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A Ticket pricing strategy for an oligopolistic space tourism market☆

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Abstract

It is important for any new launch system to develop a successful pricing strategy and to optimize launch system parameters to receive a high economic profit. A question arises, what will happen when an existing suborbital flight market (the first likely to be established in space) is interfered with by a new established orbital flight market for space tourism. There is a risk that the suborbital space tourism market could be almost instantly displaced when a product capable of reaching orbit was introduced. This is best discussed using the following three cases whose results are presented in this paper. Case A presents a ticket pricing strategy for a suborbital and orbital vehicle if the two vehicles do not compete in the same market. Case B shows the necessary ticket pricing strategy for a suborbital vehicle if there is competition from an orbital flight operator. However, the suborbital vehicle would not be able to keep up with a drop in ticket prices due to its obsolete characteristics. Thus, the suborbital vehicle would be forced to stop operation in the year when flight costs became higher than flight receipts as shown in case C.
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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 has come at a high cost. It industry since market 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 gain 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 since market analysis studies [1–4] supply evidence that prospective passengers are largely driven by ticket prices as shown in Fig. 1.

The most challenging task for the successful establishment of a mass space tourism market is to link the gap between today's conditions and potential future demand in technical, economic and political terms. In the current situation, only a few manned missions are performed annually. They 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. The result of the study presented here suggest that it is desirable to realize mass space tourism by accomplishing the following three interdependent steps.

- Step 1: increasing space awareness aiming 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.

A launch operator is generally interested in maximizing economic profit and market shares by

1. optimizing launch system parameters (reducing total costs) and/or
2. developing a successful pricing strategy (increasing total revenue).

In reference to this objective of maximizing profit a question arises as to what will happen when an existing

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Nomenclature

a	system-specific constant value, (MY/Mg^{x})
B$	billion US dollars, dimensionless
C	cost, (M$)
d	cost conversion value, (M$/MY)
f_i	assessment factors, dimensionless
M	reference mass, (Mg)
Mg	mega grams, dimensionless
M$	million US dollars, dimensionless
x	system-specific cost/mass factor, dimensionless

suborbital flight market (presumed to be the first to be established) is interfered with by a new established orbital flight market for space tourism. Of particular interest is in this context is which strategy will be pursued by the suborbital operator and which by the orbital operator. An answer to this is given in the two principal sections, "Optimizing rocket fleet parameters" and "Ticket price strategy".

Results for Hopper Plus [5,6] and Kankoh Maru Plus [7–9], which are representative Reusable Launch Vehicle (RLV) concepts used in this investigation (for descriptions, see below), are presented in parallel to highlight similarities and differences. It should be kept in mind that Hopper Plus would start operations in 2013 while Kankoh Maru Plus would start operation in 2030. 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 major mass tourist space transportation systems except Hopper Plus and Kankoh Maru Plus would be in operation.

2. Representative reusable launch vehicles

2.1. General

In order to understand the economic results and strategic decisions made in this investigation, a short introduction of the two used vehicle concepts is given here.

2.2. Hopper Plus

As determined in a previous investigation, a reusable launcher concept based on Hopper project investigated by EADS ST company appears to be the best for space tourists. The author has modified the present version of Hopper in some aspects in order to make the vehicle more attractive for space tourism. In particular, an planned satellite payload with a upper stage is replaced by a passenger module, and reliability has been increased by accepting higher figures in terms of development, production, and operational costs. This modified version of Hopper is named Hopper Plus and is shown in Fig. 2.

The overall length of Hopper Plus is assumed to be 50 m with a wingspan of 27 m. Its gross lift-off weight would be 460 Mg including the passenger module. Hopper Plus might make wide use of Ariane 5 technology and elements, thus becoming within reach of mid-term realization. It would use three Vulcain 3R engines, which are Vulcain 3 engines adapted to reusability. Hopper Plus would require a larger total dry mass compared to Hopper. This is because of its added passenger module, which is supposed to be placed in the cargo bay, and because of increased power subsystem mass thanks to a higher power demand caused by the passenger module. Hopper Plus is assumed to be more complex than a high-speed aircraft but less demanding than orbital vehicles with re-entry maneuver

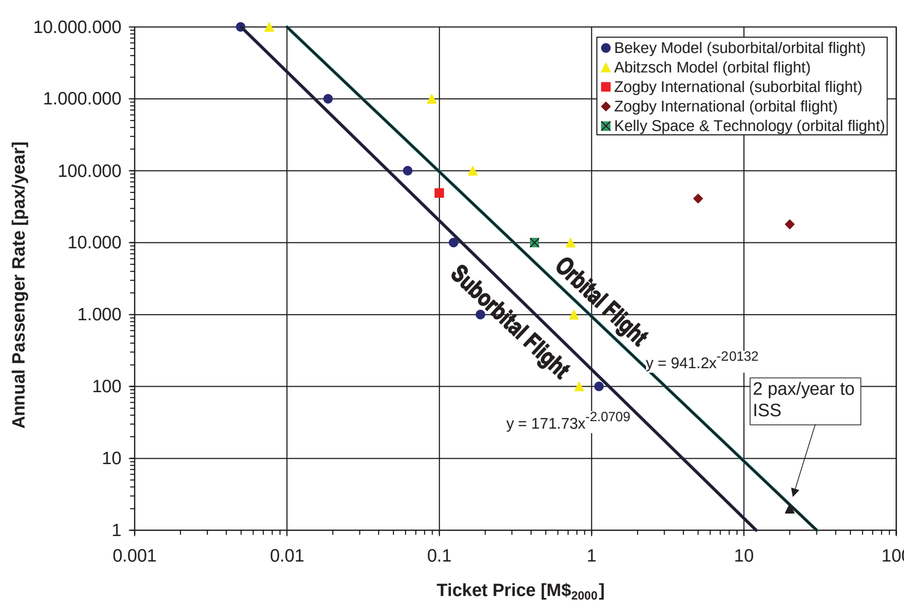

Fig. 1. Model of annual passenger rate as function of ticket price.

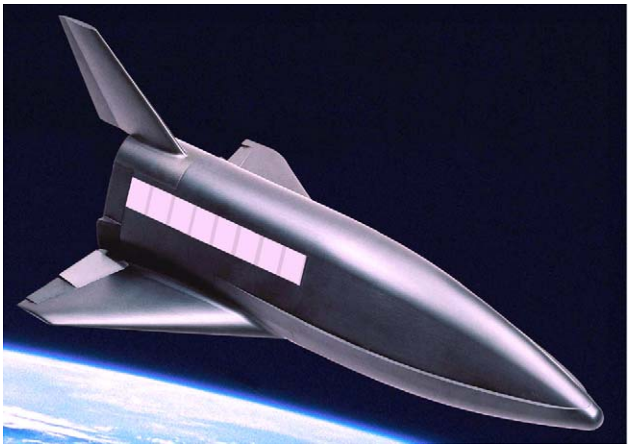

Fig. 2. Hopper Plus.

Fig. 3. Kankoh Maru Plus (Kawasaki).

would cause very high thermal loads due to higher deceleration.

Cargo bay dimensions are assumed at dia 5.4 m × 16.7 m. For comparison, aircraft cabin high-density arrangement with similar dimensions would allow the transport of 50 passengers (5 × 10 rows). To ensure a higher standard of space applications and more comfort for passengers a 4 × 8 row arrangement is used for the scenario. Passenger module dimensions might be dia 4.7 m × 16.0 m and the module would have a dry mass of 3.8 Mg. Usable volume per passenger would be about 4 m^3. This includes cabin structure (2.0 Mg), 30 passenger seats (1.0 Mg), 2 stewardess seats (0.1 Mg), 1 toilet (0.1 Mg), an environmental control system (0.5 Mg), and a 3.0 m long compartment for passengers to experience zero gravity (0.1 Mg).

2.3. *Kankoh Maru Plus*

For a future tourist orbital flight, a reusable launcher concept based on the Kankoh Maru project being conducted by the Japanese Rocket Society (JRS) since 1993 would be most suitable. The companies most involved 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 Fig. 3. In particular, more effort in terms of development costs is placed on safety equipment. Kankoh Maru Plus is assumed of be capable of performing an orbital trajectory within 24 h 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.

