AstroCab - A Space Taxi for Two People Overall Coordination - Blue Team

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***Abstract*—AstroCab is the conceptual design of a two-person spaceplane to provide frequent connections to future space stations in Low Earth Orbit with the first launch planned for 2035. The project was conducted in the Master-level course SD2905 ”Human Spaceflight” at KTH Stockholm by a team of four groups consisting of four or five members each. This report features the results of the management group labeled ”Overall Coordination”. It outlines the process followed for the development of AstroCab’s innovative reusable design and the obtained results. It includes the project management strategies implemented and the requirements defined for its design, leading to an estimated cost of 42.5 million USD per seat. Moreover, it explores potential funding sources, considers societal, legal and environmental implications, and provides a risk analysis with in-depth design of off-nominal scenarios for AstroCab to perform successfully.**

AstroCab is not just about going to space; it is about making space travel more accessible to everyone.

Fig. 1: AstroCab’s project patch

Contents

I. Introduction

A. Mission description

By the end of this decade, new commercial space stations are expected to emerge. This represents a market opportunity due to the foreseeable growing need for vehicles to shuttle people back and forth to the space stations. Therefore, the goal of this project was to design a vehicle specifically for this purpose. Designed to accommodate two passengers, the vehicle aimed for compactness, efficiency and affordability. Hence, this initiative and the resultant vehicle was named AstroCab. The vehicle and the accompanying training will make it possible to go to space for both trained astronauts and private passengers. Therefore, our target customers are governmental space agencies, companies, and private individuals.

B. Groups

The Blue Team was divided into four groups in order to focus on the critical points of the spaceplane design, simulating the real working environment of engineers in the space sector. The groups, of four to five people, focused on a different aspect of the spaceplane, which allowed to provide for a more detailed design. At the same time, communication between them was critical to ensure the consistency of the final design and reach solutions that work for all. The groups are presented and explained below:

1) Overall Coordination: The aim of this group is to coordinate the whole the project, help the other groups and give a brief overview of their results. Coordinating this project meant having an active role in organising meetings and facilitating communication between groups. Additionally, this report documents cost analysis, funding, legal aspects and other subjects relevant to the coordination of the mission.

2) Vehicle Design: The goal of the Vehicle Design group was to develop a design for the vehicle that satisfied all the given requirements. This entailed designing a safe and efficient vehicle, as well as one that can be used multiple times. [1]

3) Launch and Return: The Launch and Return group focused on determining which launchers would be the best options for launching the vehicle, as well as how a safe re-entry could be achieved for the returning vehicle. This also includes docking operations at the space station. [2]

4) Human Aspects: The goal of the Human Aspects was to design the life support system of the vehicle, i.e. all the systems required on board in order for the passengers to survive. Also, the design includes the necessary training for the passengers as well as determining the level of comfort to be expected, outside of that which is required for survival. [3]

II. Project Guidelines

A. Assumptions

Certain assumptions had to be made in order to make the project more realistic. This was possible due to the access to historical and current space missions, which were compared. Based on the researh performed, each group made certain assumptions in order to improve their results and ease the planning of the mission. The most important assumptions for each group were as follows:

1) Overall Coordination: For the Overall Coordination group, it was assumed that the first crewed launch is expected to be in 2035. The vehicle is to be reusable and five identical planes where to be build, which where all operational for 20 years with five planned launches per year for each vehicle.

2) Vehicle design: For the Vehicle Design group, Drag was not taken into account.

3) Launch and Return: For the Launch and Return group, an altitude similar to that of ISS was assumed for the destination, i.e. Low Earth Orbit (LEO) and specified in the Requirements section.

4) Human Aspects: For the Human Aspects group, it was assumed that the weight of the 2 people crew weight will be within the expectable values for the general population, to ensure adaptability for the target client of AstroCab previously presented.

B. Constraints

Constraints are limits which are applied on cost, schedule, and implementation techniques due to external and uncontrollable factors, and therefore should always be respected. As a consequence, the main constraints that AstroCab had to face were as follows:

1) All groups: A common constraint for all the groups is the Technological Readiness Level (TRL) of the systems and components that will be used in AstroCab. Since most of these will be Commercial-Off-The-Shelf (COTS) in accordance to the space sector development tendency, the TRL of these COTS had to be taken into account when planning the mission. This constrained the groups to select technologies that comply with a certain TRL threshold to comply with the presented development strategy of AstroCab ensuring reliability and safety.

2) Overall Coordination: In specifics, for the Overall Coordination group, the main constraint is that the cost of AstroCab shall not exceed the funding.

C. Requirements

In order to fulfill the project objectives, the AstroCab team developed its own requirements to ensure that the resulting spacecraft possesses the necessary functionalities through an appropriate technical design. At the beginning of the project, there was a brainstorming session during a meeting of the whole Blue Team. During this collaborative gathering, ideas were exchanged, concepts were explored and visions were articulated. It was from this collective effort that the Overall Coordination group expanded upon these ideas into the formulation of the Top Level requirements presented in Table I. Apart from that, more specific requirements for each of the groups were also developed afterwards.

