PROGRAM PROPOSAL FOR A JAPANESE TOURIST RLV FLEET

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The objective of this paper is to present a Reusable Launch Vehicle (RLV) Program as a recommendation for the establishment of a mass space tourism market. Due to the limitations existing in the past, the commercial realization of RLVs has been stifled. This study demonstrates that extensive operations of RLVs in the future are a possibility to develop the space transportation market more profitable and to pave the way for new applications of aerospace technology.

To examine a viable business model for space tourism flights, a multi-vehicle space carrier fleet cost model, called TRASIM, is used. Development, production and operation of the investigated RLV are based on novel industrial processes driven by cost engineering techniques.

Keywords: Cost Estimation, Kankoh Maru Plus, Reusable Launch Vehicle, Scenario Technique, Space Tourism

INTRODUCTION

The most challenging task for a successful establishment of a mass space tourism market is to link the gap between today's conditions and conceived future demands concerning technical, economic and political aspects. In the current situation, only few manned missions are performed annually, which are very costly and must be planned years in advance. In the future, rockets must have operating characteristics like airliners with low launch costs and high transportation volume. Mankind must get accustomed to space tourism by developing the necessary awareness, technology and infrastructure in a step to step learning process. It appears desirable to realize mass space tourism by accomplishing the following three steps, interacting with each other as shown schematically in Figure 1.[1,2]

- Step 1: Increasing space awareness for the general public
- Step 2: Developing and operating a suborbital vehicle for semi-regular flights
- Step 3: Developing and operating an orbital vehicle for regular flights

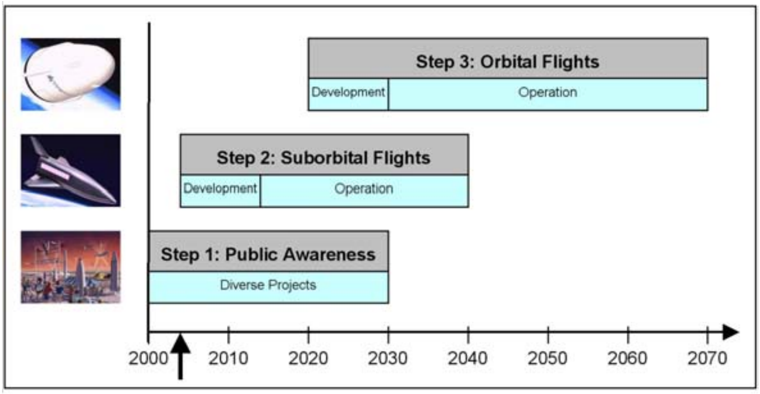

Figure 1: Proposed Life-cycle Scenario for Mass Space Tourism

This paper presents a proposal for step 3 “Developing and operating an orbital vehicle for regular flights”. A proposed time frame of this step is from year 2030 to year 2070. A reusable launcher concept based on the Kankoh Maru project investigated by the Japanese Rocket Society (JRS) since 1993 would be most suitable for that kind of flight.[2] The most involved companies are: Kawasaki Heavy Industries, Ltd., Fuji Heavy Industries, Ltd., Nissan Motor Co., Ltd. and All Nippon Airways Co., Ltd. The author has slightly modified the present version of Kankoh Maru. This modified version is named Kankoh Maru Plus and it is shown in Figure 2. In particular, more effort in terms of costs of development is placed on safety equipment. Kankoh Maru Plus is assumed to be capable to perform an orbital trajectory within 24 hours carrying 50 passengers launched from diverse spaceports around the world. The aim is to use advanced technology and infrastructure to realize an aircraft-like operation.

In Japanese, "Kankoh" means tourism and "Maru" means ship, so “Kankoh Maru” roughly means “Tourism Ship”.

