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Potential Demand for Orbital Space Tourism Opportunities Made Available via Reusable Rocket and Hypersonic Architectures

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This paper looks at the likely demands for orbital space tourism at a range of price levels significantly lower than those currently being offered via the Russian Soyuz vehicles, and explores the extent to which vehicle architectures can be developed which would make such price levels achievable. Conclusions are provided by identifying two such vehicle architectures which therefore represents a “sweet spot” where supply and demand for orbital trips would balance, and where therefore a commercial business could be developed to augment any governmental uses for such vehicles. The vehicles which emerge from the study are Two-Stage-to Orbit, fully reusable transportation systems using rockets and hypersonic RBCC.

Nomenclature

<i>COTS</i>	= commercial of-the-shelf
<i>ER</i>	= expendable rocket
<i>ISS</i>	= international space station
<i>KSC</i>	= Kennedy space center
<i>LEO</i>	= low earth orbit
<i>RBCC</i>	= rocket based combined cycle
<i>RR</i>	= reusable rocket
<i>TBCC</i>	= turbine based combined cycle
<i>TSTO</i>	= two-stage-to-orbit

I. Introduction

ORBITAL space tourism has thus far been conducted only by Russian Soyuz vehicles at supply-based prices that have ranged between \$20M and \$35M, and by the time of Guy Laliberte’s flight in October 2009, there have been nine such orbital space tourists (and one who made two trips, making ten orbital space tourism flights overall). The possibility of alternative, less cramped, approaches to achieving orbital space tourism than the Soyuz will be a positive factor in the development of orbital space tourism. There will be particular advantages to a US-based service rather than one that requires training in Russia and a launch from Kazakhstan. Such services might prove possible using US COTS-derived vehicles such as the SpaceX Dragon, designed to take cargo and potentially passengers to the International Space Station (ISS), or via revolutionary concepts such as the hypersonic architectures being explored by Astrox Corporation.

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Astrox Corporation conducted a study in 2008 of various Two-Stage-to-Orbit (TSTO) options for Low Earth Orbit (LEO) for the same payload of 20,000 lbs. as tasked by the Office of the Chief Scientist of the Air Force. Eight options were chosen which included all-rocket expendables, hybrid and reusables, as well as combinations of rockets with hypersonic airbreathers. The same software code, HySIDE © of Astrox was used to develop all designs, fly them through the trajectories, close and size all options, so an apples-to-apples comparison can be made. Empty weights, gross weights along with component weights for each of the sixteen vehicles were calculated which facilitated calculation of Development, First Unit Production, Acquisition, Maintenance and Direct Operating Costs. The comparison showed that reusability of vehicles can reduce the ‘per pound to orbit’ cost significantly for a frequency of flight of 30 or more. It was of natural curiosity and a logical extension to explore if such a frequency can be hoped for if the price dropped to such comparatively lower level. What this paper proves is that such a scenario is possible and that a strong business case can be made, which was hitherto fore not possible. The paper thus makes a case for a forceful development effort going forward, to develop such vehicles, their accompanying architectures and exploit this opportunity. The fact that such a hypersonic vehicle development can also be beneficial militarily is not a case that this paper attempts to make herein as it is beyond the present scope of the paper. The paper then effectively and implicitly synergizes the two, and makes a case that the country can benefit in both ways, militarily as well as commercially, by developing the same type of vehicles. What is significant is that this is the first time such a collective case has been made successfully.

II. TSTO STUDY

In the past, Astrox Corporation has conducted several comparative studies for SSTO and TSTO system options using Rockets and Airbreather cycles, for both Horizontal Takeoff and Horizontal Landing (HTHL) and Vertical Takeoff and Horizontal Landing (VTHL) options. The studies also quantified the Growth Factors for these options which identified the options with high uncertainty that were problematic or unable to close. The results were published previously in the Journal of Spacecrafts and Rockets¹⁻³.

Based on these studies and as a logical extension of them, only the TSTO options were next considered to be compared as they have less impact on size due to generic uncertainties and tend to be more robust compared to SSTO options. As called for by and in consultation with the Air Force, several TSTO vehicles were chosen including turbine, scramjet and rocket stages, expendable, reusable and hybrid vehicle systems. The baseline case was an expendable rocket-expendable rocket (ER-ER) with RP2 fuel and today’s available technologies and was used as a reference to compare with the other systems. A complete list of vehicle systems considered during this study is provided in Table 1. These vehicles were designed using Astrox Corporation’s code HySIDE©.

To obtain an equitable and balanced comparison, all options were required to be done using the same code. The Low Earth Orbit (LEO) chosen was a 100 nm circular orbit launched Easterly from KSC. The expendable upper stages go directly to 100 nm circular orbit and the reusable upper stages go to a 50x100 nm elliptic orbit and perform Hohmann transfer to reach the 100 nm circular orbit. Other ground rules were as follows:

- Payload Module = 20,000 lbs
- Payload Bay = $15 \times 10 \times 10 \text{ ft}^3$
- 15% Dry Margin
- Reusable vehicles
 - Lifetime = 20 years
 - Launches per year = 5, 10, 30 and 100
 - Launches per Vehicle = 200
 - Number of Vehicles = Number Computed plus 1 backup
 - Loaded Man-year rate: \$252,000

