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Space Tourism: Making it Work for Fun and Profit

J. Olds
D. McCormick
A. Charania
L. Marcus

Space Systems Design Lab
Georgia Institute of Technology
Atlanta, GA
USA

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Space Tourism: Making it Work for Fun and Profit

Dr. John R. Olds*, David McCormick†, Ashraf Charania† and Leland Marcus†
Space Systems Design Laboratory
School of Aerospace Engineering
Georgia Institute of Technology, Atlanta, GA 30332-0150

ABSTRACT

This paper summarizes the findings of a recent study of space tourism markets and vehicles conducted by the Space Systems Design Laboratory at Georgia Tech under sponsorship of the NASA Langley Research Center. The purpose of the study was to investigate and quantitatively model the driving economic factors and launch vehicle characteristics that affect businesses entering the space tourism industry. If the growing public interest in space tourism can be combined with an economically sound business plan, the opportunity to create a new and profitable era for space flight is possible. This new era will be one in which human space flight is routine and affordable for many more people. The results of the current study will hopefully serve as a guide to commercial businesses wishing to enter this potentially profitable emerging market.

NOMENCLATURE

AF	airframe
DDT&E	design, development, testing and evaluation
FY2000	fiscal year 2000
IOC	initial operating capability
IRR	internal rate of return
LMNoP	Launch Marketing for Normal People
NASA	National Aeronautics and Space Administration
NPV	net present value
RLV	reusable launch vehicle
SG&A	Selling, General and Administration
TAT	turn around time
TFU	theoretical first unit
TIF	time in flight

INTRODUCTION

Study Overview

The present research was conducted in four distinct phases. Phase 1 consisted of the development of a new flexible modeling tool for simulating the future space tourism launch market. This new tool, LMNoP, predicts the number of passengers (space tourists) available to the market in any given year as a function of ticket price, expanding market size, perceived reliability, number of launch sites, orbital vs. sub-orbital capabilities, passenger accommodations, airframe lifetime, and other variables. Coupled with launch vehicle characteristics such as development cost, turnaround time, recurring cost, and number of passengers, the LMNoP model allows an analyst to model the economic attractiveness of any proposed space tourism scenario. LMNoP is a stochastic model and directly treats uncertainty in market size and growth using Monte Carlo simulation techniques. The economic results are therefore distributions of expected return on investment, net present value, etc. for an optimized ticket pricing strategy. Phase 2 has tested this new tool is tested on several proposed space tourism transportation options to determine if any makes a strong business case. Phase 3 of the project has identified and prioritized the major economic drivers for a profitable business case and has useful established goals/targets for the most important

Assistant Professor, School of Aerospace Engineering, Senior Member AIAA.
† - *Graduate Research Assistant, School of Aerospace Engineering, Student Member AIAA.*

vehicle characteristics (e.g. reliability > 0.9999, investment cost < $1.5B). Phase 4 used the sensitivities generated by Phase 3 to find an economically viable space tourism transportation option.

Background

As regular Space Shuttle and Soyuz flights make spaceflight seem routine to many people, the subject of private space tourism is making appearances in the popular press with increasing regularity.

Figure 1 – Space Tourism Theme Park.

The conclusions of many studies to date are that this business area will be lucrative. Penn and Lindley conclude that with near-term reusable technology, a viable space tourism business can be created using very high flight rates and inexpensive propellants.[1] They also conclude that the market size is adequate to support the industry. The argument was a the extremely high flight rates, the cost of expensive cryogens actually became a driving factor in cost, contrary to current launch vehicles, where propellant costs are small enough compared to other costs that they can essentially be overlooked. To further bolster reusable launch vehicle flight rates, synergies between a high flight rate space tourism model and a high flight rate cargo market like space solar power were also identified.[2] A similar conclusion is reached by Rogers who supports a shift in mindset for future launch vehicle projects to vehicles with high operability and low costs for launch.[3]

To assist the space tourism segment of the industry, there are many other synergies with ground-based industries such as theme parks and advertising.[4] These could help reduce some of the economic burden when compared to an exclusive passenger carrier activity. These ground-based industries could also be enablers for space tourism.

Factors such as this combined with the promises of certain new technologies intended to make human space flight both safer and more cost effective, make private space flight seem more likely than ever.

Motivation

Point - Spaceflight has intrigued the popular consciousness since before mankind even knew of its possibility. The vastness of the cosmos combined with the feeling of discovery is an experience enjoyed by most only vicariously through astronauts. Just as atmospheric flight was first only experienced by few onlookers gawking at early barnstorming and select members of the military, then progressed to be experienced by only the very wealthy to the current day or routine air travel, space travel should eventually progress to the average person. It is the destiny of spaceflight to follow this same paradigm and open the heavens to the masses.

Counterpoint – That's all great, but I want to make money.

To date, it has been hard to get around Counterpoint. Certainly, as evidenced by government programs, it is technically feasible to send humans into space for extended periods of time and return them safely to earth. Thus, the economic challengeis the only thing standing in the way of the enjoyment of space for orders of magnitude more people than enjoy it today. What cost goals do the aerospace community have to meet in order to bring this industry to fruition?

To answer those questions as well as aid future inquiries into the business of space tourism is essential to its emergence. At the center of this research is a stochastic cost analysis used to evaluate several concepts, identify driving factors in the economic viability in selected areas of the design space and then use this information in a cost-as-an-independent-variable analysis to determine the "break points" for the values of the input variables for the cost analysis. These "break points" should show how far this industry must go to be successful.

LAUNCH MARKETING FOR NORMAL PEOPLE (LMNOP)

Overview

LMNoP is a new stochastic Microsoft Excel© business simulation for space tourism created during the course of this research. It takes vehicle economic characteristics such as design, development, testing and evaluation (DDT&E,) theoretical first unit (TFU) cost, reliability, etc. and inserts these data into a random process simulation. This simulation then does a life cycle cost analysis on the vehicle based on input from a stochastic market demand model, a consequence-based vehicle failure simulation and a customer-appeal analysis module.

These then use pseudo-random number generation to create a different scenario for each recalculation of the model. The model is run on the order of one thousand trials and a distribution for economic evaluation parameters is generated. These distributions provide economic feasibility information in the form of probability distributions.

Life Cycle Cost

LMNoP builds a vehicle development program around projected space tourism market demand. The financial qualities of that program are determined from user defined programmatic and cost variables. The company that is building the vehicle is assumed to be the same as the provider of launch service for the space tourists.

