PROGRAM PROPOSAL FOR A TOURIST RLV FLEET OPERATED FROM KOUROU SPACEPORT

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Abstract

A prerequisite to operate reusable launcher profitably is a high launch rate. This can be achieved by transporting passengers. Suborbital flights offer an incremental approach to develop the market and infrastructure, demonstrate the safety of space flights, obtain real flight information regarding the needs of passengers and demonstrate the profitability of space tourism.

This paper presents a proposal for a business plan to develop, produce, and operate from Kourou Spaceport in French Guiana a fleet of reusable launcher for tourists. The aim is to use existing Ariane 5 technology and infrastructure of Kourou Spaceport to the maximum extent possible. The reusable launcher being treated in this paper is named Hopper Plus based on Hopper project investigated by Astrium company. Hopper Plus is assumed to be capable to perform a suborbital trajectory with 30 passengers. It would be composed of a suborbital vehicle and a passenger module integrated in its cargo bay.

KEYWORDS: Cost Estimation, Hopper Plus, Kourou Spaceport, Scenario, Space Tourism, Reusable Launch Vehicle

Introduction

Figure 1: Hopper Plus

Although it is not clear that the anticipated large cost reductions by operating reusable launcher can indeed be achieved in the short or medium term (up to 2015), on-going developments in the USA and Japan will allow a better understanding of the critical areas and the development of new technologies. Therefore, in the longer term (2015 to 2025), Europe cannot be sure of maintaining its market share by the use of conventional expendable launchers, if a technical breakthrough is achieved elsewhere [1, 2, 3].

As determined in a previous investigation, a reusable launcher concept based on Hopper project investigated by Astrium company appears to be the best for that kind of flight for space tourists. The authors modified the present version of Hopper in some aspects in order to make the vehicle more attractive for space tourism flights. In particular, planned satellite payload with upper stage is replaced by a passenger module, and reliability has been increased by accepting higher efforts in terms of costs for development, production, and operation. This modified version of Hopper is named Hopper Plus that is discussed in this study and shown in Figure 1.

Flight Profile

Hopper Plus 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 reenter in the atmosphere and land horizontally 4500 km downrange on a runway on Santa Maria Island as shown in Figure 2 and Figure 3 [4, 5, 6].

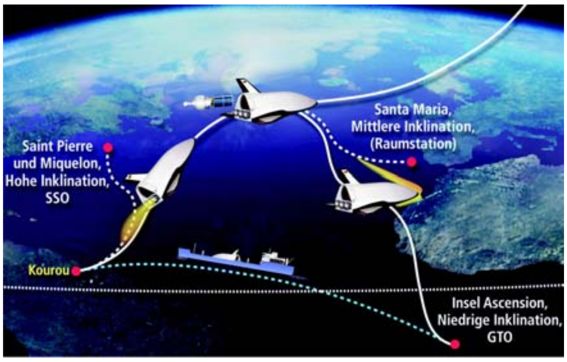

Figure 2: Flight Profile (Astrium)

After landing, Hopper Plus would be transported back to Kourou Spaceport by ship. Total flight time would be around 30 minutes, of which 5 minutes are in weightlessness. Passengers would have the opportunity to stay at Santa Maria Island for holiday before taking a flight back by aircraft to their airport of destination.

The reduction of thrust level for a horizontal launch (and thus less engine mass) is penalized by a higher delta velocity ΔV demand due to the turn maneuver and longer flight in denser atmosphere (and thus higher fuel mass). However, easier and higher safety operations make this launch method superior if compared to vertical launch.

Figure 3: Santa Maria Island (Tortoli)

Vehicle

Overall length of Hopper Plus is assumed 50 m with a wingspan of 27 m as shown in Figure 4. Its gross lift-off weight would be 460 Mg including the passenger module. Hopper Plus might make widely use of Ariane 5 technology and elements, thus becoming within reach for mid-term realization. It would use three Vulcain 3R engines, which are Vulcain 3 engines adapted to reusability.