Option	Payload	Lower Stage				Stage	Staging			Upper Stage				To	Designation
#			Fuel			Return	Mach	~Alt	Q		Fuel	Landing			
							ft	psf							
0	20K	Expendable Rocket	RP2	VTHL	RD-180	N/A	6.50	200000	5	Expendable	RP2	N/A	RD-120	100 nm Circular from KSC	ER/ER
1		Reusable Rocket	RP2	VTHL	RD-180	Boostback	6.50	175000	50	Expendable	RP2	N/A	RD-120		RR/ER
2		Reusable Rocket	RP2	VTHL	RD-180	Boostback	6.50	175000	50	Reusable Rocket	RP2	HL	RD-120		RR/RR
3		Reusable Rocket	RP2	VTHL	RD-180	Boostback	4.00	75000	700	RBCC	CH4	HL			RR/RBCC
4		TBCC	JP8/CH4	HTHL	Turbo Ram Scram	Flyback	9.50	90000	2000	Reusable Rocket	RP2	HL	RD-120		TBCC/RR
4b		TBCC	JP8/JP7	HTHL	Turbo Ram Scram	Flyback	6.00	92800	800	Expendable	RP2	N/A	RD-120		TBCC/ER_b
4c		TBCC	JP8/JP7	HTHL	Turbo Ram Scram	Flyback	6.00	92800	800	Reusable Rocket	RP2	HL	RD-120		TBCC/RR_c
5		Turbojet	JP8	HTHL	Turbine	Flyback	4.00	55000	2000	RBCC	CH4	HL			TJ/RBCC

Table 1. Study Alternatives

A representative drawing of the designed options is given in Fig 1. All options are sized until ‘closed’ for the same mission.

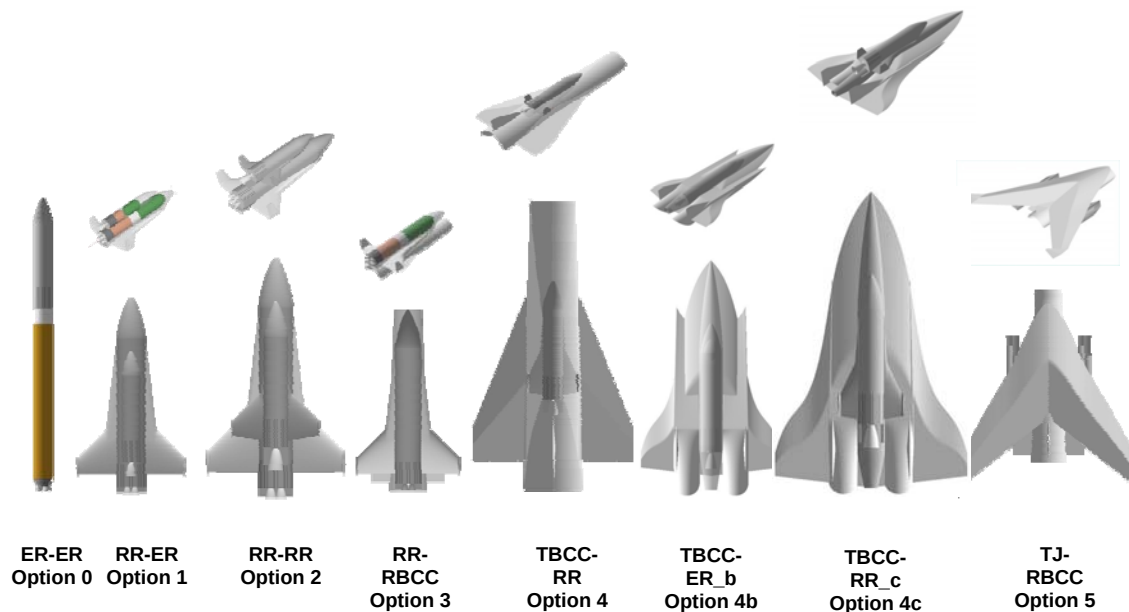


Figure 1. TSTOs for Access to Space

Having done the design of each of these 16 vehicles, their component weights, empty weights and TPS acreage, were obtained for the vehicle as well as the corresponding engines. Transcost 7.2 was then used to compute vehicle and engine FUPC and Maintenance Costs. Learning Factor curve was applied for total acquisition cost for the same vehicle or engines when multiple copies would be acquired over lifetime. Direct Operating Costs (DOC) needed to loft one pound of payload to LEO are shown in Fig. 2 which include the acquisition and maintenance costs. Maintenance costs per flight for the reusable systems are minor compared to the acquisition cost and hence the

acquisition costs dominate. Expendable and hybrid options do not fare well for this reason compared to the reusables. A significant advantage in DOC is gained by proceeding to the completely reusable path, regardless of number of flights per year, as is clearly seen from this figure. However this figure does not include the Development Cost whether funded by the Government, private industry or a combination thereof.

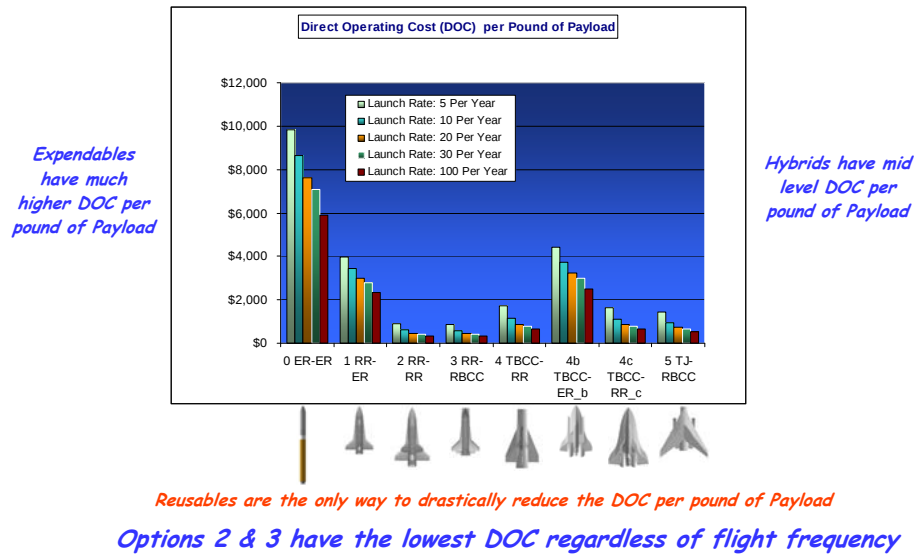


Figure 2. Direct Operating Cost (DOC) per Pound of Payload for Different Launch Rates

