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**On the Prospects of Lunar Tourism:
A Credible Scenario**

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Abstract

Space Tourism is an idea brought up already 1968, but is a relatively new subject in public discussion, particularly since the flight of Dennis Tito, who paid 20 million dollar for a visit to the International Space Station in 2001. Detailed studies on space tourism have been performed in the United States, Great Britain, Japan and Germany. Most of the proposals concentrate on sub-orbital and orbital missions. The question of the feasibility of tourist flights to the Moon has now been analyzed the first time in connection with the acquisition of an initial Lunar Base. This report summarizes a scenario in which tourists travel to a space station in lunar orbit, that serves the Lunar Base as a transportation node. This add-on program would be complementing public Lunar Base operations. It is shown that beginning about 2026, annually several hundred tourists could be transported to the Lunar Orbit Station for a weekly stay at cost in the order of about \$ 4 million/tourist. About ten years later it should be possible to visit the Lunar Base for a few days for those who are willing to pay for it, that would take additional \$ 2 million. -

This report comprises 11 tables, 11 figures, 15 references on 29 pages.

Key words: space tourism, lunar base, space operations center, lunar orbit, space transportation systems, system simulation, cost analysis

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1. Introduction

Space Tourism is a viable subject since the first commercial space tourist (Dennis Tito) has entered the International Space Station in 2001 at a ticket-price of 20 million dollar which he paid to the Russian Space Agency. Space Tourism has been discussed since 1968[1] in the past for many years in several publications by various authors. There is a consensus among specialists that space tourism is expected to develop during the next decades into a sizable market if suitable vehicles would be developed. If so, it would be a major boost to the entire field of human space travel [6,10,11,12,13].

To come up with practical solutions of the problem, one has to keep in mind, that any concept of space tourism has to fit into an overall, pessimistic or optimistic evolutionary development of human exploration and utilization of space, offering a new opportunity for growth beyond the limits of the Earth and beyond.

The development of space tourism will probably go through the following stages:

1. Development of a realistic *Tourist Program Structure* and an initial concept of converting this into reality that may be of interest to commercial investors.
2. Demonstrate by experimental flights the feasibility of space tourism to awake interest of the general public in the adventure of space tourism.
3. Develop a robust flight vehicle suitable for semi-regular space tourism with sub-orbital flights that would demonstrate an acceptable level of passenger safety and encourage investors to enter this potential market.
4. Develop high capacity space vehicles that can attract enough customers for multi- orbital space flights and create an appropriate international enterprise that can hope for an adequate return on the investment to be made.

From the purely technical viewpoint these evolutionary steps of space tourism can be defined even more precisely:

X-1: FREE GRAVITY FLIGHTS: years 2000 to 2010
with up to 1 minute duration in airplanes to develop a market and enhance the interest in space tourism(a limited activity in this area exists in the USA, Russia and Europe).

X-2: SUB-ORBITAL FLIGHTS: years 2010 to 2015
to 100 km altitude with about 20 minutes duration for those who cannot wait and afford it.

X-3: ORBITAL FLIGHTS: years 2015 to 2020
twice around the globe probably with winged vehicles in an altitude of about 150 km and about 3 hours duration, preferably with horizontal take-off and launch assist.

X-4: ORBITAL FLIGHTS: years 2020-2030
with large size ballistic carrier to an orbital station in an altitude of about 450 km and with a duration of 1 to 2 days.

X-5: LUNAR ORBITAL MISSIONS: 2030-2040
with large size ballistic vehicle and a 10 to 14 day duration, ending with a HOHMANN- type brake ellipse at Earth at return.

X-6: LUNAR ORBITAL MISSIONS of about two weeks supplemented by optional one-day excursions to the lunar surface feasible in years 2040-50.

X-7: ONE MONTH VISITS to a LUNAR BASE HOTEL
may become feasible sometime in the second half of the 21st century.

Lunar missions for tourists have not been discussed as yet in any detail due to lack of suitable scenarios of space development that would offer a credible frame of reference for such an enterprise. This has recently been developed by the author. It analyses three representative acquisition scenarios of a lunar installation [14]. One of these three options is the development and operation of a *Permanent Lunar Base* with a 40- year life cycle that is particularly amendable for tourism to a facility in lunar-orbit. The proposed Lunar Base acquisition program would require a 10-year development phase and lead to the return of a human crew to the Moon in year 2016. This public financed program if materialized, would offer an opportunity for supplementing it by a commercial tourist program sometime about the year 2026, provided that the first operational decade is considered to be successful.

The tourist program concept discussed in this report is based on the addition of several tourist passenger missions/year to an existing and hopefully proven logistic system that is then supporting the initial Lunar Base. These additional tourist missions would initially only reach the *Space Operations Center* in lunar orbit with a one-way travel time of three days and stay there for several days. On

the long run, this stay at the lunar orbit station may include the option of a short excursion to the lunar surface. On the return flight to Earth the passenger vehicle would employ a HOHMANN-brake ellipse that would allow flying around the Earth once again before landing. The total trip would take about 2 weeks at prices to be determined for specific program scenarios. Cost of about \$ 5 M/passenger seem to be achievable.

2. General Vehicle Selection Criteria

In principle, there are two different approaches to commercial space travel:

- (1) Either there is a proven vehicle available from other programs that can be modified for commercial passenger transportation, or
- (2) there is no suitable vehicle available and a space transportation system concept must be developed from scratch, which is an unlikely but possible alternative.

In any case, the questions of technical-, economical- and political feasibility and/or quality must be answered satisfactorily for any candidate concept to attract potential investors and to be certified by the authorities for passenger transportation systems. Since it is not possible to satisfy all potential commercial passenger markets by one vehicle, these feasibility/quality contests have to be performed for all vehicles that have the capability of serving a particular segment of the potential market.

A general list of *design features* of space vehicles should be defined for future commercial applications that can be used as the basis for developing an individual vehicle concept capable to serve a specific segment of the potential commercial market as illustrated above.

As stated above, it is mandatory that a vehicle concept proposed for space tourist applications must stand the test of technical -, economical - and political feasibility/quality. A conservative and robust vehicle that is clearly *feasible* may appear acceptable from the future users viewpoint, but its technical *quality* that is not high enough to promise a satisfactory return on investment. On the other hand, a vehicle that promises a good cost-effectiveness may be too risky to develop and is unlikely to be certified as a public transportation system. This shows that there must be trades among these criteria, which together must offer the best chance to be financed and operated successfully from viewpoints of the operator, customer and government.

Suitable vehicle design features that are serving as a measure of quality can be derived by looking at the mission profile a tourist vehicle has to perform from take-off to touchdown successfully, critical ones are:

1. Attractive functional configuration
 2. Adequate number of stages to guarantee desired performance
 3. Proven safe and cheap propellants
 4. Adequate seat capacity
 5. Adequate passenger comfort
 6. Safe and convenient launch method
 7. Adequate mission duration
 8. Safe landing method
 9. Robust landing gear
 10. Short turn-around-time between missions
 11. Adequate reusability of vehicle sub-systems
- all these will determine the two crucial system parameters that must be achieved:
12. High degree of mission success

13. Low risk of catastrophic failures

In a refined analysis these system parameters have to be backed up by indicators that one could use to measure the relative quality of proposed concepts.

These desirable vehicle design features and performance parameters can be implemented by alternative approaches. Listing the alternatives available for each of the design features produce a two dimensional matrix, often called a *morphological box*. One of the options defined must be selected to come up with a complete concept comprising compatible design features. Since there are many combinations possible, the quality of the concept is represented by a figure of merit representing the degree of fulfilling the defined criteria. An illustrative example of a morphological box, applicable to Earth launch vehicles, is presented below. It is obvious that there are many combinations possible which lead to vehicle concepts of different quality.

Table 2-1: Example of a morphological box with design features and their options

	Design feature/parameter:	Options:
1.	Attractive functional configuration	winged or ballistic configuration tandem- , nested-, parallel staging,
2.	Adequate number of stages to guarantee desired performance	single stage, one 1/2 stage, two stages, three stages
3.	Proven safe and cheap propellants	LOX+RP-1, LOX+LH2, non cryogenic, solid
4.	Adequate seat capacity	> 100; 100 to 10; < 10
5.	Adequate passenger comfort	> 5 m ³ /passenger ; 5-3; < 3 maximum g < 3 g, 3-5g, > 5g
6.	Safe and convenient launch method	vertical, horizontal, launch assist , engine out capability ?
7.	Adequate mission duration	1 - 3 weeks, 1 - 3 days, 1 to 3 hours, < 1 hour
8.	Safe landing method	glide landing, vertical under power, parachute
9.	Robust landing gear	wheels, legs, pneumatic shock absorber
10.	Short vehicle turn-around-time between missions	< 1 week, 1-2 weeks, > 2 weeks
11.	Adequate reusability of vehicle sub-systems	> 100 reuses; 100 to 50; < 50
12.	High degree of mission success	>0.9999; 0.9999 to 0.999; < 0.999
13.	Low risk of catastrophic failures	>0.99999; 0.99999 to 0.9999; <0.9999

These design features are not necessarily equally important and may have different weight when designing a vehicle for a particular market and change with time.

