Design of Sky Palace
A Space Hotel in Low Earth Orbit

Overall Coordination
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***Abstract*—Space tourism will be a reality in the near future and the construction of a Low Earth Orbit space hotel is to be a viable solution to make profit. A team composed of 18 KTH students, the *Red Team*, has elaborated during three weeks a first sketch of what it could look like. This report will focus on the work done by a subsection of the Red Team, the *Overall Coordination* group.**

I. Introduction

The work of the Overall Coordination (OC) team includes a management dimension, one of the tasks as a coordination team is to suggest a path to all subteams and to handle communication within the team and project. The Red Team consist of 4 subteams, apart from OC there is the Human Aspects Team (HA), the Vehicle Design Team (VD) and the Mission Analysis Team (MA).

This report includes an introduction to the project management structure and the mass and power budgets followed by a detailed cost analysis. A market forecast and profit analysis is then described. Further details about the Sky Palace can be found in the reports written by the other subteams.

II. Project Management

This section describes the organizational structure of the project. It provides an overview of the division of tasks as well as the project's work methodology and schedule.

The issues covered at this level of the design and how they are distributed over the 4 subteams is presented in Table I.

In regard to the work methodology the following decisions where made:

- Team communication. A Facebook group is used to keep in contact with the team members. In addition a file with the telephone numbers and email addresses of everyone is accessible.
- Document management. There are folders for notes from meetings, reports and presentations sorted by subteam in Dropbox. Google Docs is used during team meetings for preparing files that require the participation of several people. All the files are named following a specified criteria so that it is clear which subteam they belong to, their contents and the date when they were written.
- Team meetings agenda. It is prepared by OC team days before based on the project schedule and its progress.
- Team meetings structure. At the beginning of every meeting there is an introduction of around 10 minutes for updates and tasks to be done that day. At the end all groups round up for more or less 30 minutes to check the progress, discuss about the results obtained and decide the next step. During the meeting three members from OC work with other subteams to be up-to-date on their tasks, one member for each of them. The remaining member of OC is around in charge of the communication between the groups.

The schedule for the conceptual design work is summarized in Table II. A first design including estimations for costs, mass, power and propellant is completed before 24-2-2016. Then there is one week's time before the critical design review to add more details as well as refining or changing some other aspects.

III. Overview

A. Perspectives

The main guidelines of the hotel must be defined first. In order to attract clients, a few keywords have been defined: the experience in the Sky Palace Hotel should be unique, unforgettable, prestigious and safe. The hotel described in this report will fulfill these requirements. In fact, clients will be able to experience the training of real astronauts at the beginning. When ready, they will have the feeling of leaving Earth in one of the fastest vehicles that ever has been built. Once in the hotel, they will experience weightlessness, have a wonderful view on Earth an live in a comfortable and safe way in the most uncomfortable and dangerous environment. They will also be able to perform an Extra Vehicular Activity (EVA) for an additional fee.

The main publicity factor that will be used is that Sky Palace's customers will do something that the generation before them could never imagine. Since then, technology have turned many impossible things into possible ones. The goal of Sky Palace is to take vacations one step further away into what recently was impossible, one step further away from Earth and into space.

TABLE I
WORK BREAKDOWN STRUCTURE

Overall Coordination	Human Aspects	Vehicle Design	Mission Analysis
Scheduling of the project	Radiation effects assessment	Hotel layout	Orbit and launch site
Agenda for team meetings	Water management system design	Structure concept	Communication concept
Intermediary between other groups	Thermal control system design	AOCS concept	Launcher
Tracking of the entire project	Purveyance requirements	Power system sizing	Ground facilities for mission control
Mass and power budgets	Air revitalization system design	Docking concept	Ground facilities for training
Cost analysis	EVA suits	Concept for hotel expansion	Schedule for building the hotel
Market forecast	Planning for guest training	Attitude propellant budget	Flight planning for sending customers
Profit evaluation	On-board leisure issues		Recycling concept
	Physical and psychological issues		Orbit propellant budget

TABLE II
PROJECT SCHEDULE

Event	Date
Kickoff	9-2-2016
Preliminary design review	16-2-2016
Deadline for cost estimates	19-2-2016
Deadline for design budgets	23-2-2016
Critical design review	1-3-2016
Presentation of the design	4-3-2016
Deadline for reports	18-3-2016

B. General Parameters

The first parameter to be decided was the number of customers per trip. The current manned spacecrafts being investigated, the upper limit in a near future will be seven people at a time (using SpaceX Crew Dragon or Boeing's CST-100 Starliner). Willing to have a reasonable payload and two pilots with the clients, we limited the clients to **4 people**.

