ZIOLKOWSKI–MODULE: A Tourist Module on the ISS as a Key for a Low-cost Return to the Moon

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Abstract

Building a separate space hotel at this time seems cost prohibitive. However, several large hotel chains might be willing to invest in a special module on the existing International Space Station (ISS). They could use this module as a learning lab for space tourism and eventually create separate hotels as follow-on projects on Moon. Primary task is to design a low-cost module by using cost engineering techniques, which fulfills passenger needs in terms of contentment, safety and positive experience.

The structure of the module, called Ziolkowsky Module, is, in principle, sub-divided into three areas: Segment A contains four living quarters, which can be used as single or double cabins. Segment B serves as a communal room with its main function being a viewing platform. Segment C contains technical equipment and sanitary facilities.

KEYWORDS: **Cost Estimation, Design, International Space Station, Space Tourism, TRANSCOST**

1 Introduction

Exploring frontiers of space stimulates the spirit in the same way as climbing Mount Everest. It is not surprising to find attempts to capitalize on this dream to bring excitement to human lives in a society driven by business and profit. Space exploration came at high costs. This exploration was driven more by political forces than the will to accumulate knowledge or even for people's pleasure. Government funding was often approved only in the hope of political gains or for national security reasons. Cost reductions are imperative to turn private travel by a small group of wealthy individuals into a fully functional tourist industry. The authors believe that a tourist module as shown in Figure 1 and Figure 2 connected to the ISS can stimulate space travel.

