Contest-Driven Development of Orbital Tourist Vehicles

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I. Abstract

We explore the size and structure of prizes intended to promote private development of orbital tourist vehicles. While inspired by the Ansari X-Prize, we argue that prizes to spur orbital tourism development must be much larger and structured to reward continued development, rather than a few flights. Mechanisms to promote development of extremely reliable vehicles are also discussed. This paper does not examine the technology or techniques necessary to develop orbital vehicles, but rather the structure of incentives to encourage such development. Analysis suggests that total prize money of one to eight billion dollars may be sufficient to jump start orbital tourism, particularly if sub-orbital tourism proves profitable. This sum is within the means of a few extremely wealthy individuals and foundations. While there is no guarantee of success, the cost of failure is minimal since no prize is awarded if no vehicle is developed.

II. Introduction

Present launch capabilities, while sufficient for communications, remote sensing, some space science and limited manned operations, are grossly inadequate for large scale space settlement. By space settlement we mean very large numbers of people living in giant orbital spacecraft, on the Moon, on Mars and/or within large asteroids. Space settlement could provides humanity with hundreds of times more living area, thousands of time more physical resources, and millions of times more energy[1, 2] than is presently at our disposal. Such a vast expansion of the resources available to human civilization would eliminate the need, although perhaps not the practice, of resource-driven war. Such warfare kills and maims large numbers of people and destroys their work. Substantially better launch capacity is a necessary precursor to space settlement, but progress over the last 50 years has been disappointing. Thus, it behooves us to examine new strategies for moving large numbers of people and massive quantities of materials from Earth to Orbit.

Over the last 50 years a wide variety of launchers have been developed up to and including the U.S. Space Shuttle, the most capable space vehicle to date. However, in spite of decades of development, Earth-to-Orbit transportation costs thousands of dollars per kilogram and suffers a catastrophic failure rate of a one or two percent. Worse, these figures have not improved with time. For example, the Saturn V was developed in the 1960's to put men on the Moon. This vehicle cost less, measured in man-hours per ton to LEO (Low Earth Orbit), than todays major launch vehicles.[3] Furthermore, the Saturn never suffered a catastrophic failure, although there were many close calls. By contrast, current shuttle costs run between $500-1,000 million per flight to deliver, at most, a few tens of tons of payload to the International Space Station, and the shuttle has suffered two catastrophic failures in just over a hundred flights.

Aircraft developed much more rapidly in their first 50 years. Hundreds of thousands, if not millions, of flights occurred in that period, but we have only launched a few thousand payloads into space. Substantial launch vehicle improvement may require tens of thousands of launches per year, not the current 50-70.[4] Unfortunately, current markets for space launch: communications, Earth-observing, science, national prestige, etc. cannot support hundreds of launches per year, let alone tens of thousands. However, a new space market has recently been created: Space Adventures, Ltd. and the Russian space program have flown three tourists to the International Space Station (ISS), reputedly for about $20 million apiece. While this sum does not, apparently, cover the entire cost of the flight, there is an extra seat available on the spacecraft which must be flown periodically to the ISS to provide a functioning life boat capability. Although the ISS

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price/ticket (1994 $)	passengers/year
$1,000	20 million
$10,000	5 million
$100,000	400 thousand
$250,000	1,000
$500,000	170

Table 1. Projected demand for orbital tourism as a function of price[8]

was originally intended to serve a host of space applications, it has not yet done so for a variety of reasons. Space tourism may be the legacy of the ISS, and it could be a very good one indeed.