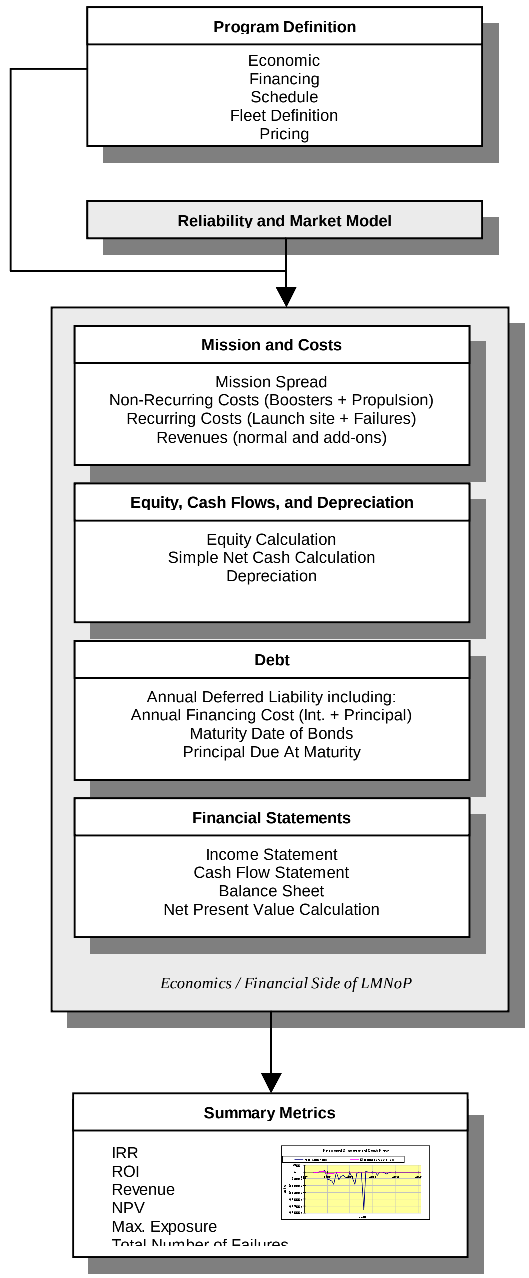

Figure 2 – LMNoP Economic Schematic

LMNoP does not have the capability to cost concepts given a particular vehicle definition. The costs in the model come from other sources (such as from literature reviews for existing concepts like the Soyuz or cost estimating relationships for *Hyperion*[10]). These costs are integrated into the LMNoP financial engine in order to determine the full financial scope of the project. LMNoP is robust enough to handle different vehicle concepts, development schemes, financing plans, and pricing structures. LMNoP is also well suited to handle new developments in operations through its use of a site fee. A built in assumption is that no vehicle will build its own indigenous launch facility (with associated capital expenditures) but rather pay user fees at some future spaceport or lease operations at existing facilities.

The economic and financial portions of the LMNoP model obtain inputs from the program definition, flight reliability, and multipliers section of the model. Financial metrics like internal rate of return (IRR) and net present value (NPV) are determined through calculation of specific program costs. These are then coupled with user-defined pricing with associated multipliers that originate in other parts of the model. Five sets of program definition inputs are needed. These are broken into economic, financing, schedule, fleet, and pricing.

Program Definition

The economic variables that need to be defined for each analysis include the dollar year that all subsequent values are based upon, inflation rate, tax rate, discount rate, and average annual interest rate (used for calculation of the interest that needs to be paid on deferred liability or debt).

The financing variables include those that determine both the frequency and amount of equity (i.e. stock) offered as well as the per-year fixed and per-flight variable selling, general, and administrative (SG&A) expense.

The scheduling variables include user determination of initial operating capability (IOC,) program termination, years for vehicle development, and years to ramp up to full operability. Before any flights can occur, LMNoP (based upon user input) segments airframe and engine development into appropriate years before IOC.

The model can handle up to three new, separate vehicle sub-developments in the program (with the capability of modeling up to two stages for each vehicle). This can account for the same company building a sub-orbital vehicle and then transitioning in a future year to an orbital vehicle. For each stage of the vehicle (as well as where appropriate its associated propulsion module) the following fleet definition variables are needed: passenger capacity per launch, overall reliability, flight lifetime, turn-around time, time in orbit, DDT&E cost, TFU cost, learning effects, and government contribution percentages.

The pricing variables include insurance definitions, charges for failures, and site fee costs per flight. Insurance in this case refers only to vehicle liability insurance per flight based upon the expected probability of failure (1- overall reliability) multiplied by the TFU cost of the vehicle's airframe and engine. If there is a failure in any particular year, two economic effects instantly result: namely the company is out of business for a specified number of years (accepting a user defined one-time charge to account for program recovery and victim redress) and all subsequent insurance changes per flight increase by a certain user defined percentage.

If the vehicle is modeled as an already existing development (i.e. like a Soyuz) a set recurring cost per flight can be set. Yearly pricing options include both static and varying (based upon either a linear or quadratic pricing). Up to five different revenue types can be used to account for additional revenues from non-direct sources (i.e. advertising on vehicle, television revenue, etc.).

<u>Financials</u>

A separate mission and costs section determines the spread of flights dependent upon market captured for various prices. This translates into non-recurring costs (booster/propulsion development and government contribution), recurring costs (launch site fees and business failure charges), and revenues (from static/ variable pricing and revenue add-ons). Equity calculations are then determined along with associated deprecation schedules. Deprecation is defined using U.S. government standards based upon a 5-year depreciation of fixed assets. A separate debt calculation is made with the assumption that negative cash flows in any given year (after accounting for revenue and equity infusion) are paid off using either long or short-term bonds (20, 15, 10, 5, or 1 year varieties). For this financial analysis, the free cash flow is defined in Eqn. 1.

Earnings before Interest and Taxes (EBIT)

- Taxes (tax shields from negative income years carried over until exhausted by tax liability) (1)

- Capital Expenditures (airframe and engine acquisition)

+ Depreciation

= Free Cash Flow

All the above information is aggregated to obtain the discounted cash flows and associated summary metrics like NPV (for NPV, based upon user defined discount rates).