TABLE I: Top Level Requirements for AstroCab

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 minimum payload mass of 260 kg.
T 3.0	The 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.
T 7.0	The vehicle shall allow communication with the space station and on ground.
T 8.0	The vehicle shall allow to be controlled remotely from the space station.
T 9.0	The vehicle shall have a quick turnaround time between launches and returns to optimize efficiency.

All these requirements were pivotal for several reasons.

- They delineated the essential features and functionalities that the AstroCab must possess to fulfill its intended purpose effectively. By defining these parameters early on, it was ensured that the design process remained focused and aligned with the overarching project goals.
- They served as a framework for communication and collaboration within the team. By clearly articulating what needed to be achieved, each group could work cohesively towards their specific objectives, knowing how their contributions fitted into the larger picture.
- Furthermore, these requirements were not static; they evolved and adapted as the project progressed. As such, they facilitated a dynamic and iterative design process, allowing for continuous improvement based on feedback and new developments.

III. Project Management

One of the tasks of the Overall Coordination group was to manage the communication between the other groups and to guarantee the punctual and complete delivery of the project. The available time of five weeks was a challenge so several measures were put in place to guide the team. In addition to the detailed descriptions below, a cloud for sharing and saving all documents, a group chat, the logo and templates for the presentation were provided.

A. Regular Meetings

The first action was to schedule a regular meeting in the last 15 minutes of each working session that was scheduled by the course professors. During these fifteen minutes every group had the possibility to share their progress and challenges. Additionally, everyone had a designated slot to pose their question. Also, the whole team discussed joint decisions.

B. Work Breakdown Structure

To allocate tasks between the different groups based on the project guidelines defined in Chapter II, a Work Breakdown Structure (WBS) [4] was created. This eliminated the probability of tasks being worked on by two groups at the same time or being forgotten by all groups. For example, initially it was unclear whether docking fell within the scope of the Vehicle Design group or the Launch and Return group's responsibilities. The Coordination Group resolved these issues: The Vehicle Design Group designed the docking adapter and the mechanics, while the Launch and Return Group developed procedures for rendezvous and docking. Once the WBS was completed, it also provided a good overview of all tasks. It is included in the Appendix.

C. Schedule

Based on the WBS, a schedule was created. Starting from the given working sessions, the project development time was split up guided by which decision must come before the other and which could be performed simultaneously. The final schedule was then distributed to all the groups in the form of a GANTT-Chart [5]. Regular encouragements and reminders to adhere to the schedule were crucial in the completion of the project.

IV. Mission overview

AstroCab has been designed to reach its destination and return to Earth shortly after that. It will launch from the same site that it returns to and it will be refurbished quickly, preferably in around two weeks. The departing crew will not to be the same as the arriving. Since AstroCab has been designed to be a taxi service that transports as many people as possible that demand this service it is not required for AstroCab to stay in space along with the crew. For instance the responsibilities of having an emergency escape vehicle on the space station does not fall on AstroCab.

Below the most important results from each group are summarized.

A. Vehicle Design group

Based on research, the Vehicle Design group suggested early on that the design should be a spaceplane, which was agreed on by the whole team after a joint discussion. The Vehicle Design group then decided that AstroCab was going to have a tower abort system, be powered by batteries recharged by extendable solar panels and that the vehicle will be fully automated with the possibility of remote control. The rendered concept of AstroCab can be seen in Figure 2.

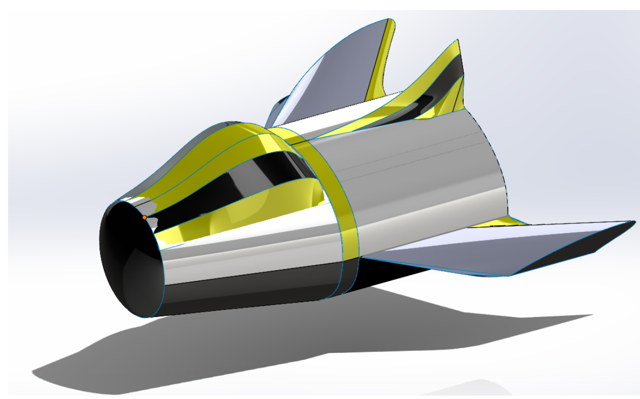

Fig. 2: Current version of the AstroCab concept

B. Launch and Return group

The Launch and Return group decided on the SpaceX Falcon 9 rocket to be used as the launcher based on the cost analysis carried by Overall Coordination and other factors including that it was the best fit to the mass profile. In collaboration with input from Overall Coordination it was also decided that the primary launch and return site was going to be Cape Canaveral in Florida. This was decided performing a trade-off analysis, in which the critical considerations were its good infrastructure, preferable geographical position and latitude as well as the development state and the adaptability of their infrastructure to AstroCab needs. The group also decided that Spaceport America in New Mexico will be a backup return site.

