Skypalace
Mission, logistics and operations

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Space travel for leisure or recreational purposes may develop in the coming decades. New launchers will be ready for use soon and space tourists will be able to fly to regularly to low earth orbit. As a consequence of this, there will be a new demand for tourism infrastructure in Low Earth Orbit. The Red Team worked on this project and developed the Skypalace, a low earth orbit hotel that could be ready for 2022. This report presents the logistic and operations part of this project. The work of the Mission group who studied those aspects was fundamental, as it covers all the aspects from the construction of the Skypalace and its commercial exploitation.

I. Introduction

To develop the Skypalace, the Red Team was divided in several groups. Mission group gathered the information coming from both Vehicle Desing group and Human aspects group. With the boundary conditions set by the design of the Skypalace and human factors the main objective was to plan all the operational aspects.

First, investigations to choose launch site were conducted along with studies to decide on an orbit and altitude of the SkyPalace. The group then reviewed the existing and future launchers and capsules for the travel to the hotel and its construction. It was assumed that Falcon 9 and Falcon Heavy currently under development will be available by 2022. The subject of ground infrastructures and communications with the SkyPalace was also explored.

The main responsabilities of the Mission Group were the mass budget, cost estimations, construction plans, resupply, flight plans and crew rotation schedules.

Finally, to ensure smooth operation in case of an emergency, off-nominal cases have to considered. It has been decided to investigate the problem of our proposed launch site not being in an operational state due to a natural disaster.

II. Launchers and spacecraft

This section will discuss the choice of the rockets used for launching the hotel and also the customers and the crew. Comparison and choice of spacecraft which carries the customers, crew and supplies to the hotel will also be discussed.

A. Discussion about the choice of the launchers

The choice of vehicles was limited due to the boundary conditions that allowed the mission to use vehicles that are currently under construction or already in use. With this information duly noted it was possible to narrow the choices down to a few rockets. Looking at NASA and ESA contracts for commercial flights it was possible to find 3 rockets that suited a mission for a space hotel. The rockets are the american Atlas V from ULA, the european Ariane 5 used in the Ariane programme and the Falcon rockets Heavy and 9 from SpaceX. Some other rockets such as Blue origin and Proton were taken into consideration but due to limited information such as price, payload mass and size these were dismissed.

1. Comparison of rockets

A very important factor when building a hotel is that the price has to be as low as possible to maximise potential profit and attract customers. A high cost would not only increase the payback time for the hotel but would also raise ticket costs, potentially resulting in a loss of customers. With this in mind it was obvious to look at the price tag for these rocket and compare them. What is also important is to look at what the rockets are capable of delivering in terms of payload, mass and size.

Table 1 – Rocket comparison

Rocket	Payload Mass To LEO [kg]	Price [Million $]
Ariane 5	20 000[4]	200[3]
Atlas V	20 520[6]	160[3]
Falcon Heavy	53 000[7]	61[7]
Falcon 9	13 150[7]	90[7]

Table for comparison of rockets price and payload mass

As the Falcon Heavy is capable of carrying a mass up to 53 metric tons to LEO, it was an obvious choice to use to build the hotel, as some of the modules will weigh more than what the other launch vehicles can carry. Choosing the rocket for carrying customers, crew and supplies was only a question of the price, since all of the remaining launch vehicles are able to carry enough mass to the hotel. The choice was therefore Falcon 9. The first stage of the Falcon 9 rocket is reusable as it is able to perform a controlled landing. This is favourable because it will reduce the cost for launching since only refurbishment is needed and not a new rocket.

2. Comparison of spacecrafts

Space crafts compatible with the Falcon 9 rocket that were compared are the Dragon capsule from SpaceX and CST100 capsule from Boeing.

Table 2 – Space craft comparison

Spacecraft	Number of passengers	Payload up mass	Payload down mass	number of reuse	Thrusters?
Dragon	7[9]	3310[8]	2500[8]	10[9]	Yes[9]
CST100	7[10]	2500	2500[12]	10[10]	Yes[7]

Table for comparison of space crafts, Dragon and CST100

As seen in the table above, the space crafts are very similar so the choice lies in the up mass since it is needed for the missions. Assuming the up mass is equal to the down mass for CST100 since no other information was found the Dragon capsule was chosen due to the larger up mass. The reason for looking at if they have thrusters is that they can be used for landing but also for the altitude control of the hotel. The Dragon also have a automated docking system which is beneficial because it can reduce training for pilots or to only use one pilot.

