The Next Challenge in Amateur Space Access

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This article discusses the value of competitions and their founders, culminating on the N-Prize. It begins a series by contributing calculations for the minimum target altitude for a rocket launch, and concludes with ideas on how NZ might be more competitive against very well resourced countries like the USA.

Every now and then, a great philanthropist comes along with a different vision of the way the world needs to be. Although we all remember the competition winners, the importance of the philanthropist's contribution: vision, financing and legitimacy, must never be overlooked. Everybody has heard of Charles Lindberg, famed for the first non-stop flight from New York to Paris. Less known but more important is Raymond Orteig, the privately wealthy businessman that offered the $25,000 Orteig Prize. There were many entrants that attempted the competition with near wins, and arguably, if Lindberg had not succeeded, there were other contestants that were only days behind that were ready to take the prize. What carried this competition forward was the substantial prize offered that would repay the entrants for their monumental efforts. The prize was worth well over 1.5 million NZD[Y2010] at the time it was originally offered, and at the time the prize was offered, the goal was considered "impossible". Part of what made this such a great accomplishment was the years of time that went by without a single attempt; time that was necessary for the goal to become possible. A re-extension of the prize past its deadline to kept the competitive spirit alive, and six years passed before anyone was ready to make an attempt. Six lives was the price paid, however, once the milestone was achieved, we have all benefitted from ever faster, safer and more efficient trans-oceanic travel.

The most recent era-defining competition was the XPrize. This was the brain-child of Peter Diamandis, the man that makes his living at Zero-G by flying giant parabolic arcs. It is without a doubt that his vision wasn't focussed on the intermediate step of space tourism, but of the inevitable outcome which will allow us to take a quick shot from New York to Paris in under an hour with far less fuel than is used commercially today. Although space tourism hasn't yet come to fruition, we should not forget that the China Clipper took a further eight years to make its first regular commercial transoceanic voyage.

While vision and financing are the more obvious contributions of the philanthropist founder, one of the most easily undervalued assets brought by the competition is legitimacy. Before the Ansari XPrize, it was hard to get anyone to take the fledgling space industry seriously. The groups were not without suspicion and investigation from authorities and they were often seen as a joke by suppliers and business financiers. This sentiment was so strong that of the $10 million dollars of prize money offered by the XPrize, only 1 million dollars was raised through a single donation by Anousheh Ansari. The remaining $9 million dollars of the prize money was raised directly through the scepticism from the business sector. An insurance company, created a policy that essentially "bet" nine-to-one odds that no team would ever attain the required goals before the deadline. Assured that companies like Boeing and Lockheed would not participate, the stage was set for the substantial cash prize offer. Unlike the Orteig prize, however, this prize was not re-extendable. This was truly a one-time-offer. During the competion, participants that had spent years struggling with their ambitions were suddenly given a lot of freedom to recruit participants and investors. This was directly as a result of being able to point towards a legitimate competition and a substantial reward. Fortunately for the entire private space access industry, Burt Rutan of Scaled Composites was able to take the prize. This win was a boost for the entire private and amateur space access industry. Since then, a rush of new challenges have cropped up with the same prize model including ones from DARPA, NASA and new XPrize. The most interesting in relation to space is the N-Prize.

What is the significance of the N-Prize?
Although the N-Prize is modelled after the Ansari XPrize, this completion has the potential to revolutionize the world in a far more profound way. The value of access to orbital space is of far greater commercial and scientific value. Orbital access has all sorts of applications including military, geological observation, weather, communication, navigation, astronomy and numerous scientific research fields. As such, orbital access will garner the lion's share of interest from the business sector, that is, until space tourism evolves into aerospace transport. On the forward looking side, any vehicle capable of efficient orbital access can be more easily adapted to a sub-orbital role than the other way around.

