in capsule and the pressurized potion are can be seen in figure 4. The motivation behind having fuel in the capsule is so slight maneuvers can be performed when the capsule has been aborted.

D. Landing

Regarding the landing of the AstroCab, inspiration is drawn primarily from the Dream Chaser's landing method. The AstroCab will employ a similar approach, utilizing runway landing procedures akin to an aircraft. This entails a deployable front skid along with two rear wheels, as illustrated in Figure 5.

Fig. 5. Dream Chaser landi'ng method as an airplane (left), with a front skid to facilitate this (right)

Complete automation is imperative to meet the requirements of the designed system. Therefore, as a contingency measure, autoland capabilities will be integrated. This decision is driven by the necessity for reliability, especially considering the challenges associated with managing wheels in space (pressure inside). The front skid is deemed critical for landing, further emphasizing the need for a reliable system. Additionally, unlike traditional aircraft, the AstroCab does not require the ability to taxi on the ground, hence eliminating the need for a front wheel. Further research is being conducted to provide concrete evidence supporting the reliability advantages associated with skid landing.

E. Life Support

In order to have a coherent system for all the departments in the blue team, the team in charge of this work was asked to define the Life Support System's volume requirements. The pressurized volume is one of the determining criteria in the sizing of our system. This volume of 8.9 m^3 is important, as it must allow the AstroCab's passengers to move around as they wish, and must include the seats as well as all the subsystems required for the passengers.

To facilitate passenger movement and the organization of the various subsystems in the pressurized section, a circular shape with a conical base was chosen, as shown in Figure 6.

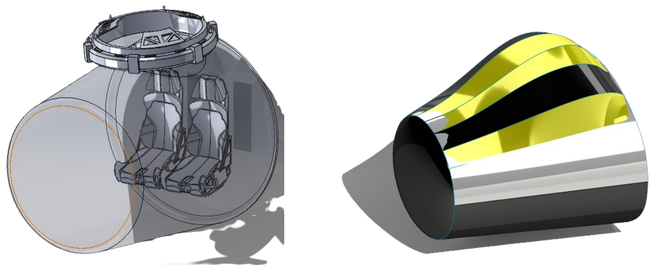

Fig. 6. The pressurized capsule (left) volume with an extruded part for the docking system and ejector seats already positioned in it and the outside of the capsule (right).

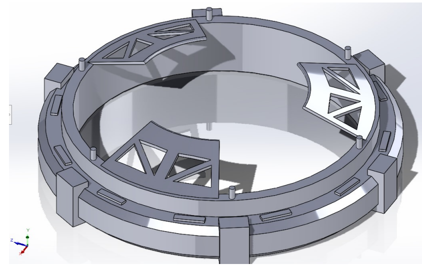

Fig. 7. IBDM docking port CAD part designed for the project.

F. Docking system

Regarding the docking system, the choice of ESA's IBDM (International Berthing and Docking Mechanism) docking system was a natural one. Firstly, because this technology is compatible with the future ISS USOS docking ports. Moreover, this is a future choice thanks to its international compatibility, as the IBDM docking system is designed to be compatible with the docking systems of various international space agencies such as NASA, Roscosmos and Jaxa.

Another benefit of the IBDM is the versatility of the technology, which is not limited to ISS scenarios but can also be used to dock another vehicle.

Additionally, it was decided to integrate LIDAR (Light Detection and Ranging) technology, which is a remote sensing system that uses laser beams to measure the distance to an object or surface. This will provide real-time data between the vehicle and its environment, which is crucial for avoiding collisions and ensuring safe and precise docking.

In order to fully meet the requirements, it has to be fully automated. As passengers are not trained in docking operations, and no one in the ISS is expected to be involved in the docking process, or at least not paid to be, the process will be fully automated. In the event of a problem during the docking process, a team present on the ground for the smooth running of the AstroCab mission will be able to intervene and help the docking process to run smoothly.

Finally, to be consistent with our entire CAD model, it was decided to design the IBDM docking port, using the available plan. This piece, shown in Figure 7, will be useful for the rest of our design.