The second parameter to be decided was the duration of stay of the clients. We chose a trip of **10 days**. This is the optimal duration as it is long enough to have a good experience of weightlessness, and to be able to provide an EVA to all the 4 clients. As well, it is short enough to avoid any boredom of the customers. If the trip would have been longer it cannot be considered a trip that you can fit during a vacation since you also have to consider time for training and recovery, thus limiting the number of available customers.

The last important parameter was the price of the ticket, essential to the profit estimation. The seven existing space tourists paid between 20 and 35 million dollars to go to ISS. The chosen price is **10 million dollars**. The price can be adjusted downward in the future, but it seems a good starting point. After the first operating years, acting as a proof of concept, the interest in the hotel is expected to grow and the needed cost margins for uncertainties will be reduced as the project gains experience.

As the hotel is supposed to be launched in 2022, the development and launch time is fixed to be **6 years**.

IV. DESIGN BUDGETS

Most of the numbers in the mass and power budgets were estimated by the Vehicle Design (VD) team and the Human Aspects (HA) team. Overall Coordination (OC) was responsible for gathering and completing the estimations from these groups.

Only those calculations made by OC will be explained in depth. The details about the rest can be found in the reports of VD and HA.

A. Mass

The mass budget sorted by subsystems is presented in Table III. All numbers are obtained mainly by comparing with existing technology. Datasheets and rules of thumb were also used in some cases.

Communication system and on board computer are not taken into account given that their contributions are usually negligible [2]. Besides, there are no quick procedures for reckoning their masses.

For the mass of thermal control system and wiring they are typically 5% and 4% of the dry mass respectively [2]. Since the main contribution it is the structure it was assumed as the dry mass when estimating for these two items.

A margin from 5% to 25% is considered based on the design maturity [2]. Hence 25% was selected due to the current level of uncertainty in the design.

The dry mass (including margin) of Sky Palace is around 40% of ISS while the size is around 50% [4]. The lower mass is due to the fact that the Bigelow module is inflatable and much lighter than a non-inflatable structure. In addition the inside of the hotel is on average more spacious than ISS in order to provide a higher comfort to the customers.

B. Power

The Table IV summarizes the power required by the different elements. As to the methods considered for the estimations the same can be said as in the case of mass budget.

For AOCS, communications and OBC typical percentages of 15%, 10% and 10% were used respectively [2]. To simplify the calculations for these subsystems the total operating power is obtaining by comparison with ISS and scaling with the size of Sky Palace. Therefore it results in 50% of ISS, i.e., 40kW [4].

The power dissipation for the wiring is estimated taking into account that it is usually 5% of the required power [2].

The power needed for the batteries is computed as:

$$P_{Bat} = \frac{P_{Ecl} T_{Ecl}}{T - T_{Ecl}}. \tag{1}$$

Where P_{Ecl} is the consumption during eclipse, T_{Ecl} the eclipse time (around 36 minutes) and T the orbit period (approx. 93 minutes).

Similar to the case of mass a margin from 5% to 25% is applied depending on the design maturity [2]. However the

TABLE III
MASS BUDGET

Subsystem	Element	Mass (kg)
Life support	O_2 generator	500
	CO_2 removal system	500
	Water recovery system	2000
	Waste management system	2000
	Air conditioning system	50
	Cycle ergometer CEVIS	60
	Exercise computer	10
	Treadmill COLBERT	100
	Weight training system ARED	150
	3 hard-shell space suits	75
	3 extra-mobility units	130
	Medical equipment	250
Total		**5825**
Structure and mechanics	Bigelow B330 module	20000
	Guest module	25000
	EVA node module	25000
	EVA module	11000
	Fake EVA module	20000
	Solar panels module	14000
	Robotic arm	300
Total		**115300**
Power	Solar panels	1100
	Batteries	800
	Wiring	4600
Total		**6500**
Thermal		
Total		**5800**
AOCS	4 CMG wheels	1100
	4 thrusters	600
Total		**1700**
Total dry mass		**135125**
(+25% margin)		**168910**

budget is already oversized since it is around 65% of ISS while the size is half [4]. The reason for this is that the devices are not full operating at the same time. Thus no additional margin will be considered here.