The only market for humans-in-space potentially capable of sustaining thousands of flights per year is tourism; particularly if the cost is in the $10-20,000 range and catastrophic failures are extremely rare. Published market research suggests that the space tourism market may become very large if the price is right. In 1994, Patrick Colins, et al.[5] found that the Japanese market could provide about one million customers per year for space flight at about $10,000 per passenger. In 1996, Sven Abitzsch[6] found that approximately 20% of the U.S., Canadian and German populations and nearly 40% of the Japanese population would be will to pay over $10,000 (actually, six months salary) for a trip into space. This represents nearly a hundred million people. In 1999, Oily Barrett[7] found that 12% of United Kingdom residents, representing 3.5 million people, said they were willing to pay over $10,000 for a trip to space. In 2001, Crouch[8] surveyed the literature and found that the global space tourism market is a strong function of price, with an annual demand of five million per year at $10,000 per flight and 170 at $500,00 per flight, representing annual markets of $5 billion and $85 million respectively. Table 1 shows Crouch's demand vs. price per ticket. If these projections are optimistic by no more than a factor of ten, and the price per ticket can be brought down to about $10,000, there is good reason to believe space tourism can support tens of thousands of launches per year, a rate comparable to the early decades of aviation.

Traditional approaches to launch vehicle development emphasize the choice of technology, manufacturing issues, launch site improvements, etc. Although obviously necessary, this approach has failed to deliver and thus appears to be insufficient. For perspective, it may be interesting to consider the experience of the genetic algorithm community (the author spent several years developing genetic algorithms for aerospace applications[9–11]). Genetic algorithm practitioners solve problems computationally not by devising detailed instructions to solve the problem, but rather by representing solutions as data structures in computer memory, generating many random (and very bad) solutions, then evolving these solutions. Evolution is accomplished by testing solutions with a 'fitness function' that evaluates quality, then breeding the best solutions with 'crossover' and 'mutation' to produce new, sometimes better solutions, and discarding the worst ones. A rule of thumb in the genetic algorithm business is that when evolution isn't working, it's very often a problem with the fitness function, not the breeding. For example, genetic algorithm lore has it that there was once a project to evolve a robot that could navigate in a space filled with obsticles. A reasonable fitness function was chosen, the distance the robot could travel without a collision. The algorithm quickly evolved robots that found a small unobstructed space and went around in circles forever. This paper assumes (without proof!) that launch vehicle development is stuck not because it's impossible to develop the technology (the equivalent of breeding), but because the incentives (the equivalent of the fitness function) are improperly structured. Thus we attempt to improve launch vehicles not by directly developing technology or manufacturing processes, but by changing the equivalent of the fitness function, by changing the way launch vehicle development efforts are rewarded.

All human-capable orbital vehicles to date have been developed as national projects by the U.S., Russia/USSR, and China. For sub-orbital vehicles the picture is quite different. Spurred by the $10 million Ansari X-Prize, a change in the way launch development was rewarded, Scaled Composites, LLC built and flew SpaceShipOne into space twice in as many weeks in 2004. Interestingly, these were the only U.S. manned space flights that year as the Shuttle was grounded after a fatal accident in 2003. While Scaled Composites reportedly spent considerably more than the purse to win, other commercial deals involving advertising and technology sales netted a small profit.[12] As a direct result, Scaled is now developing SpaceShipTwo for Virgin Galactic. Virgin Galactic is building a space port in New Mexico and intends to fly tourists into space for a few hundred thousand dollars per trip within a few years. Furthermore, Virgin has a couple of competitors. Not only did the X-Prize spur a promising effort to initiate a sub-orbital tourism industry, but over 20 teams competed for the X-Prize. Only Scaled won, but the other 20+ efforts provided training for well over a hundred individuals in human space flight development.

If \$10 million may have jump-started the sub-orbital tourism industry, what prize might do the same for orbital flight? Orbital flight is far more difficult due to much higher Δv, longer exposure to the space environment, and high-speed atmospheric reentry. Also, failure is common, particularly during the first few launches of a new system. Only 5 of the first 9 Pegasus launches succeeded, 9 of 20 for Atlas, 3 of 5 for Ariane, 9 of 18 for Proton, and 9 of 21 for Soyuz. Thus, one might expect orbital flight to require a much larger prize. Indeed, Bigalow Aerospace has offered a \$50 million prize for private development of an orbital vehicle,[13] but this has not generated a level of effort comparable to that expended for the X-Prize. Not only is the prize money apparently insufficient, a differently structured prize may be needed.

