Selection of Favorite Reusable Launch Vehicle Concepts by using the Method of Pairwise Comparison

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Abstract

The attempt of this paper is to select promising Reusable Launch Vehicle (RLV) concepts by using a formal evaluation procedure. The vehicle system is divided into design features. Every design feature can have alternative characteristics. All combinations of design features and characteristics are compared pairwise with each other with respect to relative importance for a feasible vehicle concept as seen from technical, economic, and political aspects. This valuation process leads to a ranked list of design features for suborbital and orbital applications. The result is a theoretical optimized suborbital and orbital vehicle each. The method of pairwise comparison allows to determine not only ranking but also assessing the relative weight of each feature compared to others.

Keywords: Pairwise Comparison, Reusable Launch Vehicle, Space Tourism

Introduction

The potential for an introduction of reusable launch vehicles is derived from an expected increasing demand for transportation of passengers in the decades to come. The assumed future satellite market does not justify to operate reusable launch vehicles only for satellites due to a low launch rate. Finding feasible vehicle concepts, which satisfy operator's, passenger's, and public's needs, will be a challenging task. Since it is not possible to satisfy all space tourism markets by one vehicle, different vehicles that are capable to serve one particular segment (suborbital or orbital) are needed. From a theoretical approach, one nearly optimized vehicle is developed for suborbital applications and one for orbital applications. These optimized vehicle characteristics are compared to existing worldwide 153 vehicle concepts.

Evaluation Procedure

Figure 1 shows the evaluation procedure used for suborbital and orbital vehicle concepts. The procedure to select a nearly optimized vehicle concept is done in three stages: Firstly, preferred key characteristics for a promising vehicle are determined in three groups with regard to technical, economic and political aspects by using the method of paired comparison. This evaluation process leads to a ranked list of design features for suborbital and orbital applications. The result of this investigation is a theoretical optimized suborbital and orbital vehicle each.

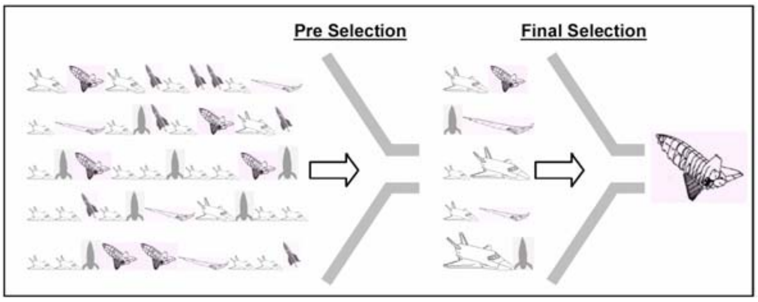

Figure 1: Evaluation Procedure based on Optimized Vehicle Characteristics

Secondly, in a pre-selection, the characteristics are compared to totally 153 proposed concepts for reusable launch vehicles existing worldwide from which are 44 for suborbital applications and 109 for orbital ones. Those suborbital and orbital vehicle concepts that are closest to theoretical optimized vehicles are selected. Thirdly, in a final selection, theoretical characteristics are compared in detail again with the remaining 10 studies for reusable launcher concepts each for suborbital and orbital applications. One suborbital and one orbital vehicle concept that are closest to the theoretical optimized vehicles are selected. The result is a nearly optimized vehicle for suborbital flight and one for orbital flight.

The necessity to use proposed vehicle concepts instead of a theoretically derived vehicle model is due to lack of information and data on facilities, research budget, time and manpower to carry out experimental tests and various kinds of simulation, which have been available only for some of the investigated vehicle concepts.

The time frame covers the period from today to the year 2070 emphasizing the middle of this century. The separation in three groups of criteria (technical, economic and political aspects) allows obtaining clearer results concerning requirements for: certification by authorities, attraction of potential investors and positive adventure for passengers.

Method of Paired Comparison

The method of paired comparison [1] is used in this study for preliminary rating of alternative vehicle concepts with respect to the relative importance of design features as well as to preferred characteristics of each design feature. This is a first approach under uncertainty in a situation, where detailed feasibility studies have not yet been performed.