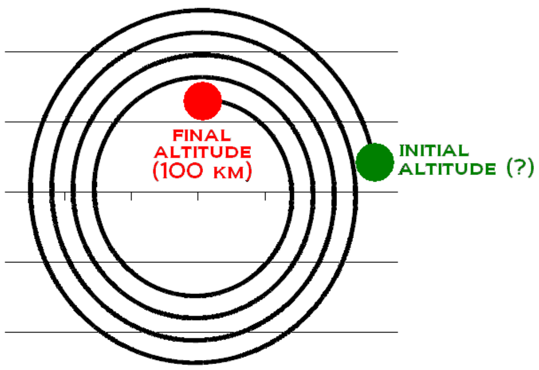
An unforeseen benefit of the N-Prize is the minuscule prize. This may sound like a weak argument, but stay with me for a while. N-Prize reward is so small that it is far more worthwhile to get a commercially viable launch platform than to solely attempt to win the prize. As this competition seems to have attracted participants on all sorts of shoestring budgets, everyone will naturally be seeking to minimize their total costs. If participants are able to plan on future commercialization in the early stages of their planning by looking at the total costs including launch support, then designs should focus on the big picture. Considerations such as safe, inexpensive, storable, transferable and transportable fuels and oxidizers will have immense benefits if it can reach a mass market. Participants may have no choice due to budget. For example, Scaled Composites has made inarguably impressive achievements, but their technology was based on winning a substantial prize which was then adapted for business. This market is unfortunately extremely niche, and as such, their fuel selection may be an expensive technological dead-end unsuitable for either orbital access or mass suborbital transport. If launch support and launch costs can both be kept as low as possible by looking at this as a long term business, then this will have the profoundest benefits in the future.

Why is the N-Prize so challenging?
The N-Prize is rivalled in its technical complexity only by the Google Lunar XPrize, and as such, there are few competitions that have ever demanded more from their participants. This competition would have been completely impossible only a few decade ago, but thanks to the widening availability of high performance materials and access to information, this competition is now only “very nearly impossible” according to the organizers. The goals of the competition, in a nutshell, are to launch a nanosatellite and have it orbit the earth nine times at a cost of less than $2150 NZD. Although the competition is open internationally, it is not too surprising that 12% (3 out of 25) of the competition entrants are from New Zealand (a mere 188 times higher than the global per-capita average). When I first heard of the competition over a coffee, I wondered what aspects of the competition were going to be most difficult and what the actual targets would be after the affects of the atmosphere.

Unfortunately, the goals aren’t easy. The rules doesn't merely state that you must reach space (100km), nor does it just state that you must attain orbit. Unfortunately, the rules state that you must track a full nine orbits of a 10-20 gram nanosatellite, with no part of any orbit being at an altitude of less than 99.9km.

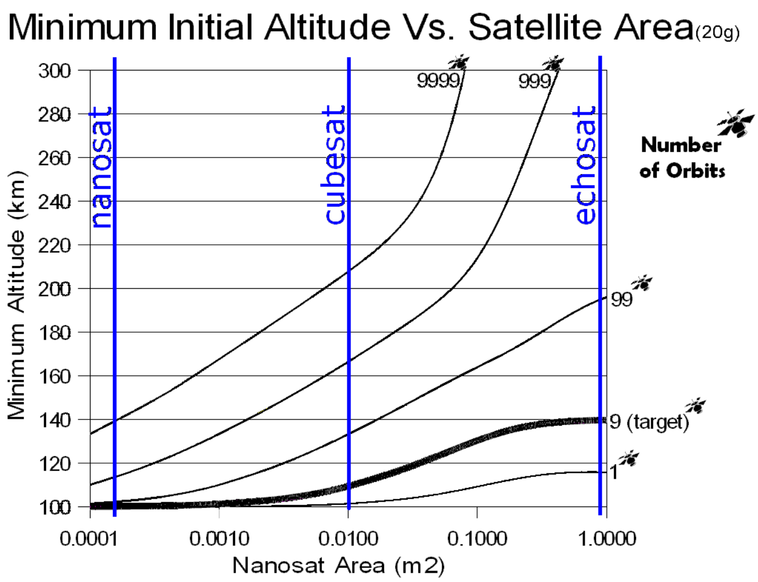
For example, one enormous challenge that we will return to later is the constraints imposed by the interaction of the atmosphere and the nanosat which must weigh less that 20 grams but more than 10 grams, and will inevitably affect the most important aspects of the competition: the target altitude.

As if just reaching space wasn't difficult enough, attaining orbit is far more energetically demanding. To give you a small taste of the difference, the potential energy required to raise one kilogram to 100 km requires approximately 1MJ, but the energy needed to get that same object up to orbital velocity requires an additional 63MJ. Though this is an overly simplistic comparison, this begins to shed a little light on the massive gulf that separates reaching the edge of space and the attainment of a sustained orbit, and will be covered more rigorously in the next article. This is, incidentally, also the exact same gulf that separates the suborbital space tourism industry from the orbital satellite launch industry, a fact that is occasionally not fully understood by some critics. To attain nine orbits in space will require a bit of extra altitude due to orbital decay, and as we will see, this altitude is significantly impacted by the design of the satellite.



What is the competition's real target altitude?