III. Prize Structure for Orbital Launch Vehicle Development

We now explore the structure and size of prizes to stimulate the development of a large scale orbital tourism industry. The X-Prize was structured to provide a large fraction of the development cost in a lump sum, with the hope that flying tourists at one or two hundred thousand dollars per trip would turn a profit. This appears to have worked well, as there are a number of current efforts that expect to fly customers at these prices within the next few years.

However, the lowest published cost estimate to develop a Earth-to-LEO vehicle is \$400 million for development and \$20 million per four person flight[14] by Transformational Space Corporation (t/Space), and this may be optimistic. If t/Space could meet their cost targets and recoup all of development cost from a prize, seats would still cost at least \$5 million per passenger. This would continue to limit the market to a small number of extremely wealthy individuals. Furthermore, if all the prize money is expended on a single entrant, there may be no competitive pressure to reduce prices to the \$10-100 thousand range that market research suggests is required to support a truly high flight rate..

IV. Prize Structure

We propose avoiding these pitfalls with a series of prizes for successive launch of people into orbit. The dollars-per-passenger ratio decreases as more and more passengers are flown; starting at near current costs (\$20 million) and ending at the desired price point of \$10,000. A simple computer program, written in Java, was developed to explore the implications of this model. Tables 3-7 contain different prize structures produced by the program. Each prize structure is defined by the number of levels, prize value per person flown, and the number of passengers (or crew) at each level. Source code is available on request.

The program has been used to investigate the consequences of the five prize structures on three hypothetical competitors. Table 2 contains the results. Each competitor is characterized by development cost, cost per flight, and number of passengers (and crew) on board. This simple model assumes that costs will never change. Three competitors were created, one based on t/Space and the other two on DreamChaser, a six passenger reusable vehicle under development at SpaceDev. Although there are no published data on projected development and operational costs, SpaceDev's Richard Slansky was kind enough to provide high and low figures for 'DreamChaser-like' spacecraft: development cost between \$250 million and \$1 billion and cost per flight of 10% of development cost. These are represented in table 2 as DC Low and DC High respectively. Table 2 shows that DC Low is profitable for all contests, and DC High for only the two most expensive contests. Note that the X Prize by itself was not enough to bring SpaceShipOne to profitability. However, it was enough for Scaled Composites to build a successful vehicle and many other competitors to try.

The costs for all three of the hypothetical competitors are far below those of current launch vehicles (current orbital tourist rides are effectively and heavily subsidized by the ISS program which requires the flights in any case). For example, the Shuttle cost many billions to develop and per-flight costs are between half and one billion depending on accounting assumptions. The CEV/CLV, based on shuttle technology, is expected to cost far more than even DC High. Of course, the Java program can be used to examine prize structure for any cost vehicle, but there is some reason to believe the hypothetical vehicles may be in the ballpark. First, note that SpaceShipOne was developed for a few tens of millions of dollars. Few, if any,

contest	competitor	dev. cost ($M)	cost/flight ($M)	pass./flight	break even	profit(loss) ($M)
1	DC Low	250	25	6	5	65
1	t/Space	400	20	4	N/A	(130)
1	DC High	1000	100	6	N/A	(1010)
2	DC Low	250	25	6	3	208
2	t/Space	400	20	4	10	20
2	DC High	1000	100	6	N/A	(960)
3	DC Low	250	25	6	3	335
3	t/Space	400	20	4	6	150
3	DC High	1000	100	6	N/A	(875)
4	DC Low	250	25	6	2	3308
4	t/Space	400	20	4	4	2900
4	DC High	1000	100	6	20	0
5	DC Low	250	25	6	2	3308
5	t/Space	400	20	4	4	2915
5	DC High	1000	100	6	19	50