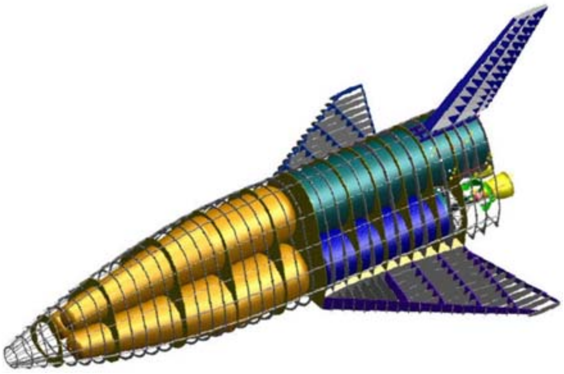

Figure 4: Vehicle (Astrium)

Hopper Plus would require a larger total dry mass compared to Hopper. This is due to added passenger module, which is supposed to be placed into the cargo bay, and because of increased power subsystem mass due to higher power demand caused by passenger module. Hopper Plus is assumed more complex than a high-speed aircraft but less demanding than orbital vehicles with reentry maneuver causing very high thermal loads due to higher deceleration.

Passenger Module

Cargo bay dimensions are supposed to be Ø5,4 m x 16,7 m. For comparison, Figure 5 shows an aircraft cabin arrangement for high-density seating with similar dimensions allowing to transport 50 passengers (5 x 10 rows) with same dimensions. Because of higher standard of space applications and more comfort for passengers a 4 x 8 rows arrangement is used for the scenario. Passenger module dimensions might be Ø4,7 m x 16,0 m and it would have a dry mass of 3,8 Mg. Usable volume per passenger would be about 4 m³. It 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 zero gravity experience for passengers (0,1 Mg).

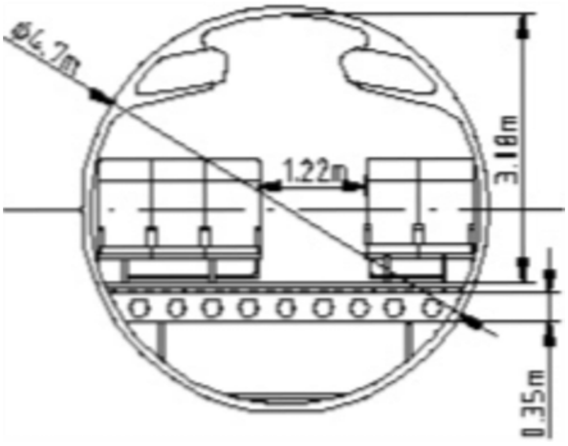

Figure 5: Aircraft Cabin Arrangement

Estimation of cabin structure mass is based on Spacelab specifications, while remaining component masses are based on typical aircraft specifications. Each Spacelab core module segment is 2,7 m long and has a weight of 0,5 Mg. Each Spacelab conical end segment is 0,8 m long and has a weight of 0,3 Mg [7]. If passenger module structure would be made from Spacelab's aluminum components (5 core module segments + 2 conical end segments) it would have a mass of 2,9 Mg. Using composite materials instead of aluminum could reduce mass by 30 % to 2,0 Mg.

Mass Characteristics

The mass characteristic of Hopper Plus is shown in Table 1. A 10 % mass margin is distributed over all components.