There are several ways to estimate the relative importance among these criteria. One method often applied, is the systematic "pair wise comparison" of all combinations of criteria considered. Their interdependency should be intuitively be observed, or analyzed systematically. When properly done, these design features will receive relative weights, totaling 1.00 or 100%, and they can be put in a ranking order by such a weighting process.

In this context it is extremely important how this is done, especially asking and answering the right question in this valuation process. Definition of the question to be answered depends on the *purpose* of the valuation exercise. What does one want to do with this ranked list? -

A carefully derived set of weighted design features can be used for two purposes: (1) To *derive promising vehicle concepts* using the *morphological approach* determining relative weights of the design features and relative weights assigned to the options. This would require a double weighting procedure in conjunction with exclusion of design features that are not compatible (such as a glide landing of a ballistic stage).

In this case one has to ask: "Is the implementation of design feature A in principle *more desirable* than feature B"?

Additional assessment: Which of the defined options is preferable (requires ranking) and how close (percent) does this option come to the ideal solution?

(2) To determine the *ranking of well defined candidate concepts* on the basis of degree of fulfilling design goals, calculated with the help of utility functions.

In the second case listed above the *relative importance* of two design features is compared systematically by pair wise comparison to obtain a ranked list representing the relative importance of the specific design feature which has now the role of a selection criteria. In this case the options have to be quantified in the form of utility functions defined for each relevant parameter. For this application the valuation question leading to a weighted ranked list to be asked would be:

"Comparing two design features, which one of these two features is *more important* to be fulfilled from the overall viewpoint A or B?"

In both cases a proper scale, e.g. +/- 5, could be used to result in a weighted ranking!

If several vehicle concepts are under discussion, these can be critically analyzed and compared. A generally applicable analysis in depth has been performed elsewhere. A tentative weighted list for Earth launch vehicles serving in a program of space tourism has been developed that may be used for a preliminary comparison of proposed concepts (table 2-2).

This preliminary evaluation may be performed with the restriction that a concept to be eligible as a candidate must satisfy at least 50 percent of the specified criteria in each of the technical-, economical- and political areas, and in total should achieve 2/3 of the specified criteria. Only those should be subjected to a detailed analysis comparing performance-, benefits and cost in a specific market scenario.

Table 2-2: Proposed ranking order of favored vehicle attributes

1. Low risk of catastrophic failures = high passenger safety	12,3 %
2. High probability of mission success	9,7 %
3. High seat capacity	9,2 %
3. Adequate passenger comfort	9,2 %
5. Proven propellants	8,1 %
6. Proven and safe launch method	7,8 %
6. High rate of subsystem reusability	7,8 %
8. Adequate mission duration	7,1 %
9. Safe and comfortable landing method	6,4 %
10. Short turn-around time	6,2 %
11. Proven landing gear	5,8 %
12. Adequate number of vehicle stages	5,4 %
13. Attractive vehicle configuration	5,0 %
Total	100 %

3. A Space Program Scenario compatible with Lunar Tourism

3.1 Introduction

A plausible scenario of lunar tourism can be developed in case both of the following two suppositions are fulfilled:

(a) Human Space Travel is developed to a point that regular missions are executed to a space facility in low Earth orbit with paying passengers to enjoy the pleasure and adventure of circling the Earth and looking at it from outer space in an environment of zero gravity. This next stage of human space travel would be within reach during the second decade of the 21st century in case a third generation space transportation system (SPACE SHUTTLE II?), now under consideration, would be developed that can transport cargo and passengers safely and economically to the International Space Station (ISS) or its successors.

(b) A public supported Lunar Base has demonstrated for several years the utility of an extraterrestrial installation on the Moon for purposes of research, exploration and pilot production of rocket propellants or construction materials. This will become feasible only if a heavy lift fully reusable space transportation system has been developed that can transport humans safely and economically between Earth and Moon.

3.2 Representative Lunar Base Development Scenario [14]

Possible lunar development scenarios have been discussed in the past with the most recent one by the author (14). It envisions a 10-year public supported development program commencing in 2005/6 that could lead to a return to the Moon by the first lunar crew in 2016. During a 10 year construction phase following the landing of the first crew, an initial Lunar Base will be assembled and put into operation. After ten years of experimental operation the Lunar Base would have a crew of 75 people, many of them occupied with research and pilot production activities. During the follow-on 20-year consolidation phase, some production processes would be optimized for the existing or conceived market. In addition, research facilities could be constructed that can be leased to interested institutions and corporations.

The characteristics and performance of such an initial Lunar Base has been published elsewhere [14,15] and is best summarized by some key performance and cost data.

Table 3-1: Lunar Program Options: Overview of performance and cost including recurrent logistic cost, but excluding STS acquisition cost and financing of base facility acquisition (results as of January 2002)

System Parameter:	10+10 year Base Program	10+30 year Base Program
Average scientific crew during life cycle	10	26
Average production crew during life cycle	8	11
Average service crew during life cycle	28	38
Average total lunar crew during life cycle	46	75
Labor years used for research and development	103	789
Total lunar labor years during lifespan	466	2,265
Average installed facility mass (t)	885	1,373
Average oxygen production rate (t/a)	79	112
Average construction material prod. rate (t/a)	1,001	1,314
Average import rate from Earth (t/a)	186	212
Total Program Cost (B \$)	32.14	71,750
Average annual Program Cost (B \$)	1.61	1.79
Specific lunar labor cost (M \$/year)	69.0	31.68
Specific lunar R & D labor cost (M \$/year)	341	90.9

A somewhat different viewpoint is presented in the next table. In this case the Lunar Base and the respective Space Transportation System, including its

development, are considered to be the total program. This would be the worst-case scenario as seen from the investor.

Table 3-2: Overview of Lunar Base cost and cost-effectiveness including financing cost of the Base acquisition as well as development and operation of Space Transportation System (STS) employed in the logistic support

Options:	10+10 year LC	10+30 year LC
Life cycle cost of Lunar Base (B \$)	28.1	48.7
Life cycle STS Logistics cost (B \$)	29.0	50.7
Life cycle Total Program Cost (B \$)	57.1	99.4
Average annual program cost (B \$/a)	2.85	2.49
Specific cost of lunar laboratory space (M \$/a)	275	62
Life cycle LB Cost/lunar labor-year- (M \$/a)	60	22
LC LB Cost/commercial labor-year - (M \$/a)	156	44
Specific logistic cost per lunar crew (M \$/a)	62	22
Specific logistic cost per scientific or commercial lunar crew labor year (M \$/a)	317	90
Specific program cost of lunar labor year (M \$/a)	123	44
Specific program cost per scientific or commercial lunar labor year (M \$/a)	317	90

This is the background information available on the reference Lunar Base Program. It must be pointed out that this representative, but not optimized. It does not yet include a commercial tourist program. Such an endeavor could be added after about ten successful years of public operations, at the same time when lunar laboratory facilities could become available for lease to interested private companies. However, tourist operations would begin with trips to lunar orbit and not to the Lunar Base, limited to a program in which the Lunar Orbital Space Operations Center would be the point of destination and modified to accommodate tourists. Thus this facility must be described more closely [15].

3.3 Lunar Orbit Facility [2,4,5,7,8,15]

It is generally agreed that one of the major elements of a Lunar Base program is a Space Operations Center (SOC) in lunar orbit. It serves as a transportation node between Earth and Moon where passengers and cargo are transferred from the Earth launch vehicle to the lunar landing- and launch vehicle and vice versa. The SOC is a modified second stage of the Heavy Lift Launch Vehicle (HLLV) that is permanently stationed in lunar orbit. This illustrative example has the configuration shown below. Its central body has a size of about 30 m in diameter and 50 m in length. The configuration has been shown in figure 3-1, the mass model of the initial SOC is presented in table 3-3 and initial cost data are provided in table 3-4.

The SOC concept presented is planned to provide the following services:

1. Pre-launch operations: Refueling and checkout, loading.

2. Vehicle recovery: flight control, docking operations, unloading, rescue.
3. Temporary passenger services, safe heaven function.
4. Maintenance and repair services of space vehicles (refurbishment of structures, engines, equipment, thermal protection system).
5. Storage of propellants (liquid oxygen, liquid hydrogen and other working fluids).
6. Storage of space vehicles and vehicle subsystem spares
7. Information collection, storage and transfer.
8. Communication link to Earth, Moon and space vehicles en route
9. Scientific research tasks for own benefit or contractors
10. Surveillance of cis-lunar space
11. Housekeeping of SOC installations
12. Maintenance and repair of SOC equipment
13. Integration and checkout of SOC extensions

(Taking care of temporary tourists would be covered primarily by point 3!)