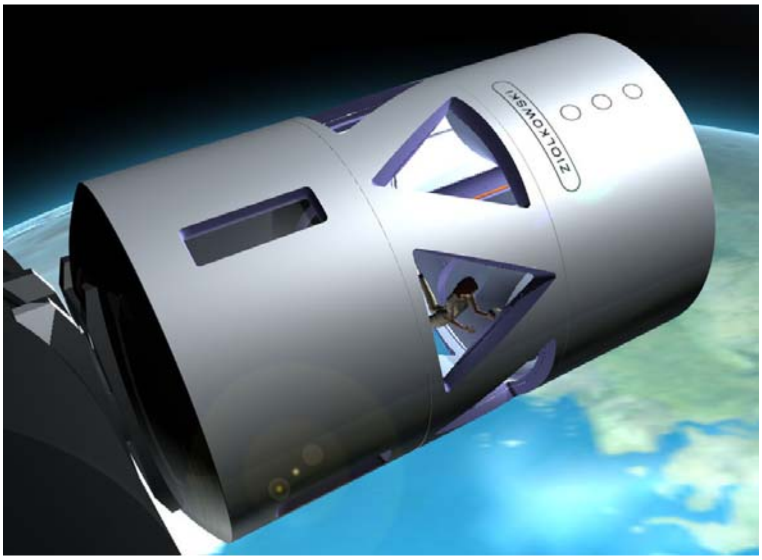

Figure 1: Ziolkowski Module

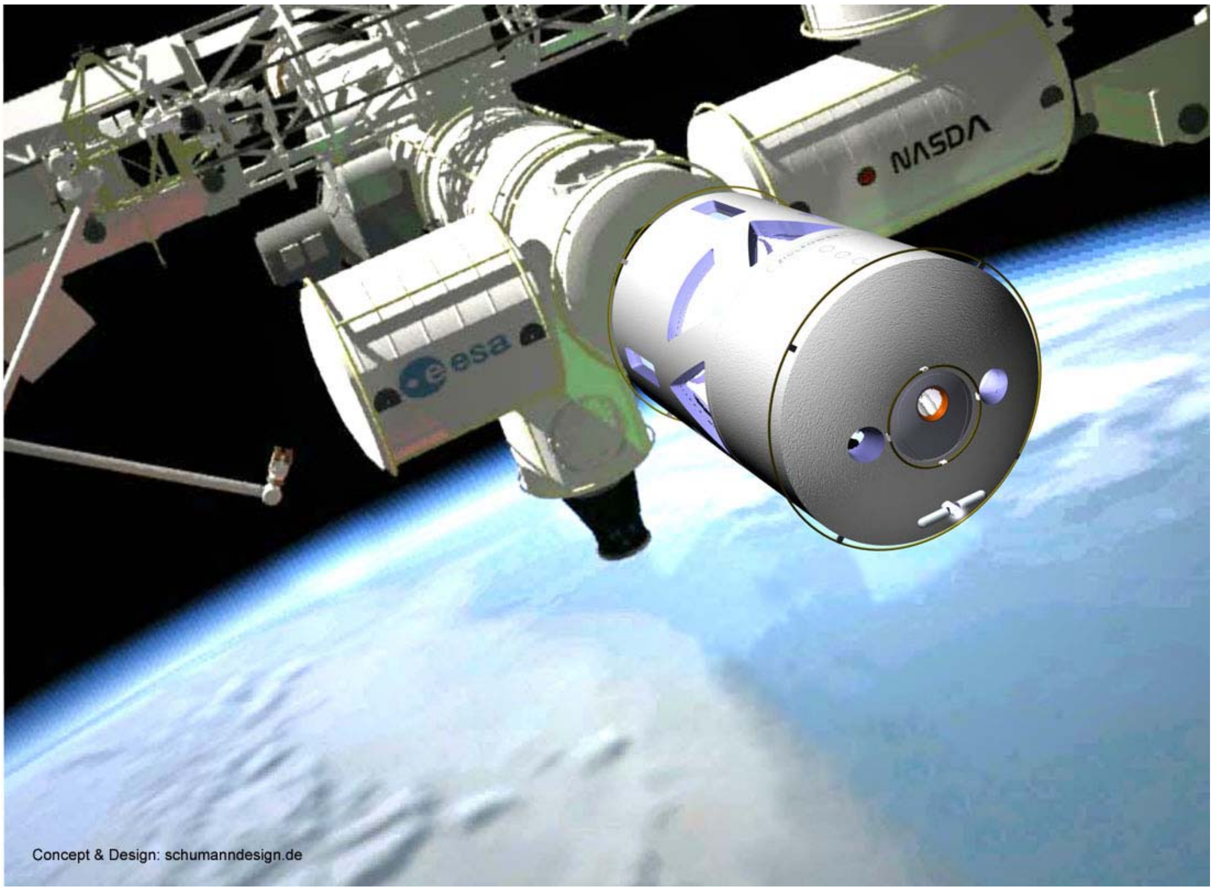

Figure 2: Ziolkowski Module connected to International Space Station

2 Concept & Design

2.1 Concept

The module's key conception is to emphasize the relevant aspects of tourist usage, such as high experience value and to grasp the psychological state of non-professional visitors. The creative structure of the internal compartments is characterised by a pure, emotional use of forms, which relates to the sheer pragmatic actuality, yet transmits a clear matter-of-factness. This applies to the colour and light scheme of the internal compartments. This has a positive effect on the visitors' mood and furthermore, transmits a strong feeling of safety and security. The design of the technical system, e.g. the air-conditioning, should take into consideration the acoustics as well as the quality of the visitors' well being. The external design of the module is defined by guidelines of the space transportation system in use.

The concept relates to an orbital residential module for tourism uses, in combination with existing larger structures such as the ISS and making use of the infrastructure of the latter. A considerable market potential for tourist use of near-earth space can be seen from the initial developments of Dennis Tito and Mark Shuttleworth as well as the planning of various companies in this direction.

This development could be fostered by the design of a module specifically geared to this purpose. Operating in combination with the ISS, the costs for a stay in orbit could be reduced. A concept of this kind would generate symbiotic effects, enabling the utility installations of the ISS to be used and thus avoiding the need for such systems in the module. In view of the current situation of the ISS, a concept of this nature would constitute a meaningful complementary activity.

Compared to other concepts intended for tourist use, such as parabolic flights, high-altitude flights or sub-orbital flights, the concept presented here would offer visitors the opportunity to satisfy their interests continuously and over an extended period of time. This would offer a substantially higher utility and enjoyment value and hence significantly enhance the attractiveness of this newly developing area of tourism.

2.2 Design

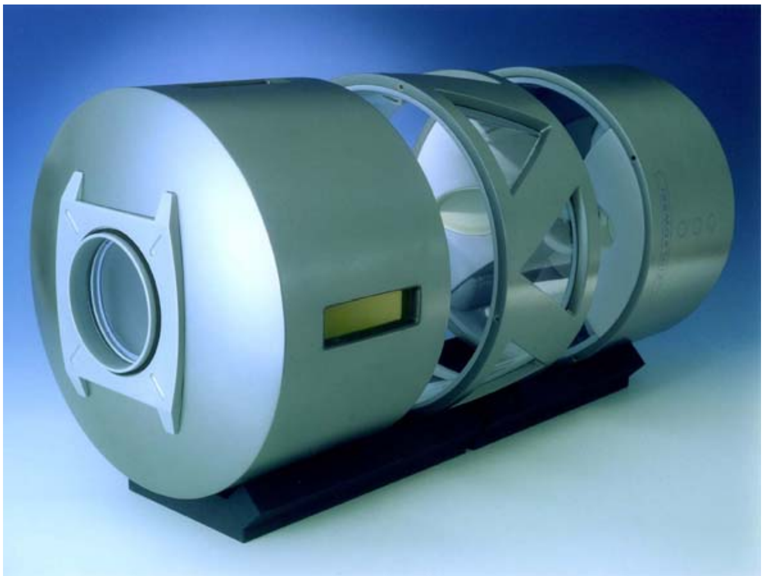

Figure 3: Mock-up

Figure 3 shows a 1:10 scaled mock-up of the Ziolkowsky Module. The structure of the module basically consists of three areas (from left to right):

- Segment A contains four living quarters, which can be used as single or double cabins. The cabins are quarter elements placed around the central connection tunnels, which connect the module with the ISS' main structure.

- Segment B serves as a communal room with its main function being a viewing platform. Here, visitors can pursue their main interests: viewing of the Earth, outer space and observable ISS areas, as well as experiencing the effect of zero-gravity on their body. The interior of segment B is characterized by flowing forms and is provided with large viewing windows.