C. Human Aspects group

The Human Aspects group decided that the crew will be required to undergo basic training of approximately 30 hours before launch. If desired, an additional training lasting three days will be offered. To facilitate operations and turn around time one-fit-all seating and Intra Vehicular Activity (IVA) suits will be used. They also decided that there will be an emergency abort button accessible to the crew during certain phases of the mission and that the consumables have to to last for two days in both directions making them need to last a total of four days.

D. Everyone

Based on combined results from the groups, the vehicle dry mass was estimated to be 8176 kg, in which the engines take up 240 kg and the fuel 724 kg.

V. Mission Logistics

A. Site Selection

The mission logistics include finding attractive locations for launch, return, development and manufacturing, as well as the relationship between these sites, i.e. distance and transportation, export control between countries, existing infrastructure, etc. Especially because of the last point, the decision from AstroCab is to develop, build, launch, and return from one single economic area fell quickly.

Part of the spaceplane concept includes the quick turnaround times. Therefore, it was favourable to keep the manufacturing and development site close to launch and return. Also launch and return should take place close to each other to maximize the time advantage.

With that in mind, probable options were collected. The selection was then narrowed to locations with the (future) capability to launch humans to space. The Chinese and Russian interest zones were ruled out because of political and economical concerns. India and the United States were the only contenders left, but Europe (EU and/or ESA) was later included in consideration due to the suspected market for commercial spaceflight programs. The options were discussed with the Launch and Return Group and arguments were collected. Subsequently, a trade-off analysis for all the locations considered was performed. In the end, the decision fell on the Kennedy Space Center in Florida, United States. The main arguments for this selection were:

- The most important infrastructure is available (Launch pads for lease, runway suitable for spaceplanes, ...),
- The US is considered a business friendly economy,
- Compared to French Guiana and India the weather is better (but hurricanes are a challenge to be considered).

B. Production and Launch Frequency

This report does not dive deep into the development and production process but a few key points are important for the financial and operational schedule.

It was assumed that there will be a market for about 24 launches per year (cf. Chapter VI). To be able to sustain this launch frequency for 20 years, so a total of 480 launches, it is assumed that five AstroCab vehicles will be needed. 96 launches per vehicle is an ambitious endeavour, more than doubling the 39 launches of the most used Space Shuttle, Discovery [6]. Still, it is assumed to be possible since Discovery still was operational at the end of the Shuttle program and all Space Shuttle Orbiters were originally designed and certified for 100 launches each [7]. Additionally, technology has advanced in the last 40 years and will still advance until the first AstroCab launch in 2035 to meet the time schedule.

VI. Mission Cost Estimation

Calculating the cost of building a rocket is a highly complex task. There are no straightforward formulas, limited published research, and it is challenging to draw a valid conclusion. This cost analysis is a combination of research published by Greg J. Gstattenbauer [8], James Michael Snead [9], and James R. Wertz [10]. The cost for AstroCab's launch has been calculated considering six individual components:

$$C_{\text{launch}} = C_{\text{development}} + C_{\text{plane}} + C_{\text{Rocketloan}} + C_{\text{flightops}} + C_{\text{recovery+refurb}} + C_{\text{insurance}} \tag{1}$$

In the coming subsections, each components of the cost will be examined. The calculation presented is based on a 20-year lifespan, incorporating 24 launches annually. As this is a reusable spaceplane, it will have a very high upfront development cost and will be sensitive to inflation. However, this cost analysis has not taken inflation into consideration.

A. $C_{\text{development}}$

The development cost is a one-time expense and must be amortized evenly across each launch. To calculate the total development cost, the spaceplane's and engine's dry masses are needed (cf. Eq. 2 and Eq. 3). The overall development cost is the sum of the development expenses associated with the engine and those related to the construction of the spaceplane (cf. Eq. 4). [8]

$$C_{\text{Plane dev.}} = 250 \cdot \text{PlaneDryMass}^{0.48} + 2000 \tag{2}$$

$$C_{\text{Engine dev.}} = 1,5 \cdot 124 \cdot \text{EngineDryMass}^{0.52} \tag{3}$$

$$C_{\text{Total dev.}} = C_{\text{Plane dev.}} + C_{\text{Engine dev.}} \tag{4}$$

Calculation of the recurring cost for a single launch can be done using Eq. 5, where N is the number of launches during 20 years, which amountsto 480. A man year (MYR). amounted to 374000 USD in 2023 [11] [8].

$$C_{\text{development}} = \frac{C_{\text{Dev.tot}} \cdot \text{MYR}}{\text{N}} \tag{5}$$

B. $C_{\text{Rocketloan}}$

The space plane is scheduled to launch from the reusable Falcon 9 rocket.[2] This is expected to make up the most significant cost for the launch, a factor that is projected to become considerably more economical in the future, given that the first launch of AstroCab is planned for 2035. However, for this cost analysis, the current price of a Falcon 9 rocket launch is considered.

