# Benefit Estimation Model for Tourist Spaceflights

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**Abstract.** It is believed that the only potential means for significant reduction of the recurrent launch cost, which results in a stimulation of human space colonization, is to make the launcher reusable, to increase its reliability, and to make it suitable for new markets such as mass space tourism. But such space projects, that have long range aspects are very difficult to finance, because even politicians would like to see a reasonable benefit during their term in office, because they want to be able to explain this investment to the taxpayer. This forces planners to use benefit models instead of intuitive judgement to convince sceptical decision-makers to support new investments in space. Benefit models provide insights into complex relationships and force a better definition of goals. A new approach is introduced in the paper that allows to estimate the benefits to be expected from a new space venture. The main objective why humans should explore space is determined in this study to "improve the quality of life". This main objective is broken down in sub objectives, which can be analysed with respect to different interest groups. Such interest groups are the operator of a space transportation system, the passenger, and the government. For example, the operator is strongly interested in profit, while the passenger is mainly interested in amusement, while the government is primarily interested in self-esteem and prestige. This leads to different individual satisfactory levels, which are usable for the optimisation process of reusable launch vehicles.

## INTRODUCTION

Currently, there are only two possibilities getting access to space as far as human spaceflight is concerned: the USA Space Shuttle and the Russian Soyuz. For the time being, only the Soyuz has been used for space tourism, and there are no indications that the Space Shuttle will be used for this purpose in the near future. The lack of alternative access is a critical factor limiting the supply of space tourism services. A breakthrough in this area, such as the development of new generation reusable lauchers, will have a significant impact on space tourism. Clearly, low-cost and low-risk access to space are critical for the expansion of the space tourism market. Traditionally, human spaceflight activities have been characterized by very high levels of public funding and minimal private investment. Space tourism flights have the potential of changing the balance of private versus public expenditures in human spaceflight.

The true potential of space tourism in the coming decade does not reside within one or two flights per year for $20 million per trip but in providing a wide range of services with different levels of prices as shown in Figure 1 (Goehlich; 2002a, 2002b). Less expensive activities are parabolic flights and high-altitude flights, while suborbital flighs and orbital flights are more expensive. The high-end activities are Space Station flights.

Future trends in space tourism can only be identified by considering the concurrent supply (i.e. operator or investor), demand (i.e. passenger), and regulatory sides (i.e. public or government). The uncertainty revolving around these three sides is a significant hindrance for the development of space tourism. This paper attempts to shed new light onto the future of space tourism by focusing on these critical factors.


**FIGURE 1.** Overview of Space Tourism Market.

## BENEFIT MODEL

Space projects, that have long range aspects are very difficult to finance. This forces planners to use benefit models instead of intuitive judgement to convince sceptical decision-makers to support new investments in space. Benefit models provide insights into complex relationships and force a better definition of goals.

### Model Applications

The introduced model can be used for suborbital as well as for orbital reusable launch vehicles and it is adjusted to a timeframe from year 2003 to 2050. Due to the modular concept of the model, extensions in investigated time periods and destinations such as Moon and Mars can easily be adopted.

### Model Limitations

A general rule for all models is, that the results can only be as accurate as the input values are set. More proper results can be achieved by market surveys of the three interest groups (passenger, operator, and public) to improve step 1 and 2 introduced below.

### Model Structure

The introduced model describes the quality attributes of space tourism activities as seen to be valid for the industrial nations, which are the ones leading the effort in space tourism development. The process to estimate the benefits of individual reusable vehicle concepts for comparison is structured in steps delineated below (modified from: Koelle, Johenning, 1998). Each step is supported by an example for better understanding. Due to the limitations of the circumference of this paper only 1 out of 25 sub objectives is treated.

*Step 1: Defining Objectives and Future Trends*

The main objective why humans should explore space is determined in this study to “improve the quality of life”. This main objective is broken down in sub objectives as shown in Figure 2, which can be analysed with respect to different interest groups. Table 1 shows a list of sub objectives that are limited to those aspects of improvements of space tourism activities which can be influenced by operating Reusable Launch Vehicles (RLVs). The list contains direct sub objectives such as “12 Reduce Catastrophic Failure Rate” as well as indirect ones such as “30 Enhance Social Standard of Society”. Typical goals for each sub objective are inserted in the last column for the purpose of illustration. These goals describe a scenario of space developments which appear desirable, likely, and feasible.