This technical choice then had to be integrated into the modeling of our system, and certain constraints existed in this respect. As mentioned above, the AstroCab is a compromise between a space plane and a space capsule. This meant that the placement of docking systems for these two different types of vehicle had to be investigated. For space planes such as the dream chaser, the docking system is located at the rear, after separation of the trunk. It is not placed at the front because the heat shield is present to ensure proper reentry. Whereas on a space capsule like the Crew Dragon, the docking system is protected and located at the front of the capsule, as in Figure 8 left. Because during reentry, the conical base of the capsule (previously in contact with the trunk) will be exposed and therefore heat-shielded.

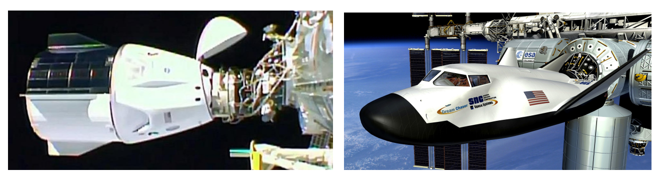

Fig. 8. Location of the docking system at the front for the Crew Dragon (left) and at the back for the Dream Chaser (right).

Assuming our vehicle is fully reusable and in the perfect scenario, it's possible to return to earth at the end of the mission with the trunk still on the AstroCab, it is therefore not possible to place the docking system at the separation between the part of the vehicle where there are passengers in the space plane and the trunk. In fact, the Dream Chaser's docking system is at the back as in the Figure 8 right. A reentry mode similar to the Dream Chaser was chosen, so that requires a heat shield at the front, eliminating the possibility of locating the docking system at the front as with the Crew Dragon. The docking system was therefore placed on top of the pressurized system, but to make this possible it had to be placed further out, with extruded material added to prevent any interactions with our vehicle that might interfere with the docking process. A hatch was then added to our CAD model to protect the docking system during the various phases of the Astrocad mission as can be seen in Figure 9 below. Its shape follows the docking system, its geometry obviously needs to be taken into account in aerodynamic studies, which are assumed to be outside the scope of our project.

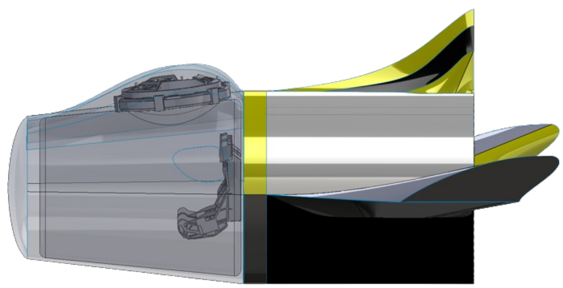

Fig. 9. Profile view of the AstroCab with capsule in transparent, the hatch protects the docking system and optimizes the system's volume.

G. Abort system

The abort system is essential for the continuous safety of the crew on the pad as well as during launch. Different abort modes have been put in place to ensure that there are backups for the different stages of the launch.

Mode 1: One of the key benefits of the AstroCab design is the characteristic of a space plane having a separable capsule. In the case of abort mode 1 which is initiated on the pad, the separable capsule is pulled by an abort tower to safety from an exploding launcher underneath. The alternative of using a ”pusher” type abort system was considered, but due these thrusters only activating in case of abort, they would be more dead mass than the abort tower in nominal cases.

The abort tower was modeled according to the Apollo missions, the main assumption being the thrust to mass ratio of the tower would remain the same[6] [7], but be scaled down to our capsule mass . This would give the AstroCab an abort tower with a mass of 1882 kg. As this technology is not new by any standards this estimate is conservative compared to a modern launch escape system (LES). The requirements set by the Human aspects team were 9gs for no more than 2 seconds. In case of problems shortly after ignition, the tower is used to drag the capsule away from the launcher flight path. While not common in the industry today, the abort tower is ideally recovered and reused using landing parachutes. This would not add too much recovery costs in nominal cases as the LES would land where there already are ships waiting in case of capsule abort. However the effect of saltwater corrosion could impact the total launches a given LES can handle and should be investigated further. Preliminary abort tower design can be seen in figure 10.