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. Its gross lift-off weight is would 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 would be sustainer engines, optimized for vacuum operation. 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 co-pilot, 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.

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 Fig. 4. Seats might be lined up forming a circle to provide a better view through the 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 dia 9.5 m × 2 m, while upper deck dimensions would be dia 6.5 m × 2 m. Usable volume per passenger would be about 9 m^3.

A suborbital market might be serviced by Hopper Plus. Later an orbital market – which would be an extension of a suborbital market in terms of value of attractions, excitement, relaxation, etc – might be serviced by an Kankoh Maru Plus. Customer expectations might be more satisfied by an orbital flight as long as the ticket price was in a similar range to that for a suborbital flight. That is why passengers might drift to an orbital flight it became available.

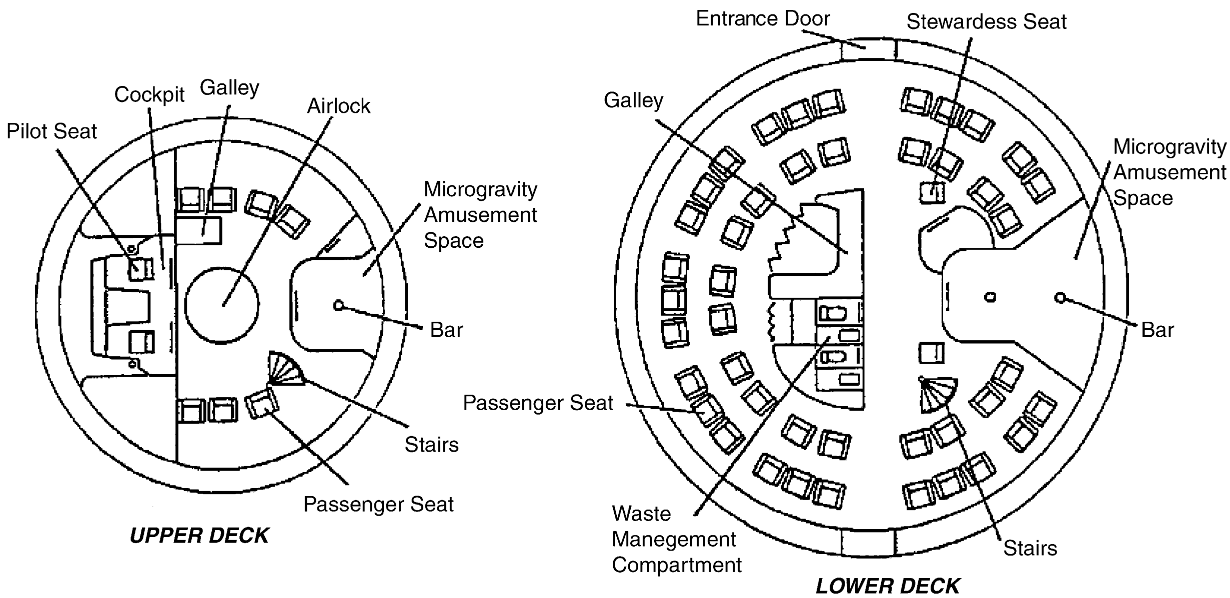

Fig. 4. Upper (left) and lower (right) deck arrangement (Isozaki et al.).

Table 1
Estimated development and production costs

Subsystem and other Items	Hopper Plus		Kankoh Maru Plus		Unit
	Development cost	Production cost (1st unit)	Development cost	Production cost (1st unit)	
Cold structure	813	190	587	84	M$
Hot structure	316	23	262	26	M$
LH2 tanks	158	17	859	64	M$
LOX tanks	153	11	368	35	M$
Equipment	2322	275	2048	226	M$
Engines	1114	71	2445	166	M$
Recovery	28	18	40	12	M$
Tooling	85	–	26	–	M$
System integration	1280	–	1924	–	M$
Prototype	605	–	613	–	M$
Ground facility (1st Unit)	1000	–	500	–	M$
Total	7874	605	9672	613	M$

3. Optimizing Rocket Fleet Parameter

3.1. General

The necessary ticket price is in correlation with many system and business performances of the vehicle fleet relating to achieving a high profit. The following parameters are investigated in detail:

- development and production costs,
- launch rate,
- full operational fleet,
- fleet life-cycle costs and receipts,
- enterprise receipts and cost per launch,
- ticket price and enterprise ticket cost,
- year of initial operational capability,
- cash flow,
- return on investment.

3.2. Development and production costs

As shown in Table 1, the total development cost is calculated to be $7.9 billion for Hopper Plus and $9.7 billion for Kankoh Maru Plus, which would be acceptable values for such fully reusable launch vehicles compared with existing aircraft and rockets. The first unit production cost is estimated to be about $0.6 billion for both Hopper Plus and Kankoh Maru Plus.

In an attempt to validate this data, the specific costs of Hopper Plus and Kankoh Maru Plus are compared to existing conventional rockets, rocket engines, aircraft and aircraft engines. The following trend curves [10] are complemented by some selected original vehicle and engine data for illustration. Trend curves are only a first indication and it is normal that existing data deviate from trend curves because various types of aircraft, rockets, rocket engines and aircraft engines exist.

It can be seen in Fig. 5 that specific development costs of conventional rockets are much higher than those of conventional aircraft. Some reasons are that spacecrafts have a more complex structure than aircraft when viewed per mass (in kg) and that spacecraft development is mostly carried out in a government-business environment where cost reductions are less important. Hopper Plus and Kankoh Maru Plus would be below the specific development costs of conventional rockets due to smart business the strategies. Ariane 5's core stage is below the specific development costs of conventional rockets due to its relatively simple technology requirements compared with other rocket stages. The reverse was the case for Concorde's relatively high technology requirements, which resulted in higher specific development costs than those of conventional aircraft.

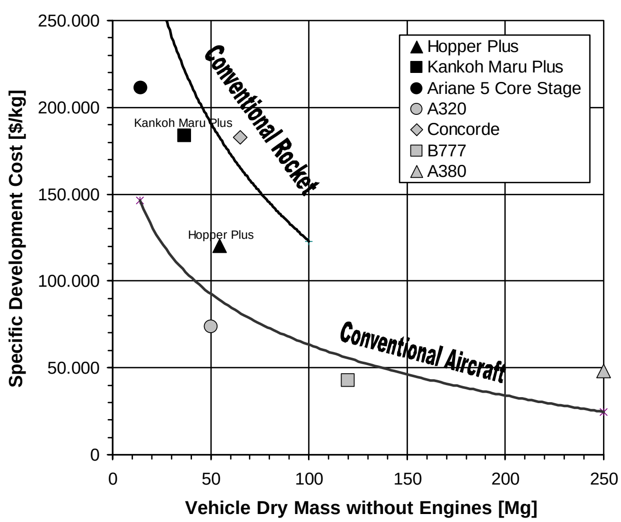

Fig. 5. Vehicle specific development cost.

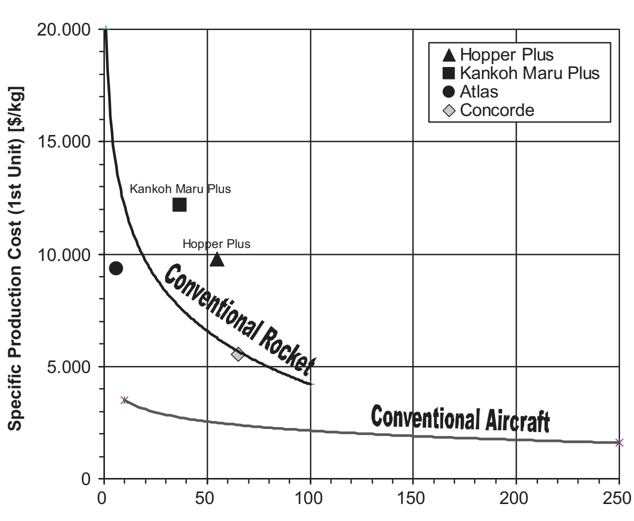

Fig. 6. Vehicle specific production cost.