The vehicle system is defined by 13 design features (e.g. "Launch Method", "Number of Stages", "Turn-around Time", etc.). All combinations of design features are compared pairwise with each other with respect to relative importance for a feasible vehicle concept as seen from technical, economic and political points of view. Every design feature can have alternative characteristics (e.g. "Air Launch", "Horizontal" and "Vertical" are characteristics that can be selected for the design feature "Launch Method"). Again, all combinations of alternative characteristics are compared pairwise with each other with respect to a relative preference for a feasible vehicle concept as seen from technical, economic and political aspects. The result is a two-dimensional list of ranked design features with ranked alternative characteristics for each design feature, or one list each for technical aspects, one for economic aspects and one for political aspects respectively.

Evaluation is performed in a qualitative and a quantitative assessment. For the qualitative assessment, evaluation is taken into account by shortly discussing each design feature. For a quantitative assessment, the evaluation is taken into account by assigning a number of a scale from plus five to minus five representing the sum of all arguments. These arguments receive relative weights totaling 100 %.

Any of two desirable attributes may be in conflict with each other, resulting in optimizing only one at the cost of the other. Figure 2 shows an example for method of paired comparison for design features. The design feature "Number of Stages" is expected to influence technical feasibility much more strongly than the design feature "Passenger Comfort". Therefore, the value for this pair is set to "+5". By doing this comparison for all criteria, preliminary results are gained for evaluation presented in this chapter.

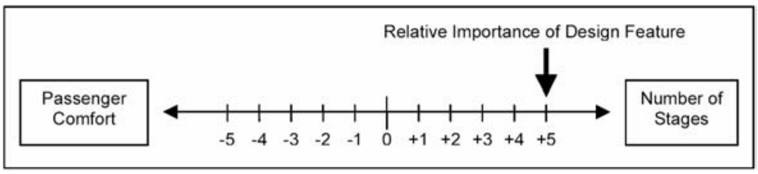

Figure 2: Example for Method of Pairwise Comparison

The method of pairwise comparison is a powerful tool to perform a fair and comprehensive transparent ranking of criteria of any kind. It allows to determine not only ranking but also assessing the relative weight of each feature compared to others. However, results of the pairwise comparison have to be checked for plausibility. A detailed description of application, accuracy and limitations of this method is published by H.H. Koelle [2].

Defining Design Features and Characteristics

A morphological box [3] listing typical alternative characteristics available for each design feature is determined for this study and shown in Table 1. This box can be used for deriving systematically promising vehicle concepts. There are many combinations possible that lead to vehicle concepts of different quality concerning technical, economic and political feasibility, which are investigated separately in the following three sections but only the criteria of technical feasibility is shown in detail due to limitation of pages.

Table 1: Morphological Box of Design Features and Characteristics

<table>
<tr><th>Design Features</th><th colspan="12">Choice of Characteristics</th></tr>
<tr><td>Number of Stages</td><td colspan="3">1 Stage</td><td colspan="3">1 Stage + Assist</td><td colspan="3">2 Stages</td><td colspan="3">2 Stages + Assist</td></tr>
<tr><td>Configuration</td><td colspan="4">Tandem Staging</td><td colspan="4">Parallel Staging</td><td colspan="4">Nested</td></tr>
<tr><td>Propellant</td><td colspan="4">LOX/LH2</td><td colspan="4">LOX/RP-1</td><td colspan="4">LOX/C3H8</td></tr>
<tr><td>Launch Method</td><td colspan="4">Vertical</td><td colspan="4">Horizontal</td><td colspan="4">Air Launch</td></tr>
<tr><td>Landing Method</td><td colspan="3">Ballistic (Rocket Eng.)</td><td colspan="3">Ballistic (Parachute)</td><td colspan="3">Aerodynamic (Jet Eng.)</td><td colspan="3">Aerodynamic (Glider)</td></tr>
<tr><td>Impact Absorber</td><td colspan="4">Landing Legs</td><td colspan="4">Air Bags</td><td colspan="4">Brake Rockets</td></tr>
<tr><td>Mission Duration</td><td colspan="4">Short
Suborbit: < 0,5 hour
Orbit: < 3 hours</td><td colspan="4">Medium
Suborbit: 0,5-3 hours
Orbit: 3-24 hours</td><td colspan="4">Long
Suborbit: > 3 hours
Orbit: > 1day</td></tr>
<tr><td>Mission Success</td><td colspan="4">0,99 probability (low)</td><td colspan="4">0,999 probability (medium)</td><td colspan="4">0,9999 probability (high)</td></tr>
<tr><td>Catastrophic Failure</td><td colspan="4">0,0001 probability (low)</td><td colspan="4">0,001 probability (medium)</td><td colspan="4">0,01 probability (high)</td></tr>
<tr><td>Reusability</td><td colspan="3">< 100</td><td colspan="3">100 to 1000</td><td colspan="3">1001 to 10 000</td><td colspan="3">> 10 000</td></tr>
<tr><td>Turn-around Time</td><td colspan="4">< 2 days</td><td colspan="4">2 days to 1 week</td><td colspan="4">> 1 week</td></tr>
<tr><td>Seat Capacity</td><td colspan="4">< 10</td><td colspan="4">10 to 50</td><td colspan="4">> 50</td></tr>
<tr><td>Passenger Comfort</td><td colspan="4">Seatbound (low)</td><td colspan="4">Some movement (medium)</td><td colspan="4">Free floating room (high)</td></tr>
</table>