III. Launch site, orbit and altitude

In this section the choice of launch site and orbit will be discussed. The launch site is an important choice both for the orbit and for the customers that need to get there. Several aspects has to be taken into consideration when choosing an orbit, such as altitude and inclination due to medical issues, performance and altitude control of hotel.

A. Orbit and altitude of the hotel

An orbit of 400 km was chosen because the extra amount of fuel needed to go further would be to expensive due to gravitational pull from earth and a lower altitude would increase the drag force from the atmosphere resulting in increasing altitude control of the hotel. Regarding the inclination, what has to be taken into consideration is to avoid the South Atlantic Anomaly to reduce dangerous radiation for customers and crew. With this in mind a inclination of 51° was chosen, this will also give a better view of the Earth for the customers as it will cover more land areas and not just the oceans and also the customers may also be able to see the Aurora Borealis.

B. Discussion about the choice of the launch site

Looking at what SpaceX is currently using to launch their vehicles,[13] it was noted that they use Cape Canaveral, Florida, USA for the majority of their launches. This is a good location both for the orbit and for the customers. Even though Cape Canaveral have missed a lot of their launch dates, this was the obvious choice for launch site because it already has all the infrastructure that is needed and can be easily accessed by the customers.

IV. Ground infrastructure and communications

A. Infrastructure

1. Mission Control Center (MCC)

Now that the launch site and the spacecraft have been determined, discussion about the infrastructures needed will be done. The first facility which seems the most important is the Mission Control Centre (MCC). It enables the management of spaceflights from launching to landing. In our case it would be use continuously to manage the hotel and the smooth running of the tourists stay. Indeed, as SpaceX has been chosen to launch the facilities to the SkyPalace, the MCC do not need to have a launch and spacecraft control service.

2. Training Centre

The second most important facility to think of is the Training Centre need to train the tourist before them leaving for the unique experience of Spaceflight. According to the planning provided by the Medical Aspect Team, the guest would have to discover the different living aspects on the station like the hygiene issues, the use of the kitchen. They would have to follow information about the risks and safety on the hotel. Special training is included for the people who would like to do an EVA, and a parabolic flight is also planned.

To provide these services, Johnson Space Center in Houston has been chosen to get close to the launch site and the control centre.

B. Communication

The SkyPalace would provide the same quality of communication than in the ISS. However, as the TDRS is reserved for US military use and not for commercial use, other means have to be found. One of the solution would be to use the future EDRS (European Data Relay Satellite) which could be operational in 2017. At first, the guest would have the same communication experiences as the current astronaut. They will be able to conduct conferences or recieve/make phone calls from the hotel. The customers may also send emails from the hotel. An important aspect of the SkyPalace is to provide an internet connection to the guests, so they may share their experience in live from space. This could be improved in the future using a private Data Relay Satellite.

V. Mass, size and cost estimation

This section contains a brief discussion of the total mass required to launch for construction and preparation of the SkyPalace.

A. Total Mass and Size Estimates

The total mass of the SkyPalace is determined by the combined masses of the construction modules, control systems, thermal systems, life support systems, equipment and daily supplies. In order to calculate the total mass, we received mass estimates from each of the other groups: Vehicle Design and Human Aspects. Details are shown in figure 3 in the appendix. The breakdown per group is as follows:

Table 3 – Mass per Group

Group	Mass[kg]
Vehicle Design	109730
Human Aspects	5825

The large majority of this mass belongs to the Vehicle Design Group, as they require large modules, docking ports etc. These are the bulkiest of items to be launched to LEO. A smaller percentage of the mass was related to the Human Aspects group. These were essential items to human occupation of the Skypalace.

B. Cost Estimates

The cost of each launch was estimated as per information supplied in the project description. These costs are an optimistic estimation of what a launch would cost in 2022. For one launch of a Falcon 9, the price was taken to be 5m USD and a launch of a Falcon Heavy was taken to be 12m USD. Current costs of these rockets is much greater than the estimates used in our planning. With increased recycling and refurbishment of launchers, the prices used are roughly equal to the total price of purchasing each rocket and reusing it ten times, which was believed to be very reasonable.