Table 1: Mass Characteristics

Subsystem	Vehicle	Pax Module	Total	Unit
Cold Structure	16,8	2,1	18,9	Mg
Hot Structure	12,6	0	12,6	Mg
LH2 Tanks	6,2	0	6,2	Mg
LO2 Tanks	3,9	0	3,9	Mg
Equipment	9,3	1,7	11,0	Mg
Engines	8,4	0	8,4	Mg
Recovery	2,0	0	2,0	Mg
DRY MASS	**59,2**	**3,8**	**63,0**	**Mg**
Payload	0	3,0	3,0	Mg
Propellants	394	0	394	Mg
TAKE-OFF MASS	**453,2**	**6,8**	**460,0**	**Mg**

Phases of System Realization

In addition to feasibility aspects of a vehicle concept, the probability of realization the vehicle under real world political and financial conditions must be analyzed. Figure 6 shows a first approach to a representative life-cycle scenario for Hopper Plus. It is assumed that the period from Preliminary Phase (Pre-phase A) to Production Phase (Phase D) could be accomplished within 10 years. 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 those satellite launches would exist.

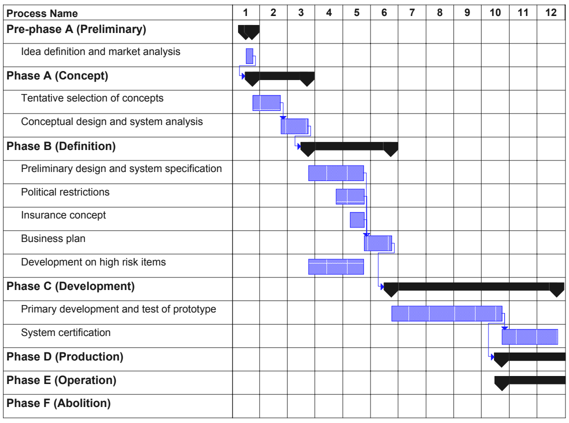

Figure 6: Representative Master Schedule

Business Case Studies

A business case is a “tool” that supports planning and decision-making – including decisions about whether to buy, which vendor to choose, and when to implement. Business cases are generally designed to answer the question: What will be the financial consequences if choosing X or doing Y? The organizing backbone of the case is a time line extending across years, as Figure 7 suggests. This gives a framework for showing management how they can work to implement financial tactics: reduce costs, increase gains, and accelerate gains [8].

Figure 7: Business Case (Solution Matrix)

This paper investigates costs of Hopper Plus for two different business cases namely “Business as Usual” and “Smart Business” processes.

Case Study A: Business as Usual

This case study is based on Business as Usual (BAU) processes. Business as Usual costs in the aerospace sector are caused by overspecification, high bureaucracy, many design changes, extended schedules, parallel work on identical topics, poor and mostly too late communication, and too many meetings beside necessary costs. Under these conditions, it was not possible to create a scenario to develop, produce, or operate a reusable vehicle fleet for tourists economically. Therefore, this case is not further discussed in this paper.

Case Study B: Smart Business

This case study is based on Smart Business processes using Cost Engineering techniques. The goal of Cost Engineering is to determine a vehicle design and its operation for minimum life-cycle costs. This means that costs have to be taken into account as a main decision criterion for the whole program duration. If applied all cost-saving strategies, the cost of governmentally contracted projects could be reduced drastically of the traditional Business as Usual costs. Those strategies are applied for the Hopper Plus program proposal.

Cost Engineering Tools

For assessment of a vehicle’s success, it is important to estimate realistic launch cost. This is done by calculation of life-cycle costs for a simulated scenario.

Used tools for cost estimation are TRASIM 2.0 [9, 10] and TRANSCOST 7.0 [11], which are statistical-analytical models for cost estimation and economical optimization of launch vehicles. These models are based on Cost Estimation Relationships (CERs). CERs are equations, which are often mass-related and consist of 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 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. 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 order of magnitude of system costs with an accuracy of ±20 %. Using both tools each other for reciprocal verification of results lead to a cost estimation process of high quality.

Program Assumptions

Table 2 to Table 6 show a selection of key assumptions made for this scenario, which are used for a simulation with TRASIM 2.0. It is assumed that no other mass tourist space transportation system except Hopper Plus would be in operation.