Criteria of Technical Feasibility

The feasibility of a technical development within a schedule and a cost frame expected is enhanced if the individual design concept is considered to be within the current state-of-the-art, well known, or easy to assess. If the individual design criterion is clearly contributing to these goals, than it should get a high mark (+5) if compared with another design criteria that requires new technology or unknown risks (-5).

Number of Stages: Two-stage concepts are proven and enhance technical feasibility; single-stage concepts for orbital applications are marginal but common for suborbital applications.

Configuration: A clean aerodynamic configuration without stage separation problems under high pressure is simple, proven and enhances feasibility.

Propellant: Propellants that are available, well tested and classified as "non-toxic" are enhancing technical feasibility.

Launch Method: Any launch method that is based on experience is favored since it reduces test effort required to provide evidence.

Landing Method: A concept that comes close to practices applied in air-transportation deserves high marks since it enhances technical feasibility.

Impact Absorber: A soft landing at low speed as applied in air transportation is well proven and enhances technical feasibility.

Mission Duration: Extended flights require more technical effort and equipment. They are a matter of technical feasibility because long flight durations lead to bigger vehicles. Those vehicles increase high development risk.

Mission Success: The problem of mission success is a matter of achieving a high degree of mission reliability, vehicle characteristics that are based on available and proven hardware components and a large number of tests and operational flights. Low mission success rates are therefore easier to achieve from a technical viewpoint.

Catastrophic Failures: A concept with low probability of catastrophic failure should get low marks with respect to chances of achieving this design goal.

Reusability: A high degree of reuses (design lifetime) of subsystems like engines and equipment requires a special effort and should get low marks. Proven systems should get high marks since they enhance chances of early availability and good economy.

Turn-around Time: Accessibility and maintainability are design criteria that insure short time intervals between two missions but require high technical development effort. Vehicle concepts that are designed with this objective deserve low marks.

Number of Pax Seats: Vehicles with large seat capacity are promising a better cost-effectiveness. On the other hand, vehicles with few passengers are smaller and easier to realize from technical aspects and should therefore get higher marks.

Passenger Comfort: The higher the comfort, the larger the vehicle and the higher the technical effort to achieve this. From technical viewpoint, a low comfort should get high marks.

Table 2 shows the results of a quantitative evaluation using the method of paired comparison. Full documentation of the necessary tables is published by R.A. Goehlich [4]. The first column shows design features in a ranked order concerning relative importance, while the other columns show corresponding characteristics in a ranked order for each design feature as well as their relative weights. For ranking purposes, figures are shown with one decimal, while knowing that true accuracy is lower than these values express.

If technical aspects would be the only ones, a conservative vehicle close to the state-of-the-art would be the preferred one, because it does require only a low level of effort and is associated with small risks to implement its development. Thus, design criteria received a high share of maximum points of merit if the concept considered promises to have only a low technical problem potential. In general, concepts using mature technology and proven subsystems are most desirable because they have highest potential for achieving high marks in reducing catastrophic failures and increasing mission success.