TABLE IV
POWER CONSUMPTION BUDGET

Subsystem	Element	Power (W)
Life support	O_2 generator	1500
	CO_2 removal system	1500
	Water recovery system	3000
	Waste management system	1000
	Air conditioning system	3000
	Exercise computer	250
	Treadmill COLBERT	2400
	3 hard-shell space suits	75
	3 extra-mobility units	75
Total		**12800**
Mechanisms	Robotic arm	120
	Fake EVA shells	30
Total		**150**
AOCS		
Total		**6000**
Communications		
Total		**4000**
OBC		
Total		**4000**
Thermal	Heaters	5400
Total		**5400**
Power	Batteries	21500
	Wiring	1600
Total		**23100**
Total operating power		**55450**

V. COST ANALYSIS

The cost estimate of Sky Palace has been done using two separate methods in order to make the estimate as accurate as possible. Using two models with different points of view can indicate a plausible deviation in the cost estimate due to chosen model, it was therefore decided to do one estimate from the top down and another estimate from the bottom up. The top-down estimate was done using the Advanced Mission Cost Model (AMCM) and the bottom-up estimate was done using mainly the analogy method.

Apart from the cost estimate the extra fee for EVAs is determined, the reserve factor is investigated using NASA's headquarters reserve model and the cost-schedule relationship is modeled using a beta curve.

A. Advanced Mission Cost Model

The Advanced Mission Cost Model (AMCM) was developed at NASA Johnson Space Center by the Exploration Programs Office using regression analysis and a database of more than 260 different flown space programs. The model was developed to enable efficient forecasts of cost for larger missions far in the future using few parameters and thus being useful during conceptual studies when not much details is known about the mission [6], [1].

The cost estimate is given by the following formula:

$$Cost = \alpha Q^{\beta} M^{\Xi} \delta^{S} \epsilon^{(1/(IOC-1900))} B^{\phi} \gamma^{D}. \tag{2}$$

The statistically defined constants and user defined parameters can be found in Table V and Table VI [1].

TABLE V
STATISTICALLY DEFINED CONSTANTS

Constant	Value
α	5.56 x 10^{-4}
β	0.5941
Ξ	0.6604
δ	80.599
ϵ	3.8085 x 10^{-55}
ϕ	-0.3553
γ	1.5691

TABLE VI
USER DEFINED PARAMETERS

Parameter	Description	Value for Sky Palace
Q	Quantity	1
M	Dry Mass (lbs)	297900
S	Specification value	2.13 (Human Habitat)
IOC	Initial Operating Capability	2022
B	Block Number	1
D	Difficulty	-1

The specification value is chosen from a table with statistically defined values depending on type of mission, for Sky Palace the value for human habitats is used.

The Initial Operating Capability is defined as the first year of operations and the Block Number describes the level of design inheritance. For example a Block Number of 1 equals a new design while a Block Number of 5 equals the fifth major change to an already existing system. For Sky Palace the Block number is assumed to be 1, corresponding to the worst case with no design inheritance although some parts can be considered as modifications of ISS.

Difficulty is defined on a range from -2.5 to +2.5 where 0 equals average difficulty. Since Sky Palace is mainly built with already flown technology the difficulty can be considered quite low with a few exceptions as for the Fake EVA Room (described further by the Vehicle Design Report). The difficulty was therefor set to the value -1.

The output of the AMCM formula equals the total development cost and production cost in millions of US dollars using 1999's currency. In order to know the price in todays currency the result have to be scaled with an inflation factor. NASA's New Start Inflation Index is used for the cost estimate of Sky Palace. This index takes into account the price development for labor rates and materials often used when building spacecraft [1].

Financial Year 1999 to Financial Year 2016 = 1.613 [7]

Different cost adjustment factors can be applied to the result from a parametric cost model in order to adapt to the unique features of the program that is being investigated. One of the most common ones is a complexity factor, usually chosen on a scale between 0 and 2, depending on the systems degree of design inheritance. In this case no complexity factor is used since a corresponding parameter, the difficulty parameter, is already included in the Advanced Mission Cost Model.