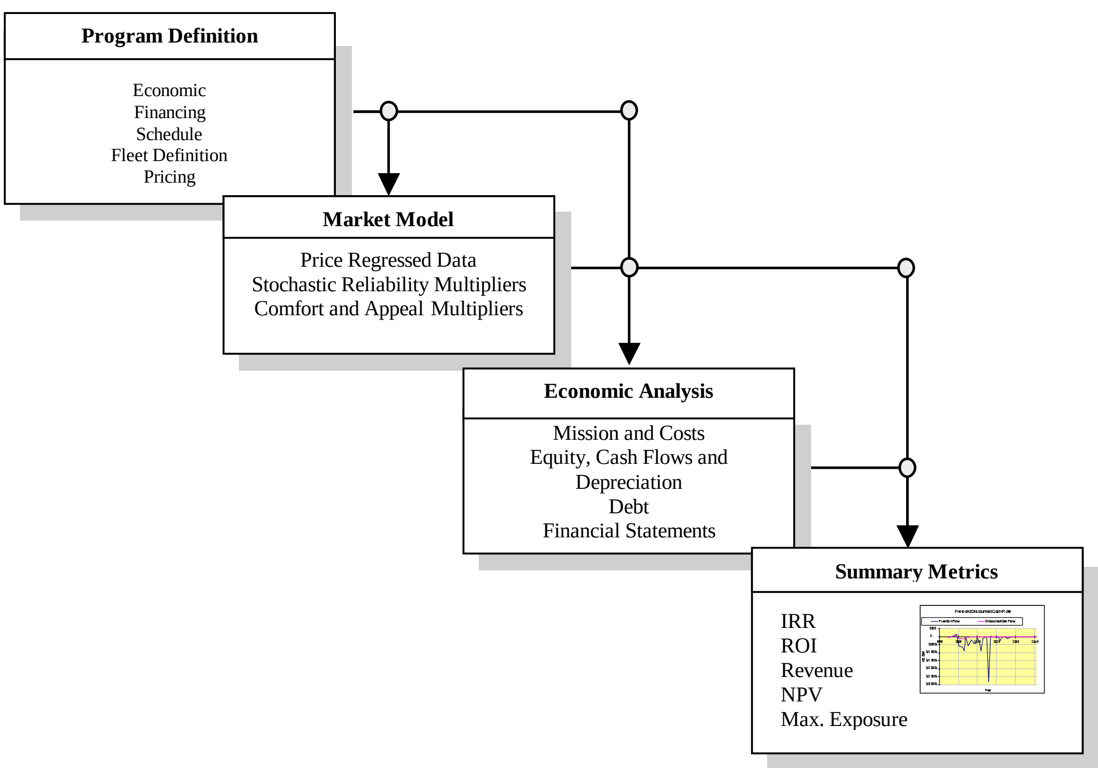

Figure 3 – LMNoP Schematic.

Market Demand Model

The pre-adjusted market demand is based on a literature search. This search focused on survey results that specified launch market demand as a function of ticket price. It resulted in two market surveys that are used in LMNoP.

The primary source for market information is the Commercial Space Transportation Study conducted by a consortium of aerospace companies for the National Aeronautics and Space Administration (NASA.)[5] This provides information based on worldwide incomes and the likelihood of those with sufficient income interested in a space trip purchasing a ticket. This represents a more bottom-up approach. The second is a top-down approach by Nagatomo and Collins.[6] This provides market survey data to augment the CSTS information. All market information used is for worldwide demand.

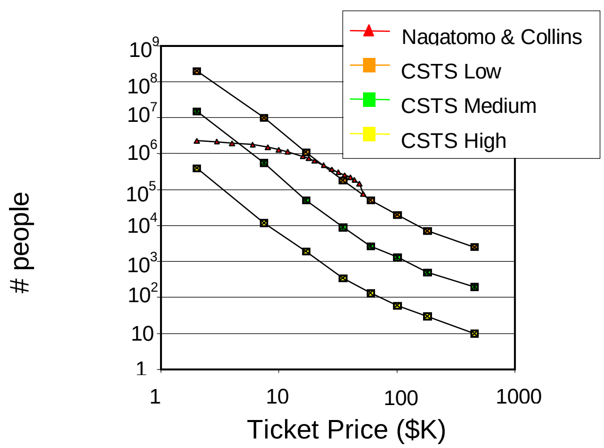

Figure 4 – Market Curves for LMNoP.

This results in a population of results for each of the price points of the investigation. To account for this population spread, a normal distribution is fitted to the data at selected price cross-sections. From this, the model interpolates the mean and variance of the normal distribution to obtain the probability distribution for the number of customers at a specified price. Then for each year of the simulation, a random member of that distribution is selected to be the number of customers for that particular year. This results in a randomly fluctuating customer base for each simulation that tests the robustness of a project against changing market conditions.

This market information is then fed to the reliability and customer appeal modules for adjustment before it is sent to the life cycle cost model.

Reliability Module

The reliability module contributes to LMNoP by placing a multiplier on the baseline customer demand information provided by the market module. When there are no failures, this multiplier is unity and there is no change to the remaining sections of LMNoP. Once a failure occurs, the module begins to modify the market demand as well as affect cash flow. Whether or not a failure occurs is modeled by a constant hazard rate for each year based on the number of flights in that year. There is no break-in period or age effects on reliability.

The most immediate impact of a failure in LMNoP is a fixed charge to the operating expenses of the company. This represents the liability associated with carrying members of the general public. This charge can be user-specified and should be in line with the expenses associated with an airline accident involving loss of life. The one time charge should be punitive enough so as to discourage reliability low enough to cause failure.

The second aspect of a launch failure is a complete shutdown of market demand and therefore flight operations while the cause of the failure is investigated and remedied. This period of time can be more than a year and significantly affects the profitability of a space tourism concept.

The third impact of a failure is a slow linear ramp-up in customer demand following a failure. This is designed to simulate the rebuilding of trust in the company over time after operating successfully.

The final impact of failure results from the possibility of a second failure during the ramp-up period. It is expected that this would completely obliterate public confidence in the project, driving market demand and therefore the flight rate of the project to zero. In LMNoP, this results complete business shutdown and halts life cycle cost analysis.

Fig. 3 shows an example of the market multiplier effect of a failure. There is a failure in year 25 and then another in year 30 during the recovery period. This is fatal to the business and the analysis of this case ends at that time.

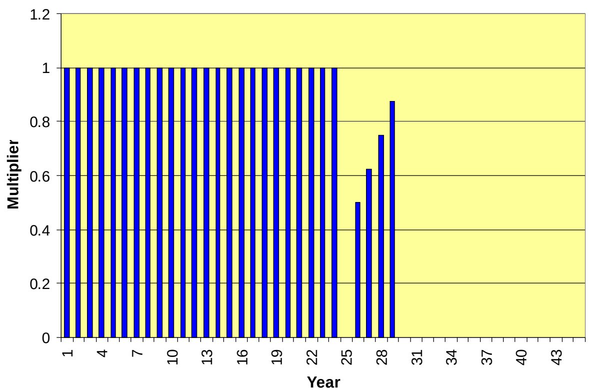

Figure 5 – Consequences of Failure.

Customer Appeal Market Multipliers

It is obvious that certain entertainment value factors of a space tour will increase desirability. LMNoP divides these factors into comfort, visibility, duration and availability. Unfortunately, the literature search did not reveal the quantitative effects of these intangible items on customer demand, so engineering judgment determined the values for each of these factors.

Comfort

Comfort is divided into four categories, all directly modeled after airline comfort levels. Comfort level for this model is primarily defines by the amount of volume afforded each passenger. LMNoP recognizes the following categories of passenger comfort:

- Sub-Coach – This level of comfort is less than that of the average Coach-level airline flight. There is a minimal amount of room with no amenities. This has a market multiplication factor of 0.5.
- Coach – This level is the same as that for airline coach class, with the exception of food and beverage service. It is doubtful this will be possible during an earth-to-orbit ascent. This has a market multiplication factor of 1.0
- Business Class – This offers more room than coach, with the possibility of flight crew service during extended flights. This has a market multiplication factor of 1.5.
- First Class – This is everything a first class passenger might expect on a major airline. This has a market multiplication factor of 2.0.