Table 2: Morphological Box of Design Options concerning Technical Aspects

Design Features	1. Choice of Characteristics	2. Choice of Characteristics	3. Choice of Characteristics	4. Choice of Characteristics
Catastrophic Failure (13,3%)	0,01 probability (60,0%)	0,001 probability (33,3%)	0,0001 probability (6,7%)	-
Mission Success (12,6%)	0,99 probability (60,0%)	0,999 probability (33,3%)	0,9999 probability (6,7%)	-
Mission Duration (12,4%)	Suborbit: < 0,5 hour Orbit: < 3 hours (60,0%)	Suborbit: 0,5-3 hours Orbit: 3-24 hours (30,0%)	Suborbit: > 3 hours Orbit: > 1day (10,0%)	-
Reusability (11,5%)	< 100 (45,0%)	100 to 1000 (35,0%)	1001 to 10 000 (20,0%)	> 10 000 (0,0%)
Launch Method (9,1%)	Air Launch (50,0%)	Vertical (33,3%)	Horizontal (16,7%)	-
Number of Stages (8,5%)	2 Stages + Assist (38,3%)	2 Stages (36,7%)	1 Stage + Assist (18,3%)	1 Stage (6,7%)
Propellant (7,8%)	LOX/LH2 (56,7%)	LOX/RP-1 (26,7%)	LOX/C3H8 (16,7%)	-
Landing Method (7,6%)	Aerodynamic (Jet Eng.) (38,3%)	Aerodynamic (Glider) (28,3%)	Ballistic (Parachute) (23,3%)	Ballistic (Rocket Eng.) (10,0%)
Configuration (5,2%)	Parallel Staging (46,7%)	Tandem Staging (33,3%)	Nested (20,0%)	-
Impact Absorber (5,1%)	Landing Legs (53,3%)	Air Bags (33,3%)	Brake Rockets (13,3%)	-
Turn-around Time (4,4%)	> 1 week (60,0%)	2 days to 1 week (30,0%)	< 2 days (10,0%)	-
Seat Capacity (2,4%)	< 10 (60,0%)	10 to 50 (30,0%)	> 50 (10,0%)	-
Passenger Comfort (0,0%)	Seat bound (50,0%)	Some movement (40,0%)	Free floating room (10,0%)	-

Criteria of Economical Feasibility

If economical feasibility would be the only criterion of choice, then the preferable concepts should be those promising the highest contribution to achieve good system cost-effectiveness during program life-cycle. Thus, those design criteria received a high share of maximum points of merit where the concept considered promises to have a good cost-effectiveness potential. Detailed description of results for economical feasibility is published by R.A. Goehlich [4].

Criteria of Political Feasibility

If political feasibility and public acceptability would be the only criteria of choice, then the preferable concepts should be those promising the easiest process leading to a certification as a transportation system. Thus, a design criterion received a high share of maximum points of merit if the concept considered promises to pass certification process relatively fast. It is also a matter of general concern of social institutions, particularly media and travel organizations. Detailed description of results for political feasibility is published by R.A. Goehlich [4].

Results

For suborbital applications, special emphasis should be given for low development risk and high safety rather than low-cost aspects. Suborbital vehicles are something like to demonstrate the realization of mass space tourism market by airline-like operations. Therefore, relative weights are set to 40 % for technical feasibility (low risk), 20 % for economic feasibility (low cost) and 40 % for political feasibility (high safety) resulting in an aggregated ranked list as shown in Table 3.

Table 3: Morphological Box of Suborbital Vehicle

Design Features	1. Choice of Characteristics	2. Choice of Characteristics	3. Choice of Characteristics	4. Choice of Characteristics
Catastrophic Failure (14,3%)	0,0001 probability (38,7%)	0,001 probability (31,3%)	0,01 probability (30,0%)	-
Mission Success (12,3%)	0,9999 probability (36,7%)	0,999 probability (35,3%)	0,99 probability (28,0%)	-
Mission Duration (10,5%)	< 0,5 hour (50,0%)	0,5-3 hours (34,0%)	> 3 hours (16,0%)	-
Reusability (9,3%)	< 100 (33,0%)	100 to 1000 (30,3%)	1001 to 10 000 (23,0%)	> 10 000 (13,7%)
Launch Method (9,0%)	Air Launch (43,3%)	Horizontal (37,3%)	Vertical (19,3%)	-
Propellant (8,2%)	LOX/RP-1 (40,0%)	LOX/C3H8 (30,7%)	LOX/LH2 (29,3%)	-
Landing Method (7,6%)	Aerodynamic (Jet Eng.) (34,3%)	Aerodynamic (Glider) (31,0%)	Ballistic (Parachute) (25,3%)	Ballistic (Rocket Eng.) (9,3%)
Number of Stages (5,9%)	2 Stages (27,3%)	1 Stage + Assist (25,3%)	2 Stages + Assist (22,7%)	1 Stage (24,7%)
Turn-around Time (5,7%)	> 1 week (43,3%)	2 days to 1 week (31,3%)	< 2 days (25,3%)	-
Impact Absorber (5,1%)	Landing Legs (56,7%)	Air Bags (30,0%)	Brake Rockets (13,3%)	-
Seat Capacity (4,5%)	< 10 (45,3%)	10 to 50 (31,3%)	> 50 (23,3%)	-
Configuration (4,4%)	Parallel Staging (46,0%)	Tandem Staging (30,0%)	Nested 24,0%)	-
Passenger Comfort (3,0%)	Seat bound (41,3%)	Some movement (40,0%)	Free floating room (18,7%)	-