Figure 2: Kankoh Maru Plus (Kawasaki)

FLIGHT PROFILE

After boarding, Kankoh Maru Plus would start vertically from a launch pad as shown in Figure 3. Thrust for take-off would be supplied by 12 engines. After 6 minutes of ascent, the vehicle would achieve an altitude of 200 km and orbit Earth for a maximum of 24 hours. The minimum flight duration would be about two to three hours, or one or two orbits respectively as shown in Figure 4.[3] There would be sufficient time in space for passengers to explore weightlessness and watch the Earth. Then, a tail first reentry in the atmosphere would be performed and the vehicle would land vertically by using rocket engines to slow down. Spaceports could be located next to existing airports. Thus, passengers could just change from one terminal to the other for their connection flights back to their home airport. The orbital flight events should be also surrounded by an optional pre-flight and post-flight program taking about one or two weeks.

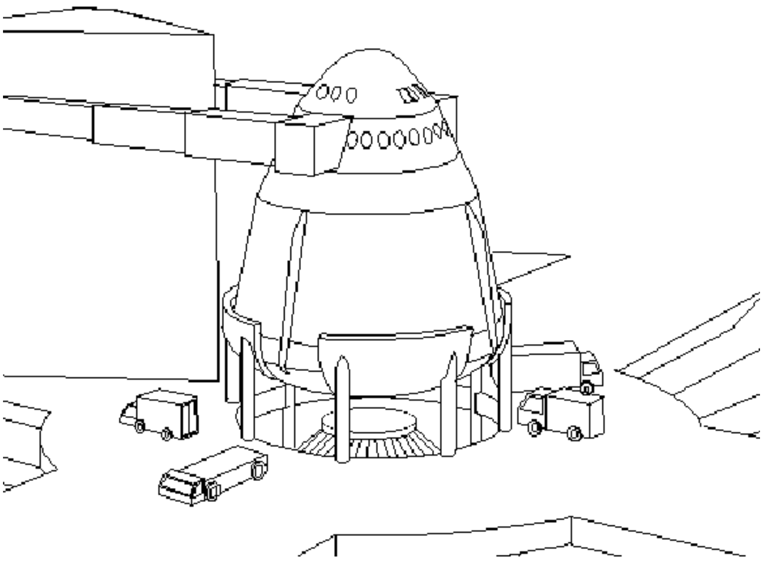

Figure 3: Boarding of Kankoh Maru Plus (Anderson)

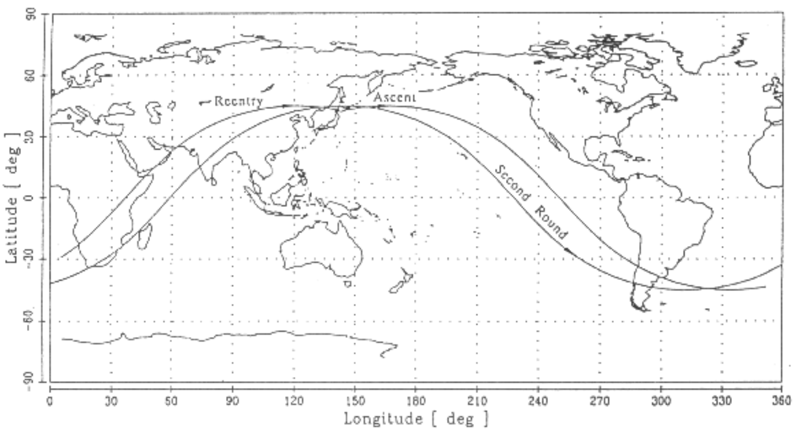

Figure 4: Ground Track for short Flight Duration (Isozaki et al.)

For verification of the ascent trajectory a simulation model called ATS[4,5] has been used. A thrust versus time profile from a Kankoh Maru study[6] has been used for the input data of the model. Table 1 shows estimated ascent phases.