Visibility

Visibility provides a better passenger experience and affects the market model as follows:

- Multiple people per window – 0.5 times standard market.
- One window per person – 1.0 times standard market.
- One large window per person – 1.5 times standard market.
- “Glass ceiling” view – 2.0 times standard market

Duration

Duration of the flight also influences passenger experience and therefore affects the market as:

- Sub-Orbital – 0.5 times standard market
- Single Earth Orbit – 1.0 times standard market
- Multiple Earth Orbits – 1.5 times standard market

- Space Hotel – 2 times standard market

Availability

The number of global launch sites can affect the market size for a space entertainment venture. Here it is assumed that 3 launch sites enables global market capture. This is based on the assumptions of the market surveys that make up the base global market model that the three main markets for space tourism will be Europe, North America and the Pacific Rim. A curve fit to the market capture for 1, 2 and 3 sites was extracted and this is used as a multiplier for the base market model. This given in Eqn. 2:

$$0.57735\sqrt{Number\_sites} \qquad (2)$$

CONCEPT RESULTS AND DISCUSSION

Overview

To both test the LMNoP model and see where several concepts stand as far as their profitability in a space tourism environment, LMNoP was run on four concepts. They vary from currently flying (Soyuz) to many years into the future using a representative third generation launch vehicle concept. All analyze the business case for an owner/operator of some type of hardware component for carrying people into space.

Soyuz Purchase

The Soyuz (Fig. 6) test is designed to test current space tourism opportunities using the LMNoP model.[7,8] Because trips to Mir via Soyuz capsules are already being marketed to an elite clientele, this should give a relative idea of how our modeling technique would evaluate such a plan. The basic idea is to purchase a Soyuz flight for a fixed price for 3 passengers from the Russian government in exchange for an orbital flight for paying passengers. This is a low up-front investment space tourism strategy.

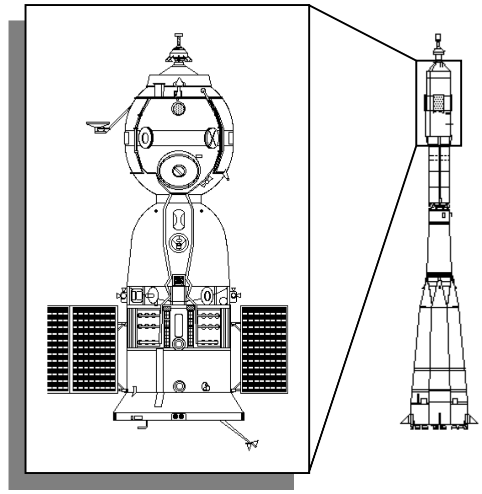

Figure 6– Soyuz Spacecraft and Launch Vehicle.[8]

Concept Assumptions

Soyuz was selected to represent using a current expendable launch vehicle in the space tourism market. Because it used existing technology DDT&E and TFU were assumed to be zero. Also, because there was no risk associated with developing a new launch system, the discount rate for calculating NPV was chosen as 15%, the lowest of all the candidate designs. The fee paid to the Russian government is assumed to be $28M.

Price Sweep

As is evident from Fig. 7, the optimal pricing strategy is largely determined by the price paid to the Russian government for the Soyuz launch. This optimal price is very close to the maximum of $10M per passenger for the LMNoP market model. It is to be expected as the cost to the space tour company is $9M per person on the flight. This profit margin does not compare well to the 15% discount rate. The price also means this is not the gateway to space for the average person.

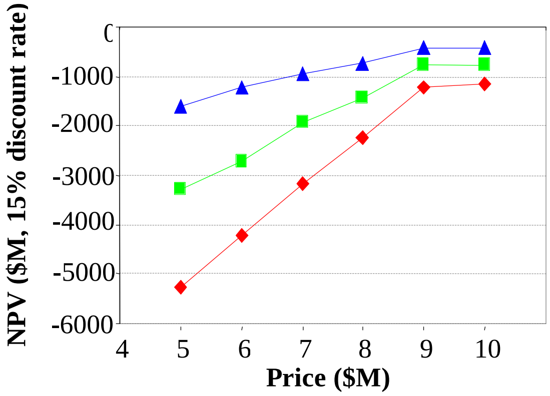

Figure 7 - Price Sweep for Soyuz Purchase.

Reliability Sweep

Fig. 8 is a very interesting result. Here, the lower the reliability, the better the business case. This is because the project does better when it is driven out of business early by the failure model. Obviously, this should not be taken as encouraging low launch vehicle reliability, but it may indicate a proper time limit on this particular project. This trade was done for a constant $10M ticket price.

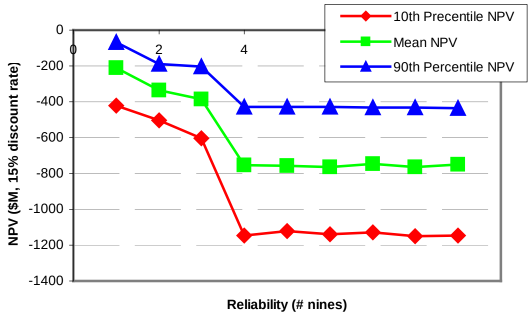

Figure 8 – Reliability Sweep.

Sub-orbital Reusable Rocket

The inclusion of this vehicle is designed to test the feasibility of near-term sub-orbital Reusable Launch Vehicles (RLV's) at providing entertainment class space transportation. When compared to an orbital rocket of similar design, the sub-orbital rocket is much smaller, with lower up front and operating costs. It also performs a less stressful mission profile than a comparable orbital RLV.

Concept Assumptions

This vehicle is an X-Prize-class 10 passenger sub-orbital reusable rocket.[9] It has one rocket engine for power and a wing-body configuration using kerosene for fuel and liquid oxygen for oxidizer. As it requires cargo aircraft transportation to return to the launch site, this amount is included in the launch site fee. It is important to note that this is a zero-order estimate and not a complete concept, but it should be representative of this class of vehicle. The engineering vehicle characteristics are given in Table 1.

Table 1 – Sub-Orbital Vehicle Characteristics

Parameter	Value
Gross Weight	265 klb.
Dry Weight	35 klb.
Vacuum Thrust	370 klb.
Sea Level Thrust	330 klb.
Mass Ratio	6.80

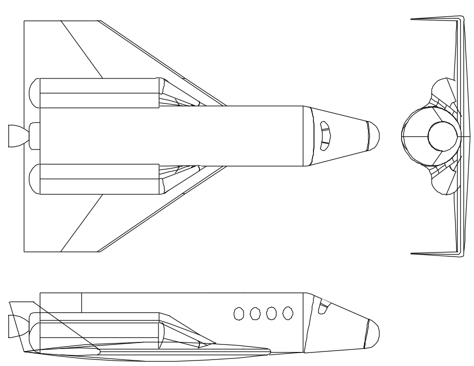

Figure 9 – Sub-Orbital Vehicle Three View.

Price Sweep

It is evident from Fig. 10 that there is an optimum price at around $8M. This is not surprising since there is a recurring cost associated with this vehicle on the same order of magnitude as this ticket price.