As a summary of the list, the ideal vehicle applicable for suborbital market should apparently be designed to meet the following first choice of characteristics ranked according to their relative importance:

> *"A low catastrophic failure rate, a high mission success rate, a short mission duration of less than 30 minutes, a low reusability of less than 100 reuses, air launched, using liquid oxygen and kerosene as propellants, landing aerodynamically with jet engines, a two-stage vehicle, a turn-around time of more than one week, using landing legs, a low seat capacity of less than 10 seats, parallel staged and low passenger comfort permanently wearing seatbelts."*

Designing a vehicle with less preferable characteristics is possible, but would result in a reduced feasibility.

Suborbital vehicles should have proven low development risk and high safety standards by operating space vehicles similar to aircraft. However, for orbital applications, special emphasis should be given for low cost aspects. Therefore, relative weights are set to 30 % for technical feasibility (low risk), 50 % for economic feasibility (low cost) and 20 % for political feasibility (high safety) resulting in a ranked list as shown in Table 4.

Table 4: Morphological Box of Orbital Vehicle

Design Features	1. Choice of Characteristics	2. Choice of Characteristics	3. Choice of Characteristics	4. Choice of Characteristics
Catastrophic Failure (14,5%)	0,0001 probability (44,0%)	0,001 probability (31,0%)	0,01 probability (25,0%)	-
Mission Success (11,9%)	0,9999 probability (41,7%)	0,999 probability (35,7%)	0,99 probability (22,7%)	-
Mission Duration (10,8%)	3-24 hours (40,0%)	< 3 hours (35,0%)	> 1 day (25,0%)	-
Reusability (10,2%)	100 to 1000 (28,7%)	1001 to 10 000 (26,1%)	< 100 (23,0%)	> 10 000 (22,2%)
Launch Method (8,0%)	Horizontal (41,7%)	Air Launch (41,4%)	Vertical (17,0%)	-
Seat Capacity (7,0%)	> 50 (35,4%)	10 to 50 (33,4%)	< 10 (31,4%)	-
Turn-around Time (6,6%)	< 2 days (37,7%)	> 1 week (31,7%)	2 days to 1 week (30,7%)	-
Number of Stages (6,4%)	1 Stage (29,0%)	1 Stage + Assist (27,8%)	2 Stages (25,4%)	2 Stages + Assist (17,8%)
Propellant (6,3%)	LOX/RP-1 (41,4%)	LOX/C3H8 (33,0%)	LOX/LH2 (25,7%)	-
Landing Method (6,1%)	Aerodynamic (Glider) (33,6%)	Aerodynamic (Jet Eng.) (29,7%)	Ballistic (Parachute) (28,3%)	Ballistic (Rocket Eng.) (8,4%)
Configuration (4,6%)	Parallel Staging (47,7%)	Nested 27,3%)	Tandem Staging (25,0%)	-
Passenger Comfort (3,9%)	Some movement (42,7%)	Seat bound (31,0%)	Free floating room (26,3%)	-
Impact Absorber (3,7%)	Landing Legs (59,0%)	Air Bags (30,3%)	Brake Rockets (10,7%)	-

As a summary of the list, the ideal vehicle applicable for the orbital market should apparently be designed to meet the following first choice of characteristics ranked according to their relative importance:

