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A Vision for Long-Term, Private Space Investment

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ABSTRACT

One of the biggest roadblocks met with by "space entrepreneurs" is that of attracting adequate outside capital. The roadblock exists because the vast majority of angel, VC, and institutional investors believe (1) the opportunity costs for space-related deals are too high, and (2) the up front investment requirements themselves in space ventures are beyond their risk zone. The author offers a roadmap for long-term private investment in key space infrastructure that will be much more attractive to potential seed and 1st stage investors, in the $500k to $20M range, the optimum range for the bulk of early investment risk. He does this by simply redefining key terms, and applying those new definitions to solving the problems of building space-commerce infrastructure. The goal of this is to educate investors that many important technologies necessary to settling and exploiting space resources are technologies in which they may already be investing.

FULL TEXT

"[the entrepreneur]…*neither intends to promote the public interest, nor knows how much he is promoting it… he intends only his own gain, and he is in this, as in many other cases, led by an invisible hand to promote an end which was no part of his intention."*

--Adam Smith, "The Wealth of Nations"

Introduction: Why investors shy away.

Since the end of the Apollo era, hundreds of millions of US$ have been spent by private investors in companies attempting to significantly reduce the prohibitive costs-per-kg to low earth orbit (LEO), in hopes of ushering in a new era of space tourism, expanded exploration, resource exploitation, and human settlement, thus creating the next wave of human civilization. So far, the results have been lackluster, at best. Put more plainly, the vast bulk of those hundreds of millions have been lost in failed ventures, and such capital that is invested currently has been relatively stagnant in terms of growth, compared to other sectors.

The reasons are fairly obvious, if one cares to study the subject dispassionately:

In the first place, the entire focus on space commerce, today, judging from the ubiquitous presentations at US space advocacy conferences, centers around three areas – *launch, tourism, and spaceports*. While all of these elements are successful in driving media attention, they are nevertheless very capital-intensive and risky enterprises, where only those wealthy enough to risk tens, or even hundreds of millions $US can afford to play.

The launch aspect is particularly important, because the cost of getting to LEO or geosynchronous orbit (GEO) has been unattractively high for decades. Space advocates insist that lowering launch costs significantly is key to opening up the solar system for resource development, a point largely considered beyond debate. The challenge is the technology itself, which hasn't fundamentally changed in 50 years – consisting of liquid fuel rockets, carrying fuel and oxidizer tanks, with the occasional strap-on solid rocket boosters for an assist with heavier payloads. The engines and tanks are heavy, and, fully fueled on the pad, perhaps no more than 4-5% of the total mass consists of payload. As a result, there is not much wiggle room, to date, for innovation – lighter parts here, a fraction more I^{sp} there, that's all. Again, hundreds of millions $US have been risked on this problem, and after over two decades of effort, the results have been discouraging.

In addition, while many US-based space entrepreneurial startups are staffed with brilliant, innovative engineers, there are few, if any, business managers, market analysts, or anyone even remotely knowledgeable about the regulatory environment among them. As a result, their "elevator pitch" to angels and VCs is reduced to glowing PowerPoint slide shows, with stunning 3D animations embedded within, but the market and practical realities of starting up a launch services company are glossed over. The primary argument appears to be that space is "cool" and hence, deserving of funding, in a sort of "if we build it they will come" marketing scenario reminiscent of the film "Field of Dreams". Unfortunately for this fledgling industry, the "signal to noise ratio" of business plans deserving of consideration is extremely poor, compared to other tech-sector industries. This turns off potential investors, who seek more rational opportunities elsewhere. However, even those few, visionary startups deserving of a second look will generally not hit the due diligence marks demanded by typical Silicon Valley Venture Capitalists, whose ideal outcome is to receive ten times return on investment within three to five years. Clearly a more creative capitalization solution is needed.