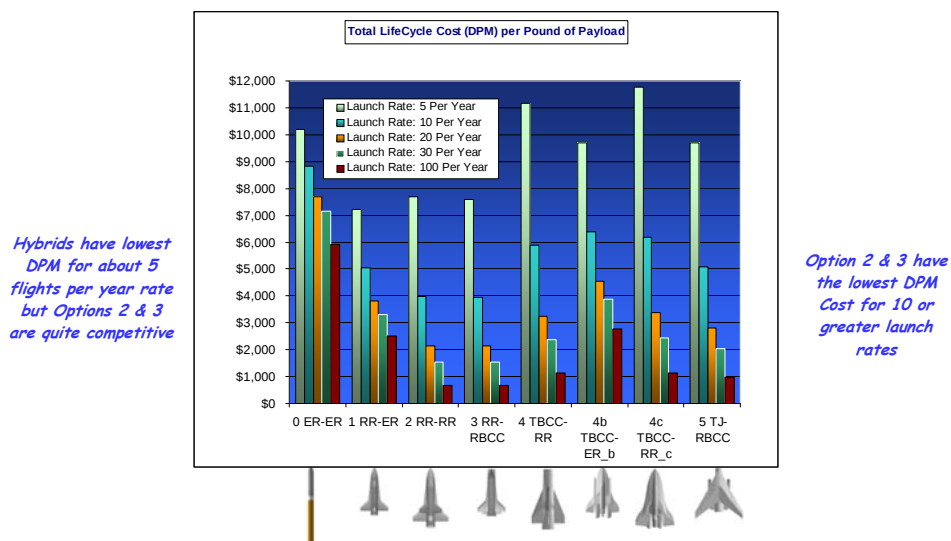


Figure 3. Total Development, Procurement & Maintenance Costs (DPM) per Pound of Payload for Different Launch Rates

The Development Costs for the reusable programs can be expected to be and were computed to be high. The expendable vehicles on the other hand have already been developed and hence only the portion needed specific to the campaign was used which was assumed to be 15% of the Transcost Development Cost number. As expected the behavior of the DPM cost per pound of payload, shown in Fig. 3, is very much a function of the annual number of flights. Development Costs make it unpalatable to proceed with the Reusable System

development for frequency of flights less than 10 and certainly for five or less per year. As the frequency increases, the Development Costs are spread over a larger pool and a dramatic decrease in DPM cost is feasible. The frequency rate has a much more dramatic effect on DPM as opposed to DOC where it also goes down with increased frequency albeit by smaller ratios. The ratio of DPM cost to DOC cost per pound is also significantly smaller for all case as the flight rate increases.

As can be seen from Figs. 2 and 3, the cost per pound is about \$340 and \$680 for DOC and DPM respectively for Options 2 and 3 which are both completely reusable architectures. Based on the more conservative DPM number and surmising 40 passengers per flight that the 20,000 lbs payload the study was done for can afford, a number of \$340,000 per ticket can be deduced. For this study, a more conservative number of \$340,000 per ticket was used.

The questions then are: what is the impact on a commercial business case with such flight rates and is such a flight rate sustainable over a reasonable period of time to be able to make a business case? Would private investors be able to recoup their investments and make profit? Surely both scenarios feed on each other but if we were to breakout of this chain of smaller frequency, what can be expected? What can that mean to the aerospace economy of the country and by inference to the entire economy and economic competitiveness of the country?

The answer to this seems to be very promising, as what follows in this paper will illustrate.

III. MARKET DATA BASED DEMAND FORECASTING

A critical part of the process of forecasting the demand of wealthy individuals for orbital space tourism is to know how many high net worth individuals there are in the first place, and how they are distributed around the world. This is simply because, at least for the initial 20 years or so, only high net worth individuals will be able to afford the flights, and so the demand must therefore be determined from within the pool of wealthy individuals only. Apart from the possibility of some few TV game show prize winners of space tourism tickets, or maybe the chance of some space-oriented lottery winners, or just possibly the recipients of corporate performance awards, any demand within the ranks of the less-wealthy will need to go unsatisfied until the initial price levels of seats are significantly reduced. So the distribution of wealthy individuals is the starting point for the demand estimation process.

Once we have an understanding of the characteristics and numbers of the world's wealthy populations, we can then explore the intentions to undertake space tourism from within this pool of at least financially-capable potential space travelers. It is a critically important aspect of forecasting to ensure that the projections are demand-based, and not simply the supply-driven hopes and dreams of manufacturers or potential service providers. We need to have the statistically valid responses of millionaires to questions related to their interest in space tourism. Then other factors than simply wealth level and level of interest, that influence the decision making process for undertaking orbital space tourism, are considered.

IV. DATA ON WEALTH DISTRIBUTION

This paper forecasts the potential future global demand for passenger travel to orbit, based upon the number of people worldwide who are both wealthy enough to afford the ticket, and who indicate to pollsters that they are interested in such travel. The underlying data come from the Futron/Zogby study⁴⁾ that surveyed people with at least a million dollars net worth – to date the only survey of space travel intentions that focused on a statistically valid sample of wealthy individuals who might actually afford such tickets. The bottom-line predictions for orbital space tourism in the original 2002 Futron report assumed an unappetizing combination of very high ticket prices (\$20 million), long six-month training regimens, and the requirement to learn Russian for a launch on a Soviet-era rocket. This current paper shows the estimated demand that will be possible after a company, perhaps as a result of operating hypersonic vehicles as proposed by Astrox Corporation, is able to offer short U.S.- based training periods and much lower prices – in the \$1/2 million range. Even at \$1/2 million per ticket, it is still essential to begin the forecasting approach with a good assessment of the numbers and distribution of wealthy individuals in the world.