Table 3-3: Mass model of SOC

SUBSYSTEM	SUB-SYSTEM MASS [KG]
PRIMARY STRUCTURE	67000
PROPELLANT TANKS	32000
FUELLING EQUIPMENT	10000
ENGINES	18000
STORAGE MODULES	42000
CREW QUARTERS	25000
GUIDANCE & CONTROL	6000
POWER SYSTEM	10000
OTHER EQUIPMENT	40000

Figure 3-1: Representative Configuration of a Space Operations Center

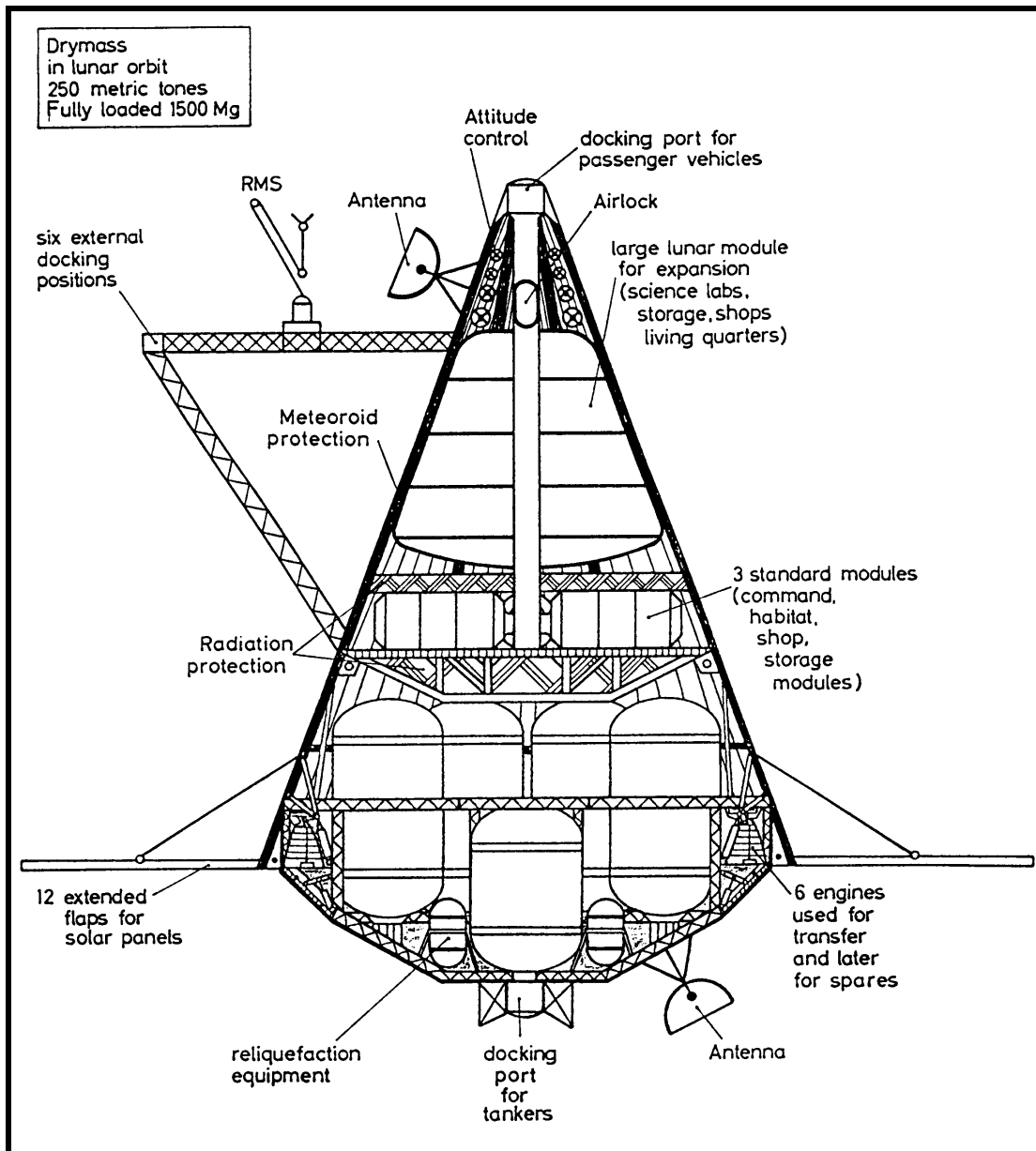


Table 3-4: SOC Development cost and production cost overview

SUBSYSTEM	DEVELOPMENT COST (M \$)	FIRST UNIT COST (M\$)
PRIMARY STRUCTURE	39	127
PROPELLANT TANKS	13	42
FUELING EQUIPMENT	56	188
ENGINES	41	138
STORAGE MODULES	95	317
CREW QUARTERS	69	230
AVIONICS	52	174
POWER SYSTEM	37	121
OTHER EQUIPMENT	92	307
TOTAL	496	1644
ENGINEERING AND INTEGRATION	50	
TOTAL DEVELOPMENT COST	546	+1644

Performance and cost characteristics of a transportation node (excluding tourist services) that can be summarized as follows:

Table 3-5: Overview of Space Operations Center cost data (Reference Case)

	Cost category:	Annual Cost M \$	40 yr LC Cost M \$
1.	SOC development cost		546
2.	Production cost of first SOC unit		1,644
3.	Production cost of SOC extensions	NA	NA
4.	Production cost of SOC spare parts	33	990
5.	Production cost of SOC supplies	1	30
6.	Transportation of SOC to destination		390
7.	Transportation of SOC extensions to destination	NA	NA
8.	Transportation of SOC personnel	25.2	757
9.	Transportation of SOC spares & supplies	6.85	206
10.	Crew salaries	8.38	251
11.	Sustained engineering for updating SOC design	2	60
12.	Earth operational support	2	60
	Total SOC expenditures M \$		4,934
	Share of program total of 46 B \$		10.7%
	SOC burden/primary mission (M \$/mission)		20.5

As soon as this initial Lunar Base and its logistic system would prove to be safe and cost-effective, it should be no major problem to extend the size of some sub-systems of this space facility. This mode of operation is included in the LUBSIM code as an option. The goal would be to accommodate comfortably a larger group of space tourists for several days. This approach of a delayed supplement tourist program has two distinct advantages:

(1) Acquisition cost would have been paid already by participating investors,
 (2) existing hardware and equipment would be shared by more users. This would be of benefit to all participants. In this scenario it is obvious that these benefits have to be estimated and discussed whether such an option is of interest to potential private investors.

3.4 Cost-effectiveness of Lunar Orbit Tourism [9,10,11]

The basic information to depart from in order to estimate cost is the number of annual space missions because this information is required for all services specified.

The number of missions to be executed in a specified year is driven by the conceived market. It is assumed that market projections justify four annual

commercial missions, beginning in operational year 11, and are increasing gradually to 12 missions/a in the 20th year of Lunar Base operations in this sector of the space tourist market, resulting trend of annual mission rate is shown below.

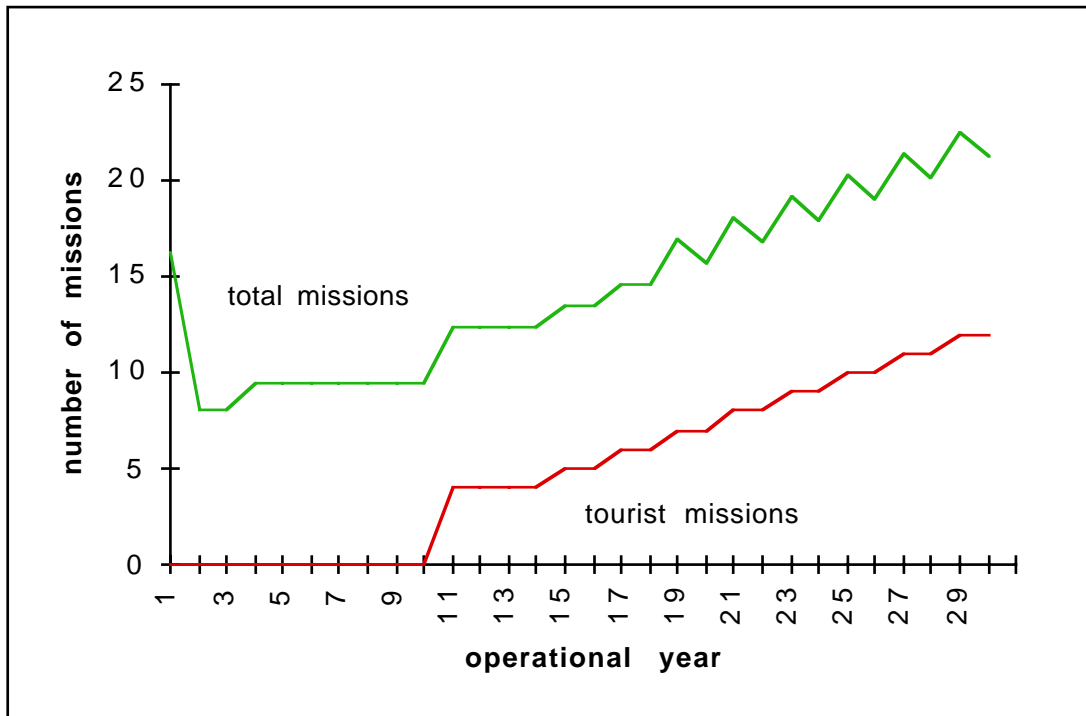


Figure 3-2: Number of total missions and number of commercial passenger missions to lunar orbit space operations center

The Lunar Orbit Service Center requirements in such a scenario are shown in figure 3-3.