> *"A low catastrophic failure rate, a high mission success rate, a medium mission duration of 3 to 24 hours, a medium reusability between 100 to 1000 reuses, horizontally launched, a high seat capacity of more than 50 seats, a turn-around time of less than 2 days, a two-stage vehicle, using liquid oxygen and kerosene as propellants, landing aerodynamically as a glider, a medium passenger comfort allowing some movements and using landing legs."*

Designing a vehicle with less preferable characteristics is possible, but would result in reduced feasibility. If two characteristics are in conflict to be realized both (here: "1 Stage" and "Parallel Staging"), the characteristic that corresponds to the design feature of higher importance ("Number of Stages" is more important than "Configuration") should receive priority.

Pre-selection

There are a total of 153 proposed concepts of which 44 are for suborbital vehicles and 109 are for orbital vehicles. A pre-selection is necessary because each vehicle concept causes 130 data for technical, 130 data for economic and 130 data for political aspects, resulting in a total of about 60 000 data, which is not manageable any more. Resulting from the pre-selection, 9 suborbital vehicles and 11 orbital vehicles are left for detailed investigations to determine a possible suitability for space tourism flights which are summarized in Table 5 for suborbital vehicle concepts and Table 6 for orbital vehicle concepts.

Table 5: Pre-selection of Suborbital Vehicle Concepts

Design:				
Vehicle:	C-21	Eclipse Astroliner	Hopper (suborbital)	Hopper (once-around-earth)
Inventor:	Cosmopolis XXI	Kelly Space and Technology	Astrium	Astrium
Country:	Russia	USA	Germany	Germany
Launch Mass:	27 Mg (incl. M-55X)	327 Mg	491 Mg	491 Mg
Payload:	2 pax + 2 crew	(40 pax)	7,5 Mg	> 7,5 Mg
Status:	active	inactive	active	active
Design:				
Vehicle:	MiG 31 System	Rocketplane XP	Star Booster 200	X-15 System
Inventor:	n.a.	Pioneer Rocketplane	Buzz Aldrin	NASA
Country:	Russia	USA	USA	USA
Launch Mass:	46 Mg (incl. MiG 31)	n.a.	n.a.	204 Mg (incl. B-52)
Payload:	2 pax + 2 crew	2 pax + 1 crew	n.a.	0 Mg + 1 crew
Status:	active	active	active	inactive; realized
Design:		-	-	-
Vehicle:	Xerus	-	-	-
Inventor:	XCOR Aerospace	-	-	-
Country:	USA	-	-	-
Launch Mass:	n.a.	-	-	-
Payload:	1 pax + 1 crew	-	-	-
Status:	active	-	-	-

Table 6: Pre-selection of Orbital Vehicle Concepts

Design:				
Vehicle:	ALS	Buran	HOPE	K-1
Inventor:	Boeing/Thiokol	RSC Energia	NASDA	Kistler Aerospace
Country:	USA	Russia	Japan	USA
Launch Mass:	363 Mg (incl. B747)	2525 Mg (incl. Energia)	430 Mg (incl. H2-D)	382 Mg
Payload:	3 Mg	30 Mg	3,0 Mg	4,0 Mg
Status:	active	inactive; realized	active	active

(continued from page 7)

Design:				
Vehicle:	Kankoh Maru	MAKS-M	Rocket Plane	SLI (Bimese)
Inventor:	Japanese Rocket Society	NPO Molniya	NAL	Boeing
Country:	Japan	Russia	Japan	USA
Launch Mass:	550 Mg	620 Mg (incl. An-225)	n.a.	n.a.
Payload:	50 pax + 4 crew	7 Mg	n.a.	n.a.
Status:	active	active	active	active

Design:				-
Vehicle:	SLI 2	Space Shuttle	Venture Star	-
Inventor:	Northrop Grumman	NASA	Lockheed Martin	-
Country:	USA	USA	USA	-
Launch Mass:	n.a.	2035 (incl. ET and SRB)	1200 Mg	-
Payload:	n.a.	25 Mg + 7crew	23 Mg	-
Status:	active	active; realized	inactive	-

Final Selection

Preferred design criteria from first part of this paper are used to measure the goal achievement of pre-selected vehicles. However, for fine-tuning it is necessary to extend the limited decision options of three or four to a ten-scale goal achievement matrix. With this, it is also possible to determine values in between. It is not possible to achieve a level of more than 85 % goal achievement because some of the attributes are resulting in conflicting demands. On the other hand, vehicle concepts should succeed in each category (technical, economical and political) to at least 50 %.