While Cheap and Reliable Access to Space (CRATS) is a major goal of commercial space development, and should continue to be, one is forced to conclude that without major innovations in propulsion technologies and materials science, we may not see success in this area for a great many years. The "Rocket Equation" is rigid, pitiless, and certainly no respecter of the "coolness factor". [1]

The Challenge

How does one, then, attract capital investment to build a space commerce infrastructure? More to the point, how does the "space sector" attract seed and startup capital in the US$ 500K to US$ 20M range, the range for the bulk of initial investments in competing sectors? If the standard "incremental steps" (build a little, fly a little) approach proves to be impractical from a business/marketing/finance perspective, then how do we get from here to there – or do we just admit defeat and leave the process to large, inefficient, wasteful, government programs, that nevertheless have billions of taxpayer dollars at their disposal, to throw at the same big dumb

[1] One entrepreneur in particular, Elon Musk, CEO of SpaceX, who has risked roughly US$100 million of his PayPal profits to date developing the Falcon rocket line, recently admitted (ISDC 2008) that if all went as planned going forward, the best he could do is make some improvements around "the margins", i.e., there would be no innovations to the Falcon itself, or the Merlin engine, so profound as to significantly reduce launch costs as a whole.

boosters they've been building since Apollo?

Unfortunately, governments rarely think through the long-term commercialization opportunities for custom space hardware, built to achieve only one particular mission. Rather, to keep the public funds flowing they instead engage in the bait-and-switch tactic of promoting "spin-offs", i.e., innovations that were serendipitously discovered while building something else, that have been since commercialized, and are busy enhancing taxpayer's lives. (One of the spin-offs one never hears about, of course, is cheaper access to space itself.)

So let us digress for a moment, as, before continuing, I want to define two key terms – terms that should be obvious to everyone, yet bear repeating in the interests of clarity:

Investor: Participates in raising society's collective standard of living, balancing risk with the reward that comes from funding business improvements.

Entrepreneur: Solves society's problems, in a manner that provides market value.

So in reviewing these definitions, one needs to ask the rhetorical question: *What "problems" are the majority of space entrepreneurs "solving", in a manner that provides market value?* Besides the clear desire of said entrepreneurs to get into space themselves, any way they can, they are otherwise, for the most part, pitching a solution in search of a problem. Overall launch demand has actually dropped over the last decade. The "build it and they will come" argument is extremely difficult to sell, today – yet such arguments persist in the rush to build new "spaceports" for the projected thousand of annual suborbital tourist flights, that are always, in the promotional materials, only a short two years away.

Economic development has always created the most prosperous outcomes for the most people when private entrepreneurs, backed by private risk capital, were allowed to flourish. Governments helped the most, historically, by governing the *least*, i.e., by simply regulating with a light touch, to prevent fraud and enforce contract, but otherwise letting events play out as they will in a level, competitive field. Space commercial development offers the greatest challenge, in this regard. If one truly sees the long-term value of space commerce, and exploration and resource development of the solar system, it becomes necessary to rethink the problem. And that may mean looking elsewhere than *launch, tourism, and spaceports*, near term, if we hope to attract sufficient risk capital.

Working backwards from the goal

So, let's begin with a blank sheet. What is the desired *outcome* of space development, whether that occurs 20, 30, or 50 years hence? I would posit the main goals are: (1) the establishment of a robust commercial infrastructure, which certainly includes cheaper access to orbit and beyond, (2) tourism and adventure travel, (3) resource exploitation, particularly energy, and (4) large, self-sustaining settlements or colonies on the Moon, Mars, and elsewhere, allowing for the next wave of human civilization to establish itself, thus (5) rendering humanity a truly multi-planet species.

To achieve these things, there are certain key problems we need to solve on a grand scale, and a lot of smaller ones as well. As mentioned above, entrepreneurs exist to *solve problems*. Investors invest in entrepreneurs for their problem-solving ability, which they believe will lead to market success and profitability. So lets look at the grand goal, the problems we have to solve to get there, and the investment opportunities that will present

themselves along the way. The focus, here, is to find investment opportunities in enabling technologies that are being developed right here on Earth to improve human living standards, engendering short-term earnings and growth. But from our perspective, we also seek technologies that are "scalable", ultimately, into solving problems on the high frontier. So there are profits/earnings/growth every step of the way, thus encouraging investors to stay in for the long haul.