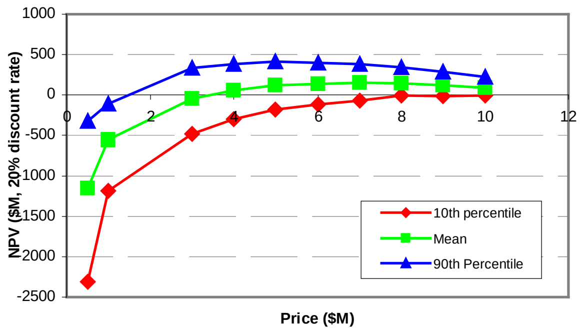

Figure 10 – Price Sweep for Sub-Orbital Rocket.

Reliability Sweep

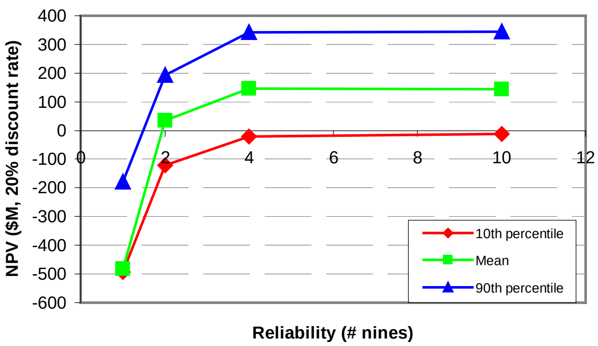

Figure 11 – Reliability Sweep for Sub-Orbital Rocket.

The reliability sweep at a constant ticket price of $8M for this vehicle shows a more conventional set of curves than that of the Soyuz purchase plan. It appears that a vehicle of this type will need 99.99% (four nines) reliability in order to avoid economic penalties for failure. All three confidence levels seem to follow the same trend.

Second Generation RLV Add-on Module

There is a chance that in the near future, there will be a commercial RLV with the capability to return payload from orbit. If the reliability of this RLV is high enough, a low cost option for space tourism might be to use this existing platform with the addition of a passenger pod, or SpaceCab. This concept represents minimal up-front cost with low recurring cost for an orbital vehicle.

Concept Assumptions

SpaceCab uses a 2nd Generation (RLV) to carry a specially designed passenger cabin in its payload bay, similar to the way the Space Lab module rides in the payload bay of the Space Shuttle. The defining characteristics for this module are the number of passengers and total time on internal power. The number of passengers is determined by a gross mass constraint of 40 klb., the estimated payload capacity of a typical 2nd Generation RLV concept. Based on these weights, development costs are estimated at 912 M$ DDT&E and 208 M$ TFU. Because of this additional financial risk, the discount rate is 20%.

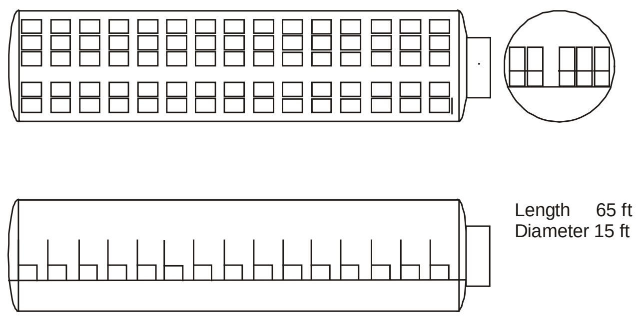

Figure 12 – Three View of Example Space Cab.

Price Sweep

The pricing information for the SpaceCab in Fig. 13 concept seems to indicate the higher, the better. From this graph, an optimum ticket price of $10M is selected. This is partly due to its positive NPV and partly due to it low NPV variance.

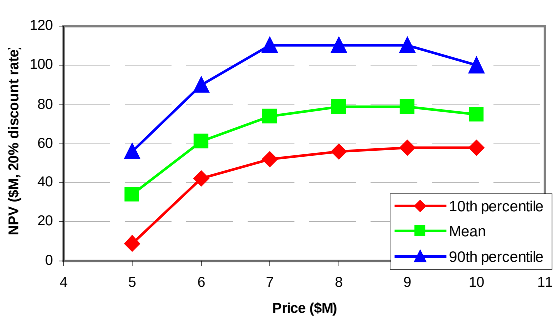

Figure 13 – Price Sweep of RLV Add-on Module.

Reliability Sweep

The curves for reliability in Fig. 14 show that the concept is fairly insensitive to the possibility of failure. This is most likely due to its low flight rate and high ticket price. Only when the chance of failure is greater than one percent does the NPV begin to suffer.

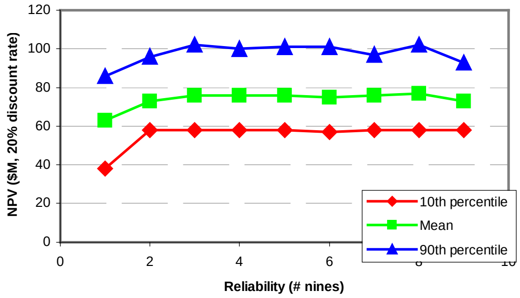

Figure 14 - Reliability Sweep of RLV Add-On Module

Third Generation Dedicated RLV

An advanced third generation RLV was tested to determine how well a dedicated space tourism vehicle designed to ferry passengers to and from low earth orbit would fare economically. This vehicle has a considerable non-recurring cost with low recurring cost. It also has a high level of customer appeal, which helps the market demand.

Concept Assumptions

Here a modified third generation launch vehicle (Fig. 15) is considered.[10] It is an RBCC-engined SSTO vehicle with horizontal takeoff and landing capability. It is assumed to be the transportation segment of an orbiting space hotel project and therefore has more market appeal than a simple orbital vehicle.

For the business analysis in LMNoP, an owner/operator is assumed for the launch vehicle and the passengers pay the transportation segment of their journey independently from the hotel stay. This somewhat isolates the business plan for the shuttle from the business plan for the hotel.

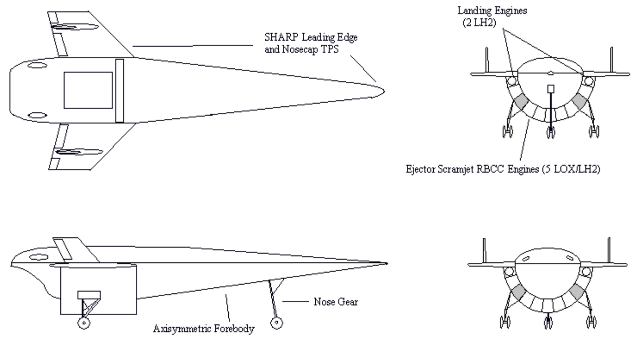

Figure 15 – Advanced RLV Three View

Price Sweep

To get an idea of far future business opportunities, an advanced RLV concept was analyzed with LMNoP across a range of prices. Apparently, the low recurring cost estimate for this vehicle was not enough to overcome the high nonrecurring costs. This vehicle loses money for all price ranges relative to a 25% discount rate.