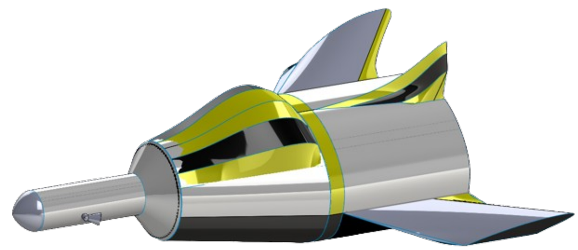

Fig. 10. AstroCab in its launch configuration with the mounted abort tower. Abort tower is not proportionally sized.

Due to the geographical layout of Cape Canaveral a down range distance of 2 km is required to reach the sea and due to safety of the crew a vertical distance of 2km was set, this is so the multiple stages of parachutes have time to deploy properly.

Mode 2: At a certain altitude separating only the capsule is not feasible due to being only partially heat shielded and reentry heat would be too high for the non protected parts. A potential solution was to use the LES to propel the entire spacecraft, but due to the trunk containing a large portion of the weight this was deemed non feasible. The approach that was eventually taken before first stage separation was similar to the Orion capsule [8]. It uses the second stage of the launcher to propel the capsule away from the failing first stage. As a result of this the spacecraft reaches higher altitudes and velocities, where the entire space plane could safely perform a reentry at desired location and land on a runway.

Mode 3: At first stage separation the LES is also jettisoned which makes a second stage failure a large problem. Due to having quite low thrust overall as well as having vacuum optimized thrusters, it is not safe to assume the AstroCab will have sufficient thrust to perform aborts at all stages of the flight.Thus it is possible that with a second stage failure the spacecraft might not have sufficient altitude and velocity to land safely. This would need to be further investigated to provide exact data on which sections of the mission there is no possibility to abort.

Mode 4: For when an emergency occurs post second stage separation, the orbital abort is commenced and the entire space plane performs a reentry at soonest possible moment. If it is closer to abort to nearby station, a docking is also an option which can be weighed by ground control.

H. Heat shielding

When reentering the Earth's atmosphere, temperatures that can reach 1,650°C, low weight and cost while ensuring the protection of the vehicle is highly desired. Both Dream Chaser and the Crew Dragon use heat shielding during reentry to protect the spacecraft from the intense heat generated by atmospheric friction.

The Dream Chaser utilizes advanced heat shielding technologies during reentry. DC employs a combination of thermal blankets and tiles. There are three main components and materials: Reinforced Carbon-Carbon (RCC), insulation tiles, and insulation blankets. In the High heat load area, like the leading edge of the wings, nose chine, and flaps, use Toughened Unipiece Fibrous Reinforced Oxidation-resistant Composite (TUFROC), and at the top of Dream Chaser will consist of white AETB tiles and FRSI because they are in a lower heat area.

Similar to Dream Chaser, our vehicle utilizes Reinforced Carbon-Carbon (RCC) to withstand high-temperature loads, placed in the nose chine, fuselage, and wings, as depicted by the black sections in Figure 1. The remaining sections of the spacecraft are covered and protected by Toughened Unipiece Fibrous Reinforced Oxidation-resistant Composite (TUFROC). The overall thickness of our vehicle's heat shield is approximately 80mm.

III. Discussion & Conclusion

A. Mass distribution

AstroCab has a total wet mass of 6290 kg, with the capsule amounting to 2490 kg of these. The wet mass includes 720 kg of fuel, all but 10 kg stored in the trunk, which results in dry masses of the whole vehicle and capsule of 5570 kg and 2480 kg respectively. Important to note is that because of the external abort tower at 1880 kg, the launch mass emerges as 8170 kg. The division into subsystems and their final mass distribution can be seen in Figure 11, and a table of mass contribution of specific components can be found in Appendix C. Note that the abort system section only includes mass in the actual vehicle, parachutes, flotation devices and separation pyrotechnics, the external abort tower not considered part of the vehicle in terms of mass optimization purposes.