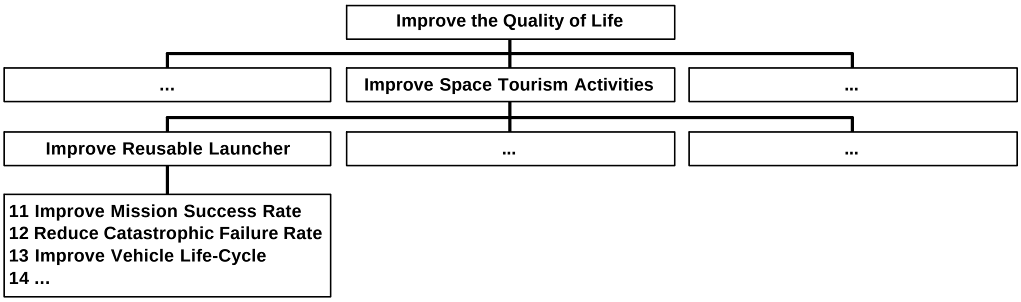


**FIGURE 2.** Top-down Objectives Approach.

**TABLE 1.** Sub Objectives and Goals.

| Sub Objectives | Goals for Year 2050 |
|---|---|
| 11 Improve mission success rate | 0,999 probability of mission success |
| 12 Reduce catastrophic failure rate | 0,0001 probability of catastrophic failure |
| 13 Improve vehicle life-cycle | 1000 reuses of vehicle |
| 14 Improve launch method procedure | Comfortable and safe launch |
| 15 Improve landing method procedure | Comfortable and safe landing |
| 16 Reduce number of stages | One-stage vehicle |
| 17 Improve configuration | Clean and simple functional configuration |
| 18 Improve propellant | Proven safe, green, and cheap propellants |
| 19 Improve impact absorber | Robust and comfortable impact absorber |
| 20 Improve passenger enthusiasm | Flights satisfies passenger wishes |
| 21 Improve passenger comfort | No necessity of special health requirements |
| 22 Reduce technical development risk | All subsystems are existing in-production hardware |
| 23 Improve mission flexibility | Vehicle serves tourism market and different satellite markets |
| 24 Improve seat capacity | 100 passengers per vehicle |
| 25 Improve profitability | The business case is financial attractive to find enough investors |
| 26 Improve market share | Passenger ticket of a 1 day LEO trip costs $50 000 |
| 27 Improve mission duration | 1 day mission with a high share of free-gravity flight |
| 28 Reduce turn-around time | 1 day |
| 29 Simplify licensing process | Grant license after one test year |
| 30 Enhance social standard of society | Sensitiveness in having respect for mankind and Earth |
| 31 Reduce environmental pollution | Low emission engines |
| 32 Enhance national self-esteem and prestige | 50% of all UN members participate in space programs |
| 33 Provide realization of resettlement to other planets | Develop infrastructure for an extraterrestrial population of 100 |
| 34 Provide a useful employment of the military sector | 1 million people employed in the aerospace sector |
| 35 Provide more international cooperation | Space tourism market reaches 0,1% of global GNP |

*Step 2: Estimating Relative Weights*

As the goals defined in step 1 are fixed, the relative importance of the sub objectives of RLVs are changing with time due to the dynamics of values conceived by people and are changing with communities due to different interests. Figure 3 shows this behaviour for the sub objective "12 Reduce Catastrophic Failure Rate". For example, it means that the relative importance for this sub objective is 60%, while 40% are for the remaining sub objectives when viewed from a passenger in year 2010. It also shows that the relative importance of this sub objective decreases if people are more used to safe operation in future. The share of each community to the group result can be varied and it is set to 33% for passenger weight, 33% for operator weight, and 33% for public weight. Relative weights assigned to the sub objectives depict the current needs of the majority of the Earth population. The relative importance of the defined sub objectives has to be estimated on the basis of currently observed development trends. The reference years are fixed to 2003 (begin of scenario), 2025 (mean of scenario), and 2050 (end of scenario) permitting interpolation to determine relative weights for any year selected. The primary interest groups are passenger, operator, and public who have a stake in the realization and use of the reusable launchers.