Perhaps surprisingly, the hardest part of the entire forecasting process is obtaining good data on the base populations of wealthy individuals. Some US government statistical data is available from the Internal Revenue Service⁵ and some publications have also collected relevant data^{6, 7, 8}.

The Table 2 and Fig. 4 below are provided to bring together these multiple findings in a single place, but because of the multiplicity of sources, there is bound to be some inconsistency between the various sub-classifications, if only because the original primary research was conducted at different times. Nevertheless, the results in the table are sufficient to allow the eventual calculation of a pool of individuals capable of affording orbital space flight, and this process is described below.

Households by net worth:

\$1 million plus	3,500,000	United States ⁷
\$1 million plus	7,300,000	World ⁸
\$7 million plus	1,000,000	World ⁴
\$20 million plus	100,000	World ⁵
\$30 million plus	58,000	World ⁸
\$200 million plus	6,000	World ⁴
\$1 billion plus	690	World ⁷

Table 2. Households by Net Worth

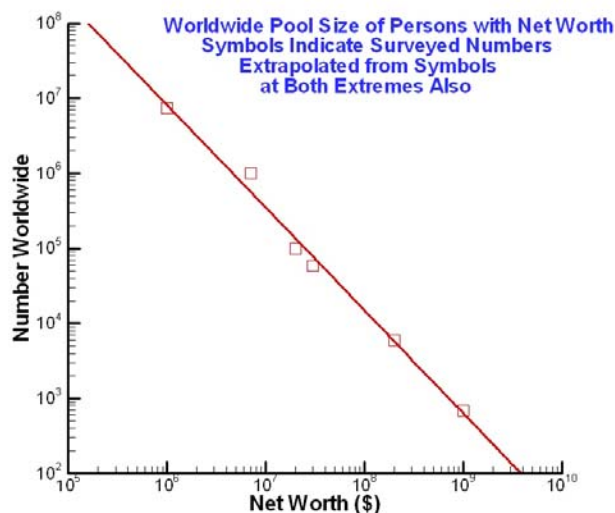


Figure 4. Households by Net Worth

What is perhaps obvious, but can be seen quantitatively in the table, is that while there are only a few *hundred* billionaires, there are several *million* millionaires. This has a massive impact on determining the pool of available rich people for orbital space flight opportunities at varying ticket prices, as we shall see. Also, because of this, there is an upper limit on the price for orbital space flight, and it has been established at around \$20-30 million by the first orbital space tourists. There will be a dramatic increase of potential travelers if it becomes possible for the price per flight to be reduced from the \$20 - \$30 million quoted for today's Soyuz missions towards a level of \$1 million or less, as is demonstrated below.

Wealth data usually is available only on a "per household" basis. For this paper, it is assumed that only one millionaire exists per household, although there may sometimes be more. Despite numerous Hollywood stories to the contrary, typical wealthy people do *not* commonly spend millions of dollars on items of pleasure and consumption. Only 17% report spending more than \$10,000 on their vacations, and some 80% said they spent less than \$41,000 on their last vehicle⁸. With this in mind, a critical factor in estimating future demand is *the percentage of net worth spent on discretionary items*. One source (Ref. 4) reports that only 40% spent more than \$15,000 on a purchase (*this would reflect only 1.5% of net worth for millionaires*) in the previous year, and only 10% spent more than \$50,000 (5% of net worth for a millionaire). Another source⁶ reports that only 7.1% of wealth is realized by millionaires in a given year. For comparison, the first two space tourists, Tito and Shuttleworth, spent perhaps 10% of their net worth on their tickets, which must be seen as an *extreme upper bound* to an affordability indicator. A *conservative* assumption would be based on the 1.5% figure.

The next step is to determine, for any given price level, how many people in the world could potentially afford the ticket price. This, then, becomes the pool of potential travelers at the start of the demand forecasting process. In the original Futron/Zogby survey, a range of orbital trip prices from \$20 million down to \$1 million were offered to respondents. For the proportion of net worth that a millionaire is likely to spend on a once-in-a-lifetime orbital space trip, we have decided to focus the forecasts on the two values of 1.5% and 5% of net worth. Clearly, if all millionaires would spend as much as the 10% of net worth that Tito and Shuttleworth expended, then the potential

market would be very much greater. But for these initial forecasts, a conservative 1.5% was chosen as the mainline value, with the 5% case representing an upper opportunity boundary to the range of uncertainty. *If a viable business case can be demonstrated at the 1.5% level, then clearly there is upside potential that can be explored to advantage.*

For example (as shown in Table 3), if the price is \$5 million, then a potential traveler would require a net worth of \$100 million in order to be able to buy a ticket, under the assumption that he/she spends 5% of net worth on the trip. The size of the pool in this case is then obtained by looking at the millionaire base population figures, and determining how many there are who have a net worth of \$100 million or more, and the finding in this case is only 10,000. The table shows the dramatic increase in the available pool as prices drop to \$1 million. For instance, for the mainline 1.5% case, there are only 4,000 people globally who could afford the \$5 million ticket price, yet this number increases to 40,000 at a price of \$1 million. *This is a non-linear phenomenon*, and the numbers in the pool at prices below \$1 million expand very rapidly. At \$1/2 million, there are 55,000 at 1.5% and *almost a million* at 5% of net worth. Because of the non-linearity of the variation of pool size with ticket price, we shall see that *pool size is a more important factor in determining forecast demand than even the precise value of the stated intentions of potential space tourists* as obtained in surveys such as the Futron/Zogby survey in 2002.