Since the AMCM only estimates the development and production cost of the project, additional costs for preliminary studies, planning of the project, operations and maintenance have to be taken into account in order to find the total life cycle cost. This can be done using wrap factors, statistically defined parameters stating a percentage of a certain cost, usually the development and production cost, that would equal the cost related to that specific wrap factor.[1]

The wrap factors used in the cost estimate for Sky Palace using AMCM can be found in Table VII. All wrap factors applies to the development and production cost except for *Program management* which applies to the total cost.

TABLE VII
APPLIED WRAP FACTORS - AMCM

Wrap factor for	Generic value for human missions
Conceptual studies	0.3%
Definition studies	3.5%
Operations capability development	15.0%
Launch and landing capability	8.0%
Program management	10.0%

The wrap factor *Operations capability development* includes operations analysis, mission planning, development of flight procedures and also preparation of astronaut training facilities and mission control center. Ground support equipment and preparations of launch facilities are included in the wrap factor *Launch and landing capability* assuming that the mission can use existing launch infrastructure with some modifications.

Although the wrap factors consider many additional expenses the major cost, the operational cost, is still not included. This cost is estimated by a comparison to the operational cost for ISS which, when including the first 10 years of operations, constitutes 51% of the total cost for the station [1]. Considering that Sky Palace will require up to 30 launches per year, approximately 5 times as many as for the ISS, this value should be increased significantly. On the other hand, considering that the cost to launch a space shuttle was on average 450 million US dollars [8] and that the Mission Analysis Team for Sky Palace estimated the cost to launch a Dragon capsule as low as 10 million US dollars, this number should be possible to reduce.

Since the value of 10 million US dollars per launch of the Dragon capsule relies on the reusability of the Falcon-9 rocket, which is not yet proved to be working, the estimated price per launched is doubled as a safety measure. This means that we assumes the price per launch to be approximately 20 million US dollars. Also, since the details of what is included in the price for launching the Space shuttle is unknown, this number should be assumed to include mission specific cost and thus be significantly higher than the cost for launch. We estimate the minimum cost for launching the space shuttle to be 100 million US dollars, not including development or mission specific costs. Thus the total cost reduction is estimated to be 20% when using the Crew Dragon instead of launching using the space shuttle.

The reason for comparing with the space shuttle and not Soyuz is that the number 51% for ISS includes the 10 first years of operations when the shuttle was used to a large extent.

With given assumptions the operational cost over 20 years is estimated to be 102% of the development and production cost for Sky Palace.

Using AMCM with parameters described in Table VI and an inflation factor of 1.613 yields the following result:

Development and production cost
(Financial Year 2016)
= 9 700 million US dollars

Using wrap factors described in Table VII and an operational cost equivalent to a wrap factor of 102% yields the following result:

Total cost including lifetime of 20 years
(Financial Year 2016)
= 24 400 million US dollars

B. Estimate by Analogy

The second method used for estimating the cost of Sky Palace is based on the work breakdown structure, summarizing all cost from the subsystems up to the top level. The cost estimates for every individual subsystem, shown i Table VIII, was done separately by the different subteams in the Red team and summarized by the Overall Coordination team. The method used to derive the cost estimates for development and productions cost was the analogy method, i.e. the estimates are based on similar projects that has already been developed.

The technology used as reference for the development and production cost estimates in Table VIII is to a very large extent

TABLE VIII
COST ESTIMATES

Element	Development cost ($)	Cost/launch ($)
Human Aspects		
O_2 generator	10 000 000	
CO_2 removal system	10 000 000	100 000
Water recovery system	50 000 000	250 000
Waste management system	20 000 000	100 000
Air conditioning system	5 000 000	25 000
Temperature control system	709 000	
Cycle ergometer CEVIS	80 000	
Exercise computer	2 000	
Treadmill COLBERT	100 000	
Weight training system ARED	150 000	
3 hard-shell space suits	45 000 000	
3 extra-mobility units	36 000 000	
Medical equipment	10 000	50
Total	**177 051 000**	**475 050**
Vehicle Design		
Bigelow B330 module	125 000 000	
Guest module	240 000 000	
EVA node module	110 000 000	
EVA module	164 000 000	
Fake EVA module	340 000 000	
Solar panels module	110 000 000	
Solar panels	75 000 000	
Robotic arm	70 000 000	
Total	**1 234 000 000**	**0**
Mission logistics		
Launch of the station	45000000	
One launch of clients		10000000
Infrastructure		967000
Insurance and Training		350000
Total	**45 000 000**	**11 317 000**
Total cost	**1 456 051 000**	**11 792 050**

technology developed for the ISS. Most of this technology, with a few exceptions, was thus developed before the year 2000 when the first resident crew entered the station. An inflation factor from NASA's New Start Inflation Index is therefor used to transfer the cost estimates to today's currency. Some of the estimations will be based on newer technology, this is considered to be compensated by the fact that some of the reference technology is much older than from the year 2000.