Table 1: Ascent Phases of Kankoh Maru Plus

Phase	Description	Begin [s]	End [s]	Pitch Rate [°/s]
0	Liftoff (Begin)	0	0	-
1	Vertical ascent	0	17	-
2	Pitch rate	17	38	0,9
3	Gravity turn	38	242	-
4	Pitch rate	242	330	0,6
5	Low Earth Orbit (End)	330	86 400	-

As a result of this simulation, Figure 5 shows the expected thrust and altitude profile during the ascent of Kankoh Maru Plus. An increase in thrust for the first 90 seconds would result from the fact that specific impulse increases with lower air density. After 90 seconds of flight, engines would begin to be throttled in order not to exceed accelerations of 3 g for passenger comfort. An orbit of 200 km for perigee altitude, 362 km for apogee altitude and an inclination of 45° might be reached after 330 seconds. Due to the high cross section area of 254 m^2, Kankoh Maru Plus would be decelerated by air particles while orbiting and would need occasional small thrust impulses to maintain its orbit trajectory.

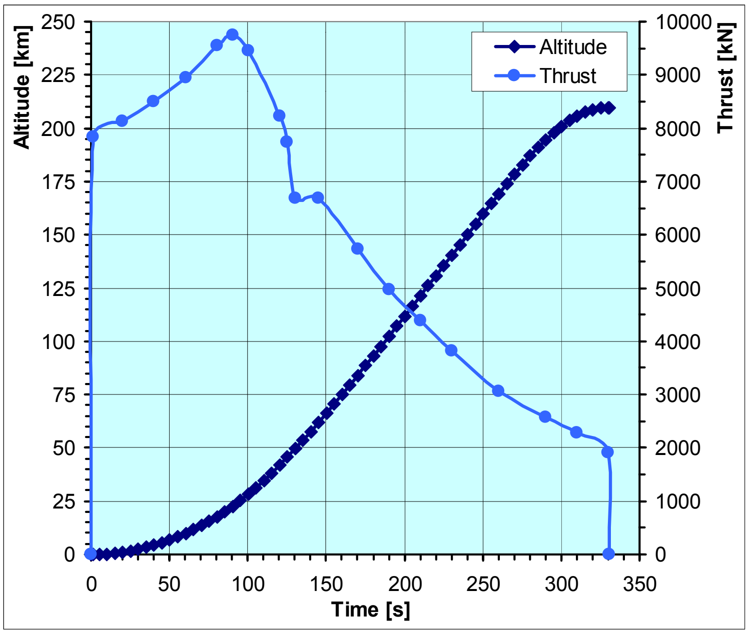

Figure 5: Thrust and Altitude Profile during Ascent of Kankoh Maru Plus

The technique of vertical take-off and landing, as well as a short turn-around time with a minimum ground staff was demonstrated by two experimental vehicles: the American DC-XA (Delta Clipper Experimental Advanced) in 1996 and the Japanese RVT (Reusable Vehicle Test) in 2001. Take-off and landing procedures are some of the critical items that are very different from that of aircraft and helicopters in the matter of abort capability. Generally, ballistic Single-Stage-To-Orbit (SSTO) vehicles would have a lower launch mass and a lower dry mass compared to winged SSTO vehicles. However, they would require a higher net mass due to the propellant demand for vertical landing mode.

VEHICLE

Kankoh Maru Plus is assumed to be an aluminum and composite spacecraft. It might have a body length of 22 m with a bottom diameter of 18 m as shown in Figure 6.[7] Its gross lift-off weight is supposed to be 550 Mg. The vehicle afterbody would be designed to use the vehicle exhaust as an aerospike nozzle flow in order to increase efficiency at all altitudes. It would consist of two sections: the propulsion section and the main passenger compartment surmounting it. Kankoh Maru Plus would use 12 engines, burning liquid oxygen and liquid hydrogen. Four of the engines are assumed to be booster engines, optimized for low altitude operation and shut down a few minutes after lift-off. The other eight engines are supposed to be sustainer engines, optimized for vacuum operation.[8]