Table 2: Vehicle Model (80 input values)

Parameter	Value	Unit
Vehicle Life Time	20	years
Fleet Operational Period	40	years
Initial Operating Capability	2015	year
Development Period (+ margin)	8 (+ 2)	years
Cold Structure Reuses	600	-
Hot Structure Reuses	200	-
Fuel Tank Reuses	200	-
Oxidizer Tank Reuses	250	-
Equipment Reuses	250	-
Engine Reuses	100	-
Recovery Equipment Reuses	170	-

Table 3: Mission Model (50 input values)

Parameter	Value	Unit
Missions (for year 1, year 2, …, year 40)	12-90	LpA

Table 4: Operations Model (60 input values)

Parameter	Value	Unit
Manpower Cost for Development	205 000	$/MY
Manpower Cost for Production	200 000	$/MY
Manpower Cost for Operations	220 000	$/MY
Payload	30	pax
Mission Reliability	97	%
Learning Factor for Prelaunch, Integration, and Refurbishment of Subsystems (<100 missions)	0,85	-
Learning Factor for Prelaunch, Integration, and Refurbishment of Subsystems (100-1000 missions)	0,90	-
Learning Factor for Prelaunch, Integration, and Refurbishment of Subsystems (>1000 missions)	1,00	-

Table 5: Production Model (120 input values)

Parameter	Value	Unit
Production Rate (for year 1, year 2, …, year 40)	in batches	-
Catastrophic Failure Rate (year 1-10)	0,001	-
Catastrophic Failure Rate (year 11-30)	0,0009	-
Catastrophic Failure Rate (year 31-40)	0,0008	-
Minimum Allowable Launch Pad Interval	2	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	0,4-0,5	%/CpF
Learning Factor for Spare Parts of Subsystems	0,90	-

Table 6: Financing Model (70 input values)

Parameter	Value	Unit
Ticket Price (for year 1, year 2, …, year 40)	0,650-0,260	M$
Fiscal Share of Frontend Investment	90	%
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

Development and Production Cost

As shown in Table 7, total development cost for Hopper Plus is calculated to be 7,7 B$$_{2000}$, which is an acceptable value for such kind of fully reusable launch vehicle compared to existing aircraft and rockets. First unit production cost for Hopper Plus is calculated to be about 0,6 B$$_{2000}$.

Table 7: Development and Production Costs

Subsystem	Development Cost	Production Cost (first unit)	Unit
Cold Structure	793	190	M$
Hot Structure	308	23	M$
LH2 Tanks	154	17	M$
LOX Tanks	149	11	M$
Equipment	2267	275	M$
Engines	1087	71	M$
Recovery	28	18	M$
Tooling	85	-	M$
Engineering and Integration	1250	-	M$
Prototype	605	-	M$
Ground Facility (First Unit)	1000	-	M$
Total	**7726**	**605**	**M$**

Launch Rate

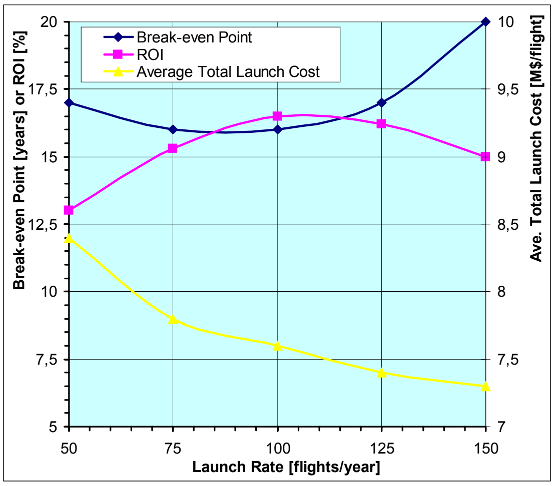

Figure 8: Optimized Launch Rate

Desirable maximal launch rate is determined to 90 launches per year by performing a sensitivity analysis. Figure 8 shows the influence of launch rate to economical performance as seen from enterprise. A higher launch rate would result in lower launch costs but also in a lower Return on Investment (ROI) and a later Break-even Point.