Fig. 6 shows that the first unit-specific production costs of conventional rockets are higher than those of conventional aircraft. The reason for this is the assembly-line production of aircraft, while rockets are still produced unit by unit. With this in mind, Hopper Plus and Kankoh Maru Plus would have to lie below the standard specific production costs of conventional rockets because they are supposed to be produced similarly to aircraft due to their high production rate. However, the reusability character of these rockets would make them more expensive to produce in comparison with conventional expendable rockets [11].

3.3. Launch rate

The desirable maximum launch rate is determined to be 90 launches per year for Hopper Plus and 2000 launches per year for Kankoh Maru Plus as a result of a parametric variation. Figs. 7 and 8 show the influence of the launch rate on the economical performance as seen from the enterprise point of view.

In case of Hopper Plus, a higher launch rate would result in lower launch costs but also in a constant return on investment (ROI) and a later break-even point. The reason for this is that the market demand for passenger flights would be limited. A lower ticket price would stimulate demand. However, a decrease in ticket prices would be greater than a decrease in launch costs per passenger for higher launch rates. Thus, a higher launch rate would result in poorer economic parameters. A low launch rate would cause poor economic parameters too, due to relatively high operating costs and a small total learning effect.

In the case of Kankoh Maru Plus, an optimum launch rate for the break-even point and ROI, as shown for Hopper Plus, would not exist in the selected launch rate spectrum. Here, a higher launch rate would result in lower

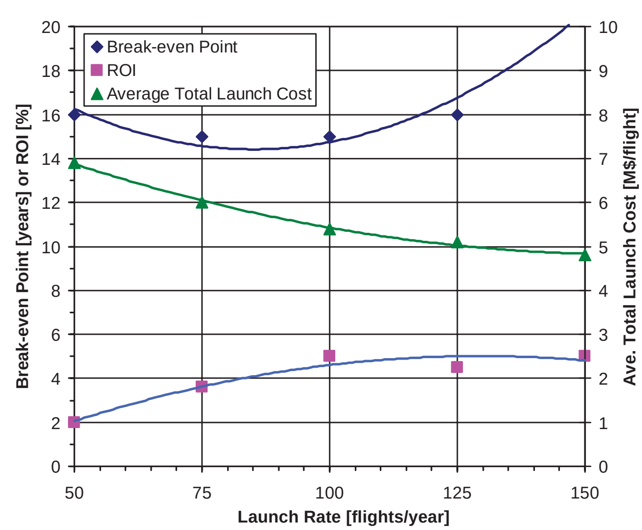

Fig. 7. Optimized launch rate of Hopper Plus.

launch costs and in a higher ROI and an earlier break-even point. The reason for this is that decreasing launch costs would be more effective than decreasing receipts per launch. From this point of view, a very high launch rate is desirable. Considering that the financial risk would increase with a larger fleet and that the necessary infrastructure (spaceports, propellant production facilities, etc.) would have to be established, a maximum launch rate should be limited to 2000 flights per year.

3.4. Full operational fleet

As shown in Figs. 9–11, the annual launch rate could be increased over time as result of learning effects achieved by maintenance and refurbishment improvements. The period to reach a full operational fleet is determined to be 10 years for Hopper Plus and 30 years for Kankoh Maru Plus. Figs. 10 and 12 show the influence of the period the to

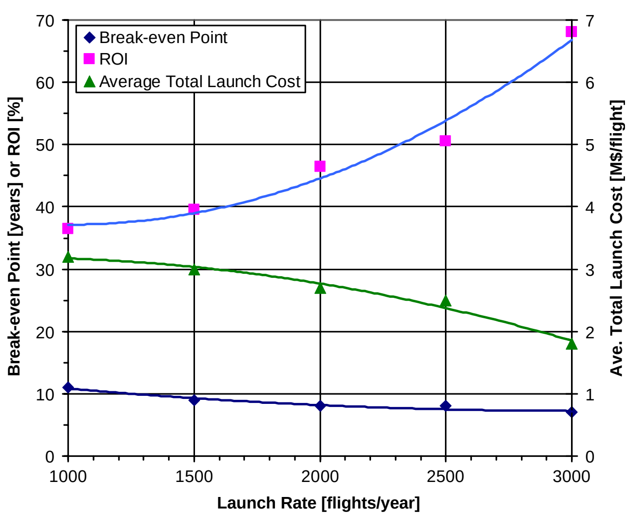

Fig. 8. Optimized launch rate of Kankoh Maru Plus.

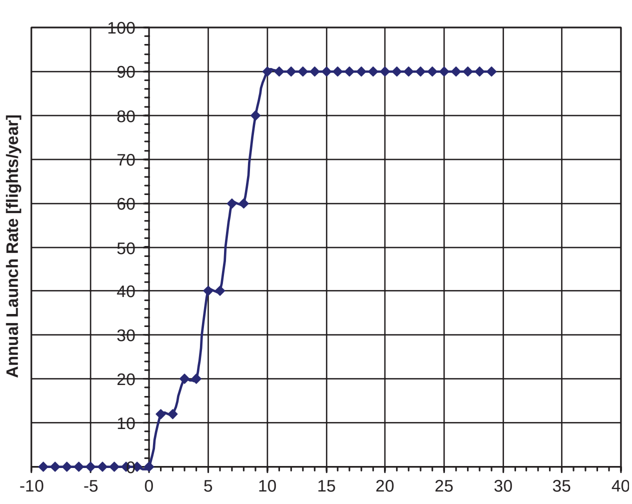

Fig. 9. Assumed annual launch rate for Hopper Plus.

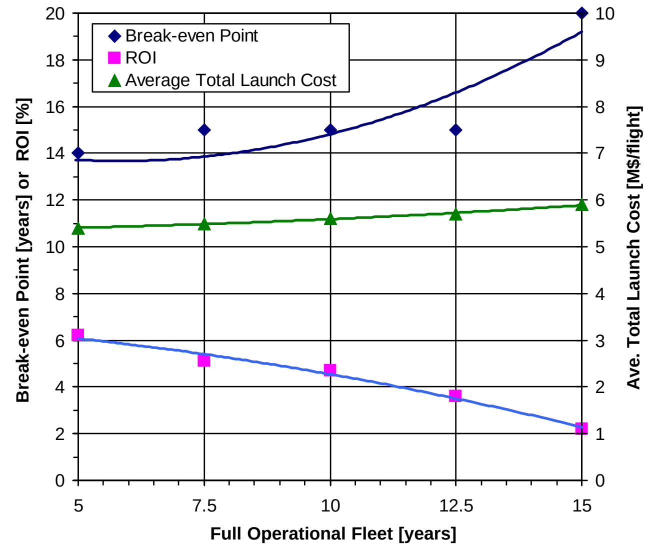

Fig. 10. Optimized full operational fleet for Hopper Plus.

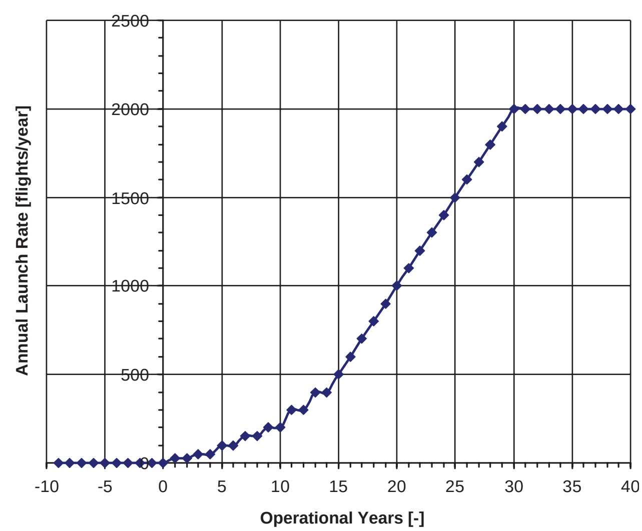

Fig. 11. Assumed annual launch rate of Kankoh Maru Plus.