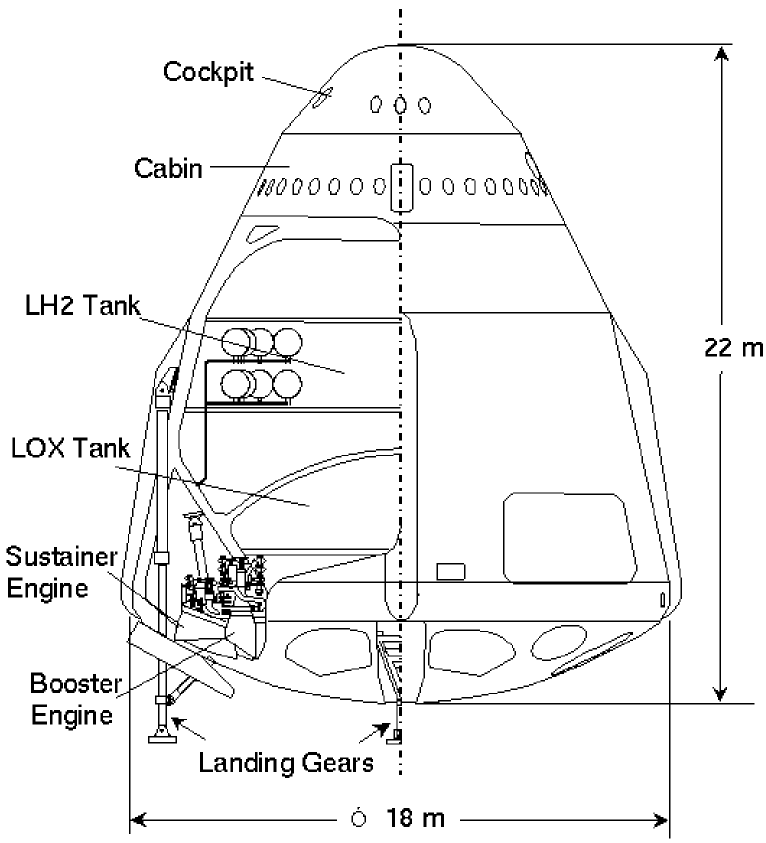

Figure 6: Vehicle Design (Isozaki et al.)

The cockpit is assumed to be located atop the main passenger compartment. The vehicle might employ a split crew concept. Onboard crew stations would be provided for a pilot and a flight engineer, while the copilot, navigator and ground crew chief would be located on the ground. They would maintain a continuous real-time link to Kankoh Maru Plus through satellites. This arrangement is assumed to provide safety through redundancy and reduction of individual workload.

PASSENGER COMPARTMENT

There would be a main passenger compartment consisting of 43 standard seats plus two flight attendant seats in the lower deck and a small passenger compartment with 7 first class seats next to the cockpit in the upper deck as shown in Figure 7. Seats might be lined up forming circle to provide better view through windows. Two zero gravity amusement spaces would be provided to prevent the floating passengers from kicking each other's head. Lower deck dimensions are assumed to be Ø9,5 m x 2 m, while upper deck dimensions would be Ø6,5 m x 2 m. Usable volume per passenger would be about 9 m³.