VI. Planning flights, crew rotation

A. Assemblage of Skypalace

Since the Skypalace in total is too big to be launched in one part, it is made out of several modules which will be launched separately. Every launch costs money which is the reason why less launches are desirable. As mentioned in subsection 1 on page 2, for the launch of the modules the rocket Falcon Heavy is used. It has the best cost per mass ratio and is able to carry payloads which are bigger than the maximum mass of the particular modules. Because the Falcon Heavy has a payload of about 53 tons it is possible to stow more than one module in the fairing. Furthermore the packing of the modules is volume- and not mass-limited. For that reason it was decided to modify the standard fairing of SpaceX by enlarging it. In this way the number of launches could be reduced to four. Figure 1 shows the schedule and order in which the different modules will be brought into LEO. All the interior systems, for example the life support system and the training equipment (see figure 3), are already installed inside of the different modules on ground and are brought up together with them. The first launch includes the guest module and the robotic arm attached to it. Using the robotic arm in the next steps the additional modules can be docked and assembled easier. Since the robotic arm is remote controlled by the ground, no astronauts have to be in space to perform EVAs to build up the station. This procedure saves money and decreases the risk to humans. The launches of the modules take place in the right order of assemblage which means the modules will be in their final order from the beginning. Until the main solar panels are launched with the third flight the station will be provided with power by smaller side solar arrays mounted at the guest module (see report of vehicle design group). These smaller solar arrays make the station self-sufficient during construction, since several power-consuming systems, e.g. the life support system, are switched off. A Falcon Heavy launches every 4 weeks, thus there is enough time for the modules to rendezvous and assemble. The whole assembly of SkyPalace is complete after about 12-14 weeks.

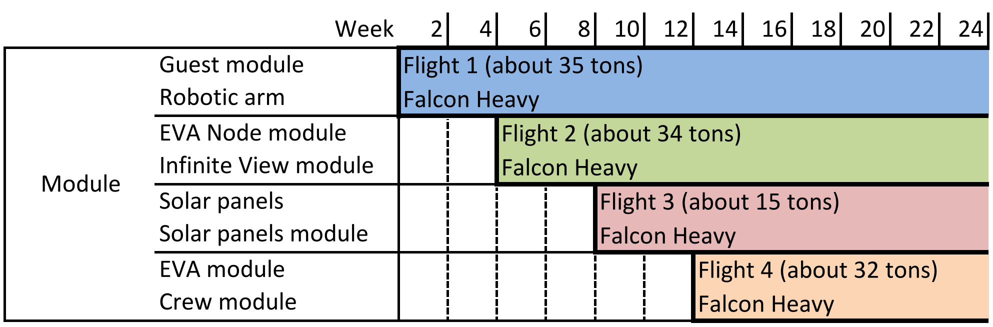

Figure 1 – Schedule of how to build up the Skypalace station

B. Operation of Skypalace

As mentioned before the Dragon Capsule launched with the reusable Falcon 9 is used to bring the clients to the Skypalace. Since it has an external trunk,[14] the extra available payload mass of about 1.2 tons[a] is used to bring food, other regular supplies and spare parts to the station. On the way back to Earth the trunk is used to get rid of the waste of the station by jettisoning it short before re-entry. Out of the seven maximum

[a] 1.2 tons ≈ [(3310-2500)+1/7*2500] kg

feasible seats of the capsule one is utilized to bring mass up to Skypalace but especially down to Earth. This leads to a maximum of six people which can be aboard the flight to the station at one time. In the first few years there will be a pilot as well as a co-pilot aboard the capsule so as to make the clients feel safer. When the feeling of safety is established, there will only be the need for a pilot on board of the capsule, which will allow to increase the number of customers per flight from four to five. There are two crew members permanently on the station for maintainance and to prepare it for the next batch of clients. The clients stay at Skypalace for ten days. Adding a day between the departure of the old clients and the arrival of the new ones to prepare the station leads to a launch of the Dragon Capsule every eleven days (see figure 4 in the appendix). The permanent crew members perform shifts of six months. After that they return to Earth as the co-pilot or pilot. The pilot or co-pilot who flew the way up to Skypalace then becomes a permanent crew member. This procedure is shown in figure 4. In case of emergency and evacuation there is always a backup Dragon capsule docked to Skypalace. Since the Dragon has a orbit duration of up to two years,[14] the backup capsule has to return to Earth from time to time for maintenance. In that case the clients leave Skypalace with the backup capsule and the Dragon they arrived with becomes the new backup capsule (see figure 4). This leads to a safe stay at any time of the journey.