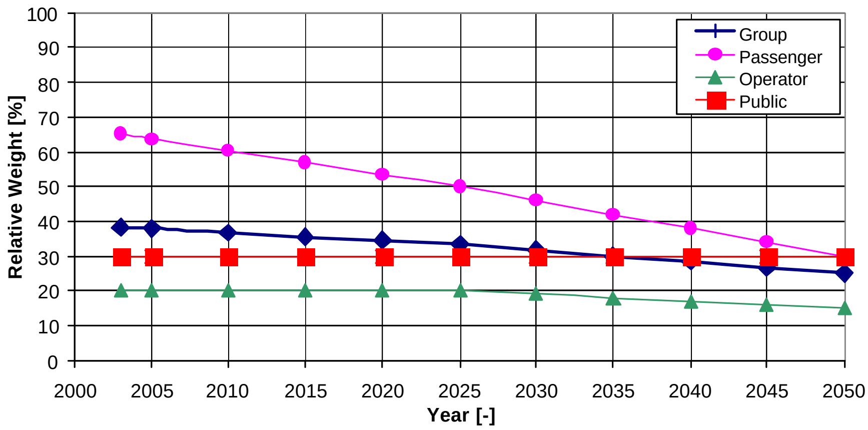


**FIGURE 3.** Relative Importance of Sub Objective "12 Reduce Catastrophic Failure Rate".

*Step 3: Selecting State Variables*

The relevant data that are used for measuring the benefit accruing from their acquisition and operation are called state variables. Table 2 shows the kind of data that can be derived by simulation models and be used in a benefit model.

**TABLE 2.** Example of State Variables.

| State Variable | Unit |
|---|---|
| 102 Degree of system health monitoring | % |
| 103 Number of alternative landing sites | - |
| 104 Degree of soft abort capability | % |
| 106 Degree of redundancy | % |
| 109 Number of reuses of cold structure | - |
| 125 Cabin volume per passenger | $m^3$/pax |
| 132 Return on Investment (ROI) | M$ |
| 133 Net Present Value (NPV) | M$ |
| 134 Year of positive cashflow | - |
| 144 Specific $NO_x$ production | kg/pax |

*Step 4: Selecting Benefit Indicators*

A systematic comparison of the state variables with the list of sub objectives leads to a tentative selection of relevant benefit indicators for each of the defined sub objectives. Within each group of indicators assigned to one sub objective the relative quality of each indicator is given, determining its relative weight in the analysis. The totals in each group add up to 1,0. As an example, Table 3 shows the benefit indicators selected for sub objective "12 Reduce Catastrophic Failure Rate".

**TABLE 3.** Benefit Indicators for Sub Objective "12 Reduce Catastrophic Failure Rate".

| Benefit Indicators | Quality | Remark |
|---|---|---|
| 103 Number of alternative landing sites | 0,3 | For comparison, the Space Shuttle can use in total 48 landing sites for emergency landing (NASA, 2002) and is assumed in this study as the maximum necessary amount of alternatives. |
| 104 Degree of soft abort capability | 0,4 | Soft abort capability means that engine failure does not cause loss of control and vehicles are engines-out landing capable. The Space Shuttle's soft abort capability is set to 50% for this indicator to be comparable to other candidate vehicles. In general, winged vehicles are superior to ballistic vehicles due to their aerodynamic surfaces. |
| 106 Degree of redundancy | 0,3 | Redundancy means to finish the mission successfully even if there is a malfunction of main engine, control engine, computer, pilot etc. The quality of the Space Shuttle's redundancy is set to 50% for this indicator to be comparable to other candidate vehicles. |

*Step 5: Determining Benefit Indicator Values*

External benefit indicator values of each space transportation system concept have to be determined for their entire life-cycle for selected years. For illustration, Table 4 shows those data, which are gained from a scenario based on an orbital reusable launcher.

**TABLE 4.** Example of Benefit Indicator Values

| Benefit Indicators | 2010 | 2015 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
|---|---|---|---|---|---|---|---|---|---|
| 103 Number of alternative landing sites | 5 | 5 | 10 | 10 | 15 | 15 | 15 | 15 | 15 |
| 104 Degree of soft abort capability | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| 106 Degree of redundancy | 70 | 70 | 80 | 80 | 80 | 80 | 85 | 85 | 85 |

*Step 6: Selecting Benefit Functions*

For assessment, it is necessary to transform objective-dimension-afflicted indicator values into subjective-dimension-free benefit values. This is done with the help of benefit functions. There are selected three types of functions to produce benefit values between 0 and 1 as shown in Equation (1), (2), (3), and Figure 4.

Linear growth (Type 1) $$y = y_0 + a \cdot x \quad (1)$$

Linear declining (Type 2) $$y = y_0 - a \cdot x \quad (2)$$

Non-linear growth to saturation (Type 3) $$y = 1 - (1 - y_0) \cdot e^{-a \cdot x} \quad (3)$$

A benefit value of 0 means that this is unacceptable while 1 means that this is the aimed optimum for the community. It suffices to define two points on the curve to calculate the constants. In case of the example, all three benefit indicators are determined as type 1.