Reason for this is that market demand for passenger flights would be limited. A lower ticket price would stimulate demand. However, decrease in ticket prices would be more than 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 small total learning effects.

Full Operational Fleet

As shown in Figure 9, annual launch rate could be increased over time due to learning effects achieved by maintenance and refurbishment improvements. Period to reach a full operational fleet is determined to be 10 years for Hopper Plus.

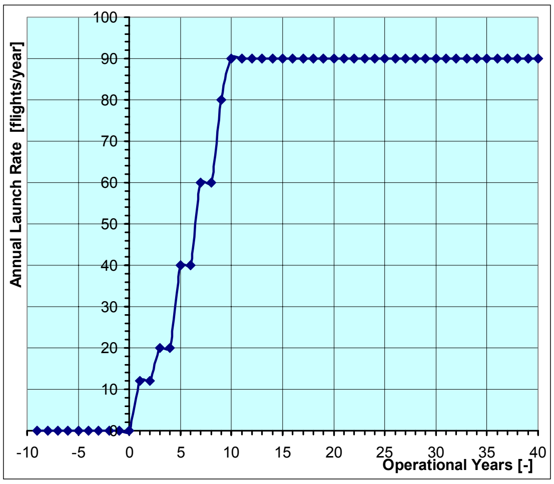

Figure 9: Annual Launch Rate

Figure 10 shows the influence of the period to reach full operational fleet to economical parameters of enterprise. A reduced period would result in better economical performance because of higher cumulative flights resulting in economies-of-scale. However, catastrophic failure rate would increase due to less time to improve vehicles. An extended period would result in lower economical performance due to high operating costs caused by small total learning effects.

In case of Hopper Plus, it would appear reasonable to start out with 3 vehicles at beginning of operation and then build 4 vehicles in second half of operation. 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 first year and would decrease to 8 days in the last year due to higher utilization. For fleet operation, there is assumed to exist one spaceport for launch and one runway for landing.

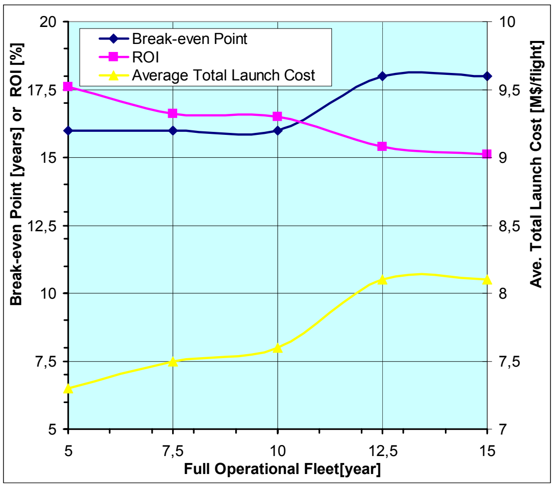

Figure 10: Optimized Full Operational Fleet

Fleet Life-cycle Costs

Figure 11 shows the distribution of frontend and recurring costs for fiscal and enterprise over fleet life-cycle. Cumulative costs might be 15,6 $\text{B\$}_{2000}$ for enterprise and 7,0 $\text{B\$}_{2000}$ for fiscal. Development and production of new vehicles (operational years 1 to 3 and 19 to 22) would cause main peaks. Smaller peaks would be caused by spare parts for subsystems. The general trend shows a decrease of costs due to learning effects.