Problems to solve

For the sake of initial argument, I've broken down the major challenges of settling space, from an economic perspective, into the following major groups: *Sustenance, Energy, Health, Resource Utilization, Communications, and Transport*. No one challenge, again from an economic perspective, is necessarily more important than another. And there may be other challenges I haven't mentioned here. But innovations in certain sectors may proceed more rapidly than in others over the coming decades, and this will drive long-term investment strategy. So lets look at each challenge, and how entrepreneurial solutions may be forthcoming from sectors that we heretofore have not considered to be "space-related".

Sustenance

Humans essentially need to eat, drink, breathe, eliminate waste, and be protected against the elements. It's true on Earth, and it's just as true on Mars or anywhere, except that anyplace other than Earth is not "user friendly" in this regard. To survive and ultimately flourish in this environment will require new technologies and methodologies.

SOLUTIONS NEEDED – Food needs to be grown and stored. Arable soil will first have to be created from scratch, and farmland protected in a pressurized environment. Nutritional supplements and "superfoods" may also need to be manufactured, should import from Earth prove uneconomical. Water sources need to be found, purified, and stored for future use. Living habitats need to be built, from as much native material as is practical. Protective clothing will need to be brought from Earth until the capability to manufacture it locally is available. Oxygen itself needs to be extracted and stored - from native sources, when available, and/or created by biological means, from Earth plants, including algae. Byproducts of human and farm animal metabolism, including natural body wastes and exhaled CO2, will need to be collected, purified and either recycled for human consumption, or used as agricultural fertilizer.

INVESTMENT OPPORTUNITIES – Nano- and biotechnology, filtration and purification systems, closed-loop waste recycling systems, agricultural technology (specifically things that can reconstitute and restore depleted soils), nutrient delivery, In-Situ Resource Utilization (ISRU), new structural materials, robotics

Energy

Energy use drives all human endeavors. Future settlers will need to exploit energy resources to maintain settlements and industry. In the current fossil-fuel era on Earth, energy was relatively easy to locate and exploit compared to conditions on the Moon or Mars, as finding a natural gas well or a coal seam on Mars, for example, is considered extremely unlikely. On the other hand, the capability to make rocket fuel from native Martian water and atmosphere, using a small nuclear reactor and a catalyst,

has already been demonstrated in the lab.[2] The first Martian settlement could also use a small-scale space-based solar power system, deployed in a separate launch prior to human arrival, to jump-start their effort.

SOLUTIONS NEEDED – Space travel and settlement is technology intensive, and available power to run it will be imperative. Simply, every potential energy source needs to be developed and exploited. Long-term storage is required, both for large-scale purposes, and small, i.e., battery-powered portable electronic devices, spacesuit systems, etc. Everything is on the table: solar, chemical (ISRU), fuel-cells, wind(?), geothermal(?), nuclear.

INVESTMENT OPPORTUNITIES – "alternative energy" in general, new innovations in battery storage, thin-film photovoltaics, heat-exchange systems, thorium-fission, space solar power technologies, microfiber nanogenerators (producing power for your personal electronics from your own body movements)

Health

A settlement on a lunar or Mars colony - indeed, even getting there - will offer its own unique hazards to human life and health, not the least of which is protection from the effects of ionizing radiation. There will be no major hospitals or trauma centers on Mars some time. Early settlers will need to know far more about medical care than the average citizen, today,

SOLUTIONS NEEDED – Portable, accurate, low-power diagnostic tools, protection from radiation exposure, and, conversely, the ability to repair radiation damage to human tissue. Remote medical monitoring systems, contained within protective clothing/spacesuits. Better methods of nutrient and pharmacological delivery.

INVESTMENT OPPORTUNITIES - Bio/Nano tech, "lab on a chip" diagnostic tools, smart clothing, radiation protection (internal and external), new cancer therapies, aggressive supplements research, pharmaceuticals

Resource Utilization

As with any terrestrial town, village, or major city, people who settle space will need to be able to find and exploit local natural resources, both for survival and construction purposes, but also for potential export. Beyond providing for its own immediate needs, any space settlement must find a way to sustain itself economically – by means of trade with Earth and other settlements - in order to grow and attract further investment and more settlers in search of opportunity.