Table 2. Hypothetical first competitor results if they capture the maximum prize money for each level. The first column is the prize schedule name, the second the name of the hypothetical competitor, third development cost for the vehicle in millions of dollars, fourth the cost per flight, fifth the number of passengers (and crew) per flight, the sixth the break even flight – if any, and the last the profit or loss. Competitors are assumed to quit flying when the prize money can no longer generate a profit. Ticket revenues and other factors may, in practice, invalidate this assumption.

with substantial experience in the aerospace sector believe that NASA or any of the traditional primes could have developed a reusable sub-orbital manned vehicle at such a low cost. Second, unlike the Shuttle and CEV/CLV, tourist vehicles can be optimized for a single mission, to be repeated many, many times. This simplifies requirements and allows mission-specific optimizations for high flight rates.

Given the assumptions above, the tables show that prize structures totaling between one and seven and a half billion dollars may be sufficient. Most competitors would be profitable after 4-6 flights for most prize structures. However, the lower-valued prizes are not utilized since it is assumed that competitors will not continue flying once the prize-per-passenger is lower than their cost-per-passenger. This may not be a valid assumption if the cost-per-flight drops with experience and/or the passengers pay a sufficiently large ticket price.

V. Safety

There is a serious safety problem with the proposed prize system as described. Suppose a competitor hires desparate people to ride in unsafe ships? Some may be killed, but a profit could still be realized on the successful flights. Fortunately, theres a simple solution based on an old French law. Crawford Greenwalt, former President of Dupont, is quoted as saying ”My company has had a safety program for 150 years. The program was instituted as a result of a French law requiring an explosives manufacturer to live on the premises with his family.” In the same vein, we propose requiring at least one major investor, top executive, or senior engineer from the competitor be on each flight. Also, any competitor suffering loss of life could be barred from further competition. Extreme measures are necessary since early fatalities could easily destroy the space tourism industry.

VI. Development Flights

While awarding companies for flying passengers directly addresses the core of problem, it places fiscal pressure on developers to put human beings in flight earlier rather than later, which will tend to increase risky behavior. As noted above, a few early accidents that kill customers is very likely to sink the industry

level	passengers	$/passenger	cost($M)	max income (comp. 1) ($M)	max income (comp. 2)($M))
1	25	15000000	375	262	113
2	25	10000000	625	437	188
3	25	5000000	750	525	226
4	50	2000000	850	595	256
5	50	1000000	900	630	271
6	100	100000	910	637	274
7	1000	50000	960	672	289
8	10000	10000	1060	742	319
total	11275		1060	742	318

Table 3. Prize schedule 1. The first column is the prize level, second the number of passengers per level, third the dollars paid for each passenger launched, fourth the cumulative cost to the prize awading entity of the level in millions of dollars, fifth the maximum income for the first competitor, and the last the maximum income for the second competitor. The last row are totals.

entirely. While other adventure travel, such as climbing Mt. Everest, is extremely dangerous and customers die frequently, the space tourist situation is psychologically quite different. When climbing Mt. Everest it's you against the mountain. The customer is actively engaged in the fight for survival. Orbital tourists are unlikely, in the extreme, to pilot the vehicle. Rather, the customer waits in a small enclosed space to see if they will blow up or not. Thus, it is reasonable to assume that a much higher level of safety will be required. A reasonable target is the safety record of general aviation, which is about one catastrophic failure in 75,000 flights.[15] Note that this is somewhat worse than the Shuttle's unrealized goal of one loss-of-crew failure in 100,000 flights.

A mechanism to reward unmanned test flights would reduce this pressure. One could give partial credit for flying instrumented dummies the size and mass of a typical customer. Simple instrumentation to measure acceleration, pressure, temperature and so for could store data for later analysis to insure that the 'customer' would have survived the flight without excessive discomfort. It is desirable to limit the fraction of prize money that can be awarded for flying dummies, so we propose that no more than one flight per prize level per competitor be awarded a prize for flying dummies. Furthermore, dummy flight should not be as profitable as flying breathing passengers, so awards for dummy flight may be limited to 1/2 or 1/4 of the amount awarded for human passengers.