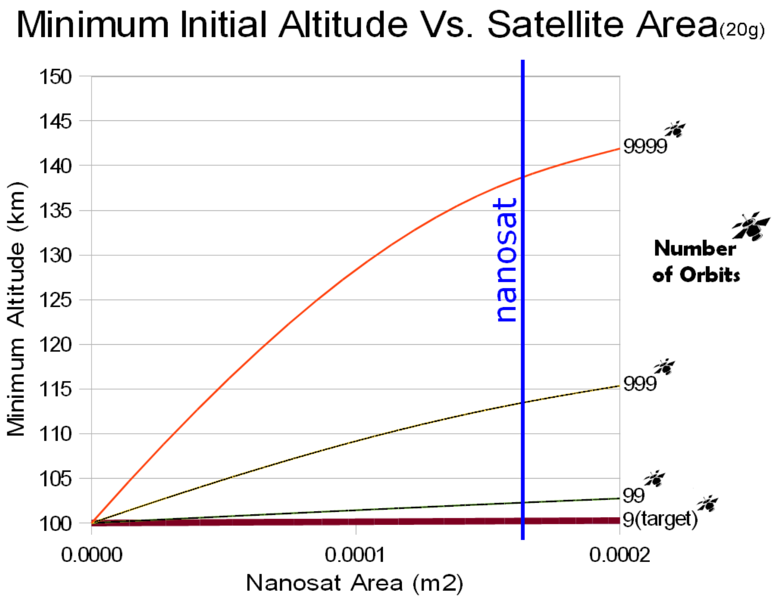
To be competitive, participants will need to find novel ways of launching their satellites. Ideas already put forward include rockoons (rockets lifted to the edge of space by balloons) and rocket-cannons and perhaps yet unseen designs, however, regardless of how the satellite is launched or fuelled, the unpropelled nanosatellite's orbit will always decay. This will directly affect the **minimum initial altitude** at which the nanosatellite must begin. For any satellite orbiting the earth, there is a drag force exerted on the windward surface which slows it down and causes it gradually to fall back to earth. If the final orbit for the N-Prize competition must be at least 100km, then it stands to reason that the starting altitude must be somewhat higher. As an added measure of difficulty, if there is any eccentricity in the orbit, then the initial altitude will need to increase significantly to ensure that the point of closest approach (periapsis) is always above 100km to stay within the competition rules. This ads an additional burden on the guidance system for the rocket, as it will need to be as precise as possible in order attain this ideal orbit. (These challenges will be discussed in a later issue.) Additionally, the exact drag tends to be unpredictable, as the air density in lower earth orbit changes significantly with the solar weather. It is, however, possible to work with ballpark figures by using globally averaged meteorological data that describes the properties of the atmosphere from ground level all the way into space. From this, it was possible to develop a representative simulation. The result shows that the minimum altitude that the rocket must launch from was between 100.9 to 140.0 km. This is a very large range and could strongly influence satellite design decisions. Anyone wanting to recreate this themselves should try running the simulation in reverse eliminates the need for optimization and saves a lot of computing time.



Why would the target altitude vary?

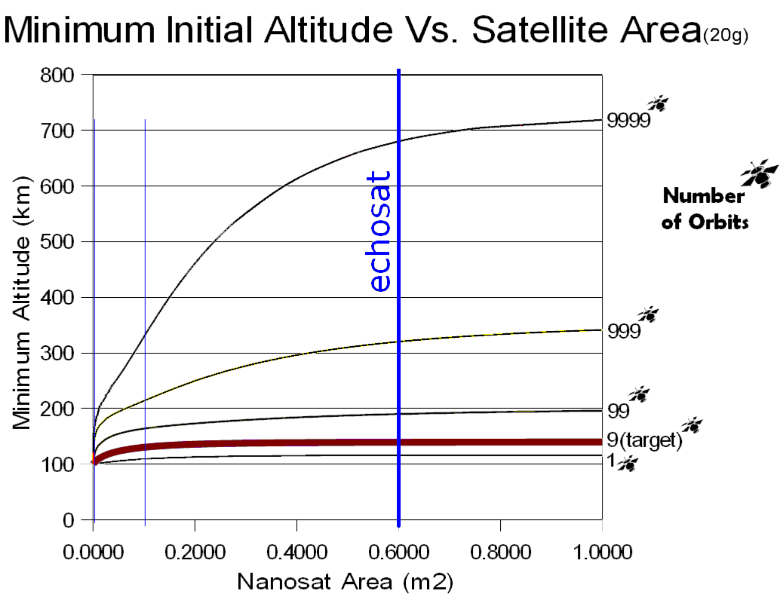
One of the biggest challenges of the competition is the design of the satellite itself. For each design, there is a different **area of incidence**. This is the effective area in the direction of motion. The coefficient of drag is assumed to be the highest possible for a block shaped satellite. A broad classification of possible satellite designs is either an active satellite design (a true nanosat effective area profile) or a passive satellite design (echosat effective area profile).