- Segment C likewise contains two of the quarter elements of the kind used in the living area. One of the elements serves as accommodation for a flight engineer and a service person. The second element contains a sanitation area and also space for the technical equipment. Located coaxially between the two elements is an airlock chamber, allowing the visitors to leave the module to go outside. The free spaces between the other two elements are used as smaller communal areas.

2.3 Segment A

Figure 4: Segment A

Segment A as shown in Figure 4 serves as the connecting element to the ISS. Mechanical coupling of the module and connection of the utilities is done in the form of an adapter system through which a connection tunnel provides access to the module. Four living areas as shown in Figure 5 for the visitors are arranged radially around the connection tunnel.

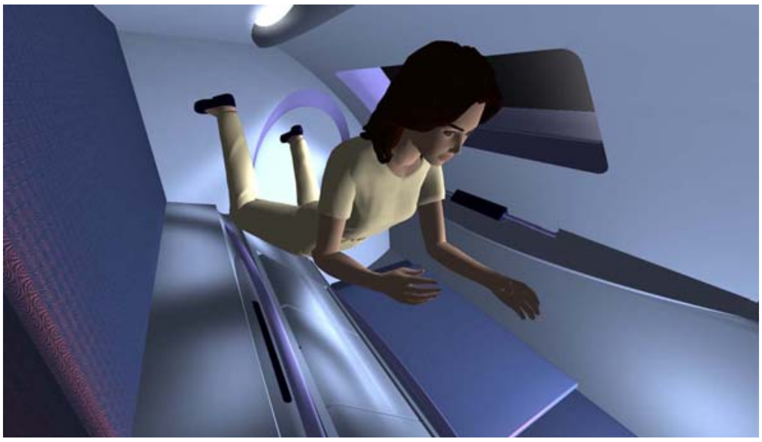

Figure 5: Passenger Accomodation (Segment A)

In view of the nature of the experiences, which will emotionally affect the visitors in different ways according to their individual psychology, as well as the different personalities of the visitors and the limitations on space, the living areas in segment A are designed not only for sleeping but also as a space to which people can withdraw. Each one is provided with small viewing windows so as to enable the visitors to observe the Earth and space in privacy. Each living area can be used as a single cabin or optionally also as a double cabin. The private areas contain personal communications equipment, but also redundant systems which are used in the communal areas and which will be described in further detail below.

The interior of the rooms is characterized by a clear emotional design language which complements the purely pragmatic aspects. The materials are finished in warm, atmospheric colors, and the design employs modern surfaces, materials and lighting technologies, as well as soft, flowing shapes and lines. This will ensure a high level of design quality.

Apart from the immediate positive effect on the visitors, this design is also intend to reinforce the sense of safety and security. Although not essential, the sleeping quarters have been given a classical, archetypical form (semantic function). To enhance the well-being of the visitors, the design of the technical systems, e.g. the air conditioning, should also pay attention to the acoustic attributes.

The basic outer form of the module is primarily defined by the needs of the transport system to be used, but is distinguished from the scientific areas of the ISS through the structure of the outer shell resulting from the special use of the module, i.e. the observation areas.

2.4 Segment B

Figure 6: Segment B

The spatial and functional centre point of the complete module is Segment B as shown in Figure 6, and this is also the central social point. This is the place where the visitors can jointly experience the visual and physical phenomena of this unusual environment.

The annular ring of segment B is equipped with eight large-size viewing windows. The areas of wall between the windows are covered in soft materials. Hand grips are provided at the edges of the windows so as to ensure a firm hold when looking out of the windows. The form and arrangement of the viewing windows gives the whole module a distinctive and characteristic appearance and gives visual structure and enlivenment to the basic cylindrical form of the module.

A special terminal provides the visitors with information on the areas of the Earth's surface they are flying over at any time. The system is GPS-controlled. Information can be selected at various levels of depth, ranging from simple basic information to detailed geographical information.