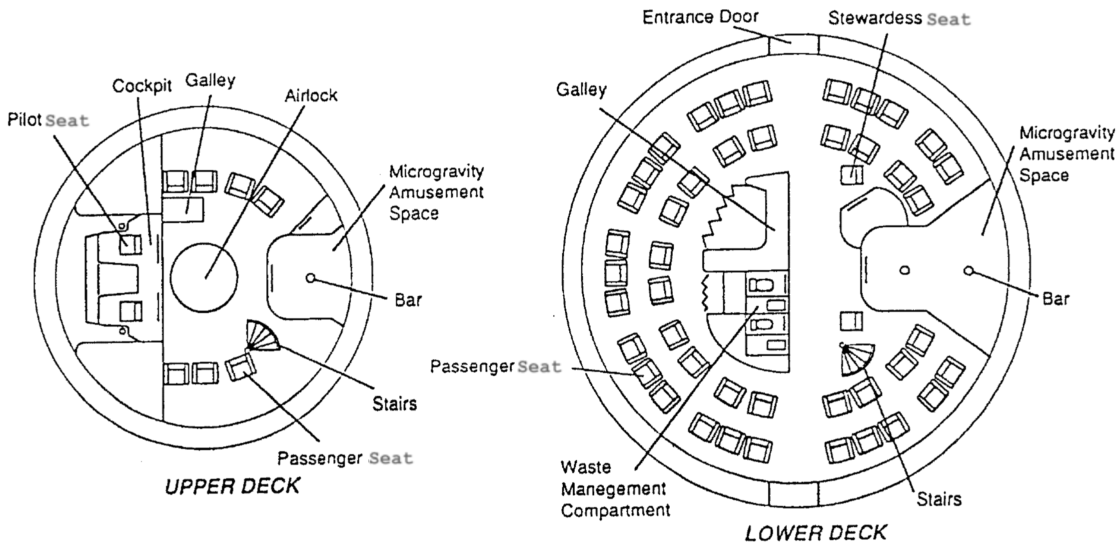

Figure 7: Upper (left) and Lower (right) Deck Arrangement (Isozaki et al.)

MASS CHARACTERISTICS

Assumed mass characteristic of Kankoh Maru Plus is shown in Table 2. A 10 % mass margin is distributed over all components.

Table 2: Mass Characteristics (based on: Isozaki et al., 1994)

Subsystem	Total	Unit
Cold Structure	10,4	Mg
Hot Structure	3,9	Mg
LH2 Tanks	8,9	Mg
LO2 Tanks	4,1	Mg
Equipment	8,0	Mg
Engines	13,5	Mg
Recovery	1,4	Mg
DRY MASS	**50,2**	**Mg**
Payload	5,0	Mg
Propellants	494,9	Mg
TAKE-OFF MASS	**550,1**	**Mg**

PROGRAM ASSUMPTIONS

Table 3 to Table 7 show a selection of key assumptions made for the scenario, which are used for a simulation with TRASIM.

Table 3: Vehicle Model (totally 80 input values each)

Parameter	Kankoh Maru Plus	Unit
Vehicle Life Time	15	years
Fleet Operational Period	40	years
Initial Development Activity	2020	year
Initial Operating Capability	2030	year
Development Period (+ margin)	8 (+ 2)	years
Cold Structure Reuses	600	-
Hot Structure Reuses	100	-
Fuel Tank Reuses	450	-
Oxidizer Tank Reuses	450	-
Equipment Reuses	250	-
Engine Reuses	300	-
Recovery Equipment Reuses	250	-

Table 4: Mission Model (totally 50 input values each)

Parameter	Kankoh Maru Plus	Unit
Missions (for year 1, year 2, …, year n)	25-2000	LpA

Table 5: Operations Model (totally 60 input values each)

Parameter	Kankoh Maru Plus	Unit
Manpower Cost for Development	205 000	$/MY
Manpower Cost for Production	200 000	$/MY
Manpower Cost for Operations	220 000	$/MY
Payload	50	pax
Mission Reliability	99,8	%
Learning Factor for Pre-launch, Integration and Refurbishment of Subsystems	0,85 (<1000 missions)	-
	0,90 (1000-4000 missions)	-
	1,00 (>4000 missions)	-

Table 6: Production Model (totally 120 input values each)

Parameter	Kankoh Maru Plus	Unit
Production Rate (for year 1, year 2, …, year n)	continuous	-
Catastrophic Failure Rate (year 1-10)	0,001	-
Catastrophic Failure Rate (year 11-30)	0,0008	-
Catastrophic Failure Rate (year 31-40)	0,0006	-
Minimum Allowable Launch Pad Interval	3	days
Learning Factor for Production of Subsystems (<100 units)	0,90	-
Learning Factor for Production of Subsystems (100-1000 units)	0,95	-
Learning Factor for Production of Subsystems (>1000 units)	1,00	-
Spare Part Factor of Subsystems of Cost per Flight	0,4-0,5	%
Learning Factor for Spare Parts of Subsystems	0,90	-