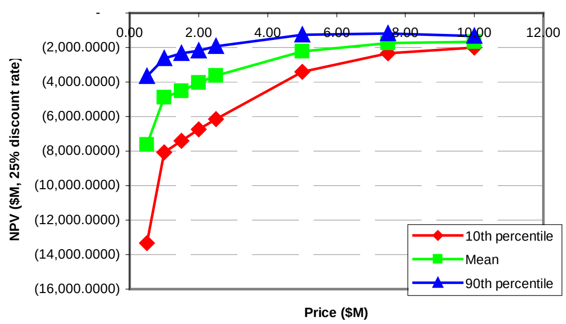

Figure 16– Price Sweep of Advanced RLV

Reliability Sweep

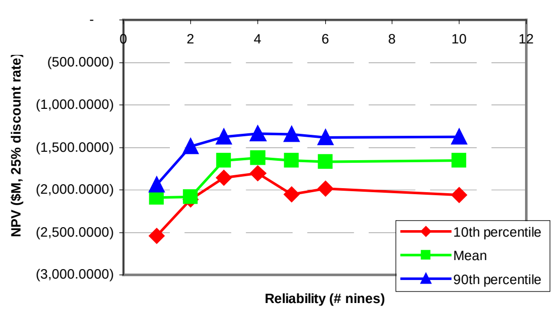

Figure 17 – Reliability Sweep of Advanced RLV

At the constant price of $8M, it does not appear that the reliability required is any different from any other vehicle in this price range. Fig. 17 shows there is again a significant penalty for going below 99%, but reliability above that is more than able to support the flight rate.

ECONOMIC PARAMETER SCREENING ARRAY

Purpose

To determine the economic drivers for a successful space tourism business, a screening array was conducted on the inputs to LMNoP. These include the vehicle performance and cost characteristics as well as the business scheduling information, such as the amount of time for DDT&E and time to build the first vehicle. This test yields valuable information regarding where cost cutting efforts should be directed in commercial RLV technology for space tourism.

Procedure

The screening array used for this test was a 32 run, 2 level fractional factorial design for 24 variables. This test yields unconfounded first order effect information with a small number of highly confounded second order effects. The final effect test was run both with and without the two level effects and showed little difference in the magnitude and ordering of the driving factors. This indicates that there is probably little interaction between the input variables.

The primary ranking criterion is the 80% confidence-level on NPV. This was chosen because it is a conservative measure of the profitability of the project being screened.

Variables

The inputs variables for the screening arrays and a brief definition of each are described below:

- Engine TFU - The theoretical first unit (TFU) cost of the first operational engine of the vehicle program. This value is irrespective of any learning curve effect.
- Engine Life - The number of total flights before replacement of an engine on the vehicle is necessary.
- Engines/ airframe (AF) - The number of engines per airframe for the vehicle.
- Equity market access count - The number of rounds (years) during the life of the program when equity in the commercial entity is sold. Financing is accomplished by selling common stock or preferred stock to investors.
- Capital on hand - The amount of capital possessed by the company at the beginning of the project. This value is irrespective of the project being evaluated for investment.
- Tax Rate - The governmental tax rate on the commercial entity's net income.
- Interest Rate - The basic value of the interest rate for long-term debt for the commercial entity (cost of debt capital).
- Equity financing frequency - The number of years from one round of equity financing to the next (if multiple offerings are desired) starting from the second round of equity financing.
- Equity-offering amount - The amount of equity in the commercial entity sold in each round (year) of financing.
- Fixed SG&A expense - Balance sheet item, which combines base salaries, commissions, and travel expenses for executives and salespeople, advertising costs, and payroll expenses per year.

- Variable SG&A expense - Balance sheet item, which combines incremental salaries, commissions, and travel expenses for executives and salespeople, advertising costs, and payroll expenses per launch.
- Time for DDT&E - The number of years required for the vehicle airframe / engine design, development, testing, and evaluation (DDT&E).
- Time from Production to IOC - The number of years from start of initial rate vehicle airframe and engine production to initial operating capability (IOC).
- Time to depreciate fixed assets - The number of years used to depreciate all fixed assets in the program.
- Passengers per Launch - The passenger capability of the vehicle.
- Reliability - The overall system reliability of the vehicle (includes airframe and engine.)
- AF life - The number of total flights before replacement of the airframe on the vehicle is necessary.
- Turn around time (TAT) - The number of elapsed days it takes for a vehicle returning from a mission to be recycled in preparation for the next launch.
- Time in flight (TIF) - The number of elapsed days for a typical vehicle mission.
- AF DDT&E - The cost for design, development, testing, and evaluation (DDT&E) of the airframe of the vehicle.
- AF TFU - The theoretical first unit (TFU) cost of the first operational airframe of the vehicle program.
- Engine DDT&E - The cost for design, development, testing, and evaluation (DDT&E) of the engine of the vehicle.
- Add-on contribution per launch - The additional revenue per launch obtained through non-primary sources.
- Customer Appeal - Multiplier placed on baseline market demand to account for factors such as comfort, flight duration and visibility

Vehicle Test Variable Ranges

For the test on the near term sub-orbital and third generation orbital RLV's, the variables described in the variables section were used. All monetary values are for fiscal year 2000 (FY2000.) Their levels for these tests were as follows:

Table 2 – Settings for Sub_Orbital RLV Screening Array

Variable	Low	High
Engine TFU	$6M	$10M
Engine Life	75 flts.	125 flts.
Engines per AF	1	2
Equity market offerings	2	4
Capital on hand	$1.5B	$2.5B
Tax rate	0%	37.5%
Interest rate	7.5%	12.5%
Equity financing offerings	2	4
Fixed SG&A expense	$22.5M	$37.5M
Variable SG&A expense	$100K	$1M
DDT&E duration	2 years	4 years
Time for production	1 year	2 years
Time to depreciate assets	3 years	7 years
Passenger Capacity	8	12
Vehicle Reliability	0.99	0.9999
Airframe life	375 flts.	625 flts.
Turnaround time	5 days	7 days
Time in flight	0.5 days	1 day
Airframe DDT&E	$2.25B	$3.75B
Airframe TFU	$750M	$1.25B
Amount at equity offering	$375M	$625M
Engine DDT&E	$0M	$0.1M
Advertising fee	$0	$0.5M
Market Appeal Factor	0.25x	0.5x

Table 3 – Variable Settings for Advanced RLV Screening Array

Variable	Low	High
Engine TFU	$62M	$104M
Engine Life	375 flts.	625 flts.
Engines per AF	4	6
Equity market offerings	2	4
Capital on hand	$1.5B	$2.5B
Tax rate	0%	37.5%
Interest rate	7.5%	12.5%
Equity financing offerings	2	4
Fixed SG&A expense	$22.5M	$37.5M
Variable SG&A expense	$100K	$1M
DDT&E duration	3 years	5 years
Time for production	1 year	2 years
Time to depreciate assets	3 years	7 years
Passenger Capacity	23	27
Vehicle Reliability	99.9%	99.9999 %
Airframe life	750 flts.	1250 flts.
Turnaround time	5 days	7 days
Time in flight	1 day	3 days
Airframe DDT&E	$5.78B	$9.63B
Airframe TFU	$1.1B	$1.8B
Amount at equity offering	$375M	$625M
Engine DDT&E	$333M	$368M
Advertising fee	$0	$0.5M
Market Appeal Factor	2x	8x

Results

Sub-orbital Reusable Rocket Variable Effects

The results for the sub-orbital RLV effect screening are interesting. As expected, the cost and scheduling variables are quite important to the response. However, the major player is the government tax rate. This is likely due to the fact that the bottom value of the experiment design for this variable was zero percent. Zero tax rate would reflect a potential tax-free policy for space tourism enterprises to help the industry get started. It is important to note that these rankings depend a great deal on the area of the design space being explored.