2.5 Segment C

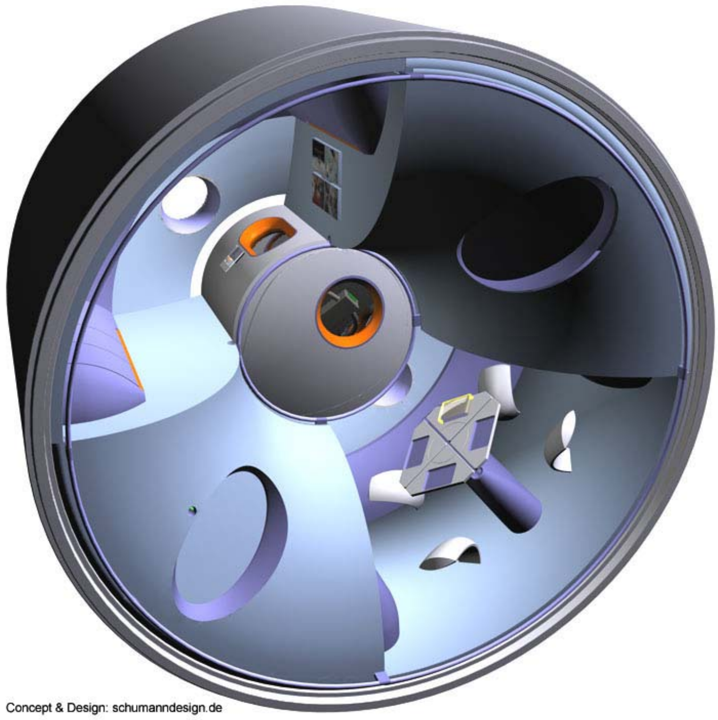

Figure 7: Segment C

The different areas of segment C as shown in Figure 7 are dedicated to various service and activity functions. Created from the same basic elements as used in segment A, segment C contains two enclosed rooms serving as sanitation and crew quarters. Between them are two open zones for use as a kitchen area and as a smaller communal area. These open zones have two small viewing windows. Located coaxially within segment C is an airlock chamber which has the special purpose of enabling access from the module to outside. This element should only be viewed as an option since it will involve considerable technical sophistication and hence increased cost.

2.5a Kitchen

The kitchen area space is surrounded in U-form by a storage element which also contains a preparation unit for meals. In the centre is an element containing fold-out table tops. When the table tops are not in use, therefore, they can be folded away to provide additional space. The table tops are provided with hollows in which the meal containers can be secured. The table element is surrounded by four seating aids, which can optionally also be designed to fold down in the interests of space saving. The room is illuminated by an arched light source integrated into the rear wall.

The seating aids are primarily intended to provide people with a fixation point at the table. As with mechanical holding devices, they are very simple to use, as the user need only cross his/her legs below the seat and then uncross them again in order to leave.

2.5b Sanitation

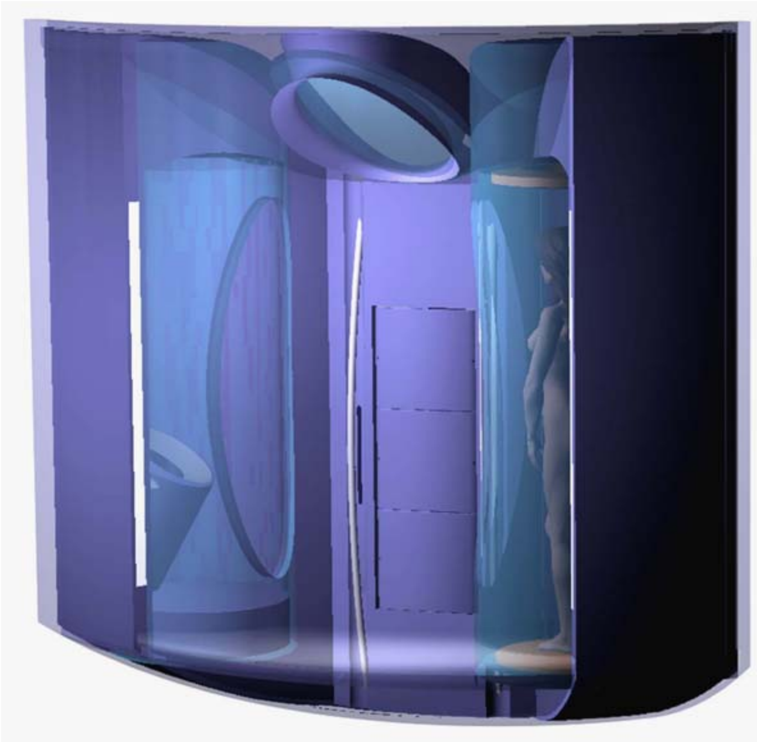

Figure 8: Sanitation (Segment C)

The sanitation area as shown in Figure 8 is contained in one of the modified interior elements. Like the living elements, it is entered via a central hatch. People first enter an area in which they can remove their clothes and place them in stowage containers to prevent them drifting away. As in the living areas, hand grips are provided throughout as an aid to orientation.

On each side of the entry room is a shower cubicle and a WC cubicle. The room lighting is located above the cubicles. The shower cubicle has a height-adjustable shower hood. For showering, the shower hood must be pulled down over the person's head and down to the shoulders. This first of all fixes the person in place, but above all it ensures that the water flows along the body to a water extraction device located beneath the feet. This means that the person's face is kept largely free of floating droplets, which can therefore not be breathed in. To wash the face, a cloth can be used.

2.5c EVA Module (optional)

Figure 9: Airlock Chamber (Segment C)

In the central area of segment C, space is provided for an optional airlock chamber as shown in Figure 9 to allow people to leave the module and go outside. A person enters the chamber under atmospheric pressure; the pressure is then reduced in order to match the pressure outside. Subsequently, the person can travel a few meters away from the module, secured on a sled system.

In order to allow observation of this procedure, the chamber has four viewing windows; these also have the psychological purpose of allowing the person inside the chamber to maintain eye contact with those outside, and so avoid problems with claustrophobia. The viewing window in the outside hatch has the primary purpose of preparing the person inside the chamber for going out into open space.