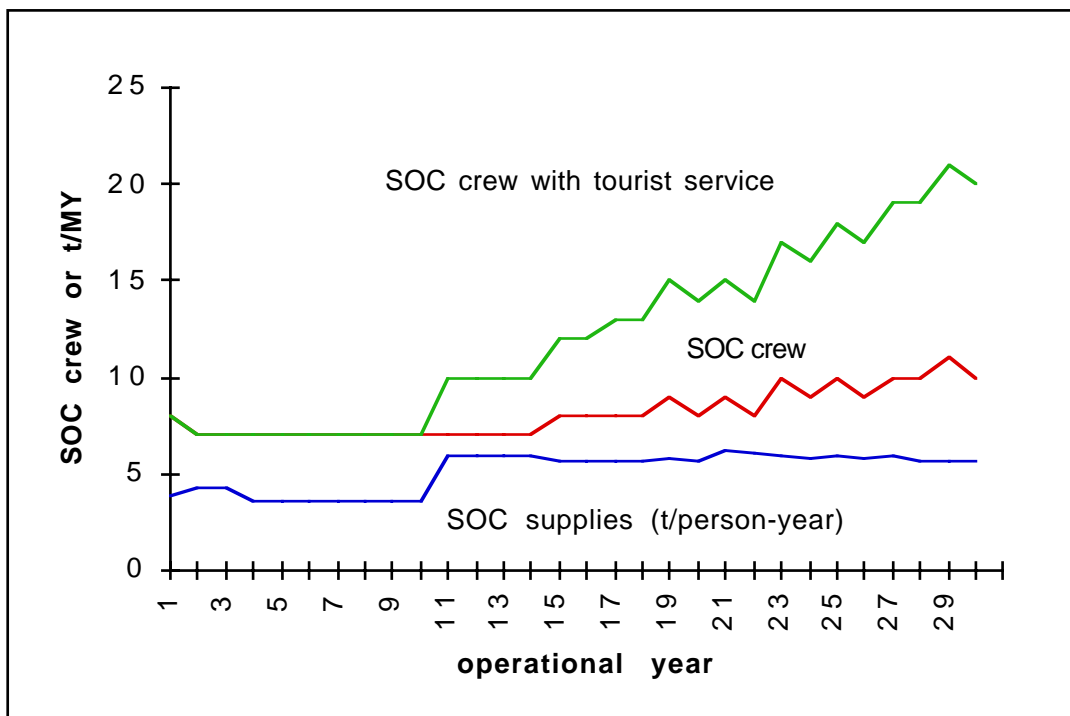


Figure 3-3: Crew size and supply rates of SOC

Details of the more important parameters are presented in table 3-6:

Table 3-6: Annual number of primary and secondary flight missions

Y E A R	comm. pass. miss.	comm. pass./ a	total pass. to LUO	lunar crew trips	SOC crew trips	Crew size w.o. tour.	tanker flights to LUO	SOC crew Mis- sions	SOC supply Mis- sions	Prime Mis- sions	Total Mis- sions
1	0	0	98	74	24	8	2,0	0,7	0,4	13,1	16,2
2	0	0	93	74	19	6	2,0	0,5	0,5	5,0	8,0
3	0	0	92	74	18	6	2,0	0,5	0,5	5,0	8,0
4	0	0	95	74	21	7	2,3	0,6	0,6	6,1	9,4
5	0	0	95	74	21	7	2,3	0,6	0,6	6,1	9,4
6	0	0	95	74	21	7	2,3	0,6	0,6	6,1	9,4
7	0	0	95	74	21	7	2,3	0,6	0,6	6,1	9,4
8	0	0	94	74	20	7	2,3	0,6	0,6	6,1	9,4
9	0	0	94	74	20	7	2,3	0,6	0,6	6,1	9,4
10	0	0	94	74	20	7	2,3	0,6	0,6	6,1	9,4
11	4	160	256	74	22	7	0,9	0,6	0,8	10,1	12,4
12	4	160	256	74	22	7	0,9	0,6	0,8	10,1	12,4
13	4	160	256	74	22	7	0,9	0,6	0,8	10,1	12,4
14	4	160	256	74	22	7	0,9	0,6	0,8	10,1	12,4
15	5	200	297	74	23	8	0,9	0,6	0,8	11,1	13,5
16	5	200	297	74	23	8	0,9	0,6	0,8	11,1	13,5
17	6	240	338	74	24	8	0,9	0,7	0,9	12,1	14,6
18	6	240	338	74	24	8	0,9	0,7	0,9	12,1	14,6
19	7	280	418	111	27	9	0,9	0,8	1,1	14,1	16,9
20	7	280	378	74	24	8	0,9	0,7	1,0	13,1	15,7
21	8	320	459	111	27	9	0,9	0,8	1,2	15,1	18,0
22	8	320	419	74	24	8	0,9	0,7	1,1	14,1	16,8
23	9	360	500	111	29	10	0,9	0,8	1,3	16,1	19,1
24	9	360	460	74	26	9	0,9	0,7	1,2	15,1	17,9
25	10	400	541	111	30	10	0,9	0,8	1,3	17,1	20,2
26	10	400	501	74	27	9	0,9	0,7	1,3	16,1	19,0
27	11	440	582	111	31	10	0,9	0,8	1,4	18,1	21,3
28	11	440	542	74	28	10	0,9	0,8	1,3	17,1	20,1
29	12	480	623	111	32	11	0,9	0,9	1,5	19,1	22,4

30	12	480	583	74	29	10	0,9	0,8	1,4	18,1	21,3
	152	6 080	9 258	2 442	767	221	40	20	28	345	433

Table 3-7 presents the relevant cost data of this scenario:

Table 3-7: Lunar Orbit Tourist Program cost summary for years 11 through 30

1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
operational year	direct Cpf (M \$)	amor. burden	prime miss. (M \$)	amor. burden	1000 (\$/pass direct)	plus burden	Total Cost/pass.	Total comm. sales	progr. totalM (\$/a)
11	100,0	45,3	109,8	48,9	2745	1222	3967	635	1265
12	99,5	45,3	109,2	48,9	2729	1222	3951	632	827
13	98,2	45,3	107,8	48,9	2695	1222	3917	627	3001
14	97,6	45,3	107,1	48,9	2677	1222	3899	624	790
15	96,4	45,3	105,8	48,9	2646	1222	3867	773	1276
16	96,0	45,3	105,3	48,9	2633	1222	3855	771	862
17	95,6	45,3	104,8	48,8	2621	1220	3842	922	882
18	95,2	45,3	104,4	48,8	2610	1220	3830	919	901
19	94,4	45,3	103,6	48,8	2589	1220	3809	1066	1660
20	91,7	45,3	100,6	48,8	2515	1220	3735	1045	1054
21	91,3	45,3	100,1	48,8	2503	1220	3723	1191	1054
22	91,1	45,3	99,9	48,8	2497	1220	3717	1189	981
23	89,9	45,3	98,6	48,8	2465	1220	3685	1327	1578
24	89,7	45,3	98,3	48,8	2459	1219	3678	1324	1024
25	89,3	45,3	97,9	48,8	2447	1219	3666	1466	1239
26	85,4	45,3	93,6	48,8	2340	1219	3559	1424	1337
27	84,8	45,3	93,0	48,8	2325	1219	3544	1559	1568
28	84,2	45,3	92,3	48,8	2307	1219	3526	1551	1205
29	80,1	45,3	87,7	48,8	2192	1219	3411	1637	1339
30	74,0	29,8	81,0	31,6	2024	790	2814	1350	1511
MEAN	89,0	44,1	97,5	47,4	2438	1186	3624	1102	1268

As can be seen from these figures it will be very important whether or not these tourists are expected to share the upfront amortization cost. The difference is close to one million dollar for each tourist to participate in this endeavor. The total income from tourism would amount to 22 B out of the program total of \$

66.5 B. Mission cost are plotted versus operational year in figure 3-4 for the purpose of comparison with other space transportation systems.