Table 7: Financing Model (totally 70 input values each)

Parameter	Kankoh Maru Plus	Unit
Ticket Price (for year 1, year 2, …, year n)	0,869-0,099	M$
Fiscal Share of Frontend Investment	40	%
Interest Rate of Capital for Enterprise Frontend Cost	2,5	%
Interest Rate of Capital for Fiscal Frontend Cost	3,0	%
Interest Rate of Capital for Enterprise Recurring Cost	3,0	%
Interest Rate of Credits for Enterprise after Break-even	5,0	%
Interest Rate of Credits for Fiscal after Break-even	5,0	%
Tax Rate on Enterprise Sales	10	%
Tax Rate on Enterprise Yield	25	%

RESULTS

It should be kept in mind that Hopper Plus, a suborbital vehicle, would start operations in year 2013 while Kankoh Maru Plus would start operation in year 2030. All results refer to assumptions made for the specific three-step scenario illustrated in the beginning of this paper. Thus, Hopper Plus' and Kankoh Maru Plus' economic performances are assumed to correlate because there would exist an overlapping period of operations of 11 years. It is assumed that no other mass tourist space transportation systems except Hopper Plus and Kankoh Maru Plus would be in operation.

Phases of System Realization

In addition to feasibility aspects of a vehicle concept, the probability of realizing the vehicle under real world political and financial conditions must be analyzed. Figure 8 shows a first approach to a representative life-cycle scenario for Kankoh Maru Plus.

It is assumed that the period from the Preliminary Phase (Pre-phase A) to the Production Phase (Phase D) could be accomplished within 10 years for Kankoh Maru Plus. Operation Phase (Phase E) is determined to be 40 years and would be completed by a 1/2 year Abolition Phase (Phase F). Necessary flights for prototype testing and system certification could be used to transport satellites or astronauts first, while civilians should only be transported after certification. In this study, it is assumed that enough demand for some satellite launches would exist.

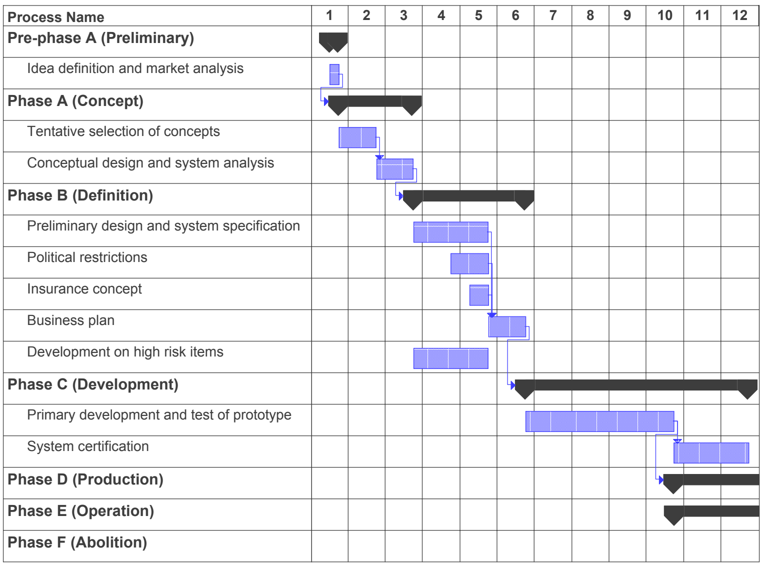

Figure 8: Master Schedule

Performances

Table 8, Table 9 and Table 10 summarize the main system, business and market performances of Kankoh Maru Plus. Used tools for cost estimation are TRASIM 2.0[9] and TRANSCOST 7.0[10], 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. Used tool for financial estimation is FINANCE 1.0[2] to process the results achieved from cost estimation models.