The sled system is of telescopic design to enable it to perform the necessary movement sequences. First, the sled is moved towards the module interior so as to allow the passenger, dressed in a protective space suit, to be secured on the seat. All securing and life support connections (air supply and temperature regulation) are located in a position behind the seat and can therefore not be reached by the person on the sled. At the back of the seat are optical control displays for the operating person outside of the chamber. When the interior hatch has been sealed, the pressure in the chamber is reduced. The outside hatch is then opened and the sled travels outside.

The phases of the procedure and the life support systems are controlled via a control panel below the side window of the chamber. The control panel has a kind of reset function which allows all the movement sequences up to the time of restabilisation of atmospheric pressure and opening of the inside hatch to be reset.

2.5d Communal Area

Like the kitchen area, the communal area also has a U-shaped element providing further storage space and housing technical components for the functions of the airlock chamber.

Also located here is a preparation device for the operations involving the airlock chamber. This device allows the temporary fixture of the space suit to make it easier for it to be put on. The room also has a monitor wall on which events on the ISS, such as docking maneuvers of supply ships, the launch of experimental platforms, outside activities of the ISS crew etc., can be observed.

In order not to disrupt the scientific work on the ISS, the people in the module should have restricted access to the ISS. Visits to the ISS should be at specified times only (excursions).

2.5e Crews Quarters

A likewise slightly modified interior module is used as crew accommodation quarters for two accompanying personnel. These persons consist of a flight engineer and a service person for the passengers.

2.5f Experimentation (optional)

Figure 10: Observation of Liquids (Segment C)

Apart from the activities for the passengers already described, i.e. the visual experiences and the experience of weightlessness, other opportunities can also be provided for witnessing the physical effects of zero gravity.

An extensive repertoire of activities can be developed for this purpose. They could include, for instance, the provision of small vessels in which the behavior of liquids can be observed as shown in Figure 10, special aspects of plant growth in conditions of weightlessness, the behavior of gyro systems or observations in the microscopic range.

3 Cost Analysis

3.1 General

Market analysis studies supply evidence that prospective passengers are largely driven by ticket prices as shown in Figure 11 (Goehlich, 2003). This causes the challenge to design a low-cost module.

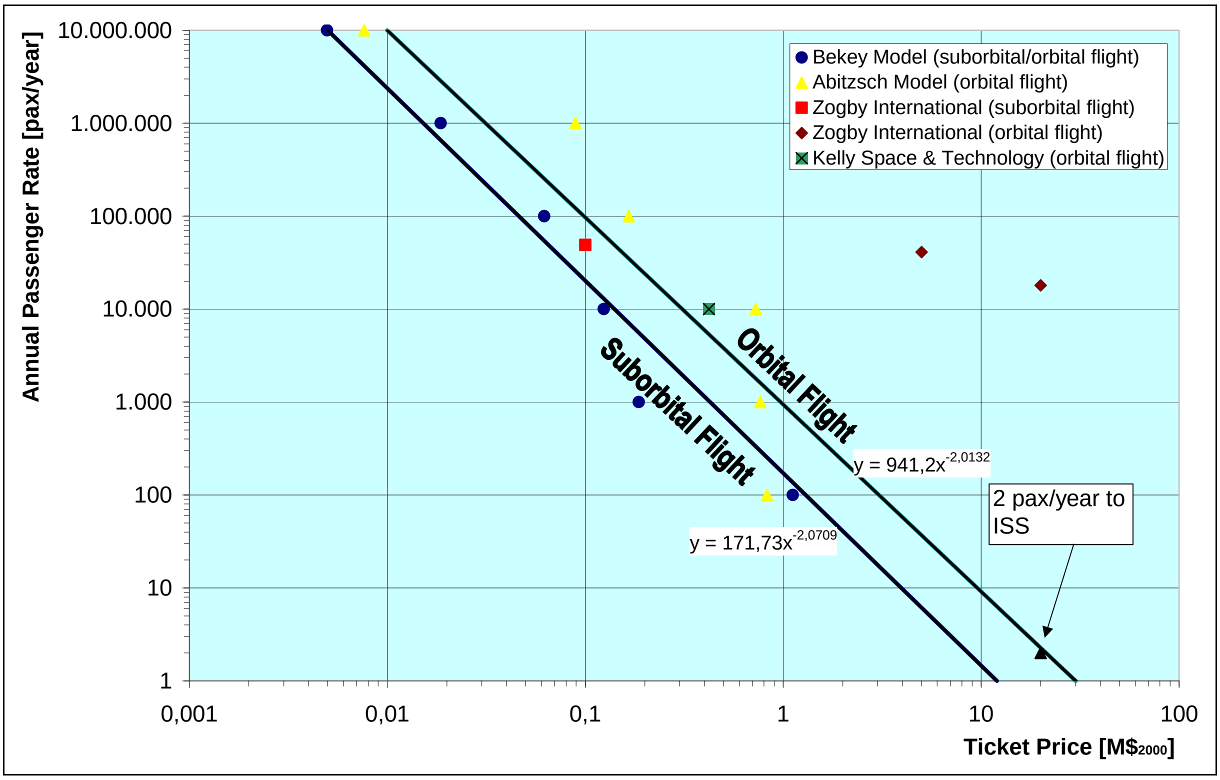

Figure 11: Model of Annual Passenger Rate as Function of Ticket Price

3.2 Mass Characteristic

As shown in Table 1 the total mass of the Ziolkowsky Module is estimated to 6,1 Mg including a 10 % mass margin, which is distributed over all components.