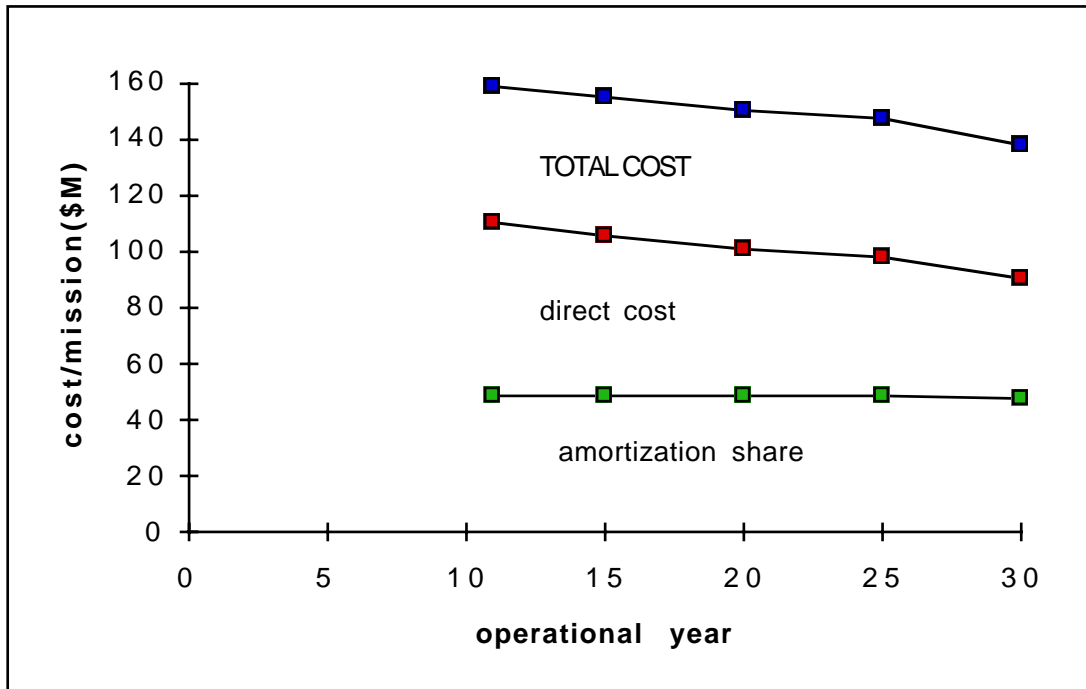


Figure 3-4: Mission cost of tourist flights to lunar orbit with and without amortization share

Figure 3-5 illustrates that the income from the tourist missions is very close to the total operational cost of the program in this phase! The peak in year 13 is caused by the cost of one additional launch vehicle required due to the higher launch rate resulting from the tourist missions.

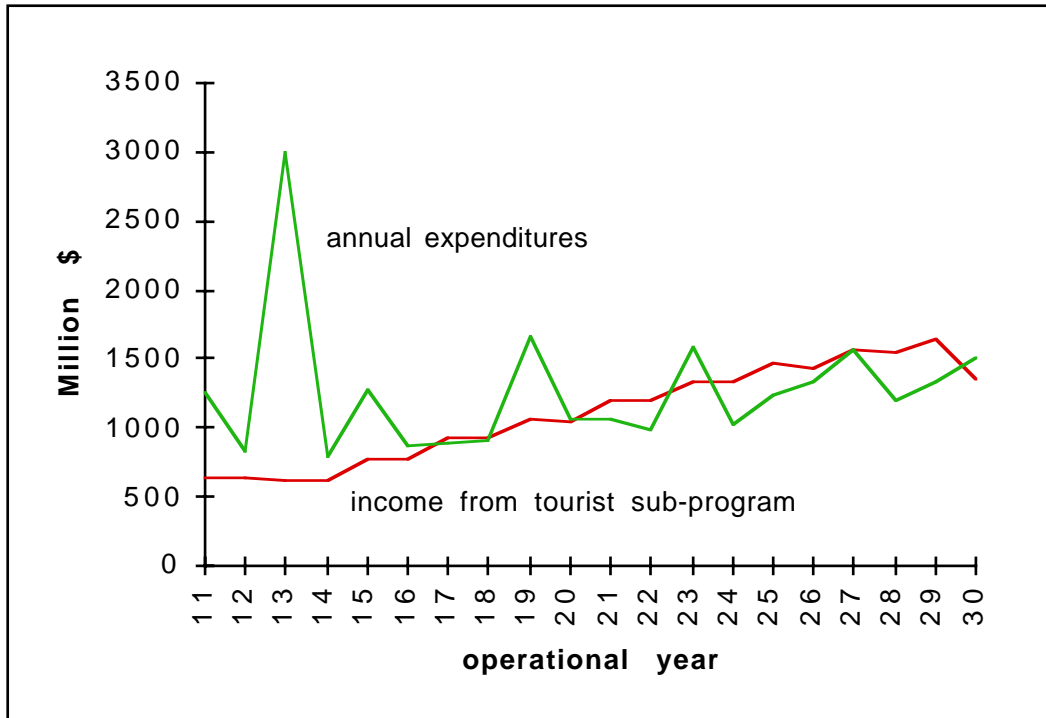


Figure 3-5: Comparison of annual total program expenditures including lunar base logistics with income from tourist flights to lunar orbit

Potential space travelers would like to know the price of a trip to the Moon. The price will be higher than the cost per roundtrip and is up to the operator. He will set prices the market can take. Thus prices cannot be projected, but the probable cost can be estimated and are depicted in figure 3-6.

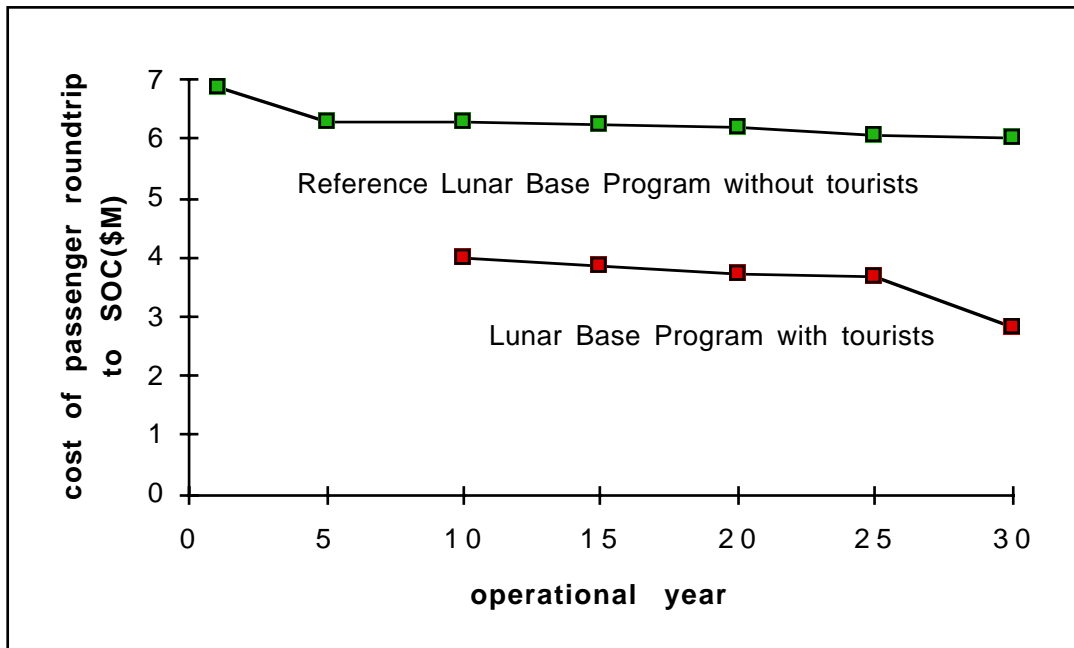


Figure 3-6: Cost of passenger roundtrips to lunar orbit (M \$/passenger) with year 2000 dollar value conversion factor 1 direct man-year = 0.2 M \$

If things go real well, it is conceivable that tourists in due course will have a chance to spend some time on the Moon as guests of the Lunar Base. Cost of the trip from a space station circling the Moon down to the surface and back can be estimated, because astronauts have do this already beginning in 2016, if the envisioned scenario comes about. In addition to the transportation cost the weekly accommodation cost in the habitat have been listed as an item to be paid by lunar tourists.