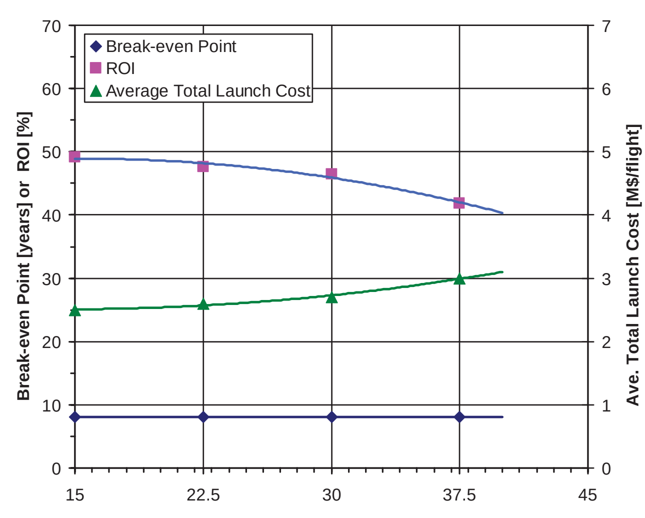

Fig. 12. Optimized full operational fleet of Kankoh Maru Plus.

reach a full operational fleet on required economic parameters of an enterprise. A reduced period would result in a better economic performance because of higher cumulative flights resulting in economies of scale. However, the catastrophic failure rate would increase as a result of there being less time to improve vehicles. An extended period would result in a lower economic performance due to high operating costs caused by small total learning effects.

In the case of Hopper Plus, it would appear reasonable to start out with three vehicles at the beginning of operations and then build three vehicles in the second-half of operations. Expansions and equipment acquisitions are assumed to have major impacts on capital requirements and financing needs, which would limit the rate of expansion. Available turn-around time of one vehicle would be 30 days for the first year but would decrease to 12 days in the final years thanks to higher utilization.

The minimum required turn-around time would be decreasing from 14 to 8 days over the operational period thanks to learning effects. Margins between available and required turn-around times are important for unexpected cases. For fleet operation, there is assumed to exist one spaceport for launch and one runway for landing.

In the case of Kankoh Maru Plus, the break-even point would be independent of the period to reach a full operational fleet. The reason for this is that the fleet architecture, and therefore economic performance, in the first decade would be similar for different periods to reach a full operational fleet. Thus, a break-even point of 8 years would be within this decade and therefore independent.

However, the influence of the period to reach a full operational fleet to ROI and average total launch cost parameters is similar to Hopper Plus trend curves. It would appear reasonable to build vehicles continuously so that a full operational fleet might consist of about 60 vehicles. The available turn-around time of one vehicle is assumed to be 29 days for the first year and would decrease to 10 days in the last year, while the minimum required turn-around time would be from 10 to 2 days. For fleet operation, there might exist 16 spaceports worldwide.

3.5. Fleet life-cycle costs and receipts

Figs. 13 and 14 show the distribution of front-end and recurring costs for enterprise and fiscal over the fleet life-cycle. As determined in the assumption section, there would be no recurring cost for public investors.

In the case of Hopper Plus, cumulative costs might be \$12.0 billion for enterprise and \$7.1 billion for fiscal. Development costs and the production of new vehicles (operational years 1–3 and 18–20) would cause the main peaks. Smaller peaks would be caused by spare parts for subsystems. The general trend shows a slight decrease of costs due to learning effects. Cumulative receipts from ticket sales for the Hopper Plus scenario would be \$16.2 billion.

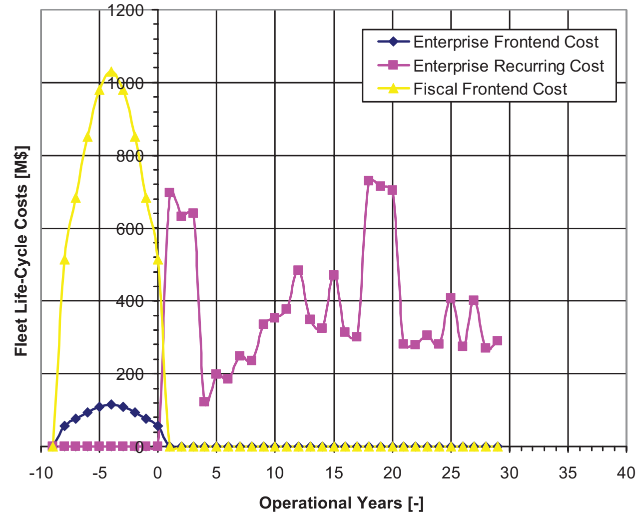

Fig. 13. Fleet life-cycle costs for Hopper Plus.

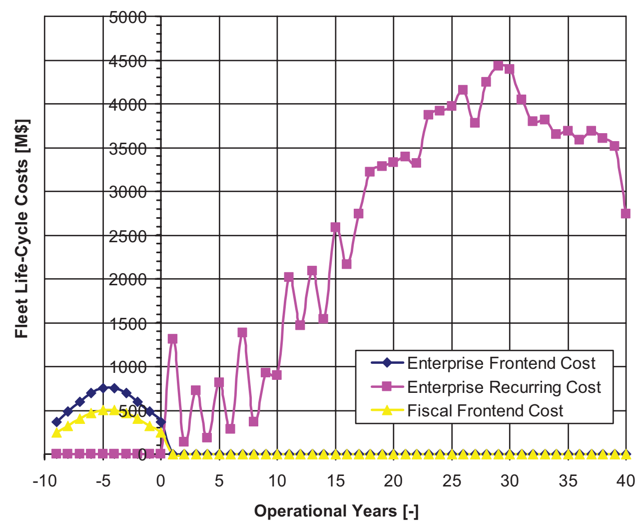

Fig. 14. Fleet life-cycle costs for Kankoh Maru Plus.

In the case of Kankoh Maru Plus, cumulative costs would be \$112.9 billion for enterprise and \$3.9 billion for fiscal. The general trend shows an increase in costs in the first 30 years due to fleet expansion. A decrease in costs due to learning effects would exist throughout the operational period but only become visible in the last 10 years of operations because of the saturated fleet size. Cumulative receipts for the Kankoh Maru Plus scenario would be \$258.1 billion.

3.6. Enterprise receipts and cost per launch

Figs. 15 and 16 show the depreciation of recurring and front-end costs as well as receipts before sales tax per launch.

In the case of Hopper Plus, the average total launch cost for the enterprise would be \$5.6 million with a share of \$5.2 million for average recurring costs and \$0.4 million for

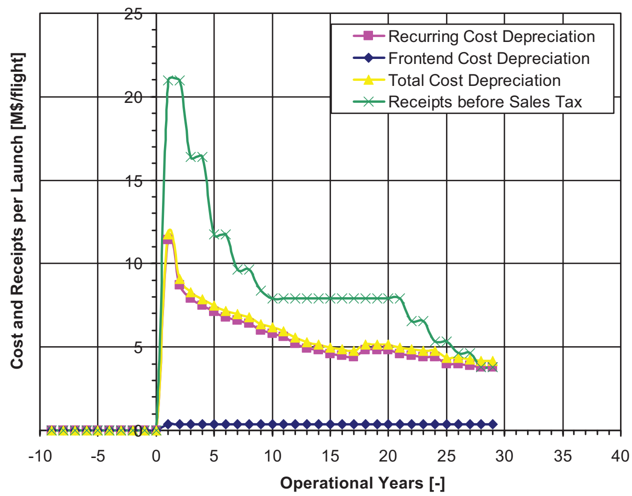

Fig. 15. Enterprise cost and receipts per launch for Hopper Plus.