Table 1: Mass Characteristics (Unit: Mg)

Subsystem	Total
Cold Structure (main structure, insulation, etc.)	3,7
Hydraulic Equipment (EVA, ISS adapter, etc.)	0,1
Electronic Equipment (communication, computer, etc.)	0,05
Electric Equipment (ECLSS, cables, light, etc.)	0,8
Furnishings Equipment (separate walls, tables, beds, chairs, etc.)	1,4
TOTAL MASS	**6,1**

3.3 Development Cost

In order to reduce development costs the Ziolkowsky Module is composed of existing subsystems for example main cold structure, electrical and life support systems. Therefore, mainly only the interior cold structure such as room separation walls, tables, chairs, shower facility has to be totally new developed. Interior cold structure is fairly simply compared to other subsystems, which allows to keep development costs moderate and avoid unexpected delays due to technical problems. The most probable development cost, which means that margin for unforeseeable technical problems and a 20 % delay from the optimum schedule are included, is $310 million. It is assumed that the module is developed in Germany and that there is a clear-cut prime contractor-subcontractor relationship.

3.4 Production Cost

Generally, production cost of crewed space systems is very high. This can be explained by the complex life support system, power supply and electronic equipment. It is assumed that the Ziolkowski Module, uses ISS systems, is based on a modular concept and does not need expensive experiment facilities. The production cost is estimated to $100 million. Note, that a prototype as well as fabrication rigs and tools cost are included in the development program. However, this prototype is only used for testing purpose and as a source for subsystem spares.

3.5 Operation Cost

It is assumed that 26 tours per year over a period of 10 years for 8 passengers staying 1 week at Ziolkowsky Module are offered resulting in a cumulative number of passengers of 2080. Further it is assumed that government supports the project in terms of an interest-free loan for front-up costs, allows to connect module to ISS at no costs and to sell passenger ticket tax-free. The “passenger hotel cost" to live at Ziolkowsky Module per week is $0,7 million per passenger, while the "passenger transportation cost" is $1,3 million per passenger. Main cost items are discussed in the following.

3.5a Passenger Hotel Cost

- Module Development Amortization Cost: This cost is $0,150 million per passenger.

- Module Production Amortization Cost: This cost is $0,050 million per passenger.

- Module Transportation Amortization Cost: It is recommended to use an Ariane 5 to transport the module to the ISS. Cost is about $130 million including launch fees, insurance, etc. Amortization of this cost is $0,060 million per passenger.

- Mission Operation Cost: The cost does not only include the on orbit activities but also the cost of the passengers and crew staff itself, its ground support and training and the ground staff involved over the full mission period. Assuming that the learning factor is 90 % it lead to an average cost reduction factor of 0,5 over operation phase. The mission operation cost is estimated to $3,6 million for 8 passengers plus 2 staff for staying at the module resulting in mission operation cost of $0,450 million per passenger.

3.5b Passenger Transportation Cost

- Passenger Transportation Cost: It is recommended to travel to and from the Ziolkowsky Module by using Russian Onega rocket with Clipper spacecraft as shown in Figure 12 and Figure 13. Clipper would be launched to orbit by means of the Russian rocket carrier "Onega", which will most likely resemble an updated version of present-day "Soyuz". A crew of this space shuttle will consist of six people - two pilots and four passengers. The crew was seated in two seats in the first row for the pilot and co-pilot, and three seats in the second row for the passengers. There was space behind the second row for a fourth passenger. In case Rosaviakosmos agrees to finance the project, the shuttle system might replace "Soyuz" by 2010 (Wade, 2004). The cost is assumed to be $1,3 million per passenger.

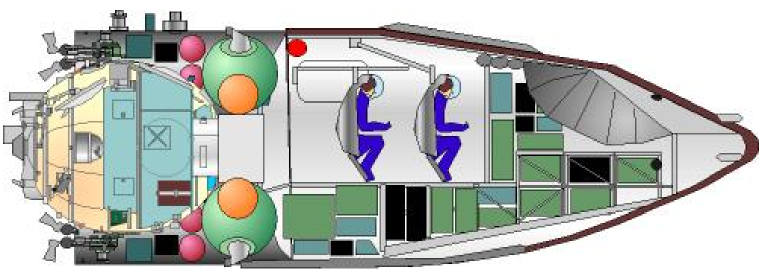

Figure 12: Clipper Spacecraft (Wade)

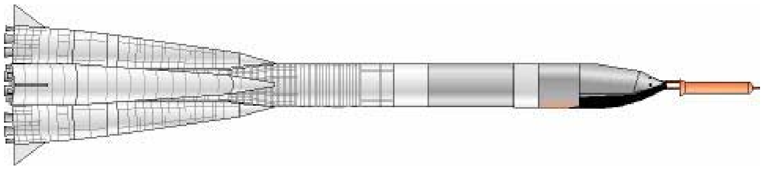

Figure 13: Onega Rocket with Clipper Spacecraft (Wade)

3.6 Total Ticket Price

Total ticket price is estimated to $2,2 million per passenger assuming that a 10 % profit margin of total operating cost is attractive for operator. A $2,2 million ticket would generate about 200 passengers per year according to Figure 11. In this case annual demand equals annual supply of available seats.