Table 3-8: Lunar crew transportation cost associated with a trip from SOC to Lunar Base with a LUBUS vehicle in the 3rd decade of reference Lunar Base operations

1.	2.	3.	4.	5.	6.	7.	8.	9.
operational year	prime mission (M\$)	amor. burden (M\$)	total cost per mission (M \$)	1000 \$/pass direct cost	1000 \$/pers. amort. burden	total cost/person (M \$)	annual habitat cost (M\$/person)	1000 \$/week and person
21	26,0	49,6	75,6	702	1339	2,04	8,54	0,164
22	26,3	49,5	75,8	710	1339	2,05	8,54	0,164
23	25,7	49,5	75,2	695	1339	2,03	8,43	0,162
24	26,2	42,0	68,2	708	1136	1,84	8,36	0,161
25	25,5	40,3	65,8	690	1090	1,78	8,25	0,159
26	25,9	40,3	66,2	700	1090	1,79	8,20	0,157
27	25,3	40,3	65,6	685	1090	1,78	8,06	0,155
28	25,8	15,1	40,9	697	409	1,11	8,03	0,154
29	24,7	1,6	26,3	668	42	0,71	7,91	0,152
30	24,8	1,5	26,3	669	42	0,71	7,87	0,151
av.	26	33	59	692	892	1,58	8,2	0,158

Respective cost data for the roundtrip from lunar orbit to lunar base are presented in the table 3-7 for the last of the three operational decades the Lunar Base operation was simulated. While these are cost to the participating governments, they should not be to far away from the prices one would have to charge to tourists. Indications are that cost totals for one week on the Moon are about \$ 2.0 M in addition to the trip cost to the space station in lunar orbit, not including a surcharge for using lunar oxygen propellant for the up-flight. The drop-off during the last years is the result of the fact that amortization costs have been paid in full. To add these costs to the Earth to lunar orbit cost, this would bring the total for such an adventure trip to the Moon close to 5 million dollar/person.

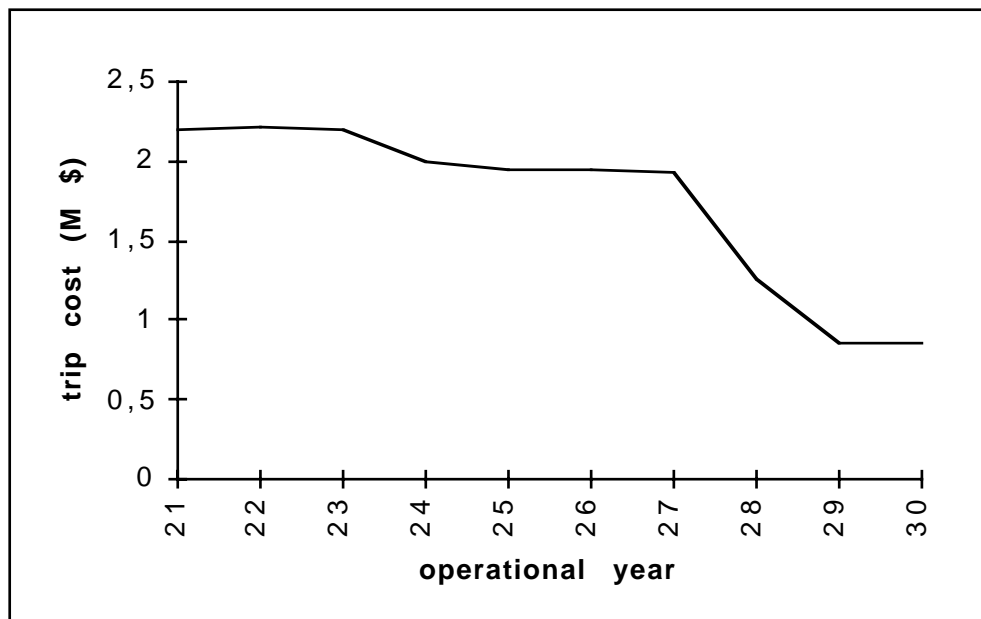


Figure 3-7: Total cost of roundtrips between lunar orbit and lunar base during third decade of base operation including habitat cost share for one week

While these are the total and annual average values, specific transportation cost of passengers to lunar orbit with and without a supplemental tourist program have an interesting trend versus time. It pays to wait, as the transportation cost go down with years of operation as one would expect. The trends are shown in figure 3-8 and 3-9. They show the difference between lunar orbit and lunar base transportation cost, as well as the influence of the add-on tourist program. Note the difference of specific direct cost/passenger and specific total cost/passenger. The latter includes a share of the up-front amortization cost.

The use of the accommodations in lunar orbit for several days does not come for free and must be calculated in detail. However, this will be small if compared to the transportation cost.

It must be pointed out that in a program that includes a trip down to the lunar surface must include a charge for using lunar oxygen on the flight back to lunar orbit. These are not included in the numbers above and depend on the type of commercial operation taking place. A surcharge of about 10% for lunar oxygen might be of the right order.

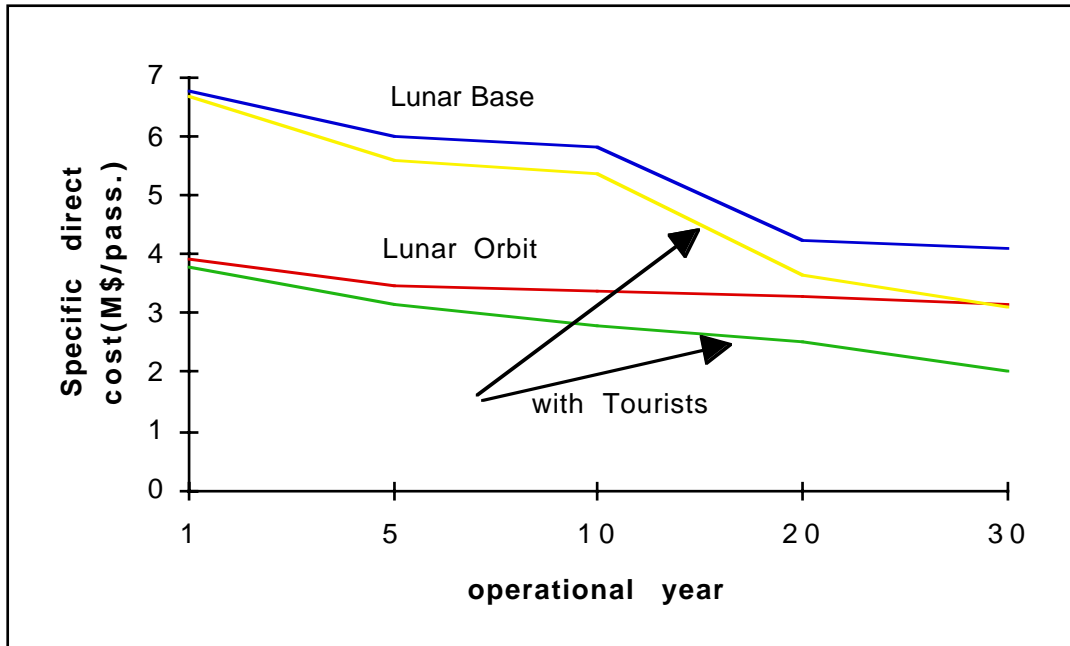


Figure 3-8: General trend of specific direct cost of passenger roundtrips to lunar orbit and lunar surface with and without a tourist supplement program

The drop after 10th year is due to the use of lunar oxygen, the drop during the last decade is due to the end of SOC and PTM amortization

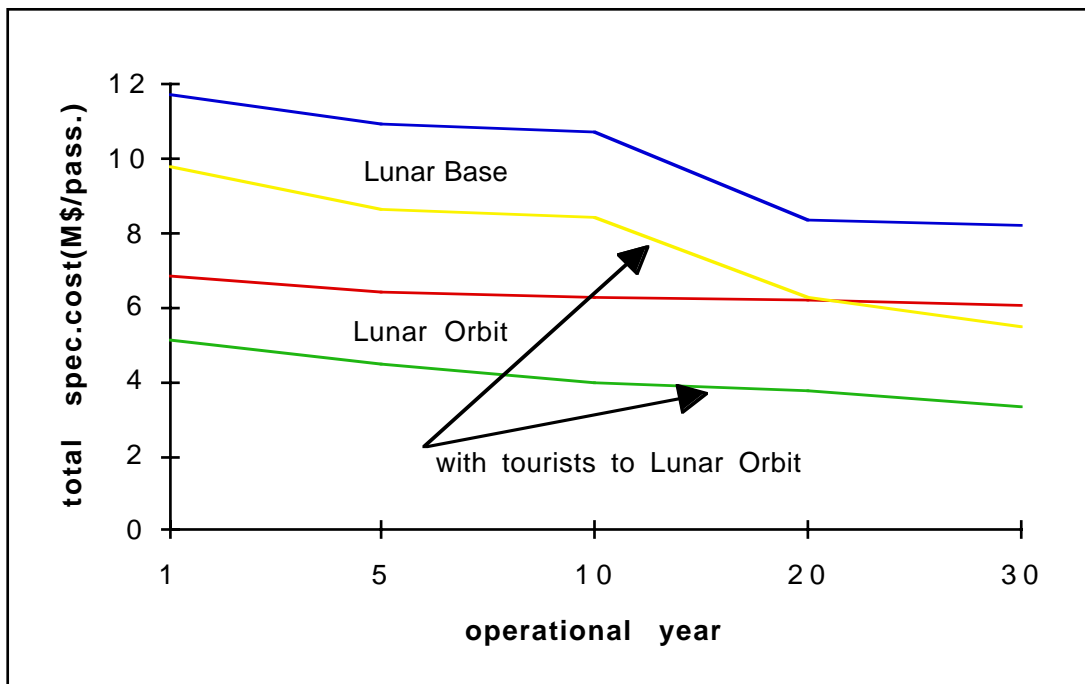


Figure 3-9: General trend of total specific cost (1000 \$/passenger) of passenger roundtrips to lunar orbit and lunar surface with and without a tourist supplement program