C. C_{plane}

This is the recurring production cost for the plane itself. For 480 launches, five spaceplanes where planned on being built. The production cost of building the five planes is amortized over the number of launches as well. Since all space planes are assumed to be built, the theoretical first unit (TFU) cost was calculated for one of them and multiplied by the total amount of planes. The recurring production cost is made up of the TFU of the plane 7 and the engine 8 and was calculated with Eq. 6. [10]

$$C_{\text{plane}} = \frac{5 \cdot \text{TFU}_{\text{Total}} \cdot \text{MYR}}{\text{N}} \tag{6}$$

$$\text{TFU}_{\text{SDM}} = 1.1 \cdot \text{Plane}_{\text{drymass}}^{0.62} \tag{7}$$

$$\text{TFU}_{\text{EDM}} = 1.3 \cdot 3.72 \cdot \text{Engine}_{\text{drymass}}^{0.45} \tag{8}$$

D. $C_{\text{flightops}}$

The operational cost includes fuel and labour cost. One work hour (WH) amounted to 217 USD in the US in 2023.[9] [11] The labour cost was made up of indirect and direct costs and the labour hours were assumed to be equivalent to the empty weight of the plane. Fuel cost for the plane's orbital maneuvering engines powered by hydrazine [12] amounts to 75.8 USD per kg.

$$C_{\text{ops}} = C_{\text{fuel}} + C_{\text{labour}} \tag{9}$$

$$C_{\text{labour}} = 2 \cdot \text{Plane\_drymass} \cdot 1.17 \cdot \text{WH} \tag{10}$$

$$C_{\text{fuel}} = 75.8 \cdot \text{Propellant}_{\text{mass}} \tag{11}$$

E. $C_{\text{recovery+refurb}}$

These are the costs of preparing AstroCab to be ready for the next launch. They includes various tasks like inspection, maintenance, cleaning, testing, and returning all equipment to the launch site. The initial cost (C_{initial}) of C_{recovery} is modeled as 20% of the operational cost and for the C_{refurb} as 2% of one plane cost. [10] Since AstroCab is reusable, the initial cost is expected to rise due to increased wear with repeated usage. This cost is modeled using the Eq. 12: [10]

$$C(t) = C_{\text{initial}} \cdot (1 + r)^t \tag{12}$$

where t represents the number of years, r denotes the annual growth rate of 15%, and $C(t)$ signifies the mean value over the years of the cost of $C_{\text{recovery + refurb}}$ for one launch.

F. $C_{\text{insurance}}$

A lot of money has been put into developing a the reusable spaceplane. Therefore, the reliability is expected to be very high which allows to assume that the insurance cost will decrease to considerably low values. It is modeled as a small percentage of the launch cost as seen in Eq. 13. [10]

$$C_{\text{insurance\_reusable}} = C_{\text{launch}} \cdot 1.5\% \tag{13}$$

G. Overall Price

The final price per seat and all its individual cost components plus a decided profit of 8% are to be seen in Table II. How much each component contributes to the total launch price can be observed in Figure 3. The price per seat amounted to 42.5 million USD. Based on this result, it can be stated that AstroCab will arise as a competitive and attractive option in the space travel market, particularly when compared to other spacecraft like Crew Dragon (priced at 55 million USD), Boeing's Starliner (valued at 90 million), and Soyuz (costing 86 million). [13] With its competitive pricing, AstroCab positions itself favorably for market acceptance.

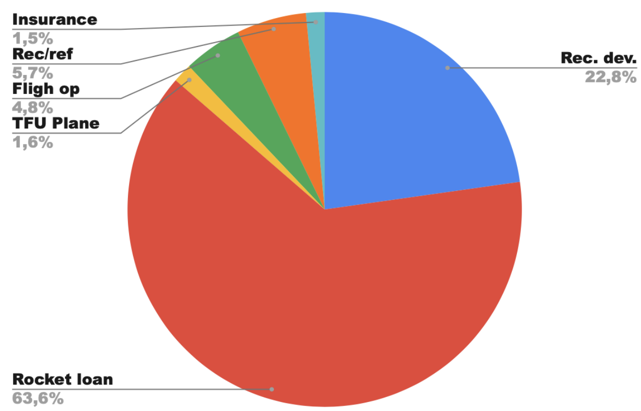

Fig. 3: Cost components

TABLE II: Price per seat estimations

Part	Cost in USD
Development	8.6 Billion
Recurring development	17.9 Million
Rocket loan	50 Million
TFU Plane	1.23 Million
Flight op	3.8 Million
Recovery/refurb	4.5 Million
Insurance	1.2 Million
Total launch cost	**78.6 Million**
Profit (8%)	6.3 Million
Price per seat	**42.5 Million**

VII. Funding and Collaboration

Both private entities and government space agencies were considered for obtaining funding for AstroCab. The intention was to diversify the funding sources in order to make the funding more reliable and not prone to changes in a country space budget for example. Table III summarizes the maximum amount of funding possible from each prospective source where this information is readily available.