3.7 Cost Engineering Tools

3.7a General

Used tools for cost estimation are TRASIM 2.0 (Koelle, H.H., 1997) and TRANSCOST 7.1 (Koelle, D., 2003) which are statistical-analytical models for cost estimation and economical optimization of launch vehicles. Using both tools each other for reciprocal verification of results lead to a cost estimation process of high quality.

3.7b Cost Estimation Relationships

The cost models are based on Cost Estimation Relationships (CERs) with the basic form shown in Equation 1. CERs are equations, which are often mass-related and contain different parameters. These parameters have to be determined by the user. CERs are derived from actual costs including cost of unforeseen technical problems and delays.

Employed cost models use Man-Year (MY) effort as cost value. This is transformed by using a cost conversion value d to equivalent US dollars for fiscal year 2000 concerning field of occupation: for development 1 MY is equivalent to $205 000, for production 1 MY is equivalent to $200 000, for operation 1 MY is equivalent to $220 000 and for unknown data 1 MY is equivalent to $208 000 representing the average of above values.

$$C = a \cdot M^{x} \cdot \prod f_i \cdot d \qquad (1)$$

with:

C [M$] Cost

A [MY/Mgx] System-specific constant value

M [Mg] Reference mass

X [-] System-specific cost/mass factor

f_i [-] Assessment factors

d [M$/MY] Cost conversion value

3.7c Assessment Factors

The assessment factors f_i are needed for a satisfactory accuracy of estimation of life-cycle costs. In general, they are defined as follows: a low value means low expenditure and vice versa. They are estimated by using sub models or expert judgment. In the following is a list of used factors:

- System Engineering Factor f_0
- Development Standard Factor f_1
- Team Experience Factor f_3
- Cost Reduction Factor f_4
- Schedule Factor f_6
- Program Organization Factor f_7
- MY Correction Factor f_8
- Commercial Factor f_9

3.7d TRASIM Model

The TRASIM 2.0 model is a bottom-up cost analysis, which means that costs are determined on a subsystem level. Its strength is the possibility for the user to identify the cost influence of each subsystem on the space transportation system. This model is a tool for the analyses of the entire life-cycle of a fleet of space transportation systems on an annual basis. It can consider transportation activities between 9 transportation nodes of 5 different space transportation systems consisting of up to 3 stages with 5 payload categories each employed in 8 different mission modes.

The model is available as a program as shown in Figure 14 processing about 380 input values to determine costs. Applying this model from 1989 has led to refinements that have been incorporated into the current version TRASIM 2.0.

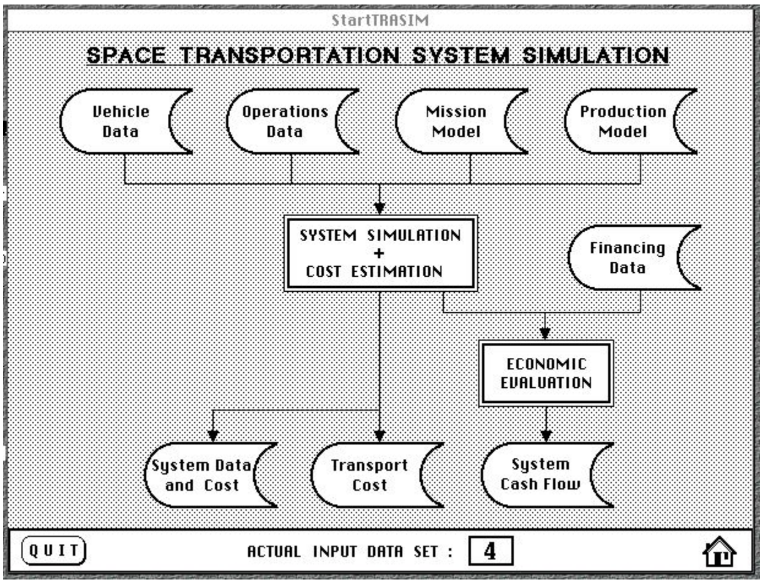

Figure 14: TRASIM Main Input Mask (Koelle, H.H., Johenning)

3.7e TRANSCOST Model

The TRANSCOST 7.1 model is a top-down cost analysis, which means that costs are determined on a system level. Its strength is to provide the user with a first order of magnitude of system costs with an accuracy of ±20 % (Koelle, D., 2003).

The model is available as a handbook containing 180 graphs as shown in Figure 15 and 30 tables to determine life-cycle costs on an average basis. It has been established for the initial conceptual design phase. The model is based on a 40-year database from US, European and Japanese space vehicle projects.