The inflation factor is not applied to the operational cost since those estimates are based on studies of the available market rather than analogy with ISS technology.

Financial Year 2000 to Financial Year 2016 = 1.551 [7]

The cost for preliminary studies as well as cost for facilities and management is not included in Table VIII, these costs are added using wrap factors similar as for the AMCM cost estimate. The wrap factors applied to the analogy model can be found in Table IX. The wrap factors are the same as for the AMCM estimate with one exception, here a wrap factor for *System level development* is added. This additional wrap factor is used to consider the fact that the expenses during testing of the complete system will add to the estimates done for every subsystem separately.

When estimating the operational cost, due to the ambitious plan to have 30 launches per year and the fact the the reusability of Falcon-9 and Crew Dragon is not proven yet, the price per launch is doubled as a safety measure. The

TABLE IX
APPLIED WRAP FACTORS - ANALOGY MODEL

Wrap factor for	Generic value
Conceptual studies	0.3%
Definition studies	3.5%
Operations capability development	15.0%
Launch and landing capability	8.0%
Program management	10.0%
System level development	20.0%

philosophy *Rather Safe Than Sorry* is important on all levels in the Sky Palace project and should be implemented also in the cost estimate. Since Sky Palace should be launched in 2022 the project has a quite tight time schedule and to add additional pressure with a tight budget would increase the risk of mistakes during the development.

In Table VIII the price per launch is about 11.8 million US dollars, this assumes that SpaceX achieves the level of reusability of both Falcon-9 and Crew Dragon as the company has set as a goal. As recently mentioned, in the total cost estimate this price is assumed to be the double, ending up to 23,6 million US dollars per launch.

Assuming the numbers from Table VIII, increased launch cost, an inflation factor of 1.551 for the development cost and wrap factors from Table IX yields the following results:

Development and production cost
(Financial Year 2016)
= 3 600 million US dollars

Total cost including lifetime of 20 years
(Financial Year 2016)
= 19 200 million US dollars

C. Extra Fee for EVA

The additional fee for EVA is established so that it covers the cost and gives a margin of profit.

The cost for EVAs is computed considering the elements; EVA module, EVA node module, hard-shell suits and the 25% of cost for the construction of the hotel (Table VIII). Applying the wrap factors from Table IX and the inflation of 1.551 the cost for EVAs is then:

EVAs cost (Financial Year 2016)
= 800 million US dollars

Assumed that half of the customers want EVA the cost distributed over them is:

EVAs cost per potential customer (Financial Year 2016)
= 0.7 million US dollars

Finally, considering that the EVA should increase the profit of the hotel, the extra fee for customers who want EVA is set to 2 million US dollars per person.

D. Reserve Factor

Here a reserve factor is assigned to the program. This is the amount of resources added to those corresponding to the total cost for unplanned events. It depends on the level of risk, i.e., more the uncertainties the larger this factor is.

NASA's headquarters reserve model is used [1]. In this model first the risk level is assessed considering the following items:

1) Investment in planning definition.
2) Uniqueness of design.
3) Complexity of hardware and software.
4) Difficulties in systems engineering.
5) Complications in structural organization.
6) Requirements for concurrent development.
7) Experience base.

For each of the items a risk factor is allocated using the Table X[1].

TABLE X
RISK FACTORS GUIDE

Item	High	Moderate	Low
1	20 for 2%	8 for 7%	3 for 10%
2	15	5	3
3	15	5	3
4	15	5	3
5	10	5	3
6	10	5	3
7	10	5	3

The risk factors were assigned taking values from the ISS and presented in Table XI. Some of them were readjusted according to the conditions of Sky Palace:

- The investment in planning definition is around 7% indeed and that is why its risk factor is 8.
- For uniqueness of design Sky Palace is nearly a replica of ISS in terms of technology. Thus a lower value was selected.
- As to the experience base a higher risk is considered. This is because up to now no mission has been designed specifically for space tourism.

The risk factor of each item is multiplied by a weight factor given by the model. Then these products are summed to get a risk score. This process for Sky Palace is illustrated in the Table XI.