TABLE III: Max funding available per year

Agency	Max. funding/year in US Dollars
ESA (Europe)	2.2 Million[14]
NASA (USA)	2.3 Billion[15]
ISRO (India)	125 Million[16]
SNSA (Sweden)	21.2 Million[17]
JAXA (Japan)	676 Million[18]

An estimate for total initial funding was made by estimating that two percent could be received from the national space agencies, assuming a 20 percent from SNSA, together with additional funding from non-governmental organisations. From this, a value of USD 70 million was obtained. The non-govermental potential sources of funding included OHB Sweden, Swedish Space Corporation, Airbus and Uber. Concrete values of funding available from these companies were more difficult to obtain. However, Uber has a substantial net worth of a similar magnitude as SpaceX and if persuaded to expand their transport activity to space they could undoubtedly give a fair amount of investment to AstroCab. The other presented private companies do offer funding opportunities for start up space related companies. Detailed results from the research of the funding are provided below.

A. ESA (Europe)

ESA offers funding to businesses either by own initiative or through calls to a specific topic. Typical individual funding grants can reach almost USD 0.6 million.

Furthermore, ESA persues independent access to space which could serve as an incentive for them to sponsor AstroCab. Part of their goals is also that "Europe should significantly increase the level of public investment to stimulate private funding...". They also want to "unleash entrepreneurship" and overall strengthen European presence in space.[19]

B. NASA (USA)

NASA is the largest national space agency and they could therefore be a key player in sponsoring the development of AstroCab. The US also wants several space vehicles to be available as well as to help commercial companies which makes it likely that they would support AstroCab. An example is that they have provided funding to both SpaceX and Boeing for the development of crewed spacecrafts. Even though Boeing has a much higher cost per seat than SpaceX, they still want the redundancy.[20]

C. ISRO (India)

India is projected to grow substantially in the space sector. In 2020 the country accounted for 2-3 % of the global space economy and it is expected to grow to 10 % by 2030.[21] India's prime minister has also stated that he believes the private sector will play a big role on such a growth. Presently, NewSpace India Limited (founded in 2019) is the entity in charge of providing funding to support the commercialization of space. In the next five years they are looking to give out USD 1.2 billion.[21] It is worth noting that the Indian yearly budget is about USD 1.5 billion while the one of ESA amounts to USD 5.19 billion[22], and of the US to USD 25.4 billion (2023).[15]

To date, India has supported about 190 start ups. In 2021 USD 67.2 million were given out and in 2023 $124.7 million.[21] At the moment they do not usually give larger grants of money to companies but it is expected that this tendency will change in the future.

D. SNSA (Sweden)

The Swedish National Space Agency is likely to provide AstroCab with funding as a swedish space company. For instance, SNSA's future strategies consist of allocating funding which "strengthens Swedish participation in space" and also work towards more manned presence in space by Swedish astronauts which AstroCab could help with.[23]

E. Summary

To summarize, it is clear that many funding opportunities are available. Space is also expected to grow in the future, especially in places such as India, which makes it reasonable that funding should be very manageable to get. Investment sources are also a powerful funding option that will be looked in detail in future development stages of AstroCab.

One counterargument for using funding from many different space agencies is that countries may want their own independent access to space. In order to resolve this and expand the market opportunities of the company, a future development for AstroCab is to not only make it a purchasable service but also a product possible to buy. This would allow companies, governments or space agency to buy an entire AstroCab vehicle and use it as they wish. This is how it works with land/air based vehicles today and there is therefore potential for AstroCab to be among the first companies to transfer this business model to space travel.

VIII. Legal and Social Aspects

A. Legal aspects

There are six international treaties negotiated to govern state behavior in space. [24] The three of them with a bigger influence on AstroCab are hereby presented. Firstly, the Rescue Obligations Treaty indicates that all states in the agreement must offer all possible assistance to rescue spacecraft passengers that have landed within their territory due to accidents, distress or other emergencies. However, this agreement is still a bit vague and has some uncertainties regarding passengers like space tourists, which could be a problem for AstroCab. But since the launch is planned in more than 10 years time, it is expected that this treaty will be improved and clarified.

Secondly, another treaty influencing AstroCab would be the Registration Convention, requiring all nations to provide the United Nations (UN) with the orbit of each space object they launch to promote transparency and international cooperation in outer space activities. Thirdly, the Space Liability Convention states that AstroCab's company has to take responsibility in case it causes any damage on Earth or space.

Since the launch is planned to take place in the US, consideration must be given to the Federal Aviation Administration/Office of Commercial Space Transportation. They are responsible for regulating and licensing commercial space launch and reentry activities, with a focus on safety and mitigating potential risks associated with commercial space launches. AstroCab must undergo five steps to be accepted as a commercial spacecraft: firstly, a Pre-Application Consultation; secondly, a Policy Review and Approval; thirdly, a Safety Review and Approval; fourthly, an Environmental Review; and finally, Compliance Monitoring, where the FAA monitors licensees and making sure they follow all the rules. [25]

B. Social

The development of AstroCab will lead to new technologies being developed that will also be useful on Earth. For instance, presently both ESA and NASA have departments that work on how to transform and use technologies developed for the space sector on Earth and a similar department could be made within the AstroCab company. Widely known inventions first developed for use in space include LED lamps, water recycling systems and memory foam.