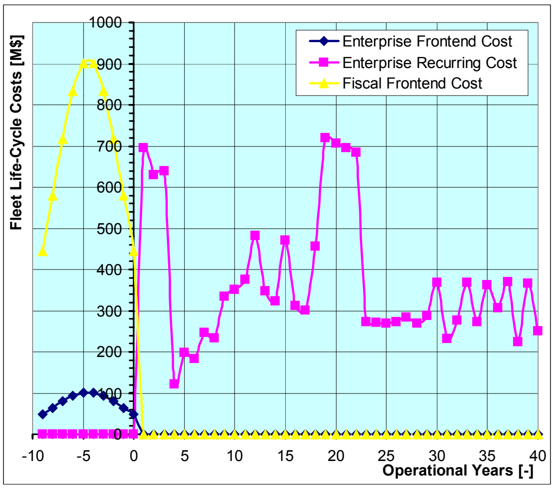

Figure 11: Fleet Life-Cycle Costs

Enterprise Receipts and Cost per Launch

Figure 12 shows depreciation of recurring and frontend costs as well as receipts before sales tax per launch. Average total launch costs would be 5,0 $\text{M\$}_{2000}$ with a share of 4,7 $\text{M\$}_{2000}$ for average recurring costs and 0,3 $\text{M\$}_{2000}$ for average frontend costs. Average receipts before sales tax would be 8,1 $\text{M\$}_{2000}$ per launch. Comparing these figures to today's figures of expendable rockets, costs would be low. Future reusable launch vehicles for mass space tourism activities require very low launch costs. But Hopper Plus potential for saving launch costs would be limited due to fact that it would use technology and infrastructure optimized for expendable launchers rather than reusable ones.

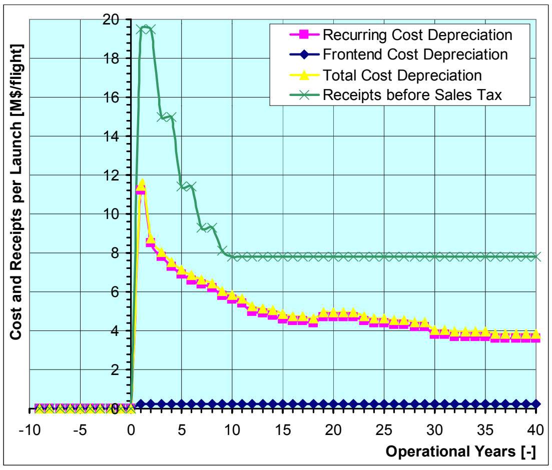

Figure 12: Cost and Receipts per Launch

Ticket Price and Enterprise Ticket Cost

Dividing Receipts and Cost per Launch by vehicle capacity of 30 passengers results in ticket price and cost distribution over time as shown in Figure 13. The skimming price strategy is used, which means that price can be high at start and those persons who do not like to wait would buy a ticket. In the first years ticket price would be set at $\$_{2000}$650 000 and it might decrease to $\$_{2000}$260 000 within 10 years. Thus, transportation volume would start with 360 passengers per year and would increase to 2700 passengers per year as maximum.

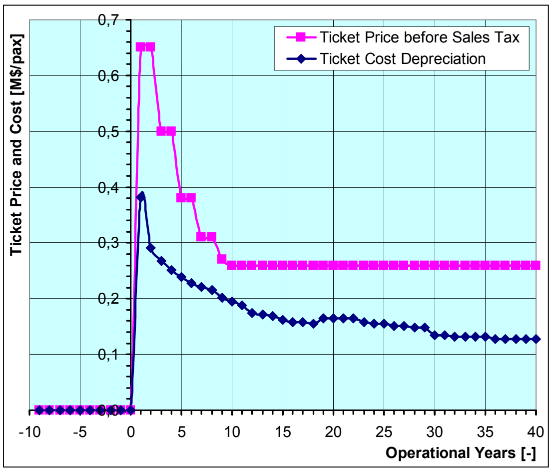

Figure 13: Ticket Price and Cost

Cash Flow

Figure 14 shows the enterprise cash flow over fleet life-cycle. Break-even point might be reached after 16 years of operation.