VII. Off-nominal case: launch site not available

Finally, as the unpredictable has to be planned, the issue of the replacement of the launch site will be discussed in this part. How would the company have to react if Cape Canaveral could not be used? This could happen if the NASA does not allow the launch of the rocket for any number of reason. Also, Cape Canaveral is located in Florida the risk of hurricane remains.

To accommodate this possibility a backup launch site is required.

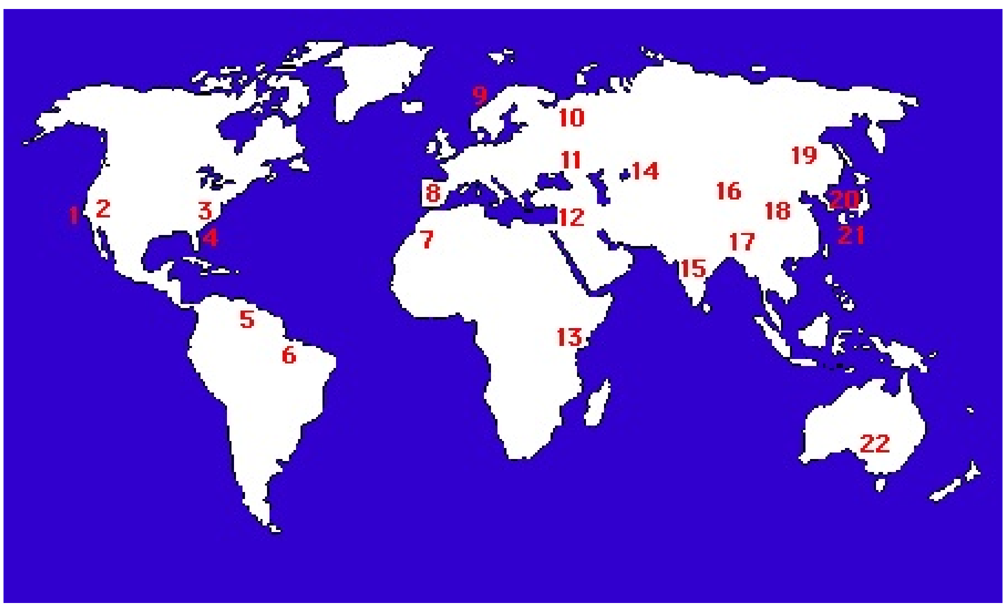

Figure 2 – Launch sites around the world

On figure 2, it can be seen that a lot of launch site exist around the world.[15] In the case of the trip of guest going to the hotel, a launch site with the closest inclination of the Space hotel is recommended: in fact, this is a gain of time and fuel mass. The launch site of Baikonur (n°10), in Russia, is the best located to launch the tourists to the hotel. However, the site is already used for the ISS crews and perhaps it could not afford to launch too many rockets.

Another viable option is the European launch site in Kourou (n°5), French Guyana. As the site is situated near the equator, the velocity of the rocket is closer to the final speed to reach the hotel. However, as it is at a different inclination angle, it will more take time and power to get to the correct position.

Finally, it must be kept in mind that SpaceX is currently building another launch site in Boca Chica Village, Texas.[16] This could be a possible solution for many of the logistic problems.

VIII. Conclusion

All mission, operational aspects and logistics have been studied. The orbit of the station have been chosen so as to offer SkyPalace clients a good view of Earth. Concerning the altitude the problem as maintaining it was also raised and the possibility to use dragon thrusters twice a year was studied. This solution was possible in terms of operational point of view. However the Dragon is supposed to dock perpendicularly to the Skypalace, maybe it could be envisioned to have an another docking port in the direction of the movement so as to make this solution possible. Otherwise the Skypalace will have to have its own thrusters. Following the information given by the vehicle design team, it was made possible to do mass estimations. Then with a previous study of possible launchers capabilities and price, a preliminary cost estimation was also done. A schedule for the assembly of the Skypalace was presented as well as a schedule for operations. As safety is one of the major aspect for such a project, one off-nominal case was studied and solutions like to it were proposed. Other aspects of the project like control and training center but also communication means were treated. So it can be said that all the major operational features for the Skypalace project have been studied. The Skypalace is planned to stay in orbit for twenty years, after that a de-orbit burn is planned such as that conducted with the Mir station in 2001.