TABLE XI
RISK SCORE

Risk Item	Risk Factor	Weight	Product
1. Investment in planning definition	8	0.3	2.4
2. Uniqueness of design	3	0.2	0.6
3. Complexity of hardware and software	15	0.1	1.5
4. Difficulties in systems engineering	5	0.2	1.0
5. Complications in structural organization	5	0.1	0.5
6. Requirements for concurrent development	10	0.05	0.5
7. Experience base	10	0.05	0.5
Risk score			**7.00**

Based on the risk score obtained finally the reserve factor is provided by Table XII. It is from 30 to 40% then and this value is typical for manned missions.

[1]In this table the percentages in the first row represent the investment in planning definition over the total cost.

TABLE XII
RESERVE FACTORS GUIDE

Risk Score	Reserve Factor
0 to 5	20 to 25%
5 to 6	25 to 30%
6 to 8	30 to 40%
8 to 10	40 to 50%
10 to 13	50 to 60%
13 to 16	60 to 70%

E. Cost-Schedule Relationship

From a financial point of view, the knowledge about how the total cost is distributed over the program is always vital.

The beta curve is used to determine the cost-schedule relationship [1]. This curve gives the cost spent at a certain moment of the program. It is a fifth-order polynomial in the time fraction F:

$$\begin{aligned}\text{Cumulative Cost Fraction} = A(10F^2 - 20F^3 + 10F^4) \\ +B(10F^3 - 20F^4 + 10F^5) + 5F^4 - 4F^5.\end{aligned} \tag{3}$$

Average values corresponding to crewed missions of 0.16 and 0.84 were considered for A and B, respectively.

Fig. 1. shows the curve obtained with those coefficients. The following aspects about this figure should be mentioned:

- The cost rate increases until reaching a constant from $F = 0$ to $F = 0.2$. This corresponds to the development and production phase.
- The cost rate is nearly constant from $F = 0.2$ to $F = 0.9$. This corresponds to the operational period of the hotel. The main cost in this stage is due to the launches and if its frequency is regular the cost rate is more or less constant indeed.
- Finally from $F = 0.9$ to $F = 1$ it is the disposal stage. The cost rate drops here. This decrease makes sense since it has stopped sending customers and the expenditures are only for recycling.

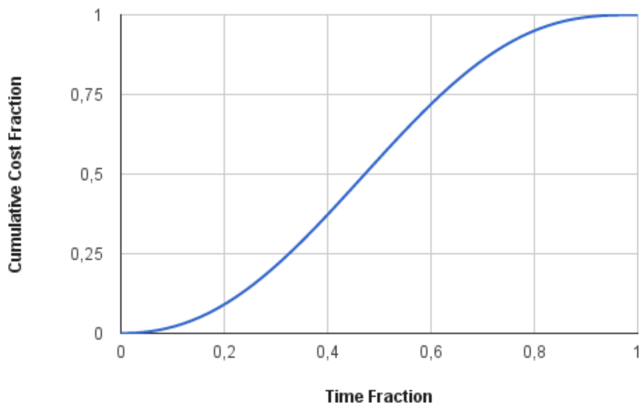

Fig. 1. Cost-schedule relationship

VI. MARKET FORECAST

For the establishment of an enterprise of such huge proportions a meticulous analysis of the availability of customers is required. With this results it is then possible to verify the feasibility of the Sky Palace operation as well as its expected incomes.

The customer availability study considered for this project is based on the Space Tourism Market Study report, by Futron Corporation [9]. This study consisted firstly in a series of surveys directed at a target group of wealthy people. The questions were mainly associated with interest on participating in a space tourism activity, willingness to pay for the expensive tickets (ranged from 1 million to 25 million dollars) and perception of risk.

The survey results coupled with additional data and analysis done by Futron were then used to refine the expected number of possible customers, proceeding with those following steps:

- Apply percentage of target group with sufficient net worth to afford ticket prices.
- Apply percentage of target group interested in space travel.
- Remove customers likely to lose interest in space flight due to the desire to be a pioneer.
- Apply percentage of target group likely to be physically fit enough to withstand training and space travel.

Finally the passenger availability forecast was modeled using an S-curve model for market adoption. However the time frame implemented on the Space Tourism Market Study (2002-2021) differs from Sky Palace one (2022-2042) and consequently the market model needed adjustments. Therefore the S-curve was expanded following the specific exponential fit that describes this market model [10]. The new curve not only suits the base data from Futron but also agrees with their market maturity prediction of 40 years.