ESTIMATION OF SIZE OF GLOBAL POOL

	\$5m ticket price		\$1m ticket price		\$1/2m ticket price	
Proportion of Net Worth Spent per Ticket	needed net worth	Size of global pool	needed net worth	Size of global pool	needed net worth	Size of global pool
5%	\$100m	10,000	\$20m	100,000	\$10m	900,000
1.50%	\$333m	4,000	\$66m	40,000	\$33m	55,000

Table 3. Estimation of Size of Global Pool

V. STATED INTENTIONS TO TAKE ORBITAL SPACE TOURISM FLIGHT

After determining the size of the potential pool of travelers, the next step is to decide how many of them actually *want* to do it. The findings of the Futron/Zogby survey⁴ are used for this purpose, and Table 4 below shows the basic responses on this question.

PROPORTION WILLING TO TRY ORBITAL SPACE TOURISM AT STATED PRICES			
"Definitely Likely"			
\$20m	\$10M	\$5m	\$1m
7%	16%	20%	30%
Note: source is Futron/Zogby Survey			

Table 4. Proportion Willing ("Definitely Likely") to Try Orbital Space Tourism at stated Prices

It should be noted at this point that the Futron/Zogby Survey of millionaires was designed so that the findings would be representative of all millionaires. There was no pre-selection for interest in space tourism, or space at all. The 450 millionaires interviewed were a truly random sample, and the sample was selected to give a full geographic coverage of the US. Nearly 62,000 attempts were needed in order to get the 450 completed millionaire surveys. The resulting data is therefore representative to an accuracy of +/- 4.7% of the views of all US millionaires. For

reasons of cost, the survey was not extended to non-US millionaires. In order to with confidence use the findings from the survey, it is important to be aware of certain characteristics of the approach that was used. The interviews were conducted by telephone, and each one lasted about 30 minutes, to ensure that the respondents had a full understanding of what was being considered for both orbital and sub-orbital space tourism. Firstly, the millionaire respondents were presented with rather detailed descriptions of an orbital mission in two separate steps. The first stage orbital space flight description was as follows:

“In an orbital flight, you would have the opportunity to experience what only astronauts and cosmonauts have experienced. The trip would begin with a launch aboard a thoroughly tested rocket. You would then dock with an orbiting space station and would have freedom to move about the facility. During your two-week stay you would be weightless. You would have the opportunity to eat, sleep, exercise and view the Earth from space.”

Respondents were then asked “How likely would you be to participate in an orbital space flight?” Then, the respondents were told more, based on suggestions from a former Space Shuttle astronaut:

“Space flight is an inherently risky activity. Currently, the flight is only available on a Russian vehicle. In order to take the trip, you would have to undergo intensive cosmonaut training in Russia for six months prior to the launch. During the flight you may experience headaches and lower backache. While in space, you might experience some nausea. You would be able to view the Earth through porthole-sized windows. Upon your return to Earth and normal gravity, you might experience some dizziness for a few days and have difficulty standing.”

Respondents were then asked “Knowing what you know now, how likely would you be to participate in an orbital space flight?”, and not surprisingly, much lower numbers indicated an interest (they fell by around 50%). It is the answer to this second question that is displayed above and used to develop the forecasts. At the time of the survey, the \$20 million price level was assumed to be the “going price”, and so the findings indicated that at that price level around 7-10% would pay for a ticket, and they indicated “definitely likely” in their responses. Note that there are considerable data numbers from the full survey that are being ignored in this conservative interpretation of the findings. For instance, a further 8% indicated “very likely”, and a further 17% indicated “somewhat likely”, and these respondents were not included in this deliberately conservative demand forecast development process.

Questions were asked at a range of price levels. In the case of the orbital space tourism questions, prices were offered at \$25M, \$20M, \$15M, \$10M, \$5M, and \$1M. It therefore becomes necessary to extrapolate the findings for price levels of around \$1/2 M. Questions were also asked of the same respondents regarding sub-orbital space tourism opportunities, however, and in this case, the assumed prices were \$250K, \$200K, \$150K, \$100K, \$50K and \$25K. It becomes possible, therefore, to help determine the intentions for orbital space tourism at price levels around \$1/2M by extrapolating the orbital Futron/Zogby survey data downwards in price, while being guided by extrapolating the sub-orbital responses upwards in price. We should note, however, that with respect to sub-orbital space tourism intentions, the respondents were offered a different two-step description of the experience:

“In a sub-orbital space flight, you would experience what only astronauts and cosmonauts have experienced. During the 15 minute flight on a vehicle that meets government safety regulations, you will go 50 miles into space, and experience the acceleration of a rocket launch. You will also experience a few minutes of weightlessness and have the unique experience of viewing the Earth from space.”

We should note incidentally that, subsequent to the survey, 62 miles (100km) has been generally adopted as the standard target for sub-orbital space tourism, rather than the 50 miles that was quoted in the original Futron/Zogby survey questions.

As in the case of the orbital questions, the respondents were subsequently provided with more “negative” data, as follows, and the data on intentions used for the forecasting process was the data obtained after the second description of the experience:

“Space flight is an inherently risky activity. The vehicle providing these flights will be privately developed with a limited flight history. In order to take the trip, you would have to undergo training for one week

prior to the launch. Although you would experience weightlessness, you would be strapped into your seat throughout the trip.”

The basic data response to the sub-orbital price elasticity of demand questions is provided in Table 5.

% To TRY SUB-ORBITAL SPACE TOURISM AT PRICES			
"Definitely Likely"			
\$250K	\$200K	\$150K	\$100K
16%	18%	22%	30%
Note: source is Futron/Zogby Survey			

Table 5. Proportion Willing (“Definitely Likely”) to Try Sub-Orbital Space Tourism at Prices

Figure 5 shows how the extrapolation has been done in order to arrive at the region of the price level of interest to Astrox Corporation.