AstroCab will also make space more accessible for the general population which could have large impacts on inspiring young people, leading to more of them pursuing science and space related careers and increasing investigation in their respective fields.

IX. Risks and Off-Nominal Scenarios

A. Risks identification and assessment

A risk is an undesirable situation that has both a likelihood of occurring and a potentially negative consequence. Due to their nature, risks must be managed for the success of any project, establishing a process for evaluating potential risks, identifying them, and implementing measures for their prevention, mitigation, and control. Such approach will be used in AstroCab.

To present risks in a clear way, they will all be assigned to a different Category (ID) as presented in Table IV, Probability (P) in Table V, and Severity (S) class in Table VI. Combining the Probability and the Severity of each risk, several Magnitude Levels (PxS) that are presented in Table VII will be defined and used to create a hierarchy of all the risks, to better comprehend the potential impact derived by the occurrence of the event during the experiment.

From all the analysed risks this document presents the Personnel and Managerial Risks respectively in the tables of Figure 4 and Figure 5, since they are the ones directly related to the Overall Coordination Group considerations. Assessing their probability and severity, the risks have been categorized. The most critical risks identified are misunderstandings and ineffective communication between the team members from the personnel perspective, and that the project costs exceed the budget from the managerial one. The new processes and control actions implemented for these risks are stated in the corresponding Figures.

TABLE IV: Risk Categories

Risk ID	
ID	**Description**
TC	Technical/Implementation
MS	Mission (operational performance)
SF	Safety
VE	Vehicle
PE	Personnel
EN	Environmental
MG	Management

TABLE V: Risk Probability

Probability (P)	
P	**Description**
A	Minimum – Almost impossible to occur
B	Low – Small chance to occur
C	Medium – Reasonable chance to occur
D	High – Quite likely to occur
E	Maximum – Certain to occur, maybe more than once

TABLE VI: Risk Severity

Severity (S)	
S	**Description**
1	Negligible – Minimal or No impact
2	Significant – Leads to reduced performance
3	Major – Leads to failure of subsystems
4	Critical – Leads to failure or minor health hazards
5	Catastrophic – Leads to termination of the mission, damage to the vehicle or injury to personnel

TABLE VII: Risk Magnitude designation

Risk Index (PxS)	**Risk Magnitude**	**Proposed Action**
E4, E5, D5	Very High Risk	Unacceptable risk: implement new process or change baseline.
E3, D4, C5	High Risk	Unacceptable risk: see above.
E2, D3, C4, B5	Medium Risk	Unacceptable risk: must be managed. Consider alternative process or baseline.
E1, D1, D2, C1, C2, C3, B3, B4, A5	Low Risk	Acceptable risk: control, monitor, consider options.
C1, B1, A1, B2, A2, A3, A4	Very Low Risk	Acceptable risk: control, monitor.

Personnel					
ID	Risk	P	S	PxS	Action
P1	One or more team members are unexpectedly unable to commit the necessary time to the project.	B	2	Very low	- All team members will communicate intensively with each other so that working tasks can be rearranged easily. - There will be at least 2 team members working on a major task to distribute all know-how.
P2	Team members do not have sufficient expertise in certain technical topics.	B	2	Very low	- The team will have support from the professor Christer and Eric, the mentor from OHB. And all the team members will work collaboratively.
P3	Team member unavailable due to sickness.	C	2	Low	- It will be ensured that work can be continued long distance. - Cross-training in critical tasks.
P4	Misunderstandings and ineffective communication between team members.	D	4	High	- Establish clear communication channels. - Conduct regular team meetings to ensure awareness and consistency on the project development.

Fig. 4: Personnel risks

Management					
ID	Risk	P	S	PxS	Action
MG1	Project costs exceeding budget.	D	4	High	- Look for several sponsoring and funding opportunities. - Budgeting with a safety factor to balance out possible budget overruns. - Lists for required material and components will be created by each subteam to estimate and monitor budget.
MG2	Time-plan delays leading to unavailability of the vehicle to be launched.	C	4	Medium	- Regular revisions and adjustments of the project plan to validate the project progress continuously. - Recruitment of new employees for the company when necessary.
MG3	Insufficient work-hours available to complete the project tasks, leading to being unable to launch.	B	4	Low	- Gantt Chart for the project duration. - Continuous updates on expected workload. - Recruitment of new employees for the company when necessary.
MG4	External manufacturers delay for external reasons.	C	4	Medium	- Estimates for delivery times will be made and ordering will take place as soon as possible to compensate for possible delays. - Search for several suppliers and manufacturers to have back up.
MG5	Regulatory compliance issues	A	4	Very low	- Stay informed about relevant regulations and legal requirements governing space exploration and commercial spaceflight. - Establish a dedicated regulatory compliance team to monitor changes in regulations and ensure adherence to compliance standards.