On Fig. 2. the available number of customers each year is expressed through the S-curve model.

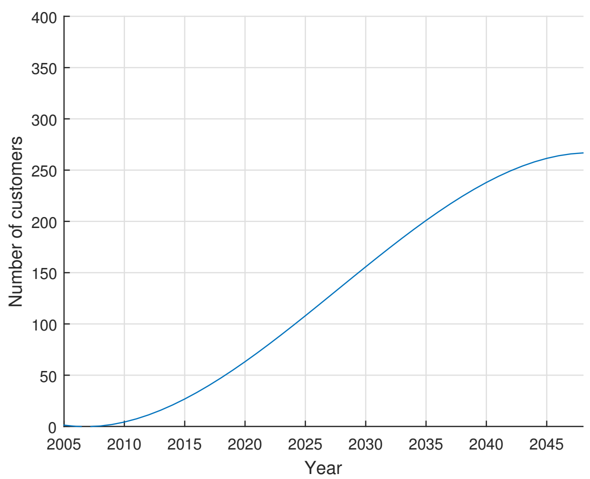

Fig. 2. Expected number of available customers per year

VII. Profit Evaluation

After gathering all data concerning customer availability, ticket prices, operational capacity and cost estimations the profit obtained over the years was obtained from the Sky Palace project.

A. Basic Profit

Firstly, the profit analysis was done for the basic space hotel configuration and assumptions discussed at the previous sections of this paper. Both cost estimations were considered: the Advanced Mission Cost Model and the Analogy Method.

Fig. 3. shows the expected profit evolution through the operation years of the Space Hotel. On this graph, the initial deficits stands for the development and production costs while the operational costs are distributed over the years of activity.

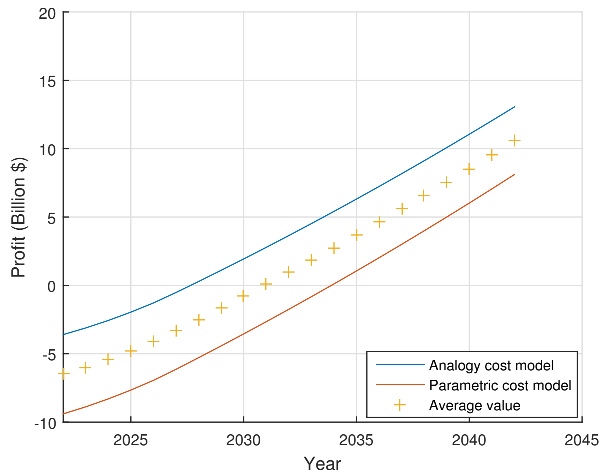

Fig. 3. Profit evolution over the operational years

Fundamental points observed on the curves in Fig. 3 are the break-even point, when the initial investment is recovered, and the profit at end of operations of Sky Palace. The first one occurs after 9 years of operations while the later one reaches around 10.6 billion dollars, both values taken as averages between the different cost estimation curves (AMCM and Analogy method).

Another aspect of the profit evolution curves to be highlighted is its linear behavior after a few years of operation. This feature is explained by the limited operative capacity of the Space Hotel, although the number of customers available is increasing each year the maximum capacity of the station remains fixed (4 customers at a time). Therefore, after a few years the market demand surpasses the Sky Palace capacity resulting in a constant yearly earning. In another words, there is an excess of customers available.

B. Profit for an Expanded Space Hotel

The finding of an excess of customers motivated a possible expansion of Sky Palace after a few years of operation. Therefore a new profit evaluation was done considering that the hotel would offer double of its capacity in nine years. This increase on the operative capacity would require an estimated value of 50 % of the initial investment as the development cost is hugely decreased.

Fig. 4. shows the expected profit evolution through the operation years of the space hotel considering the above-mentioned expansion after 9 years of operation.