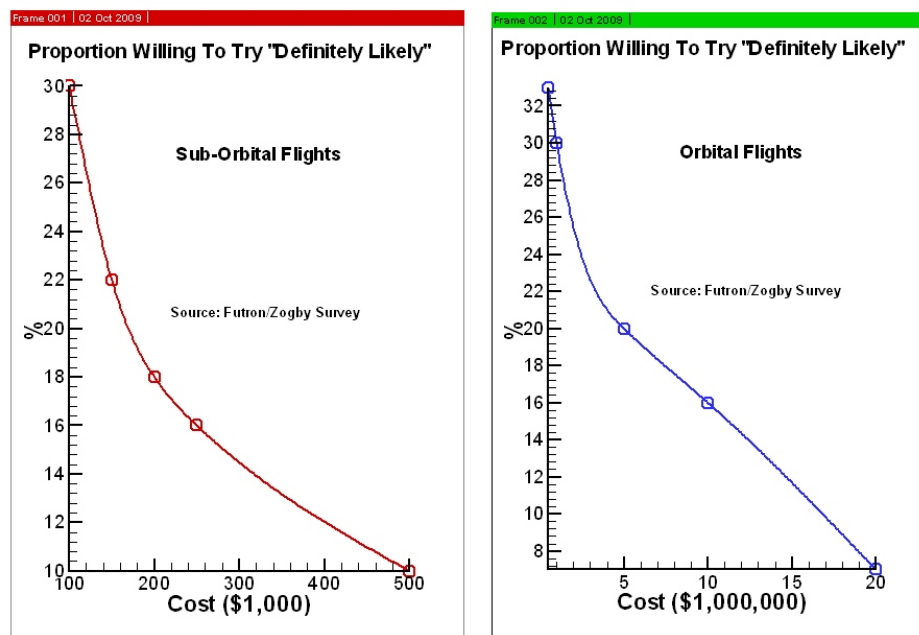


Figure 5. Households by Network

A value of 33% was therefore selected to apply to a price of \$1/2 million for an orbital space tourism experience. The sub-orbital space tourism demand data was also studied for comparison. Note that the extrapolation of sub-orbital demand, to the same \$500K price level, would seem to indicate a demand reduced to a 10% value for willingness to pay for that class of experience. The data indicates, therefore, that the orbital space tourism experience is at least three times as attractive, at the same \$500K price level, to potential space tourists, which seems intuitively reasonable. Clearly, the 10% level for demand intentions reflects an absolute minimum for our purposes, because 10% would select even a sub-orbital experience at that price level.

We should remember that we have seen in the previous Section, however, that the choice of the precise value for customer purchase intention is not nearly as significant in the overall forecast process outcome as the size of the available initial pool of wealthy individuals.

VI. OTHER FACTORS THAT WILL INFLUENCE DEMAND

There are a range of factors, other than wealth and stated level of interest, that will also influence the eventual demand for orbital space tourism, and they therefore need to be identified, and to the extent possible, quantified, in order to better determine demand. Factors include health level, availability of time for training, reasons for wanting to go into space, price elasticity of demand, attitudes to the proposed vehicle architectures, etc. We shall explore several of these factors based on available public domain market data. Some of the factors may be more relevant to market share in a situation where a range of service providers are offering orbital space tourism, than to the overall demand for orbital tourism, and we shall attempt to differentiate between them.

Because millionaires tend to be distributed towards the older end of the general population, and because achieving orbital spaceflight will involve some levels of physical exertion, it is necessary to adjust the available pool of potential flyers by removing those whose combination of age and fitness level will preclude them from taking the trip. In general, the distribution of millionaires tends to the older end of the population, with an average age of 57. The adjusted distribution⁵ is shown in Table 6, at least for US millionaires:

Under 50	34%
50 – 64	33%
65 – 74	17%
75 – 84	11%
85 +	5%

Table 6. Adjusted Pool of Millionaires Willing to try Space Tourism

Although there is no independent data of the health and fitness of wealthy individuals, the respondents of the Futron/Zogby survey⁴ were asked to self-rate their physical condition. Some 39% reported “average” fitness, with 36% claiming “above average” and a lucky 11% reporting they were “extremely fit.”

A filter is therefore developed, based on a combination of age and fitness, as the next stage in the forecast process. This is made possible because of the detail on age and health of respondents that was collected and recorded in the Futron/Zogby survey. Clearly some of these wealthy individuals would be unlikely to be physically capable of undertaking a mission, even if they wanted to, and so for planning purposes there needs to be a reduction in the pool numbers to take into account an elimination of the least healthy members of the population. It was decided to apply a more stringent criterion when potential travelers were above 65 years of age, and the method used therefore only accepts such folk when they report their fitness level as “extremely fit”. Below this age, the filter permits anyone who is of “average or above” fitness level. When both these rules are combined and applied to the population statistics, the overall combined effect is to eliminate 39% of the pool due to fitness.

Certain further modifications are needed to the basic findings, however. The first adjustment considers the impact of training considerations – location and length – on public space travel demand. When the Futron/Zogby survey was undertaken, the respondents were briefed on the realities of orbital space travel, which at the time of the survey implied only Russian launches, from a Russian-owned launch site in Kazakhstan, and Russian training facilities near Moscow. However, the survey later asked the respondents how their decision would change with a U.S. launch and U.S. training facilities. When respondents were asked whether they would prefer the possibility of training in the United States instead of in Russia, their interest increased significantly (and similar findings resulted from the question related to purchasing from a U.S. company rather than a Russian one). An overall 24% increase in interest, based on the relevant Futron/Zogby data, has therefore been applied.

The following factors are judged to have an impact on potential market share, but probably no impact on the overall ultimate market size. We can explore stated reasons for wanting to undertake a space tourism flight¹. Amongst the listed reasons, a significant percentage of potential space tourists (up to 32%) mention their wish “to be a pioneer”. We can assume, therefore, that these individuals will opt for the earlier flights, and after maybe 1,000 or so have undertaken the experience this will cease to be a significant reason. Other reasons listed include “lifelong dream”, and “to see the Earth from space”. So, the “pioneer effect” will affect the phasing of the forecasts but not the overall market size.