Fig. 5: Management risks

B. *Off-nominal scenario analysis*

From the risks identified and assessed for all the categories stated and from all the groups of AstroCab, several off-nominal scenarios were specified, including:

- Abort system failure
- Difficult weather conditions at launch and return site
- Failure to deploy the solar arrays
- Heat shield failure
- Launcher Vehicle Failure
- Leakage in waste management system
- Life support system malfunction
- Loss of communication
- Power system failure
- Spacesuit malfunction

Each group has analysed in detail at least one of the stated off-nominal scenarios. Those are:

- Vehicle Design Group: Heat shield failure and the failure to deploy the solar array [1]
- Launch and Return Group: Difficult weather conditions at launch and return site [2]
- Human Aspects Group: Life support system failure [3]
- Overall Coordination Group: Loss of communication.

In this paper, only the loss of communication off-nominal scenario will be analysed. During critical mission phases such as docking, undocking, re-entry, landing, and other off-nominal situations, the absence of effective communication presents relevant challenges. Notably, the passengers aboard are not trained astronauts, precluding the possibility of crew intervention in such circumstances.

To address the risks associated with communication loss, the mission requires robust redundancy in communication systems. This entails establishing multiple layers of communication, including direct and indirect channels with ground control, as well as maintaining connectivity with the space station. Furthermore, the mission's success depends on the full automation of all processes without constant radio connection in every scenario.

To this end, the implementation of two independent systems is imperative to mitigate the risk of system failure. These systems encompass remote control capabilities and sophisticated automation protocols, ensuring operational continuity even in the absence of constant radio communication.

X. Environmental Study

The environmental study was conducted using Granta Edupack in the aerospace category, examining the CO_2 footprint and energy requirements throughout the material acquisition, manufacturing, and usage phase of the rocket. Since the plan is to build 5 planes that are expected to last for 20 years, each plane had around 5 launches every year.

For the material acquisition, the main material in the following components were analyzed: structure, batteries, parachutes, solar cells, flotation devices, computers, harness, waste management, landing gear, and heat shielding. Approximately 200 kg of components involving pressure control, thermal control, and fire suppression were excluded due to the unspecified material choice. The only batteries available in the program were Ni-Cd rechargeable batteries which are not regularly used anymore for rockets. All materials were assumed to be virgin, and a table of the main materials is to be seen in Figure 6.

Concerning rocket usage, the analysis focused on Falcon 9 rocket fuel (kerosene) and the utilization of batteries in Astrocab. The consideration of hydrazine fuel was omitted due to the limitations of Granta Edupack's capabilities and since it will burn mostly outside the atmosphere. The battery was assumed to have the power rating of 2661 Watt[1] and to be working 24/7, 20 days a year per vehicle.

Component	Material	Recycled content* (%)	Part mass (kg)
Structure	Aluminum, 2219, T8511	Virgin (0%)	4,5e+03
Batteries	Ni-Cd rechargeable battery	Virgin (0%)	22
Parachutes	Polyamide fiber (Nylon-6)	Virgin (0%)	3,2e+02
Solar cells	PP (impact copolymer, low flow)	Virgin (0%)	20
Flotation Device	Chlorosulfonated Polyethylene (unreinforced)	Virgin (0%)	1e+02
Computer/sensor	Integrated circuit (large)	Virgin (0%)	20
Harness(cables)	Cable	Virgin (0%)	50
Waste management	PE-HD (general purpose, molding & extrusion)	Virgin (0%)	1,3e+02
Landing gear	Intermediate alloy, Fe-9Ni-4Co-0.20C steel, quenched & tempered	Virgin (0%)	75
Heat shielding	Tantalum-W-Hf alloy, T-222	Virgin (0%)	2,2e+02
Others			5,1e+02
Total			

Fig. 6: All main materials in subsystems

With regard to the manufacturing process, the primary methods chosen were forging, polymer molding, and casting, while fine machinery was used as a secondary method. However, due to the limitations of Granta Edupack, the results for the energy required and CO_2 emissions were very low. This is believed to be because Granta Edupack does not account for the complexity involved in manufacturing a rocket, hence the low environmental impact for this category. The results of the environmental process can be seen in Figure 7. The total CO_2 emissions were 509000 kg per launch, and the total energy required was 7340000 MJ. This was distributed across material acquisition, manufacturing, and use, with approximately 65% for use, 3% for manufacturing, and 32% for material acquisition.