Table 8: System Performance

	Kankoh Maru Plus	Unit
Initial Development Activity	2020	year
Initial Operating Capability	2030	year
Fleet Operational Period	40	years
Cumulative Flights	42 450	flights
Cumulative Transportation Volume	2 122 500	pax
Average Yearly Flights	1061	flights/year
Average Yearly Transportation Volume	53 063	pax/year
Total Vehicle Production	122	-
Total Vehicle Losses	37	-
Total Vehicle Withdrawn	30	-
Total Vehicle at End of Operation	55	-
Total Ground Facility Production	16	-

Table 9: Business Performance

	Kankoh Maru Plus			Unit
	Enterprise	Fiscal	Total	
Cumulative Receipts	258,1 (before sales tax)	0	258,1	B$
Cumulative 10 % Sales Tax Fee	-25,8	25,8	0	B$
Cumulative Interest Credits	68,3	49,4	117,7	B$
Cumulative Frontend Cost	-5,8	-3,9	-9,7	B$
Cumulative Recurring Cost	-107,1	0	-107,1	B$
Cumulative Financing Cost	-2,0	-2,2	-4,2	B$
Cumulative 25 % Yield Tax Fee	-46,4	46,4	0	B$
Cumulative Yield	139,3 (after yield tax)	115,5	254,8	B$
Break-even Point	8	14	-	years
Average Yearly ROI	46,5	56,3	-	%/year

Table 10: Market Performance

	Kankoh Maru Plus			Unit
	Enterprise	Fiscal	Total	
Launch Cost (average)	2,7	0,1	2,8	M$
Launch Price (average)	5,5	0,6	6,1	M$
Ticket Cost (average)	0,053	0,002	0,055	M$
Ticket Price (average)	0,110	0,012	0,122	M$
Ticket Price (first year)	0,782	0,087	0,869	M$
Ticket Price (last year)	0,089	0,010	0,099	M$

CONCLUSION

A third-generation Reusable Launch Vehicle program such as Kankoh Maru Plus might replace Hopper Plus, a suborbital vehicle, in this scenario as a vehicle with strong system, economic and market performance. It is assumed to have the ability to further establish space tourism as a mass market by its airline-like operation philosophy. Experience of operators and trust of investors would exist already for the passenger space transportation market because of using Hopper Plus for suborbital flights. The space transportation system would have an attractive economic performance and a high safety standard. Kankoh Maru Plus is assumed to have the potential and would open the market to increase flight frequency (up to 2000 flights per year) and launch/landing locations (16 spaceports worldwide) enormously.

Defined 3 steps scenario is a recommendation to establish a successful mass space tourism market. Parallel to this scenario, an individual space tourism market could exist having the following components: in the coming years up to 2008 a few tourist flights per year to International Space Station (ISS) might become normal. This could be supplemented by some “only short stay in orbit” flights with expendable rockets such as Soyuz. The next step after 2008 would be a small tourist compartment fixed to ISS and slightly increased tourist flights to ISS. Suborbital semi or full reusable flights with a tiny vehicle (such as Russian C-21 vehicle concept) for one or two tourists might be used for weakly flights. However, development of this individual space market in next decades is assumed to be limited: flight frequency would stay low and prices would stay high with less potential to decrease.

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LIST OF ABBREVIATIONS

B$	[-]	Billion US dollars
DC-XA	[-]	Delta Clipper Experimental Advanced
g	[m/s^2]	Acceleration of standard gravity

ISS	[-]	International Space Station
JRS	[-]	Japanese Rocket Society
LpA	[-]	Launches per Annum
MY	[-]	Man Year
M$	[-]	Million US dollars
pax	[-]	Passenger
RLV	[-]	Reusable Launch Vehicle
ROI	[-]	Return on Investment
RVT	[-]	Reusable Vehicle Test
SSTO	[-]	Single-Stage-To-Orbit

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