The 13 design features used for this evaluation are a basic approach for selecting vehicles for space tourism. More design features combined with detailed procedures using mathematical utility functions leave less room for intuitive judgments and could improve quality of selection. However, considering that available specifications of investigated vehicles are very rare, detailed investigations are decidedly limited. It is obvious that this evaluation process is transparent but subjective and it depends on the expertise and preferences of the person performing this valuation. Thus, it is judged to be typical but not representative.

The result of suborbital concepts evaluated and ranked by the author with respect to overall goal achievement is shown in Figure 3 (divided in groups) and Figure 4 (after weighing each group). Weighed goal achievements vary from 52 % to 73 % with Hopper (suborbital) concept - achieved 68 % - closest to the theoretical optimized concept.

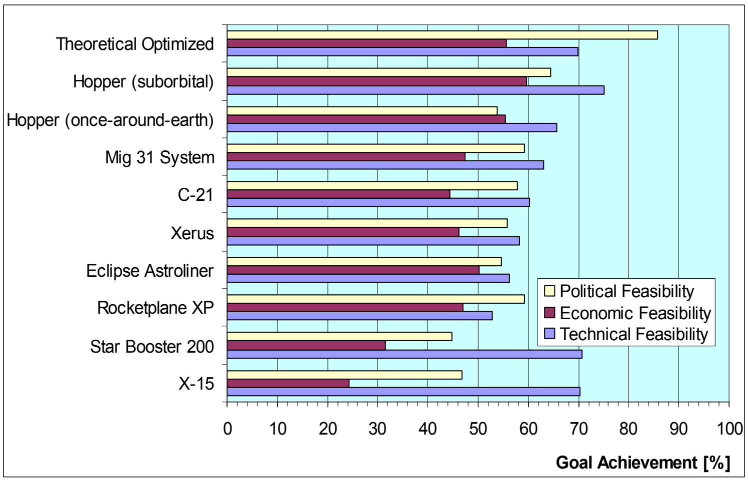

Figure 3: Estimated Shared Goal Achievement of Suborbital Vehicle Concepts

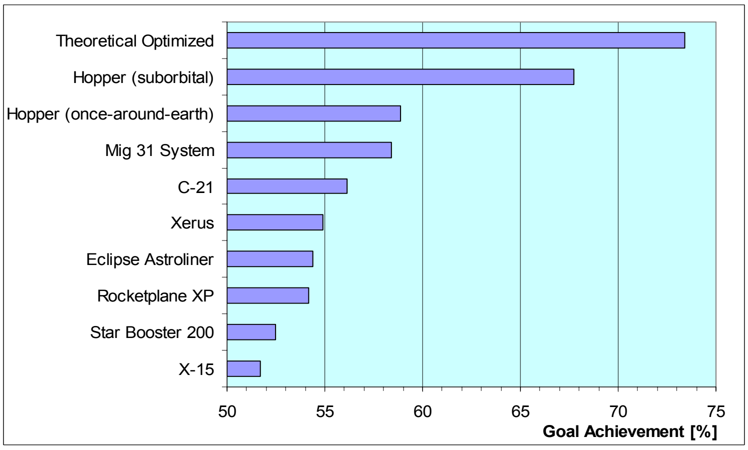

Figure 4: Estimated Total Goal Achievement of Suborbital Vehicle Concepts

The result of orbital concepts ranked by the author with respect to overall goal achievement is shown in Figure 5 (divided in groups) and Figure 6 (after weighing each group). Weighed goal achievements vary from 50 % to 73 % with the Kankoh Maru concept achieving the highest score of 65 % beside the theoretical optimized concept.