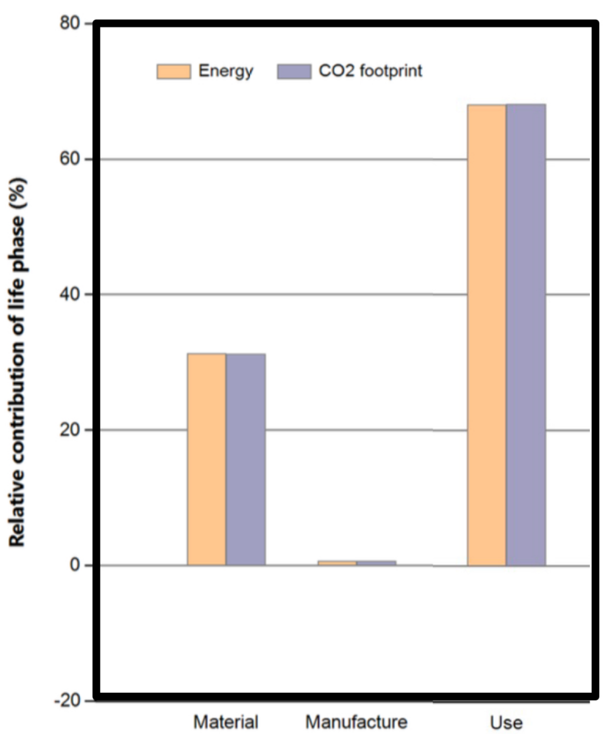

Fig. 7: Environmental Impact

XI. Discussion

Given that the AstroCab mission is successful, it gives rise to speculation on how the central concepts can be used for future missions. Since most of the costs are in the development phase, one of the ways to increase profit would be to build a larger vehicle, having three or four seats instead of two. As the price people are willing to pay would likely not change depending on whether they have one, two or three co-passengers, and assuming that development costs would not be much greater for a bigger vehicle, profit could be greatly increased if one or two extra seats were added. The same Falcon 9 rocket could be used for an even bigger vehicle, but the costs for the plane would rise since it would have a higher mass. However, it should be kept in mind that these costs are marginal compared to the development costs. Additionally, new launchers such as Starship would be a lot cheaper than the ones used now, further driving down the price.

Also of interest for planning of future missions is the expansion of the market to other locations, such as India and the EU through ESA. Making AstroCab a vehicle that both states and private companies can lease or buy would create an opportunity for new markets in other parts of the world. Broadening the market to countries where customers with sufficient means to afford such a journey live would imply an increase of the profits of AstroCab.

Another aspect to consider is the future development of fuel for spacecrafts. If a greener alternative for the rocket fuel was developed, especially for the launchers, it would make the mission more environmentally friendly overall. This would make AstroCab a more attractive product to sell to other countries, in a world increasingly concerned about the environment.

XII. Conclusion

This document presents the conceptual design of AstroCab, a two-person spaceplane whose first crewed launch is planned for 2035. As indicated in previous sections, the vehicle will be separable for launch abort purposes but in nominal conditions it will launch vertically and land horizontally at Kennedy Space Center (USA). Due to automation and remote control, the design is suitable for both space tourists and astronauts, since minimal crew training is needed.

Funding will be acquired from NASA and private investors. ESA and SNSA will be willing to provide additional funding. Because of the taxi concept negotiations with Uber will be held. The cost per seat was estimated to 42.5 million USD using five reusable orbiters for a total of 400 launches in 20 years. Moreover, the environmental study yielded that the overall impact is dominated by the launch emissions of the Falcon 9 rocket. Dividing the overall emissions by the number of launches rendered 509 t of CO_2-equivalents per launch. These could be further reduced by using sustainable kerosene obtained from renewable energies. This is a decision SpaceX would have to make, but it can be suggested to them.

A risk analysis was performed, from which the most critical Off-Nominal Scenarios were identified. Each group analyzed at least one of such scenarios. The one studied in this report was the Loss of Communication. Considering that passengers are not necessarily well-trained astronauts, the spacecraft must be able to operate completely automatically. Loss of communication cannot be ruled out in space.

In a nutshell, AstroCab is an ambitious concept for future direct transportation to and from space stations in LEO operating from 2035. Sign up to fly with us here: bit.ly/astrocab

Division of Work

A. *Arvid Althoff*

Sections written: Mission overview, Social aspects and Funding and collaboration.

Research on Funding and collaboration and Social aspects.

B. *Ioana Cosaceanu*

Sections written: Mission cost estimate, Legal aspects and Environmental Study.

Research on Mission Cost, Legal and Political aspects and Environmental Study. Also developed the GANTT-Chart.

C. *Rafael Kniese*

Sections written: Project management, Missions logistics and Conclusion.

Research on Funding and collaboration. Enhanced the Work Breakdown Structure and selected the Off-Nominal Scenario for the Overall Coordination group.

D. *Sara Sanchis Climent*

Sections written: Guidelines, Requirements and Risks and Off-Nominal Scenarios.

Research on Requirements, Risks, Off-Nominal Scenarios, Funding and Collaboration. Also designed the project logo.

E. *Edvin Svenske*

Sections written: Introduction, Guidelines, Assumptions and Constraints and Discussion.

Also contributed to the WBS.

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Appendix

Work Breakdown Structure