The drop after 10th year is due to increased use of lunar oxygen, the drop during the last decade is due to the end of SOC and PTM amortization

4. Summary

4.1 Results of the Analysis

Lunar tourism is a possibility that could become a reality during this century! Based on the technology in hand or within reach a reusable and cost-effective "Space Transportation System" could be developed during the next two decades that can support logistically a permanent Lunar Base. A "Space Operations Center" in Lunar orbit would be part of this logistic system, in such a scenario passengers and cargo would be transferred from the Earth launch vehicle to the Lunar Landing vehicle and vice versa. In due course of development it is conceivable that this space station in lunar orbit could be extended to accommodate tourists for a short period (e.g. one week). As soon as the space transportation system has demonstrated satisfactory reliability and passenger safety, tourists may also want to visit the Lunar Base for a few days.

This analysis is based on a reference lunar development scenario that envisions a return of humans to the Moon in year 2016 after a 10-year development phase[14]. Within a 10- year construction phase the lunar crew grows from about 25 to 75 and the mass of lunar facilities and equipment would be close to 1,000 metric tons. Pilot production begins with manufacturing of construction materials and lunar oxygen for life support and propellants.

This construction phase is followed by a 20-year consolidation phase. At that 30-year operational period the lunar crew increases from about 25 to 100 lunar astronauts. These would be permanently stationed at the Lunar Base, rotated initially every 6 months and later annually, to explore and utilize lunar resources. The characteristics of such a Lunar Development Program are presented in the appendix.

In such a program scenario lunar tourism would have a chance. It would begin with quarterly missions to the space operations center in lunar orbit in year 2026, with 40 tourists on each flight lasting about two weeks. If the market justifies the launch rate could grow to one per month at the end of this 20 -year consolidation period.

Two significant parameters sizing any space tourist program are the number of paying tourists that can be transported in a single mission and the annual launch of the space vehicle transporting them to the point of destination. More comfort means a smaller number of tourists! A detailed design of the Passenger Transportation Module (PTM) is not yet available, the number of passengers/mission may be estimated to be between 40 and 50 depending on level of comfort and safety features provided, probably fewer in the first years as the market develops, in this case study 40 passengers to Lunar orbit/mission have been assumed. The growth rates are illustrated in the graph below.

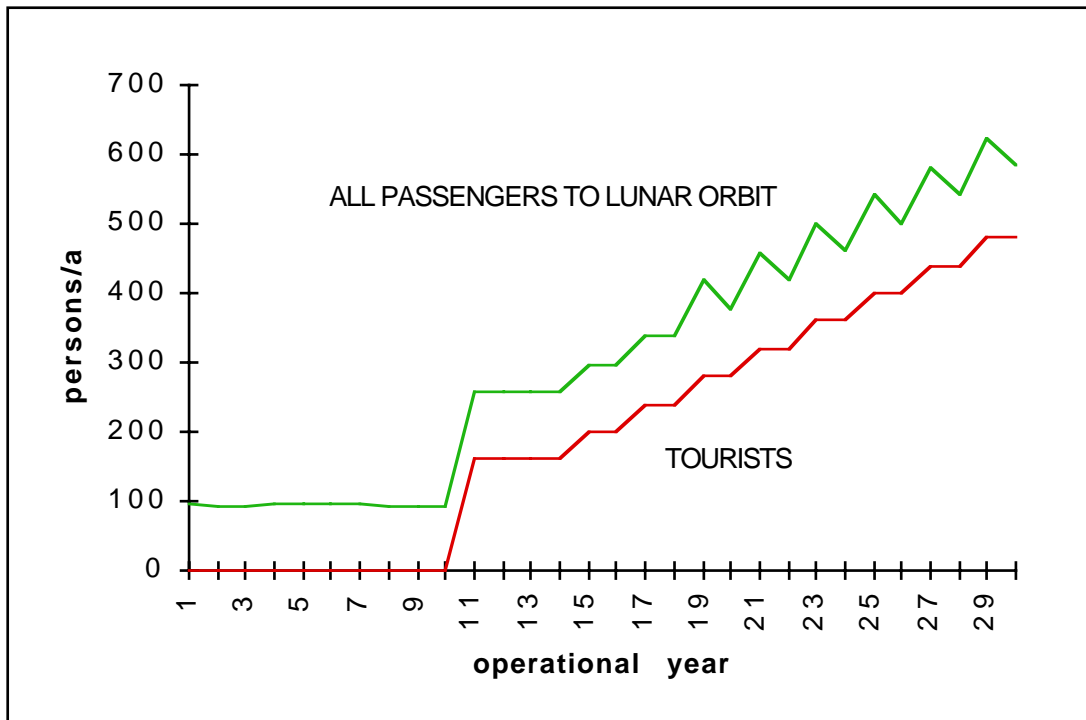


Figure 4-1: Number of lunar tourists and total sales from lunar tourism

It is not unlikely that in due course lunar tourists would want to make a short trip to the Lunar Base and make a cross country ride. This may become possible in the third decade of Lunar Base operation at a time the reliability and safety of the people has been demonstrated.

4.2 Effect of Lunar Tourism on Reference Lunar Base Program

The initial Lunar Base Program that includes development of corresponding space transportation system (STS) assumes a financing concept involving only public funds coming from the national space budgets. STS up-front costs accumulating during the acquisition period can be amortized as indirect cost and distributed over all primary missions executed during the program life cycle.

To judge the size of the proposed enterprise it is necessary to put these two program options into perspective: In the reference Lunar Base logistic support program model 257 missions are scheduled during 30 operational years. The lunar tourist add-on program proposed assumes 152 additional primary missions. These 152 missions could be charged with some of the acquisition cost and thus reduce the indirect cost of the entire Lunar Base Program. In addition, the higher launch rate leads to more efficient operation reducing recurrent cost of passenger and cargo missions to the lunar surface. These differences are savings in the order

of ten billion \$ to the public investors that need to be quantified. These effects are summarized in table 4-1 and offer an overview of the program proposed.

Table 4-1: Accumulative Effects of Tourism on Lunar Base Program Costs

1.	Total expenditures of Lunar Program including Tourists to SOC During operational years 11 - 30	66.5 B \$
2.	Total logistic expenditures for reference Lunar Base support program (10 development + 30 operational years)	53.9 B \$
3.	Difference in total program cost of these two options	12.6 B \$
4.	Logistic expenditures of 442 mission program, operational years 11-30 only, including 152 tourist missions to LUO-SOC	25.0 B \$
5.	Logistic expenditures of 257 mission program without tourist missions, operational years 11-30 only	14.5 B \$
6.	Difference during operational 20 years relative increase	10.5 B \$
7.	Total number of tourists to SOC in years 11-30 152 missions @ 40 passengers/mission	6,080
8.	Direct cost pro primary mission/SOC passenger	2.44 M \$
9.	Possible amortization charge per SOC passenger	1.19 M \$
10.	Total ticket sales during operational years 11-30 (6,080 x 2.438 M \$)	14.8 B \$
11.	Possible contribution to amortization of upfront cost (6,080 x 1.186 M \$)	7.2 B \$
12.	Total potential sales in tourism sub-program (11. + 12.)	22 B \$
13.	Total acquisition cost of space transportation system	21.6 B \$
14.	Total operating cost in years 1-30 (66.5-21.6)	44.9 B \$
15.	Possible tourist share of acquisition cost (7.2/21.6)	33 %
16.	Tourist share of logistic expenditures during operational years (14.8/44.9)	33 %
17.	Cost of the lunar base program to the public after deduction of commercial sales by tourist program (66.5 - 22.0)	45.5 B \$

18.	Savings if compared to reference lunar base program (53.9 – 45.5)	8.4 B \$
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It must be pointed out again that the lunar tourist program proposed is a complement sub-program to an existing Lunar Base Program, financed by public funds. In this case the difference of the funding profile over the forty years of the assumed life cycle are relatively small as figure 4-2 illustrates.

The income from the tourist missions would pay nearly the entire operation during the second half of the operational life cycle as the graphic presentation shows.