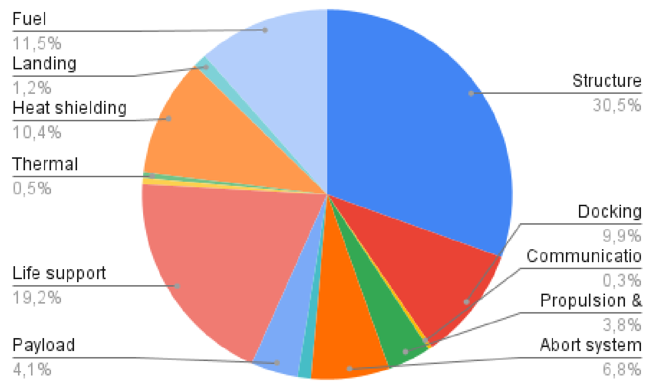

Fig. 11. Vehicle subsystem mass distribution

Achieving a low mass of is a crucial consideration for designing a feasible vehicle, but without a hard upper limit, it has been a secondary to designing appropriate systems, though always kept in mind when making design choices. Decreasing mass has varying degrees of possibility between the different subsystems. Fuel mass will scale with the vehicle mass, unless the choice of propulsion system changes completely, always requiring a 11.5% share in accordance with the well known rocket equation. Structure accounts for a large portion of the vehicle mass, but is hard to justify decreasing without a proper structural analysis. The life support system is provided by the *Human Aspects* team, complete with necessary components and their mass, volume and power requirements and is, similar to payload mass, not possible to alter without significant changes to mission requirements.

B. Turnaround time

As a requirement in the vehicle design the AstroCab would need a short turnaround time to be a viable future business. Thus a goal of 2 week turnaround time was set. The turnaround time was compared to the space shuttle. It has approximately 30 times the surface area compared to the AstroCab [9]. This is relevant when estimating the refurbishing time for the AstroCab heat shields, assuming that the most time consuming part of the refurbishment are the heat shields. The space shuttle had a lowest turnaround time of 54 days with the STS-61-B [10]. Therefore using the heat shield surface area ratio our turn around time would be less than 2 days. This is in an ideal case , however, it does give perspective that a 2 week turnaround is feasible. Using a more realistic turnaround time of 100 days for the Space shuttle still keeps our refurbishment time below a week. Additional arguments could be made that the Dream Chaser and in extension the AstroCab are using more modern thermal tiling and would require less refurbishment.

Another potential bottleneck for the refurbishment time are the thrusters , however the thrust levels at which the AstroCab operates are orders of magnitude less than the space shuttle [11]. Overall a lower thrust should in turn lead to less stresses and longer thruster lifetimes, with shorter refurbishment periods. One might also consider the transport of the AstroCab back to the launch site to take a long time, however this is only ever a problem if we abort and land away from cape Canaveral's runway. In worst case scenario we would have to transport the spaceship across the Atlantic, which might at most take few days. Yet were to be an abort, a standard refurbishment would not be relevant regardless, as testing and figuring out what went wrong would be a priority before launching more spacecrafts.

C. *Off-nominal case*

A list of off-nominal cases was created by evaluating the probability of the incident occurring and determining the respective danger levels. These two factors were considered to find high risk cases.

Case	**Probability**	**Magnitude**	**Risk (Probability x Magnitude)**
Structural failure	Very low	Lethal	Low
Abort system failure	Very low	Lethal	Low
Heat shield failure	Low	Lethal	Medium
Failure to deploy solar array	Very low	Dangerous	Low
Automation failure	Medium	Dangerous	Medium

From this list it was determined most relevant to investigate the "heat shield failure" in further detail. After the Columbia disaster heat shield failure is something that is considered thoroughly when designing a new capsule. The AstroCab is no different and the mitigation strategies implemented to avoid this are similar to the space shuttle. With through inspection and testing on ground as well as visual checks of the surface of the plane throughout the launch we can minimize the risk of accidents.