Active nanosatellites would need to provide their own power to generate a transmission whereas a passive satellite would reflect energy sent from the earth's surface back down. One of the many advantages of active satellites can be far smaller and denser but they are more complex and have more points of failure. In this situation, the weight limitation of 20 grams tends to intensely limit what is possible. The intended area of the satellite would be about the area of the front of an AA battery ($1.65E10^{-4}m^2$) with a long thin antenna tail to stabilize its flight. Although very difficult to design, the potential of modern batteries should not be underestimated. A high end off the shelf AA battery from the Warehouse is capable of outputting a burst power of over 3 Amperes and total energies of over 4500mWh in a package weighing only 14 grams. A decade ago, none of this was available at any price. With this in mind, sceptics of the N-Prize should bear in mind that although the competition might actually be impossible at the moment, it is only a matter of time before the impossible becomes possible. It will be interesting to note what will be available from manufacturers, and off-the-shelf in the near future.



One of the more interesting revelations from the simulation is the staying power of a nanosatellite. Because of the incredibly small surface area of the satellite, with the same modest initial altitude of only 140km as that of an echosat design, it would be possible to have the satellite orbit over 9999 times. That's almost two years of orbital flight, something that is not possible with a satellite with a larger area profile.

Passive satellites, on the other hand, are much more simple and reliable in design. Unfortunately, they are also far less dense. Although the Echo 1A (1960) lasted 8 years at a size of 30.5 meters, it started at a far higher altitude and had a substantial mass of 76kg. A typical passive nanosatellite could easily be made as large as 50-80 cm with store bought materials. With engineering plastics, it is possible make metalized balloons up to a size of 3 meters and larger in diameter. As a result of this range in size, you can see a large variation required in initial altitude as well as the incredibly sharp increase that occurs at an effective incidence area up until 0.1 m^2. Although the results may seem odd, the reason that there is little penalty for increasing satellite size above this area is that air density decreases around the 11^{th} power of the altitude, where drag increases linearly. For anyone interested in the software code, theory or equations used in this article, please drop a note to the editor or to me for the next issue.



What are the benefits of the N-Prize?
If nothing else, the N-Prize has offered each competitor an opportunity to dream, innovate and create new ideas. It provides a magnetic focus of anyone who had thoughts about space but no outlet to express it. As said by an N-Prize competitor "An attempt at this is enormous, whether I win or not". Even a few moments spent attempting to solve one of the hundreds of problems can very educational and gratifying. One thing is certain, the prize money, $21,000 NZD is certainly not a motivation, as teams will be lucky if the cost of equipment and materials will ever be recovered.

What could improve for the N-Prize?
One possibility to improve the competition is to increase the prize money, hold intermediate competitions and organize financial sponsorship for participating team. While the increase of prize money probably will not improve motivation, it might help teams stay to afford the tools and materials that they need. Another possible improvement would to be to extend the deadline beyond Sept 2011 (only 500 days left from the time of this publication).

Sign me up!
Are you interested in participating? No problem. Just registration is free at http://www.n-prize.com, "Nothing is impossible, it only requires sufficient time." as Dumitru Popescu of XPrize's ARCA team so eloquently told me. Even optimistically, teams should be prepared to invest tens of man-years to get a fully working launch system, but again, even walking through the design process on paper can be gratifying. A big selfless team with the skills and passion would be able to quickly demolish the hundreds of tasks and would have the best chances of success.

Ideas to help make this challenge easier have already been proposed by Mark Mackay, where possibly funding, resources and administration might be pooled to help all teams. Anyone interested in pooling assisting with New Zealand N-Prize entrants, email Mark Mackay at mark@spacefoundation.org.nz.

Another idea that has emerged from discussions that that there be an "NZ-Prize" with awards given to the best team in about a dozen subsystem categories. The winners of each category can join forces to form a cooperative of teams (which is allowable under the N-Prize rules). Perhaps a combination of these and other ideas might be one way to improve the chances of a New Zealand win. This forum is open.

Where to next?
The purpose of this article is to start a dialog of ideas on amateur space exploration with likeminded people as well as to get constructive feedback. My next article will go about evaluating various fuels, payload weight and burn profiles: "What is the smallest possible rocket that can reach orbit?" which will discuss the theory of why the rocket can and cannot scale.