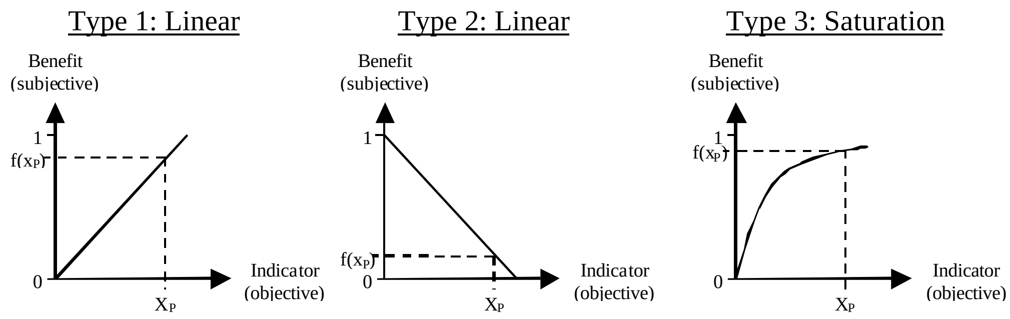


**FIGURE 4.** Used Benefit Functions.

*Step 7: Calculating Benefit of each Sub Objective*

The benefit of each sub objective for the selected years has to be calculated for different interest groups. All contributions of the individual indicators to the benefit in a particular year are added up per sub objective. Figure 5 shows the share of the sub objective "12 Reduce Catastrophic Failure Rate" to the total possible benefit.

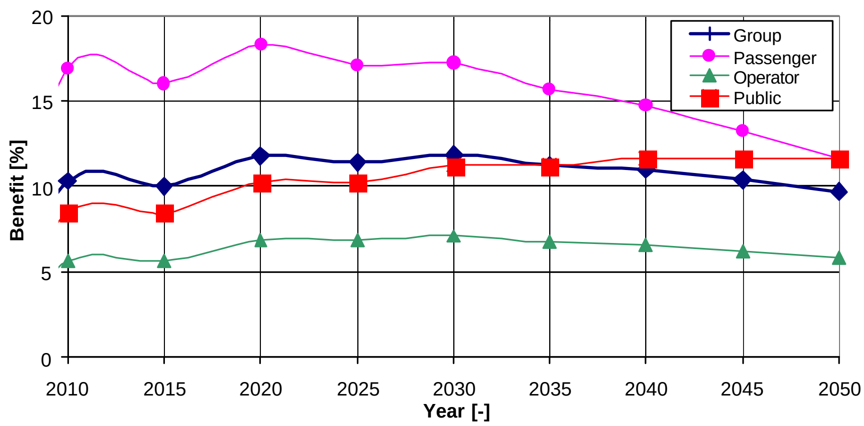


**FIGURE 5.** Benefit for Sub Objective "12 Reduce Catastrophic Failure Rate".

*Step 8: Calculating Benefit of all Sub Objectives*

Finally, the total benefit for this vehicle concept is calculated by adding up all benefit values of each sub objective for different interest groups. The results are shown in Figure 6 and discussed in section "Model Results".

## Model Results

The investigated vehicle concept would reach a total group benefit of 47% at beginning of operation changing to 61 % at end of operation 40 years later. By comparing other vehicle concepts with the same model assumptions it allows to determine the concepts with a high overall goal achievement, which is crucial for any future strategic space activity. Additionally, the user gets an insight into the different benefits for passenger, operator, and public. The benefit from this vehicle concept is nearly constant for the operator (56% to 62%), while there is an increase of benefit over the time for the passenger (37% to 56%) as well as for the public (50% to 65%). Nevertheless, in average, the passenger benefit of this vehicle concept is relatively low resulting in a preference to more "passenger friendly" vehicle concepts.