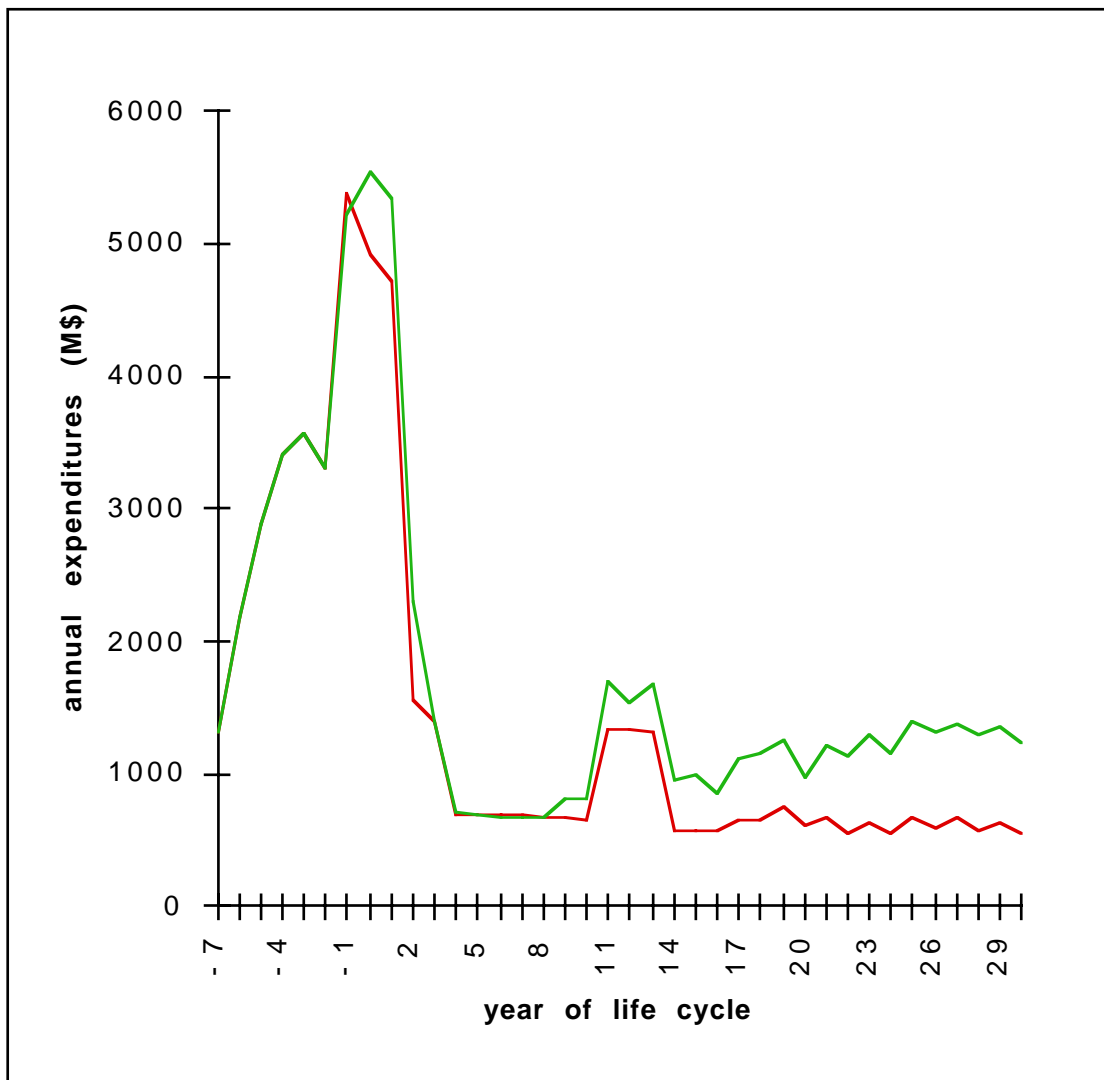


Figure 4-2: Annual expenditures over the entire life cycle for the reference lunar base program (lower curve) and the lunar program that includes a sub-program for tourists to lunar orbit.

4.3 Conclusions:

1. An opportunity for commercial tourist flights to the Moon would develop in case political priorities would allow a decision to return people to the Moon. In such a scenario investments required for lunar facilities and a companion space transportation system would be financed through national space budgets.

2. A preliminary analysis, including a life cycle simulation of the entire system, demonstrates that it may well be feasible and likely that in a complementing commercial sub-program some thirty years from now, a few hundred tourists may visit the Moon annually.

3. Preliminary estimates indicate that the ticket cost to the lunar orbit space station should be close to 4 million dollars. A visit of the lunar surface would require additional 2 million dollars.

4. A tourism program to a space station in lunar orbit would lead to higher efficiencies of the logistic system that in turn would reduce the operating cost of the Lunar Base.

4.4 Recommendations

1. In the search for a successor to the current SPACE SHUTTLE , replacing it in about ten years, the possible use of the selected space vehicle as an orbital carrier for tourists should be taken into consideration and actively supported.

2. Vehicle concepts proposed for individual market segments of the space tourism market can and should be evaluated soon systematically against weighted vehicle attributes to insure a viable selection and a long life cycle.

3. In case attractive vehicle concepts are lacking for a viable space tourist market projection, a ranked list of selection criteria could assist in finding the most attractive concepts compatible with the defined vehicle features using the morphological method.

4. This chance of developing a viable program of lunar tourism is worth to be analyzed in depth in the years to come.

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APPENDIX

In the context of the development scenario analyzed the architecture and performance characteristics of the lunar base has a great effect on the logistic system. For this reason it becomes necessary to present a summary of Lunar Base Data.

LUNAR BASE PERFORMANCE(LIFE CYCLE AVERAGES) -Date: January 2002

(1) scientific crew members, fac.7	26.3
(2) production crew members, fac.1-6,8-10	10.8
(3) service crew members, fac.11-20	38.4
(4) total crew members in situ	75.5
(5) NN	.0
(6) share of scientific crew members (%)	31.7
(7) share of production crew members (%)	15.0
(8) share of service crew members (%)	53.3
(9) lunar soil mined, fac.1 (Mt/a)	24383.
(10) beneficiated lunar soil, fac.2 (Mt/a)	2695.
(11) output of chemical plant, fac.3 (Mt/a)	1516.
(12) output of mechanical plant, fac.4 (Mt/a)	1348.
(13) output of parts shop, fac.5 (Mt/a)	140.
(14) output of assembly shop, fac.6 (Mt/a)	0.
(15) input of gas plant, fac.9 (Mt/a)	115.
(16) output of LOX plant, fac.9 (Mt/a)	112.
(17) output of power plant, fac.11 (kW)	2107.
(18) throughput of workshop, fac.15 (Mt/a)	121.
(19) transport volume performed by car pool (Mt*km/a)	113176.
(20) primary mass flow through habitat, fac.18 (Mt/a)	131.
(21) primary mass flow through recycling fac. (Mt/a)	845.
(22) gas leakages, fac.7,15,18 (Mt/a)	19.
(23) water leakages, fac.19 (Mt/a)	22.
(24) dumped lunar soil, fac.1,2 (Mt/a)	21688.
(25) mass of production & laboratory fac. 1-10 (Mt)	443.
(26) mass of living facilities 17-19 (Mt)	362.
(27) mass of infrastructure, fac.11-16 (Mt)	568.
(28) total mass of lunar facilities (Mt)	1373.
(29) mass share of production & laboratory fac. (%)	31.4
(30) mass share of living facilities (%)	26.4
(31) mass share of infrastructure (%)	42.2
(32) lunar products for export (Mt/a)	1314.
(33) lunar products for direct usage at l. base (Mt/a)	107.
(34) lunar produced propellants (Mt/a)	86.
(35) total lunar products (Mt/a)	1507.
(36) oxygen and other gases for lunar usage (Mt/a)	47.
(37) carbondioxide prod. by crew for recycling (Mt/a)	27.
(38) wastes of habitat & recycling facility (Mt/a)	9.
(39) lunar produced consumables (Mt/a)	3.
(40) lunar produced hardware (extens. & spares) (Mt/a)	20.
(41) imported extensions and spares (Mt/a)	87.
(42) imported production additives (Mt/a)	19.

(43) imported food, water & gases (Mt/a)	68.
(44) imported anorganic supplies & consumables (Mt/a)	38.
(45) imported propellants (Mt/a)	0.
(46) total lunar imports (Mt/a)	212.
(47) import rate = total imports / total products (%)	14.1
(48) mass of living facilities / total crew (Mt/pers)	4.89
(49) lunar products / production crew (Mt/a/pers)	137.8
(50) lunar products / production fac. mass (Mt/a/Mt)	3.57
(51) power plant output / lunar products (kW/Mt/a)	1.40
(52) annual spares demand / total facility mass (%/a)	6.2
(53) air & water leakage / air & water consumption (%)	35.3
(54) lunar products / lunar soil mined (%)	6.2
(55) lunar produced hardware/total hardware demand (%)	18.9
(56) lunar products/lunar products & total imports (%)	87.6