Other data indicates potential impacts on demand (although it should be noted here that this survey does not carry the same level of statistical validity as does Ref. 4). Here again, the anticipated effect would be to changes in market share, rather than the absolute market demand. The Adventurers’ Survey⁹ (approx 1,000 respondents to an on-line questionnaire, conducted via the web-site of the adventure travel company Incredible Adventures) explored the likely impact of different types of space tourism vehicle architectures. For the ascent phase, the respondents declared twice as much interest (at 29%) in a true vertical takeoff, or a horizontal spacecraft takeoff, than in a takeoff in a spacecraft suspended under a mother craft (14%) – such as the Virgin Galactic’s SpaceShipTwo design. For the descent phase, the same study found that there was a highly significant six-fold preference for a horizontal landing on dry land (at 53%), versus either of the vertical landing alternatives (illustrated as parachute landings in the survey descriptors) which come in at only 9%. Although, as stated, the respondents were not a true random sample (in fact they were adventurers), the findings nevertheless do convey a very clear preference at least for this group of potential space tourists, and particularly with regard to the preferred mode of landing, which does favor the kind of architectures described in Section 2 of the paper.

Reference 9 also provides information on spaceport preferences, but concludes that at this stage of the industry development, the potential space tourists do not consider this decision as significant. Of course it could be highly significant especially for sub-orbital space tourism, but at the time of the survey (Aug 2006), 48% of the respondents indicated they would be prepared to go anywhere for their flight. The others usually expressed a preference for flying “from my own country”. Of course, at the time of the survey, sub-orbital flights were not considered as point-to-point services, but merely as parabolic trajectories into space, returning back to the spaceport of departure.

VII. FORECASTS OF DEMAND AND SENSITIVITIES

Now we can calculate the eventual saturation level of the markets at the chosen price levels. We want to know how many passengers will ultimately want to fly per year, based on all of the preceding demographic, affordability, health and level of interest data. Global data will be used throughout.

For this step, the projections are for the price levels of \$5 million, \$1 million, and \$ ½ million, and the two levels of affordability: 1.5% of net worth, and 5% of net worth, thereby reflecting a range of uncertainty.

MARKET SATURATION FORECAST DEVELOPMENT
AT VARIOUS PRICE LEVELS

Proportion of Net Worth Spent per Ticket	Forecast elements	\$5m Ticket Price	\$1m ticket price	\$1/2m ticket price
5 percent	Global Pool	10,000	100,000	900,000
	Fitness (x 61%)	6,100	61,000	549,000
	Intention to buy	20%	30%	33%
	Likely customers	1,220	18,300	181,170
	Adapt for US launch (+24%)	1,512	22,692	224,650
1.5 percent	Global Pool	4,000	40,000	55,000
	Fitness (x 61%)	2,400	24,400	33,560
	Intention to buy	20%	30%	33%
	Likely customers	480	7,320	11,071
	Adapt for US launch (+24%)	607	9,076	13,728

Table 7. Market Saturation Forecast Development at Various Price Levels

For each combination of price and affordability, how the market saturation level is determined is shown in Table 7. For example, at a \$5 million price, and a 5% of net worth affordability assumption, we find that there are initially 10,000 people in the global pool. After removing those who are unfit, the number reduces to 6,100. The Futron/Zogby indication of “definitely likely to buy” at that price level is 20%, which means that the pool is now reduced to 1,220. However, it is increased again to a figure of 1,500 when adjusted for the U.S. location and training. 1,500 passengers per year figure then becomes the market saturation level at the \$5 million price, and the 5% affordability assumption. The figure reaches as high as 22,700 passengers per year at a price of \$1 million and the same 5% of net worth affordability assumption. And it grows to as much as 225,000 at price levels of around \$1/2 million. However, at the 1.5% proportion criterion, the global market at the \$1/2 million ticket price is around 14,000 passengers/year.

Orbital space tourism is a new industry, and it will take time to become established. This is a familiar marketing phenomenon with all new businesses. Initially, the leading edge customers come on board, and test out the proposition. The companies develop their marketing offerings, and sort out supply constraints, and the initial customers become advocates and tell their friends. At this point the rate of take up increases, and the business undergoes an expansion period. However, this process is not exponential. The curve reaches a point of inflexion and the rate of growth declines, and eventually flattens off as the target market level of passengers per year is approached. The reason for the flattening-off, is that for any given price level it becomes increasingly harder to find the remaining incremental people willing to spend that amount on the goods or service.

This process of market diffusion at any given price level is best described mathematically by an S-Curve. For this work, a formulation known as the Fisher-Pry equation has been used. This has the advantage of needing only to know the start year, the eventual saturation level, and the number of years to saturation, in order to derive the values for each year. Table 8 below shows the normalized values for three “time to maturity” assumptions:

Yrs to Mkt Maturity	Projected Penetration of Peak Market %						Max Value
	2005	2010	2015	2020	2025	2030	
40 yr	0	1%	8%	40%	83%	97%	100%
30 yr	1%	8%	40%	83%	97%	100%	100%
20 yr	8%	40%	83%	97%	100%	100%	100%

Table 8. Market Penetration Projections

The curves above use 2001 as the starting year, based on Mr. Tito's initial flight to the International Space Station.

A given S-Curve only works for a given fixed price. Clearly, the S-Curve approach is a little academic, because in practice it is never possible, even after the events, to reconstruct the classic S-Curve. This is because a number of variables enter the situation, such as the introduction of competitors, changes in marketing actions, and in particular a tendency for prices to drop through time. So, in practice, a business starts to develop along one S-Curve, but switches to another curve as time introduces changes to the initial set of assumptions. Nevertheless, at the initial stages of business development of a new company, it provides a good way of predicting the likely growth rates, for planning purposes.