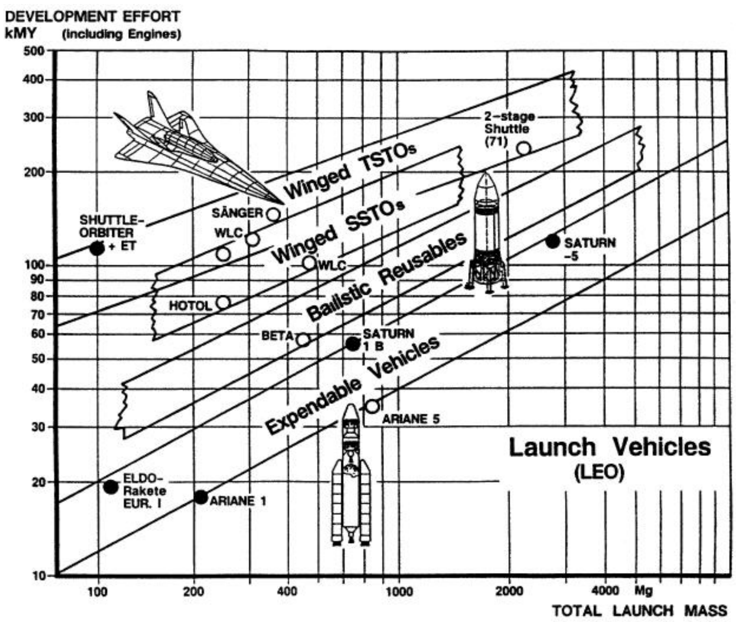

Figure 15: Example of a TRANSCOST Graph (Koelle, D.)

3.8 Cost Engineering Method

For assessment of a crew module's success, it is important to estimate realistic cost. This is done by calculation of life-cycle costs for a simulated scenario. Life-cycle costs include development cost, vehicle production cost, operating cost and abolition cost. Depending on the contracts, development and abolition costs are covered by contract of a governmental agency (Goehlich, 2002).

- Development Costs are non-recurring. They include at least one prototype, testing as well as fabrication rigs and tools cost, since, normally, a prototype unit is included in a development program requiring tools and rigs for prototype production.

- Production Costs are recurring. They include the follow-on production.

- Operating Costs are recurring. They include management, pre-launch operations, launch operations, mission control, propellants and ground transportation.

- Abolition Costs are non-recurring. During the abolition phase, vehicles and ground facilities are scrapped, employees are dismissed and licenses are sold. In general, abolition costs are the balance between expenses and proceeds, which is compensated by Variable Direct Operating Cost (DOC_{var}) of one launch (Koelle, D., 2003).

In business studies, it is common and useful to amortize development, production and abolition costs over fleet operation phase. Thus, development cost is represented by "Development Amortization Cost", production cost is represented by "Vehicle Amortization Cost" and abolition cost has a share in "Technical Support Cost".

Operating Cost is the sum of Variable Direct Operating Cost, Fix Direct Operating Cost and Indirect Operating Cost:

- Variable Direct Operating Cost (DOC_{var}) are all those costs, which are dependent on the vehicle's utilization. For example, two launches instead of one means twice the propellant cost.

- Fix Direct Operating Cost (DOC_{fix}) are all those costs, which are independent of the vehicle's utilization. In order to determine total direct operating cost per launch, DOC_{fix} is distributed over all launches of the fleet during life-cycle. For example, due to changing regulations during the fleet life-cycle, the vehicle has to be equipped with new safety equipment.

- Indirect Operating Cost (IOC) comprises all those costs that are not directly related to launch operations. For example, the marketing cost can be the same for different types of vehicles.

Conclusion

Analysts estimate the future operating costs of ISS as $5,5 billion per year (David, 2002). In comparison, the annual turnover by selling tickets for the Ziolkowsky tour is about $0,5 billion or less than 10 % of the ISS annual operating costs. It shows that there is no remarkable financial benefit for the ISS by operating the Ziolkowsky Module. Instead, the authors believe that the benefit for the ISS by operating the Ziolkowsky Module is of idealistic nature: the space station will gain in popularity with the positive side effect that space budget increases may be accepted by the taxpayers and politicians. In addition, the profit orientated operation of the Ziolkowsky Module would be of benefit for the International Space Station's objective to reduce operation costs. However, the strong interaction with the ISS will limit cost reductions for space tourism tours by using this module.

The Ziolkowsky Module can be seen as a pioneering hardware to stimulate space tourism flights to Low Earth Orbit and beyond. Once the customer market is satisfied to "just only" go to Low Earth Orbit, there might be an increase in demand for Lunar tourism as well.

Acknowledgment

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List of Abbreviations

B$	[-]	Billion US dollars
CER	[-]	Cost Estimation Relationship
DOC	[M$/launch]	Direct Operating Cost
ECLSS	[-]	Environmental Control and Life Support System
EVA	[-]	Extravehicular Activity
ISS	[-]	International Space Station
IOC	[M$/launch]	Indirect Operating Cost
Kg	[-]	Kilo grams
M$	[-]	Million US dollars
Mg	[-]	Mega grams
MY	[-]	Man Year

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