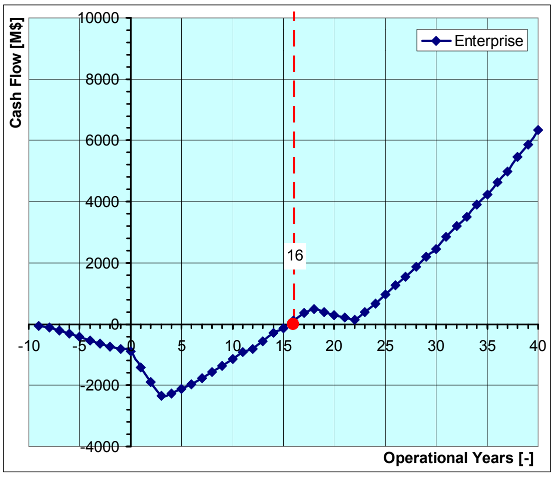

Figure 14: Enterprise Cash Flow

This is a relatively long payback period and therefore it would be difficult to find investors for this business case. Further research is needed to find strategies for low interest rates to receive capital for frontend and recurring costs in initial phase of operation.

Return on Investment

Figure 15 shows average annual enterprise Return on Investment. The average ROI at end of operation would be about 16 %. Further research is needed to increase the ROI to an acceptable level for a risky venture as what space tourism can be seen.

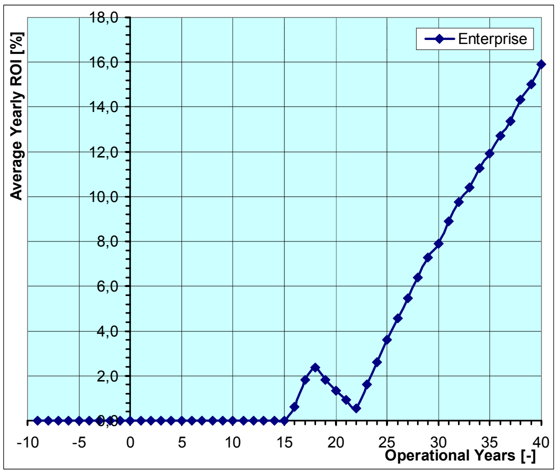

Figure 15: Average Yearly ROI

Conclusion

The idea of Hopper Plus concept is to be a connecting link between today's individual space tourism market and a future mass space tourism market. Advantages of this program proposal are hardware availability in the coming decade, assumed relatively low development costs, low risk as well as existing infrastructure at Kourou Spaceport used nowadays for Ariane 5. Disadvantages might be low economic performance and uncertainty of market demand for suborbital tourist flights when orbital tourist flights would compete with future passengers. One consideration to improve attractiveness of Hopper Plus concept would be to use it for satellite payloads in initial phase of operation. Cash flow behavior might be very sensitive for initial phase because high production costs would cause huge debts, which have to be paid off by ongoing operations. High receipts from satellite payloads could avoid debts in the initial phase. Additionally, satellite launches are a good process to certify the vehicle and show its reliability before using it for humans. Therefore, Hopper Plus should be compatible to serve other markets such as space station resupply and satellites delivery beside flights for space tourists. Hopper Plus, supposed to be a second-generation Reusable Launch Vehicle, is assumed to be a technology driver for a third-generation RLV and might have potential to increase the market of space transportation and exploration.

List of Abbreviations

B$	[-]	Billion US dollars
BAU	[-]	Business as Usual
CER	[-]	Cost Estimation Relationship
CpF	[M$/launch]	Cost per Flight
DOC	[M$/launch]	Direct Operating Cost
ELV	[-]	Expendable Launch Vehicle
FY	[-]	Fiscal Year
LpA	[-]	Launch per Annum
Mg	[-]	Mega grams
M$	[-]	Million US dollars
RLV	[-]	Reusable Launch Vehicle
ROI	[-]	Return on Investment

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