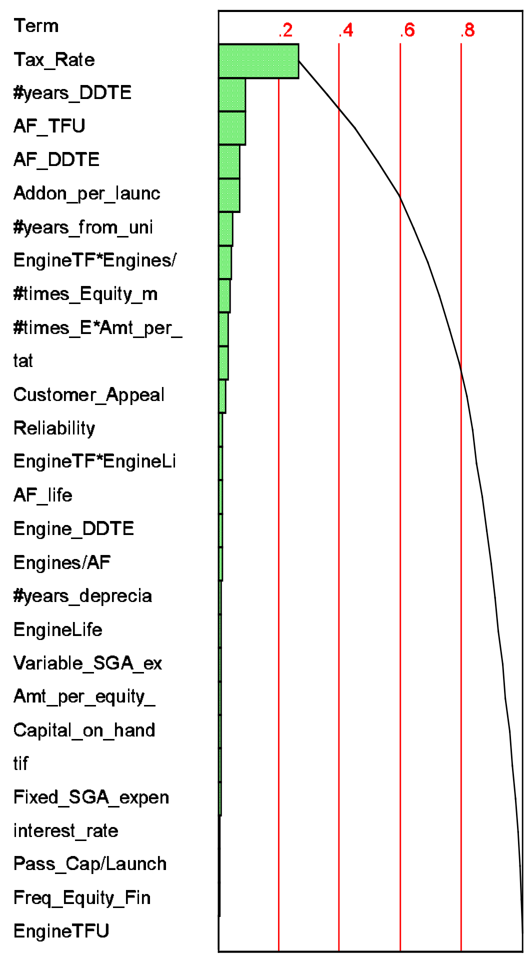

Figure 18– Pareto Plot for 80% Confidence NPV for Sub-Orbital RLV

Looking subjectively at this Pareto plot, the major variable players are:

- Tax rate
- Number of years for DDT&E
- Airframe TFU
- Airframe DDT&E
- Add-on revenue per launch
- Number of years from unit production to IOC
- Engine TFU

Engine TFU must be considered because of its interaction with engines per airframe. This information will serve as a guideline when conducting the space tourism economic goal search.

Third Generation RLV Variable Effects

The advanced RLV has customer appeal as its major factor. This translates to increased importance of the market prediction model variance for this concept. It should be noted that the overall effect of Engines/AF is to change the cost values for the engines. Therefore, the importance of all these variables can be considered linked.

Again looking subjectively at the Pareto plot, the major drivers are:

- Customer appeal
- Engines per airframe
- Number of years for DDT&E
- Engine TFU
- Turn around time
- Number of years from unit production to IOC

Most of the other effects are likely due to noise.

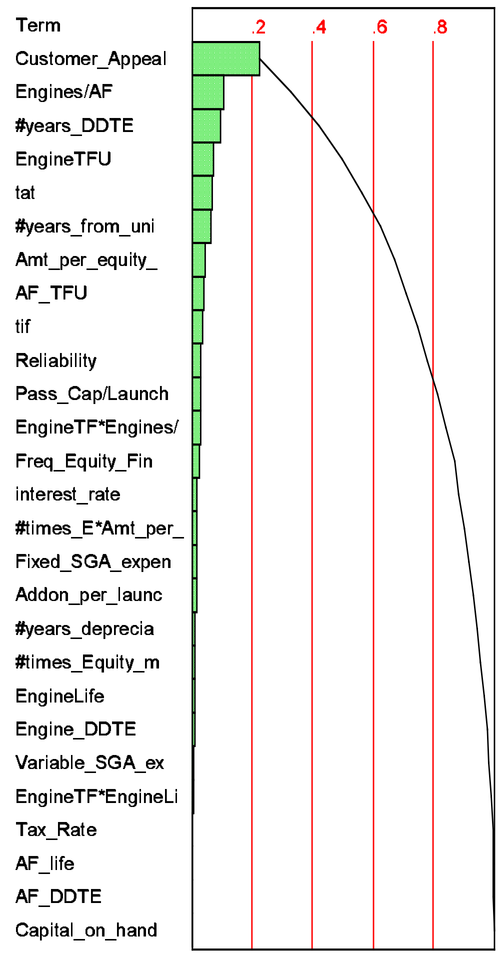

Figure 19 – Pareto Plot for 80% Confidence NPV for Advanced RLV

PRIORITIZED GOALS FOR SELECTED CONCEPTS

Procedure

For this part of the research, the variable inputs of LMNoP are changed until a viable space tourism project is attained (defined as 80% confidence of positive NPV.) This is done for the purpose of identifying an example of what cost goals will result in a viable project. Of course, it must be said the settings that result in a viable vehicle are not unique.

This is done for two vehicle projects. The first is the near term technology sub-orbital rocket from the screening array. This viability search is based on changing the variable values from their baseline values. This is possible because of the near feasibility of the screening array results.

The test for the far term vehicle is somewhat different. Using contemporary estimates, the economic parameters for this vehicle were insufficient to yield a workable concept. This means the results of the screening array are not valid for this low price, high flight rate scenario.

Sub-Orbital Rocket

Problem Statement

In order to ensure a reasonable final set of design variables, an error function (Eqn. 3) has been introduced. This function includes a reasonable range for each variable to make sure that each term is weighted properly.

$$Error = \sum_{all\ variables} \left(\frac{Variable\_setting - baseline}{Reasonable\_min - Reasonable\_max} \right)^2 \qquad (3)$$

Using this, the problem statement for this part of the research is to minimize the Error function while maintaining a viable design. To be viable, all of the input variable settings must be physically possible and the 80% confidence level of NPV must be positive.

The variable set for this problem can be inferred from the results in Table 4.

Results

Several large changes from the initial baseline values were required to attain a positive NPV for 80% of the cases. The largest adjustment was the Capital on hand. Higher capital on hand tended to lower the spread on NPV by reducing the chances of having financing costs dominate the LCC.

Table 4 – Variable Setting Results of Goal Analysis for Sub-Orbital RLV.