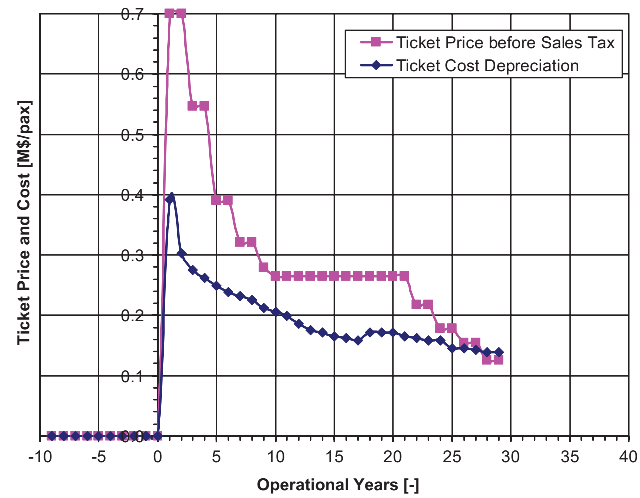

Fig. 17. Ticket price and enterprise ticket cost for Hopper Plus.

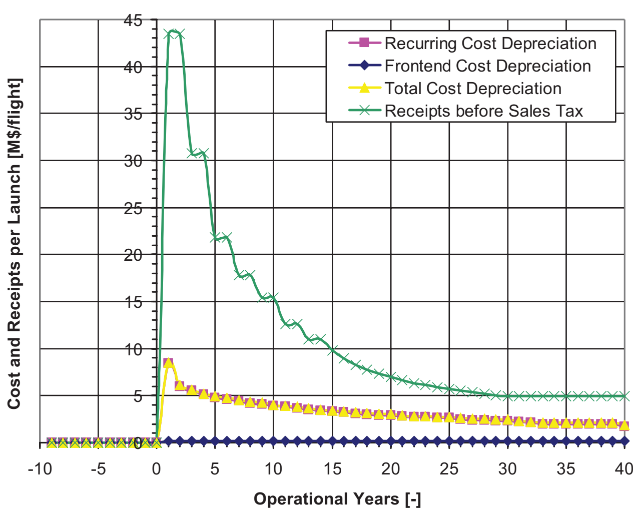

Fig. 16. Enterprise cost and receipts per launch for Kankoh Maru Plus.

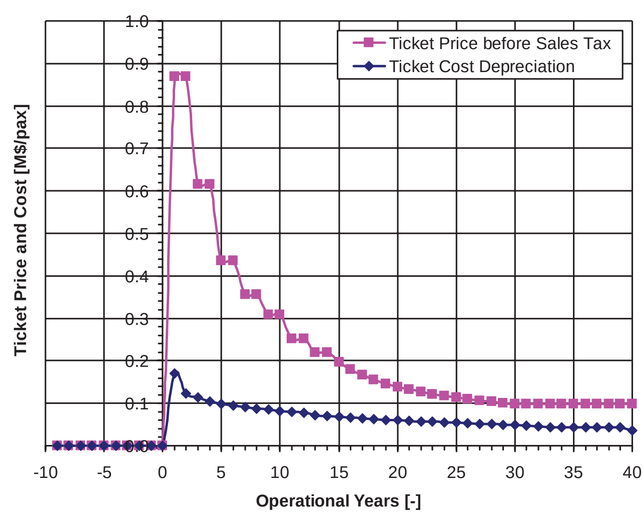

Fig. 18. Ticket price and enterprise ticket cost for Kankoh Maru Plus.

average fron-end costs. Comparing these figures with today's figures of expendable rockets, costs would be low. The potential of Hopper Plus to save on launch costs would be limited because it would use technology and infrastructure optimized for expendable launchers rather than reusable ones. Average receipts before sales tax would be $7.5 million per launch.

In the case of Kankoh Maru Plus, average total enterprise launch costs would be $2.7 million with a share of $2.5 million for average recurring costs and $0.2 million for average front-end costs. Average receipts before sales tax would be $6.1 million per launch.

3.7. Ticket price and enterprise ticket cost

Dividing receipts and cost per launch by passenger capacity per vehicle results in a ticket price and cost distribution over time as shown in Figs. 17 and 18. The so-called skimming price strategy is used, which means that the price can be high at the start because the kind of people who do not like to wait would buy a ticket anyway.

In the case of Hopper Plus, in the first year the ticket price would be set at $699 000 and it might drop to $126 000 within 29 years. Thus, transportation volume would start with 360 passengers per year and would increase to a maximum of 2700 passengers per year.

In the case of Kankoh Maru Plus, in the first year the ticket price would be set at $869 000 and it would drop to $99 000 within 30 years. Thus, the transportation volume might start with 1250 passengers per year and would increase to a maximum of 100 000 passengers per year.

3.8. Year of initial operational capability

What would happen to the economic performance of Hopper Plus if the start either of its own operations or of those of Kankoh Maru Plus were either premature or delayed? Fig. 19 shows how maximum economic perfor-

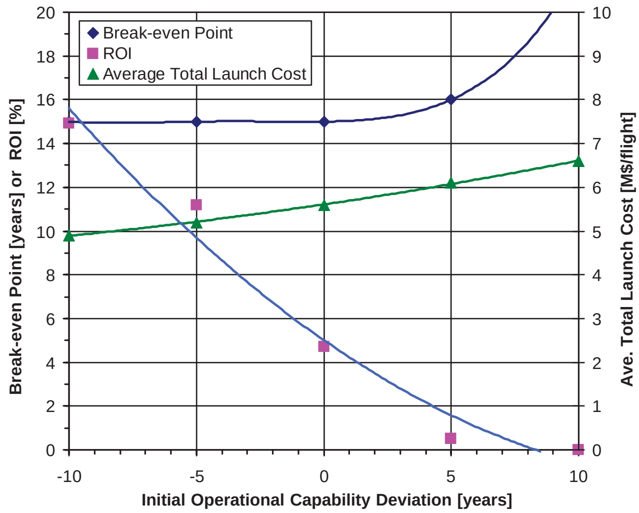

Fig. 19. Initial operational capability deviation for Hopper Plus.

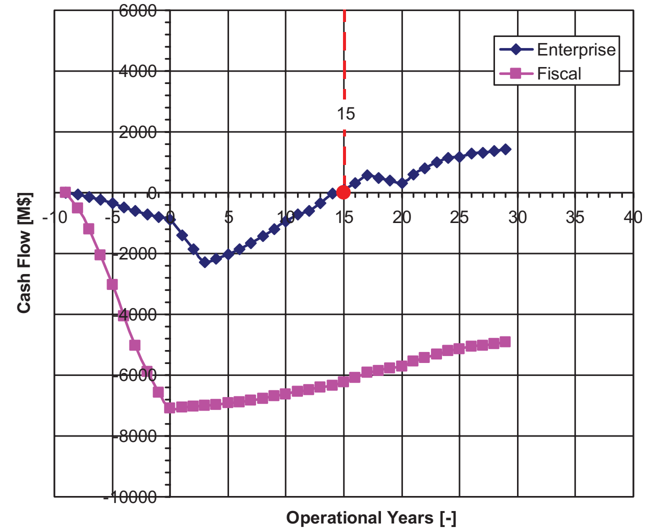

Fig. 20. Cash flow for Hopper Plus.

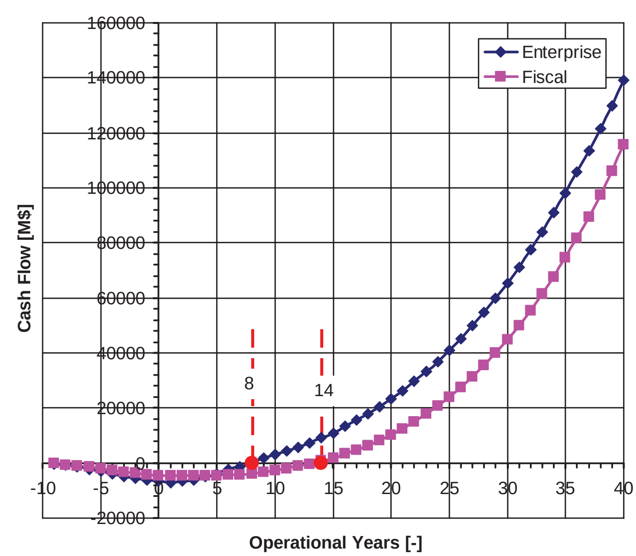

Fig. 21. Cash flow for Kankoh Maru Plus.

mance would depend on initial operational capability deviation.