There are dramatic differences, as we can see, at a given point in time depending on the particular curve being followed. History gives us examples to illuminate which curve to use. For instance, it took 44 years to get from the Wright Bros to Yeager and Mach 1. It also took 40 years to get from Gagarin to Tito. We can make other comparisons, like the time it took for personal computers to become universal, or for cell phones to become ubiquitous. This paper however focuses on a 40-year industry emergence curve for the further development of its demand forecasts. Table 9 shows the impact of using the 40-year S-Curve on the target market saturation levels developed above.

40-YEAR S-CURVE OF ACCEPTANCE, SHOWING REVENUE PER YEAR

Trip Price	% net worth	Peak Demand	2010 1%	2011 2%	2012 3%	2013 4%	2014 6%	2015 8%	2020 40%	2025 83%	2030 97%
\$5m	5%	1,512	15	30	45	60	90	121	604	1,255	1,466
		Rev \$m	75	150	225	300	450	605	3,020	6,275	7,330
	1.50%	607	6	12	18	24	36	48	242	503	588
		Rev \$m	30	60	90	120	180	240	1,210	2,515	2,940
\$1m	5%	22,692	226	453	680	907	1,361	1,815	9,076	18,834	22,011
		Rev \$m	226	453	680	907	1,361	1,815	9,076	18,834	22,011
	1.50%	9,076	90	181	272	363	544	726	3,630	7,533	8,803
		Rev \$m	90	181	272	363	544	726	3,630	7,533	8,803
\$1/2m	5%	224,650	2,246	4,493	6,739	8,986	13,479	17,972	89,860	186,459	217,910
		Rev \$m	1,123	2,246	3,369	4,493	6,739	8,986	44,930	93,229	108,955
	1.50%	13,728	137	274	411	549	823	1,098	5,491	11,394	13,316
		Rev \$m	68	137	205	274	411	549	2,745	5,697	6,658

Table 9. Forty Year Projections

Bear in mind that at this stage the forecasts are describing the total global market projections for orbital space travel. Because the start date is 2001, the curves do not quite reach saturation by 2030. The last row of Table 9 provides the revenue forecast at \$1/2 million ticket prices. Around \$1/2 billion annual global revenues would be achievable by 2015, and over \$6 billion by 2030. It is assumed for this paper that the other factors such as location of spaceport, specifics of spacecraft design, etc. will not affect the total global demand as developed above.

VIII. CAVEATS

We need to state some caveats. In estimating demand for space tourism we are attempting to quantify human behavior. Although this is an approach used on a regular basis by market planners, it must nevertheless be underlined that human behavior is not as predictable as engineering outcomes. In this case, we are using data from well-designed surveys, which were carried out to provide a statistically valid representative finding for all US millionaires. The surveys of course suffer from the same problems that all surveys do. For example, it depends on how the questions are asked. In this case, a great deal of care was taken to provide factual data to the respondent, both positive and negative, before the responses were obtained. Also, there were a number of reasonability and reality checks carried out, to check whether the respondents' past behavior was in line with the answers they were providing to the pollsters. But the main survey was nevertheless conducted nearly 8 years ago, and it might be expected that different results would be reported if the exercise were repeated today, although we cannot know if the newer findings would be higher or lower than the results of the original survey. For example, the definition of the "boundary" of space for sub-orbital space tourism has changed from 50 miles to 62 miles (ie 100km) since the original interviews were conducted. Also the Ansari X-Prize in 2004 increased peoples' awareness of the very idea of space tourism. We are also still not clear about the eventual outcome of the 2008/2010 financial crisis, and what it will have done to the global wealth distribution.

In general, however, the forecasting work has followed a decidedly conservative approach. When choices were required in the process, the lower end of the value range was used for the forecasting element. Thus, for example, we only interviewed millionaires. We are only allowing those multi-millionaires who are so rich that the ticket price is no more than 1.5% of their net worth to be in the potential pool of orbital tourists. In other words, they need to have a net worth of at least \$33m in order to be included in the potential pool at a ticket price of \$1/2 million. So, a major caveat of the forecast process is that we do not know very accurately how many such people there are. Population data for high net worth individuals is not well known to even the IRS (or perhaps, it should be said, especially to the IRS). We have, furthermore, opted to only use those respondents who reported "definitely likely" in their responses, ignoring those who replied "very likely" or "somewhat likely". We have opted for a 40-year S-curve, believing this to be a conservative assumption, but only time will tell if this proves to be correct. We removed a slice of potential respondents because of concerns over age and health levels. Again, only time will tell if the level chosen for this proves to be a valid assumption.

We have, of course, had to extrapolate data to price levels that were not even included in the original survey questionnaires, and this process always introduces uncertainties. In The Adventurers' Survey⁹, the respondents (whom we must note, for that particular survey, were pre-disposed to undertaking risky adventures) were asked a question about what they considered to be a "fair price" for orbital space tourism. 69% of them indicated that \$1 million or below was "fair", with only 8% saying the same thing for a price of \$ 20 million or above.

We are left with very little doubt that, at a ticket price of \$1/2 million, there would be substantial demand for the orbital space tourism experience. There is a definite yearning and untapped demand for people to go into space, and they state they would prefer the orbital experience if they could afford it.

IX. CONCLUSIONS

We have used available public domain data to derive demand forecasts for orbital space tourism at price levels that might be achievable for potential new reusable rocket and hypersonic vehicle architectures, at around \$0.5M per ticket.

We have studied a range of architectures and found that a Two-Stage-to-Orbit fully reusable transportation system using rockets and hypersonic RBCC, and capable of carrying around forty passengers per flight, can reduce the direct operating costs per passenger to less than \$0.5M.

The analysis has shown that there is, in addition to any potential governmental use, a potential commercial global demand conservatively estimated at around 14,000 passengers per year at price levels of around \$500,000 per ticket for orbital space tourism flights. Global revenues of the order of \$1/2 billion by 2015 would result, increasing to \$6 billion by 2030. A further decrease in price level to \$250,000 per ticket could increase the global demand to around 50,000 passengers per year.

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