VII. Developing More than One Competitor

There is at least one additional problem. A healthy market requires at least two, and preferably many, viable competitors. Limiting the prizes per company at each dollar-per-passenger level provides a mechanism to support multiple competitors. We suggest limiting any single competitor to no more than 70% of the prizes at any one level. The break even flight and profitability data in the tables assume this figure with one exception, noted in the caption. 70% is enough to give a substantial advantage to the first winner, but leaves large sums ($300 million to $2.5 billion in our examples) for a second.

VIII. Conclusion

Space settlement has tremendous potential benefits for mankind but requires a much more robust and inexpensive launch capacity than is available today. Traditional approaches to improving launch have failed to deliver a sufficiently capable system over the last few decades and shows little promise of doing so. To address this issue, we propose orienting launch development towards the tourist market, which, at the right price, is large enough to support tens of thousands of flights per year. We propose using prizes, rather than traditional development funding mechanisms, to spur such launch vehicle development. Analysis suggests that an adequate prize system may cost as little as $1 and 7.5 billion, equivalent to a few months to a year and half of Space Shuttle operations. This is within the reach of not only governments, but a few wealthy

level	passengers	$/passenger	cost($M)	max income (comp. 1) ($M)	max income (comp. 2)($M))
1	20	20000000	400	280	120
2	20	15000000	700	490	210
3	20	10000000	900	630	270
4	20	5000000	1000	700	300
5	20	2000000	1040	728	312
6	50	1000000	1090	763	327
7	100	100000	1100	770	330
8	1000	50000	1150	805	345
9	10000	10000	1250	875	375
total	11250		1250	875	375

Table 4. Prize schedule 2. The first column is the prize level, second the number of passengers per level, third the dollars paid for each passenger launched, fourth the cumulative cost to the prize awading entity of the level in millions of dollars, fifth the maximum income for the first competitor, and the last the maximum income for the second competitor. The last row are totals.

individuals and foundations. The beauty of this approach is that major costs are only incurred with success, since the prize awarding entity is under no obligation to pay for cost over runs or failure of development efforts. Prizes have been successful for human sub-orbital flight, perhaps they will work for orbital flight as well.

References

[1] Johnson, R. and Holbrow, C., "Space Settlements: A Design Study," Tech. Rep. SP-413, NASA, 1975.

[2] Lewis, J. S., *Mining the Sky*, Addison-Wesley, Reading, MA, 1996.

[3] Wetz, J. R. and Larson, W. J., *Reducing Space Mission Cost*, Microcosm Press and Kluwer Academic Publishers, El Segundo, California/Dordrecht/Boston/London, 1996.

[4] Webber, D., "The Changing Role of Spaceports," *Beyond Earth: The Future of Humans in Space*, 2006, pp. 190–194.

[5] Collins, P., Iwasaki, Y., Kanayama, H., and Ohnuki, M., "Commercial Implications of Market Research on Space Tourism," *19th International Symposium on Space Technology and Science (ISTS Yokohama)*, No. ISTS 94-g-21p, May 1994.

[6] Abitzsch, S., "Prospects of Space Tourism," *9th European Aerospace Congress - Visions and Limits of Long-term Aerospace Developments*, May 1996.

[7] Barrett, O., "An Evaluation of the Potential Demand for Space Tourism Within the United Kingdom," Tech. rep., Bournemouth University, Dorset, England, March 1999.

[8] Crouch, G. I., "Researching the Space Tourism Market," *Presented at the annual Conference of the Travel and Tourism Research Association*, June 2001.

[9] Globus, A., Menon, M., and Srivastava, D., "JavaGenes: Evolving Molecular Force Field Parameters with Genetic Algorithm," *Computer Modeling in Engineering and Science*, Vol. 3, No. 5, 2002, pp. 557–574.