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Appendix

A. Mass budget

Flight #	Group	System	Mass (kg)	Volume (m^3)	Height (m)	Width (m)	Length (m)	Diameter (m)
1	Human aspects	Water Recovery System	2000	1,70	2,00	0,50	1,70	
1	Human aspects	Waste management (includes 2 toilet)	2000	1,70	2,00	0,50	1,70	
1	Human aspects	Air Conditioning System (PCA + 6 fans)	50	0,04	0.2	0.3	0.6	
1	Human aspects	Temperature Control System						
1	Vehicle	Guest Module	25000	191,00	12,00		12,00	4,50
1	Vehicle	Robotic arm	300	0,64			9,00	0,30
1	Vehicle	Fuel for construction maneuvering	5000					
1	Vehicle	Batteries	230					
	Sum		34580					
2	Human aspects	Oxygen Generator System + C02 removal	1000	0,85	2,00	0,50	0,85	
2	Vehicle	EVA Node Module	12000	63,00			5,00	4,00
2	Vehicle	Fake EVA Module	20000	96,00	6,00		6,00	4,50
2	Vehicle	CMG wheels (2+2 spares)	1100					
	Sum		34100					
3	Vehicle	Solar panels	1100		0,51	4,60	0,51	
3	Vehicle	Solar panels module	14000	77,00			8,00	3,50
	Sum		15100					
4	Vehicle	Bigelow B330 Module	20000	74,32			4,18	4,76
4	Vehicle	EVA Module	11000	34,00			5,50	4,00
4	Human aspects	Cycle Ergometer CELVIS	60	0,00	0,11	0,06	0,13	
4	Human aspects	Exercise Computer	10	0,00	0,04	0,04	0,02	
4	Human aspects	Treadmill COLBERT	100	0,00	0,06	0,10	0,23	
4	Human aspects	ARED (Weight training)	150	0,00	0,10	0,10	0,20	
4	Human aspects	Hard-Shell Space Suit x 3	75	0,00	0,19	0,10	0,05	
4	Human aspects	Extra-Mobility Unit x 3	130	0,00	0,19	0,10	0,05	
4	Human aspects	Medical equipment	250					
	Sum		31775					

Figure 3 – Assignment and budget of masses and volumes for the construction flights

B. Schedule of operation

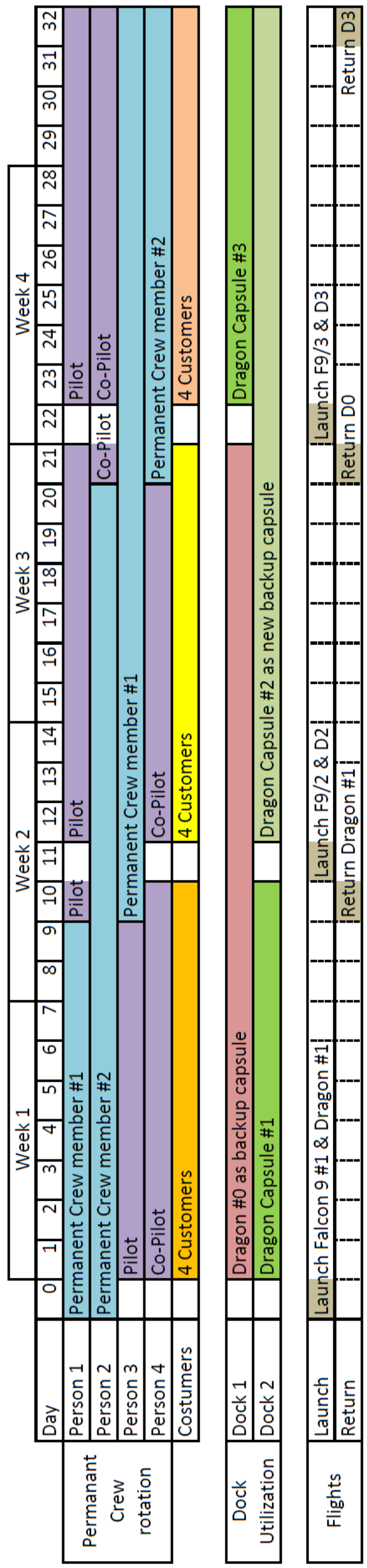

Figure 4 – Schedule of how to operate the Skypalace station