It can be seen that if Hopper Plus became operational 8 years late (2021 instead of 2013) it might not be possible to achieve a ROI or an enterprise-positive cash flow respectively. From this point of view, operating Hopper Plus earlier would increase the enterprise profit. The reason for this is the longer operational period resulting in more cumulative flights to depreciate development costs for example. Shutting down Hopper Plus operations might be forced by ticket price reductions caused by Kankoh Maru Plus' operations. Operating Hopper Plus earlier might be the consequence, but it is assumed to be limited by the non-existence of the necessary technology for economic operations.

Both risks would result in the low economic performance of Hopper Plus, either because the ticket prices would be too low (if became operational too late) or because the development costs would be too high (if operated too early). In the scenario under investigation, the optimum initial operational capability for Hopper Plus would be year 2013.

3.9. Cash flow

Figs. 20 and 21 show the enterprise and fiscal cash flow over fleet life-cycle.

In case of Hopper Plus the enterprise break-even Point might be reached after 15 years of operation. This is a relatively long time and it would therefore be difficult to find investors for this type of business. Further research is needed to find strategies for low interest rates on capital for front-end and recurring costs in the initial phase of operations. Fiscal cash flow would stay negative during the complete operational phase.

In the case of Kankoh Maru Plus, the enterprise break-even point might be reached after 8 years and the fiscal break-even point after 14 years of operations.

3.10. Return on investment

Figs. 22 and 23 show the average annual ROI for private (enterprise) and public (fiscal) investors based on this model.

In the case of Hopper Plus, the average enterprise ROI at the end of operations would be about 5%. Further research is needed to increase the ROI to an acceptable level for a risky venture, such as space tourism. Due to negative fiscal cash flow, there would be no fiscal ROI for the complete operational phase.

In the case of Kankoh Maru Plus, the average ROI at the end of operations would be 47% for enterprise and 56% for fiscal. These appear to be acceptable values for potential investors.

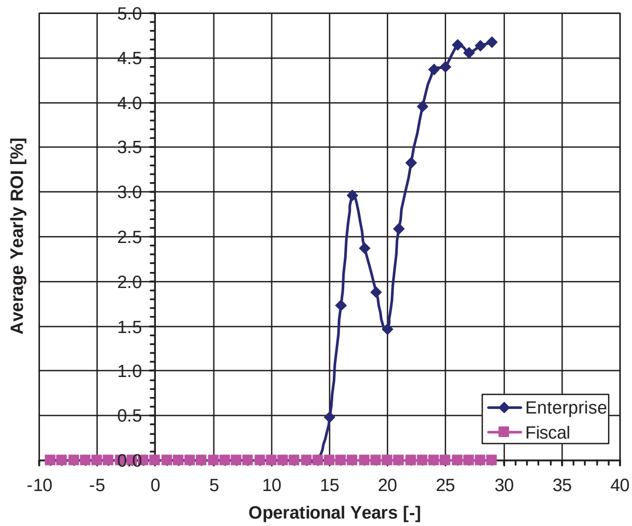

Fig. 22. Estimate of average yearly ROI for Hopper Plus.

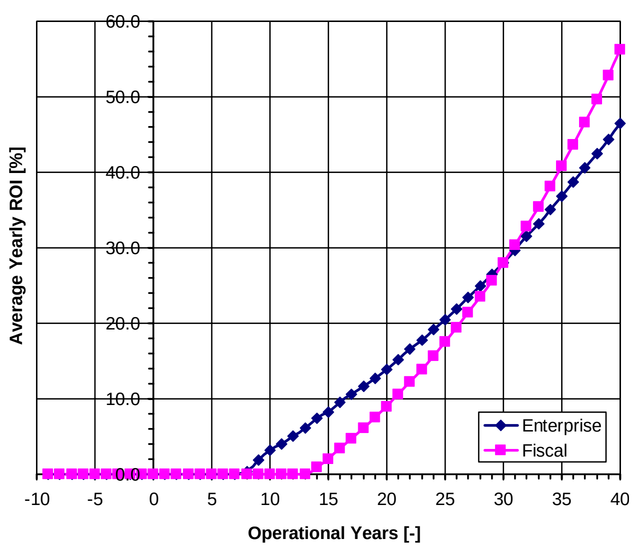

Fig. 23. Estimate of average yearly ROI for Kankoh Maru Plus.

4. Ticket pricing strategy

4.1. General

An existing suborbital flight market, which is interfered with by a newly established orbital flight market can be best discussed with the following three cases A, B and C. These cases are based on typical flights for suborbital and orbital tourists which are described in the following.

4.2. Typical space tourism flights

Hopper Plus, representing a suborbital rocket, would start horizontally on a rail sled at Kourou Spaceport on a 4 km long track. For simplicity of operations, the rail sled would be unpowered. Its design is similar to the emergency acceleration system of the German maglev high-speed train Transrapid currently operated in China. Three rocket main engines would accelerate Hopper Plus to a height of 100 km. Then it would drift to a maximum height of 150 km before it would re-enter the atmosphere and land horizontally 4500 km downrange on a runway on Santa Maria Island (Tortoli). After landing, Hopper Plus would be transported back to Kourou Spaceport by ship. Total flight time would be around 30 min of which 5 min are in weightlessness. In weightlessness, passengers might try some experiments and float around for a short time. Passengers would have the opportunity to stay at Santa Maria Island for a holiday before taking a flight back by aircraft to their destination airport.

After boarding, Kankoh Maru Plus, representing an orbital rocket, would start vertically from a launch pad. Thrust for take-off would be supplied by 12 engines. After 6 min of ascent, the vehicle would achieve an altitude of 200 km and orbit Earth for about 24 h. The minimum flight duration would be about two to three hours, or one or two orbits respectively. There would be sufficient time in space for passengers to explore weightlessness and watch the Earth. Then, a tail-first re-entry 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 connecting flights back to their home airport. The orbital flight events would be also surrounded by an optional pre- and post-flight program taking about one or two weeks.

The desire to play and eat in weightlessness can also be satisfied by parabolic flights but the more significant desire to watch the earth and space, as well as that to gain prestige require suborbital or orbital flights.

4.3. Case A

Case A presents the ticket pricing strategy for Hopper Plus and Kankoh Maru Plus, if the two vehicles do not compete in the same market as shown in Fig. 24 The idea is that operators always demand the highest possible prices for a certain annual seat capacity concerning the price–demand function shown in Fig. 1. At the beginning of operations, only a few seats per year would be offered and the ticket price could be high to fill these seats. As vehicle fleets grew with time, the number of seats offered per year would increase and ticket prices would have to decrease to attain a sufficient passenger demand. As the launch rate would stay constant at its maximum, ticket prices would also stay constant.

4.4. Case B

Case B presents the necessary ticket price strategy for Hopper Plus if there were competition from an orbital flight operator as shown in Fig. 25 It is assumed that passengers, who have the choice between buying a ticket

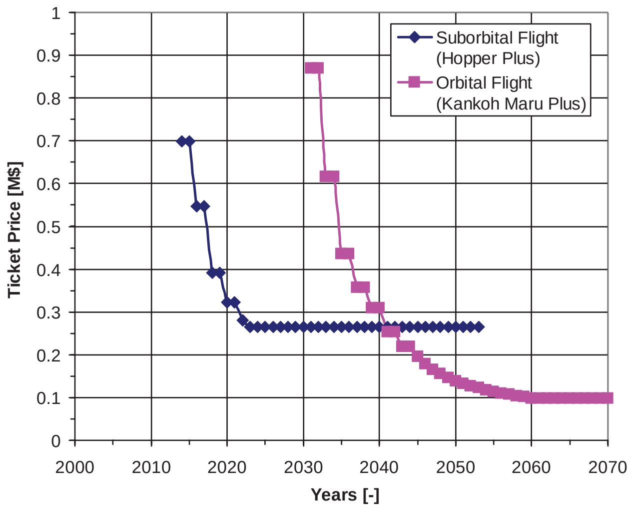

Fig. 24. Price strategy for monopoly space tourism market.