[10] Globus, A., Crawford, J., Lohn, J., and Morris, R., "Scheduling Earth Observing Fleets Using Evolutionary Algorithms: Problem Description and Approach," *Proceedings of the 3rd International NASA Workshop on Planning and Scheduling for Space*, 2002.

[11] Globus, A., Crawford, J., Lohn, J., and Pryor, A., "Scheduling Earth Observing Satellites with Evolutionary Algorithms," *Conference on Space Mission Challenges for Information Technology (SMC-IT)*, 2003.

[12] Rutan, B., "public address, San Jose, California," .

[13] Covault, C., *Bigelow's Gamble*, September 2004, Can be downloaded from `http://spaceflightnow.com/news/n0409/27bigelow/`.

[14] Berger, B., "t/Space Offers an Option for Closing Shuttle, CEV Gap," *Space News*, May 2005, pp. http://www.space.com/spacenews/businessmonday_050509.html.

[15] Hsu, F. and Duffey, R., "Managing Risks on the Space Frontier," *Beyond Earth: The Future of Humans in Space*, edited by B. Krone, 2006, pp. 214–233.

level	passengers	$/passenger	cost($M)	max income (comp. 1) ($M)	max income (comp. 2)($M))
1	15	25000000	375	262	113
2	15	20000000	675	472	203
3	15	15000000	900	630	271
4	15	10000000	1050	735	316
5	15	5000000	1125	788	339
6	25	2000000	1175	823	354
7	50	1000000	1225	858	369
8	100	100000	1235	865	372
9	1000	50000	1285	900	387
10	10000	10000	1385	970	417
total	11250		1385	969	416

Table 5. Prize schedule 3. The first column is the prize level, second the number of passengers per level, third the dollars paid for each passenger launched, fourth the cumulative cost to the prize awading entity of the level in millions of dollars, fifth the maximum income for the first competitor, and the last the maximum income for the second competitor. The last row are totals.

level	passengers	$/passenger	cost($M)	max income (comp. 1) ($M)	max income (comp. 2)($M))
1	50	30000000	1500	1200	300
2	50	25000000	2750	2200	550
3	50	20000000	3750	3000	750
4	75	15000000	4875	3900	975
5	75	10000000	5625	4500	1125
6	100	5000000	6125	4900	1225
7	100	2000000	6325	5060	1265
8	250	1000000	6575	5260	1315
9	500	100000	6625	5300	1325
10	1000	50000	6675	5340	1335
11	10000	10000	6775	5420	1355
total	12250		6775	5420	1355

Table 6. Prize schedule 4. The first column is the prize level, second the number of passengers per level, third the dollars paid for each passenger launched, fourth the cumulative cost to the prize awading entity of the level in millions of dollars, fifth the maximum income for the first competitor, and the last the maximum income for the second competitor. The last row are totals. Note: unlike all the other schedules, this one assumes that 80% of the prizes are available to a single competitor.

level	passengers	$/passenger	cost($M)	max income (comp. 1) ($M)	max income (comp. 2)($M))
1	60	30000000	1800	1260	540
2	60	25000000	3300	2310	990
3	60	20000000	4500	3150	1350
4	75	15000000	5625	3938	1688
5	75	10000000	6375	4463	1913
6	100	5000000	6875	4813	2063
7	100	2000000	7075	4953	2123
8	250	1000000	7325	5128	2198
9	500	100000	7375	5163	2213
10	1000	50000	7425	5198	2228
11	10000	10000	7525	5268	2258
total	12280		7525	5268	2258

Table 7. Prize schedule 5. The first column is the prize level, second the number of passengers per level, third the dollars paid for each passenger launched, fourth the cumulative cost to the prize awading entity of the level in millions of dollars, fifth the maximum income for the first competitor, and the last the maximum income for the second competitor. The last row are totals.