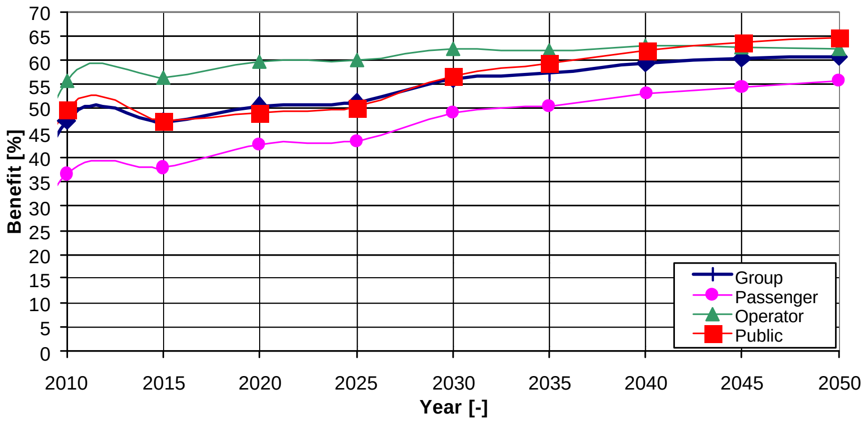


**FIGURE 6.** Benefit for all Sub Objectives.

## CONCLUSION

Spaceflight has intrigued the popular consciousness since before mankind even knew of its possibilities. As evidenced by government programs, it is technically feasible to send humans into space for extended periods of time and return them to Earth. An assessment of the current market potential and available technologies enables some conclusions to be drawn: Today, there are many experiences that are available to help the space tourism business in the near term, including parabolic flights, high altitude flights, and flights to the International Space Station. Nevertheless, there exist barriers to suborbital and orbital flights for mass space tourism employing reusable rockets, which can be viewed separately from passenger, operator/investor, and public/government side:

The passenger desires a similar reliability and safety standard for space transportation vehicles as the modern aircraft promises. Additionally, in history, travel in space has been only available to a small number of highly trained government astronauts, and the public's perception is that it cannot be otherwise.

While some space ventures already built their reputation on promising revolutionary cost reductions for access to space, potential investors do not buy it. As long as the revolutionary launchers haven't gotten off the ground, such claims lack of proof. If this situation remains, analysts and potential investors have to rely on the cost data history of previously flown launchers. But those historical launchers are based on the philosophy: "Highest performance whatever it will cost". Technology merit was all what counted and economic performance was secondary because the projects were government funded.

Government, seeking the goal of zero risk, will attempt to impose partly unreasonable standards on space tourism vehicles and operations. For instance, reliability of equipment needs high standards but if the level of training demanded is as rigorous as that currently provided to government astronaut candidates, it would scare off most of the potential space tourists due to high cost, high terms of mental health, and loss of time. Considering that today's aircraft rules had been in place during the 1920s, it probably would not have been able to develop a viable aviation business. So the current rules call for licensing of launches and returns, but not aircraft-like certification of space transportation vehicles. However, it is impossible to go against the times back to the transatlantic adventure flight of Lindbergh.

More research is needed to understand the dynamics of the space tourism market. To bridge the gap between supply, demand, and regulatory related issues will be the challenge for the coming decades. One approach is the systematically use of benefit models for the decisions "when to operate a RLV", "why to operate a RLV", and "what kind of RLV to operate". As shown in this study the benefit of a reusable launcher is changing with time differently for passenger, operator, and public side. Additionally, the benefit is also changing with vehicle concepts. This leads to the assumption that an optimum timing for the introduction of a suborbital vehicle fleet as well as an orbital vehicle fleet is rewarded with a high benefit for all interest groups who set the course for human space colonization.

## NOMENCLATURE

a = Constant Value
GNP = Gross National Product
ISS = International Space Station
M$ = Million US Dollar in fiscal year 2000
NPV = Net Present Value
$NO_x$ = Nitrous Oxide
RLV = Reusable Launch Vehicle
ROI = Return on Investment at end of fleet life-cycle
x = Indicator Value
y = Benefit Value

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## REFERENCES

Goehlich, R.A., *Space Tourism: Economic and Technical Evaluation of Suborbital Space Flight for Tourism*, ISBN 3-936231-36-2, Der Andere Verlag, Osnabrueck, Germany, 2002a

Goehlich, R.A., Koelle, H.H., Mori, T., "Cost Estimation of the NAL Spaceplane (Modeling of a Vehicle Fleet Life-Cycle)", IAC-02-IAA.1.1.08, presented at the 53rd International Astronautical Congress, Houston, USA, 2002b

Koelle, H.H., Johenning, B., "Benefit Estimating Relationships for the Evaluation of Extraterrestrial Facilities", ILR Mitt. 333, TU Berlin, Germany, 1998

NASA, NTST Shuttle Reference Manual, http://science.ksc.nasa.gov/shuttle/technology/sts-newsref/stsref-toc.html#, Kennedy Space Center, USA, 9/23/2002