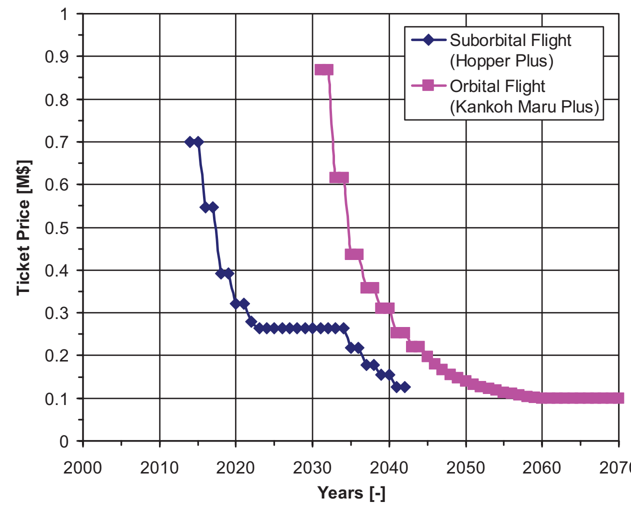

Fig. 26. Price strategy for oligopoly space tourism market at a profit.

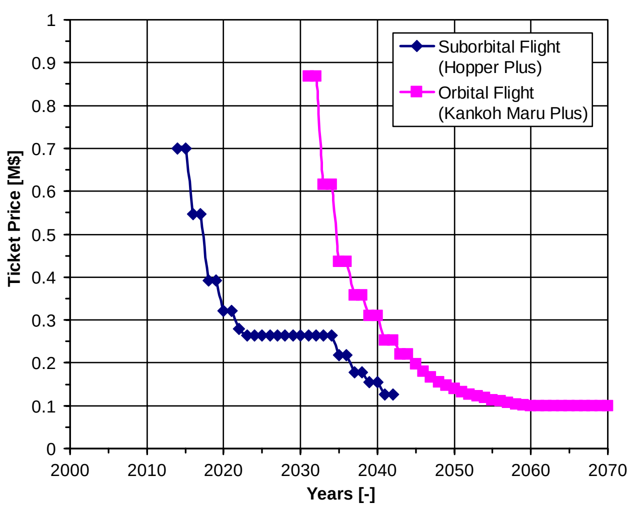

Fig. 25. Price strategy for oligopoly space tourism market.

for suborbital or orbital flights, would buy the orbital ticket unless the suborbital ticket were available for half the price of the orbital one. Further research needs to be done to verify this assumption, but it seems logical and can also be applied to the airline market if compared, e.g. to a Paris–New York flight. Not everyone will buy a Concorde ticket just because such a fast supersonic aircraft exists; instead most people buy a business class or economy ticked for half the price and fly in a conventional subsonic aircraft. Kankoh Maru Plus might be superior compared to Hopper Plus because of its high transportation volume. Kankoh Maru Plus could theoretically loose annually only a 2.7% share of the market (with 2700 of 100 000 passengers changing to suborbital flight), while Hopper Plus could annually loose a 100% share of the market (with 2700 of 2700 passengers changing to orbital flight) in case of a price war. Thus, the Kankoh Maru Plus price strategy is assumed to be independent of the existence of a suborbital operator offering flights with Hopper Plus.

4.5. Case C

However, Hopper Plus would not be able to keep up with any decrease in ticket prices. Kankoh Maru Plus' design, increase in launch rate and technology used might allow a sufficient decrease in operational costs in contrast to Hopper Plus. Thus, Hopper Plus would be forced to stop operations in the year that flight costs became higher than flight receipts. This would happen in 2042 or after 29 years in operation, as presented in Case C and shown in Fig. 26.

The question might arise whether to operate a smaller version of Kankoh Maru Plus for suborbital flights instead of Hopper Plus. The advantage would be having a "vehicle fleet family" with its typical benefits such as economies of scale by using some subsystems for suborbital and orbital Kankoh Maru Plus versions. However, it is assumed that a showstopper would be the fact that an RLV concept designed only for tourist transportation would not be attractive enough for investors because of the unknown risks. Instead, a modified RLV concept originally designed for satellite transportation is assumed to be more promising for initial tourist transportation.

5. Cost engineering tools

The tools used for cost estimation are TRASIM 2.0 [12,13] and TRANSCOST 7.0 [10], which are statistical–analytical models for cost estimation and economic optimization of launch vehicles. Using both tools for reciprocal verification of results leads to a cost estimation process of high quality. The tool used to process the results achieved from the cost estimation models for the financial estimation is FINANCE 1.0 [14].

5.1. Cost estimation relationships

The cost models are based on Cost Estimation Relationships (CERs) with the basic form shown in Eq. (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.

The cost models employed 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.

$$C = aM^x \prod f_i d \tag{1}$$

For verification of the models, the Space Shuttle, which is the only existing (but only partially) reusable launch vehicle in operation, has been simulated in parallel.

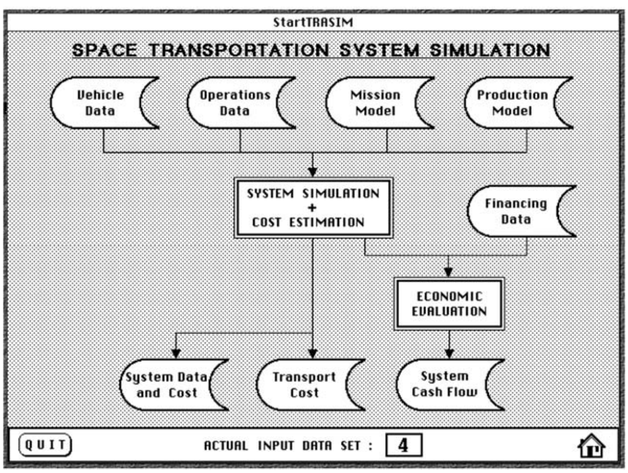

Fig. 27. TRASIM main input mask.

5.2. 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 [12,13].

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 nine transportation nodes of five different space transportation systems consisting of up to three stages with five payload categories each employed in eight different mission modes.

The model is available as a program, as shown in Fig. 27 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.

5.3. TRANSCOST model

The TRANSCOST 7.0 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

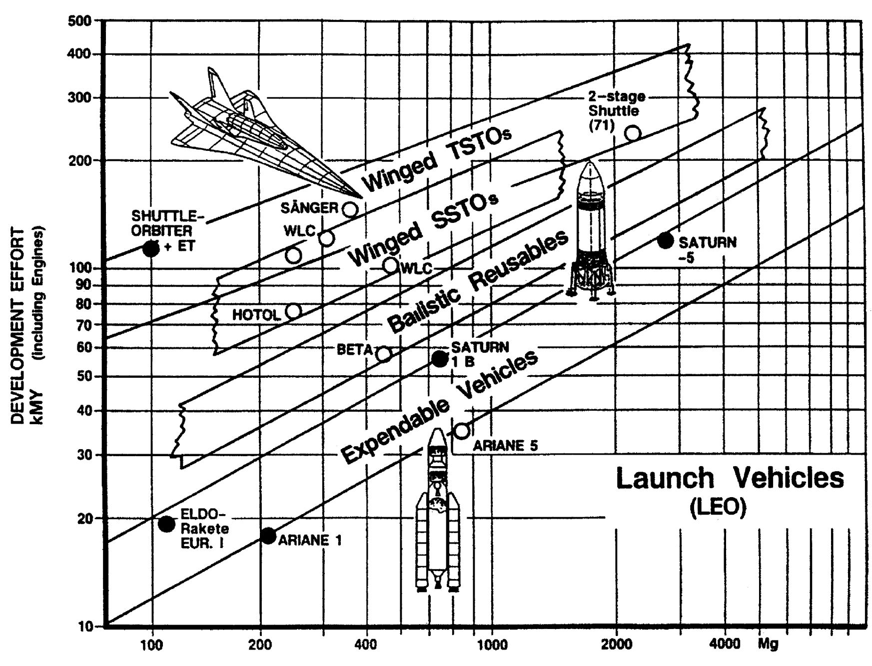

Fig. 28. Example of a TRANSCOST graph.

order of magnitude of system costs with an accuracy of ±20% [10].