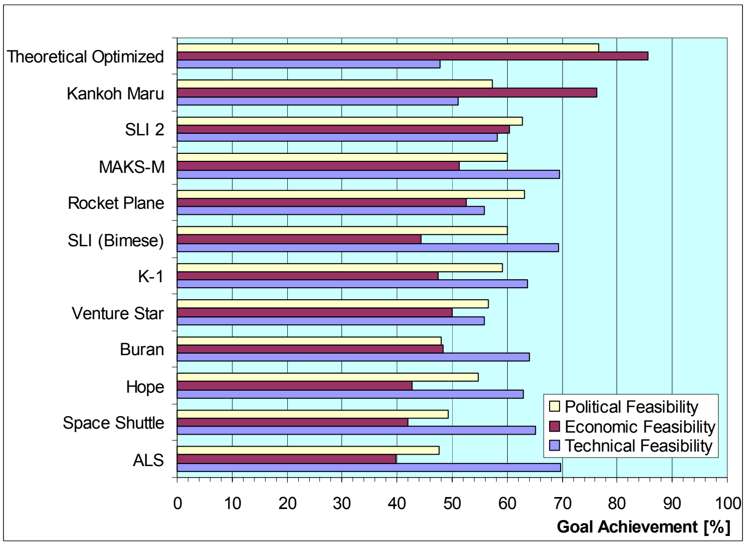

Figure 5: Estimated Shared Goal Achievement of Orbital Vehicle Concepts

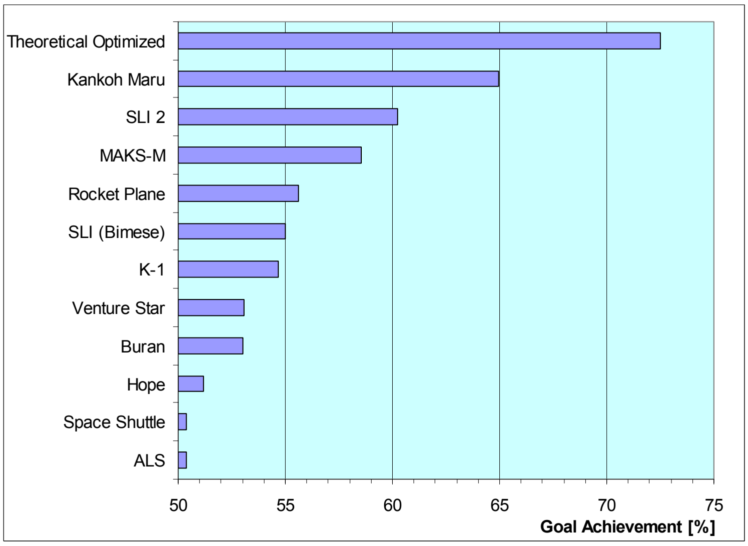

Figure 6: Estimated Total Goal Achievement of Orbital Vehicle Concepts

Concluding Remarks

Many vehicle concepts have been assessed and a few have even been tested and built. However, the majority has not reached the development stage due to numerous show-stoppers, of either technical, economic or political nature. In case of technical issues being dominant, the area in which developers need to make major progress is for example in-flight experiments. Many of the phenomena influencing the mission of a reusable launcher cannot be reproduced on the ground and in-flight experiments is the only means of verifying theoretical predictions and reducing technological risk, before starting a full-scale vehicle development. The Space Shuttle is currently providing a large amount of flight data, which the USA can use to design a second generation of reusable launch vehicles. In case of economic issues being dominant, more advanced technologies could enable the design of a RLV with full reuse capability and specific transport costs lower than those of an expendable launch vehicle in near-term future (2010-2015). In case of political issues being dominant, even if cost benefits of RLVs are not yet clear, governments are advised to support RLV programs to invest in its future space market prospective.

In general, the investigation on selecting vehicle concepts has shown that vehicle concepts, which have a high goal achievement, do not necessarily need to have to fulfill all criteria of the theoretical optimized concept. For example, the theoretical optimized concept for orbital applications is a single-stage winged body, but Kankoh Maru is a ballistic vehicle concept and SLI 2 is a two-stage vehicle concept. Therefore, the author supposes that the "right" vehicle concept for tourism transportation application will be not only depended on one main specific design criterion such as single-stage, two-stage, winged or ballistic. Much more important for the feasibility will be the "right" mixture of all criteria, i.e. a single-stage ballistic vehicle concept as well as a two-stage winged vehicle concept would be conceivable vehicles that could be realized at the right time under than prevailing trends and conditions.

Acknowledgment

The publication of this paper was funded by Japan Society for the Promotion of Science and Alexander von Humboldt Foundation, which is gratefully acknowledged by the author.

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