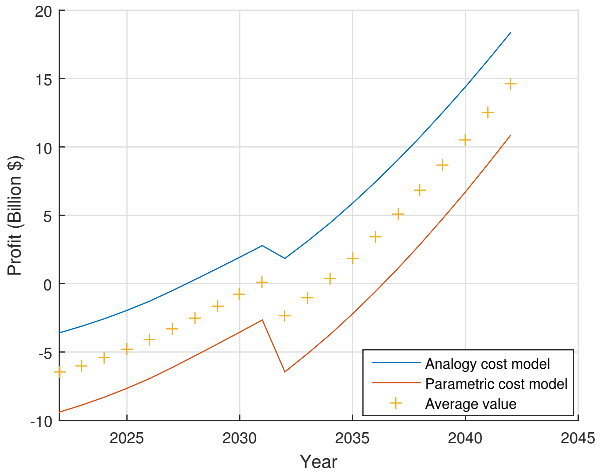

Fig. 4. Profit for an expanded hotel

Although the new investment required resulted in a three years delay of the definitive break-even point, the expansion enabled an increase of almost 38% in the maximum profit (around 4 billion dollars).

C. Off-Nominal Case: Competition for Customers

In spite of starting the Sky Palace operations in such a short time, aiming to become a pioneer of its kind, preparation on how to deal with competition for customers with another space hotel is necessary. Firstly some strategies were employed in order to turn the hotel more attractive for customers. Such as keeping the price as low as possible (around 10 million dollars) and offering a flexible schedule.

A second type of strategy that could be used while facing shortage of clients would be to sell the spare rooms to non-touristic activities. Although the target market of the space hotel are space tourists, tickets could also be sold to companies, institutes or even countries offering them the possibility to maintain a laboratory in the station for a period of time. As the International Space Station, designed for a similar purpose is going to end its operations few years after the start of Sky Palace, the hotel could supply the demand left by the ISS.

Finally regarding the availability of customers, it is shown at the market forecast (Fig. 2.) that, in only six years, there are enough customers to run two space hotels at the full capacity. This excess of customers combined with the strategies proposed before indicate that, even while competing with another space tourism provider, Sky Palace can maintain its operations with a profitability that is not significantly affected.

VIII. Conclusion

This preliminary study has come to the conclusion that it would be possible to construct a profitable space hotel in low Earth orbit. Neither the technology needed to build the hotel nor the interest among possible customers is lacking. Although, it has to be considered that the initial investment needed for the start-up of this project is rather big and the rate of return is rather slow. Even if it is possible to gain a lot of money from the hotel in the long run there will be little or no return during the first 10 years. One of the biggest foreseen challenges before Sky Palace can be realized is therefore to gain funding.

Since the Sky Palace project does not focus on scientific or technical development it is predicted to be difficult to get any major governmental support. One turnout may be to focus on selling the project to large companies which may invest in Sky Palace as a publicity factor to make their brand more competitive. Considering the difficulty and level of innovation that people usually associate with spaceflight, the fact that a company could claim to own a space hotel would likely have a big impact on their reputation.

Sky Palace is indeed an ambitious spacecraft that would break new ground for the space industry. Although a project on this scale will always meet some difficulties and challenges, the feasibility study shows that these obstacles should be possible to overcome. To go on a vacation in space may sound like a science fiction movie but the conclusion of this report is that the scenario is not as far in the future as it first may seem.

References

[1] Wiley J. Larson and Linda K. Pranke. Human Spaceflight: Mission Analysis and Design. McGraw-Hill, 1st Edition, 1999.
[2] Wiley J. Larson and James R. Wertz. Space Mission Analysis and Design. Microcosm Press, 3rd Edition, 1999.
[3] P. Collins. Space Hotels, Civil Engineering's New Frontier. http://www.spacefuture.com/archive/space_hotels_civil_engineerings_new_frontier.shtml, 2002.
[4] NASA. International Space Station. http://www.nasa.gov/mission_page/station/main/index.html.
[5] Bigelow Aerospace. B330 Module. http://bigelowaerospace.com/b330/.
[6] Harry W. Jones. Estimating the Life Cycle Cost of Space Systems. 2015 http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20160001190.pdf.
[7] NASA. FY14 New Start Inflation Indices. http://www.nasa.gov/offices/ooe/cad/publications/.
[8] NASA. Space Shuttle and International Space Station http://www.nasa.gov/centers/kennedy/about/information/shuttle_faq.html.
[9] Futron Corporation. Space Tourism Market Study: Orbital Space Travel and Destinations with Suborbital Space Travel. 2002.
[10] Clear Lines Consulting. S-shaped Market Adoption Curve. 2008 http://www.clear-lines.com/blog/post/S-shaped-market-adoption-curve.aspx.