Variable	Baseline	Final
Engine TFU	$8M	$6M
Capital on hand	$2B	$5B
Tax Rate	30%	0%
Interest Rate	10%	7.5%
DDT&E duration	3 years	3 years
Production duration	1 year	1 year
Reliability	99%	99.9%
Airframe DDT&E	$3B	$1B
Airframe TFU	$1B	$200M
Add-on Contribution	$0 / flt.	$1M / flt.
Customer Appeal	Sub-coach	1st class

Fig. 20, the final distribution of NPV, shows a large spread, but 80% of the distribution is positive. This shows that if these cost goals can be met, there is a high probability of a project like this succeeding.

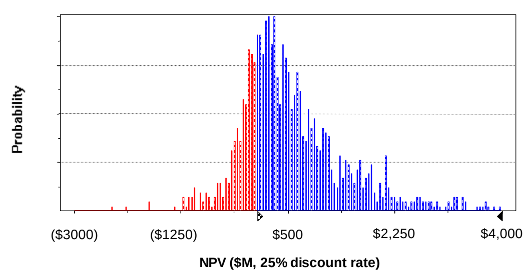

Figure 20 – Final Distribution of NPV for Sub-Orbital Rocket.

Third Generation RLV

The baseline values for the third generation RLV did not provide any chance for this concept to become feasible. Therefore, an example using the assumption of low ticket price as well as airline-like operations and recurring cost was run as an example goal for this market segment.

Assumptions

To attempt to simulate the performance of a far-future space tour airline, some rather optimistic assumptions were made. These are documented below in Table 5. All dollar values are for FY2000.

Table 5 – Third Generation RLV Optimistic Assumptions

Variable	Setting
Airframe DDT&E	$20B
Airframe TFU	$100M
Engine DDT&E	$3B
Engine TFU	$20M
Recurring Cost	$10,000 per flight
Engines per airframe	4
Reliability	99.999999%
Airframe & Engine Life	3,000 flights
Fixed SG&A expenses	$15M per year
Variable SG&A expenses	$10,000 per flight
Turn around time	0.1 days
Time in flight	0.5 days
Launch site fee	$10,000 per flight
Customer Appeal	1st class w/ Orbital Hotel
Capital on hand	$10B
Ticket Price	$15,000 per seat
Passenger Capacity	27
Tax Rate	30% per year
Inflation Rate	3% per year
Cost of failure	$200M

Results

Fig. 21 shows that the assumptions above do provide for the possibility of a viable vehicle according to the requirements of this test. However, the variance of the NPV is so large that it is still uncertain whether this business will be boom or bust.

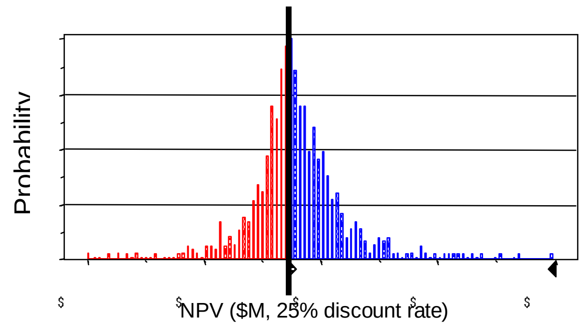

Figure 21 – NPV Results for Optimistic Assumptions

The area to the left of the line in Fig. 19 has negative NPV while the area to the right has positive. The integrated probability of positive NPV is 60%. An advanced RLV just for space tourism appears to be quite a gamble.

CONCLUSIONS

The conclusions of this research cover the areas of feasibility and technology areas for future concentration. These should be considered as recommendations.

1. Space tourism as a concept could be feasible. With maturation of certain technologies, there might be a concept capable of supporting a feasible space tourism business.

2. Large leaps in cost metrics will be required to make space tourism a reality for the average person. This type of operation requires truly airline-like operation, something out of reach for current launch vehicle approaches.

3. Design and construction cycle times are important to the feasibility of the concepts observed here. This means that advanced design and construction planning techniques are just as important as other technologies to the success of space tourism.

4. Government policy is vital to the growth of this industry. Incubation policies are important to the near term industries, while

strict safety guidelines will be needed as flight rates rise.

FUTURE WORK

Several items for potential future work have been identified during the course of this work.

1. LMNoP Market Model – The market model in LMNoP randomly selects a point from an uncertainty distribution every year. This point is unrelated to the point selected for the previous year. It would be more realistic to assume that there is a large uncertainty the first year, with small dispersions in subsequent years. This large randomness in demand causes problems with purchasing schedules, etc. that would likely not be as extreme in a real business.
2. Computational Speed – The computational cost of the LMNoP spreadsheet is significant. It currently consumes about one hour on a 500 MhZ Pentium III to complete a full Monte Carlo simulation of one vehicle. This is a hindrance to trade studies or optimization. There is a possible future effort to translate CABAM[11] (Cost and Business Analysis Module, the Space System Design Lab cost model) into a compiled code. Since LMNoP and CABAM share a few components, it might be possible to also compile LMNoP with minimal effort.
3. Vehicle Design – A more in-depth vehicle design process may yield new insight into lucrative areas of the design space.

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REFERENCES

1. Penn, J. P. and Lindley, C. A., “Requirements and Approach for a Space Tourism Launch System,” IAF paper IAA-97-IAA.1.2.08, October 1997.
2. Penn, J. P., “Synergy Between Space Power and Low-cost High Flight Rate Reusable Launch,” IAF paper IAF-98-R.2.09, October 1998.
3. Rogers, T. F., “Space Tourism: The Perspective in Japan and Some Implications For the United States,” The Space Transportation Association, August 1994.
4. Smitherman D. and McClure, W., “Space Transportation and Destination Facilities Working Group Proceedings,” STA/NASA, March 1997.
5. Commercial Space Transportation Study Final Report, Boeing, General Dynamics, Lockheed, Martin Marietta, McDonnell Douglas and Rockwell, pp. 198-229, April 1994.
6. Nagatomo, M. and Collins, P., “A Common Cost Target of Space Transportation for Space Tourism and Space Energy Development,” AAS 97-460, pp. 617-630.
7. Isakowitz, Steven J., “International Reference Guide to Space Launch Systems Second Edition,” AIAA, pp. 160-171, 1991.
8. Wade, M., “Encyclopedia Astronautica,” Web Site Address: http://www.friends-partners.org/~mwade/spaceflt.htm, 2000.
9. “X-Prize Foundation // New Race to Space,” Web Site Address: http://www.xprize.org, 2000.
10. Olds, J., Bradford, J., Charania, A., Ledsinger, L., McCormick, D. and Sorensen, K., “*Hyperion*: An SSTO Vision Vehicle Concept Utilizing Rocket-Based Combined Cycle Engines,” AIAA paper number 99-4944, November 1999.
11. Whitfield, J. and Olds, J., “Economic Uncertainty of Weight and Market Parameters for Advanced Space Launch Vehicles," AIAA 98-5179, October 1998.