Furthermore inspection must be done once the target space station is reached, a flyby when approaching the station to allow cameras onboard the station to photograph AstroCab. Through AI technology deformities or damage to the tiles could be found by image recognition. If problems are found to be critical, an autonomous return is done by the crew-less spacecraft. The spacecraft should then be examined on ground to find the fault if there is one.

D. *Further development:*

Due to the limited scope of this project some aspect of the vehicle design were disregarded. This included reentry heat analysis, aerodynamic performance, communication systems and finally radiation and its effects on the crew. *Communication:* Regarding communication a redundancy in number of systems would be necessary as the crew are assumed to be untrained and thus require help from ground. This could be done by having direct links to ground but also relaying information to nearby satellites. This equates to a video and audio feed as well as the status of the ship would be necessary for ground control to understand whats going on.

Radiation: Radiation was not a major consideration due to the short duration of the flight in nominal conditions. However, if a solar particle event were to occur, a procedure needs to be set in place with methods to shield the crew. This would have to be coordinated in accordance to the Human Aspects team.

Reentry heat analysis and aerodynamics: A full reentry heat analysis is very dependant on the aerodynamics of the space plane. While a CAD was created it was not detailed enough to perform a good CFD analysis on. Therefore assumptions were made that with modern thermal tiling the friction heat would be sufficiently low to be able to reenter. Since the design was inspired by the look of the Dream Chaser, it was also assumed to produce sufficient lift to be a functional space plane in regards to runway landing.

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APPENDIX

A. Power consumption

Power usage breakdown into subsystems.

System	Component	Avg. power use [W]
Life support	Air system	1120
	Waste management	74
	Thermal control	160
	Pressure control	30
	Fire suppression	30
Communications	Transceiver	100
Control System	Computer	900
	Sensors	200
AOCS & Propulsion	Main thrusters	6,3
	Control thrusters	0,9
Complete vehicle		2621

B. Thermal surfaces

Surfaces used for thermal calculation, with typical absorptance (α) and emittance (ϵ) for coating. Total surface area and the weighted averages of α and ϵ are what is used in equation (1).

Surface	Area [m2]	Absorptance	Emittance
Hull (Al)	39,4	0,17	0,86
Thermal tiles	36,5	0,9	0,9
Solar array	10	0,8	0,8
Radiators	10	0,14	0,9
Total & weighted avgs.	96	0,51	0,87

C. Mass breakdown

Breakdown of mass distribution among the vehicle's components, with the third column presenting the total mass of each component and the fourth column what part of that mass was in the capsule. At the bottom, dry and wet mass of the full vehicle and capsule only, can be seen respectively. The very final rows display the abort tower mass and the total mass needed to be launched until first stage separation.

Subsystem	Component	Tot. mass [kg]	Cap. mass [kg]
Structure	Hull	1920	576
Docking	Protective hatch	100	100
	Docking port	526	526
Comms	Transceiver etc.	20	6
Propulsion & AOCS	Main thrusters	30	0
	Control thrusters	16	8
	Piping	100	20
	Main fuel tanks	71	0
	Capsule fuel tank	3	3
	Helium (inc. tank)	20	0
Abort system	Separation pyro	10	0
	Parachutes	319	319
	Flotation device	100	100
Control System	Computer	20	20
	Sensors	3	3
	Harness	50	15
Payload	Crew	160	160
	Crew needs	99	99
Life support	Air system	852	0
	Waste management	127	0
	Thermal control	131	131
	Pressure control	25	25
	Fire suppression	15	15
	Suits	30	30
	Seating	30	30
Power	Battery	31	9
	Solar panels	3	0
Thermal control	Radiators	30	0
	Heaters	0	0
Heat shield	Protective tiles	654	262
Landing	Skid, front	25	25
	Wheels, rear	50	0
Dry mass		5570	2482
Fuel	Main	701	0
	Control	24	9
Wet mass		6294	2491
Abort tower		1882	
Launch mass		8176	