The model is available as a handbook containing 180 graphs, as shown in Fig. 28 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 comprised of US, European and Japanese space vehicle projects.

5.4. FINANCE model

The FINANCE 1.0 model is a finance analysis to determine the business performance of the vehicles investigated. Its strength is the capability to transform financial data rows into clear graphs and to check the sensitivity of each parameter to the overall performance [14].

The model is available as a program as shown in Fig. 29. It allows determining and optimizing economic key data such as ROI, break-even point, receipts, yields, taxes and credits. Ticket prices are determined by an integrated ticket price passenger demand model but prices can also be entered manually.

5.5. Cost discussion

Results may question why the cost of actual suborbital rocket concepts' or flight demonstrators' of such as SpaceShipOne are a fraction of the cost of Hopper Plus or Kankoh Maru. The answer is a result of the following four principal facts:

- *Costs are a function of vehicle mass*: To develop a motor glider costs well below $1 million, while developing a large aircraft, e.g. the Airbus A380, costs much more than $10 billion. The same goes for rockets.
- *Costs are a function of organizational frame*: Within a small start-up company such as Scaled Composites fast and slim development of new systems is feasible, while very large and complex organizations such as Boeing may not realize such projects for the same budget.

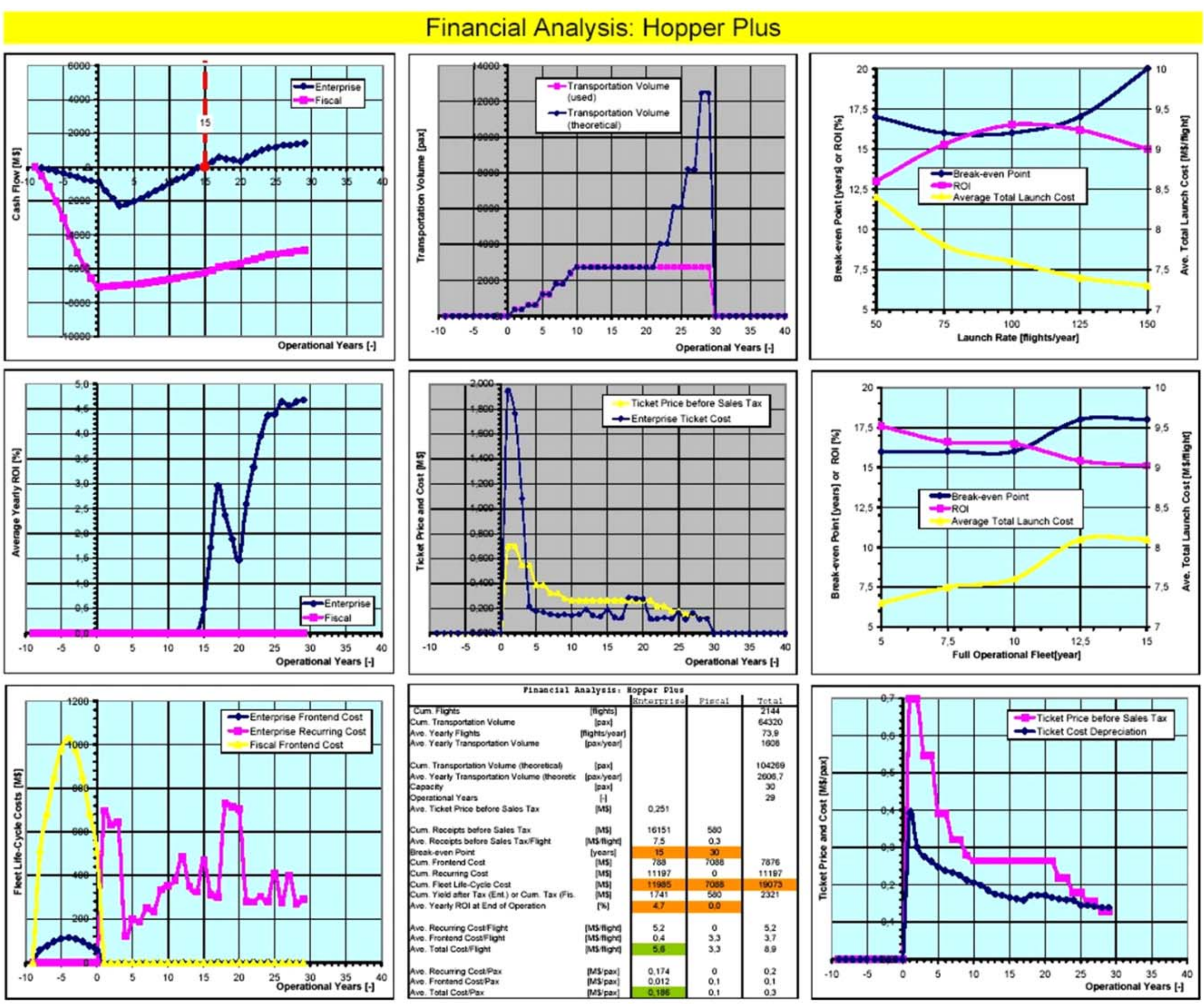

Fig. 29. FINANCE output mask.

However, only large organizations have the power and organizational characteristics to produce large rockets.

- *Costs are a function of benefit*: The objective is to maximize benefit in terms of profit for the company, surplus for the customers or positive externalities for the public. This maximization of benefit leads to a transportation system with costs that are not the most minimal.
- *Costs are a function of definition*: The term "cost" has been used with very different interpretations [10]:
  1. Effective cost to completion (CTC): total cost after completion of the program including inflation.
  2. Most probable cost: including margin for unforeseeable technical problems and delays.
  3. Ideal cost: assuming that everything goes as planned (standard industrial proposal). However, the history of rocketry teaches otherwise. In the case of Space Shuttle initial plans were for a simple operation with a high flight rate. The reality however is a very complex operation with a low flight rate and total costs of about $0.5 billion per flight.
  4. Minimum credible cost: an unrealistic cost estimate in a competitive situation in order to win a contract (some cost items are neglected, in particular: premature loss charge cost, mission abort surcharge cost, certification cost, financing cost, product improvement cost, administration cost, fees cost).
  5. Unrealistic cost: cost figures based on belief without cost studies and lack of experience.

The cost estimations done in this paper are based on "Most probable cost", while many cost studies of space tourism rocket concepts are based on "Ideal cost", "Minimum credible cost" or even "Unrealistic cost".

6. Conclusion

Economic performance sensitivities and ticket pricing strategies for different vehicle concepts have been investigated. It has been shown that the selected suborbital vehicle would be inferior to and orbital vehicle in a competitive market environment in terms of economic performance. However, the benefit of suborbital tourism flights in terms of establishment of market infrastructure and necessary technology are assumed to be a prerequisite for the successful operation of orbital vehicles.

Hopper Plus, supposed to be a second-generation RLV, is assumed to be a technology driver for a third-generation RLV and might have the potential to increase the market for space transportation and exploration. It could be much better designed and operated than the Space Shuttle, which is a first-generation RLV. However, it appears to be difficult to convince governments or private finance companies to fund such an enterprise.

A third-generation RLV program such as Kankoh Maru Plus might replace Hopper Plus 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 operational philosophy.

In historical context, a novel program for a new market such as Hopper Plus is important even if it is not profitable. Throughout history, thriving economies have relied on ready access to transportation to enable exploration and trade. In the case of commercial aviation, this economic dynamo did not arise overnight. Over the past century, at least six generations of aircraft have been developed, starting with the Wright plane and ending with the new Airbus A380. Major technological advances led to aircraft that are more capable, and to new markets from mail, passenger service, package delivery and interstate commerce. Investment in space transportation could lead to similar results in the worldwide commercial space marketplace.

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