SOLUTIONS NEEDED – Resource imaging and detection, assay, drilling, mining, ore processing technology, new methods of manufacturing in situ.

INVESTMENT OPPORTUNITIES - ISRU, resource imaging, remote assay, mining, smelting, robotics, micro-manufacturing, "metamaterials", superalloys.

Communications

A robust, reliable communications infrastructure, incorporating video, audio, and data will be vital to the success of an extra-terrestrial community, not only for internal communications and commercial purposes, but also to maintain vital links to friends and family back on the home planet. The latter offers its own unique challenges due to the tremendous distances involved, as the speed of light is the key limiting factor. While on the Moon, a signal only need 1.5 seconds to get there, and near-instantaneous real time communications are possible, the delays reaching places like

[2] Zubrin, Wagner, "The Case for Mars: The Plan to Settle the Red Planet and Why We Must", 1996

Mars or the asteroid belt make real time communications impractical.

SOLUTIONS NEEDED – Robust, lightweight, easy to maintain, voice, visual and data transmission, recording, and storage, protected against radiation, vacuum, and impact

INVESTMENT OPPORTUNITIES – Audio and visual communications, data storage, IT, artificial intelligence, virtual reality systems, nanotech (chip manufacture and casing materials), "real options" (flexible) comsats, software, entertainment

Transport

This is the biggest challenge of all, and the hardest and most capital intensive to solve. There are, at minimum, four separate forms of transportation required to explore and settle the solar system, (1) Earth to orbit, (2) inter-orbit transfer, (3) orbit to ground at destination, (4) ground transport at destination. Some of these systems may be combined with one another. All these systems will require fueling, life support, communications, and maintenance infrastructures.

As previously discussed, efforts to lower launch costs to date have been unsatisfactory. While lower cost air-launched systems are presently in use or under development, they are primarily targeted for either small satellite payloads or sub-orbital space tourism. As yet, no launch system has been demonstrated that can provide significant cost-to-orbit reductions, is scalable for "heavy lift", and can offer reliable flight rates to justify the capital investment.

SOLUTIONS NEEDED –

If the heaviest rocket components, i.e., the engines, storage tanks, pumps and internal structures, could be made of something far lighter, stronger, and pressure tolerant than materials presently required, that would, in fact, enable significantly larger payloads to reach orbit with each launch, thus lowering the cost-per-kg. Over the next 15-25 years, nanotechnology may provide the answers. Very light and extremely strong "metamaterials", deposited one molecule at a time on a lattice by nanoassemblers, are currently in the pipeline. Near-term, these developments will take the form of various consumer goods, as parts of clothing, automobiles, and electronic components. Some of the profits can be reinvested, when needed, into further R&D for more exotic requirements, such as large boosters made of industrial diamond, superstrong inflatable habitats, or Aldrin "cycler" ships that constantly travel between Earth and Mars orbit. Hence, my argument that real investment opportunities will not occur in this area for nearly a generation.

Of course, the ultimate in cheap-access-to-space transport is the Space Elevator, a proposed meter-wide ribbon of carbon nanotubes stretching approximately 100,000 KM from the Earth. The elevator climbs the ribbon, possibly powered by a laser or microwave transmission system, and would be capable of transporting both large loads and people, dropping them off virtually anywhere along its path – LEO or GEO. If one went to the very end of the ribbon, the payload could be cast off at the appropriate moment, allowing for a "slingshot" at escape velocity, thus enabling delivery at the Moon, Mars, or elsewhere. At present, efforts to make carbon nanotubes with the required tensile strength are underway, and this is already providing investment opportunity for a wide variety of terrestrial products, providing both short-term profit and improvements in human's living standard. However, as with rockets, this is a long-term endeavor, which we shouldn't expect

before mid-century, when nanotech is a more mature industry.

INVESTMENT OPPORTUNITIES - Batteries, motors, nanotech, exotic metamaterials, fuels, components

A new term: "Crossover" technology

Technologies that are poised to make lives better for billions of people the world over, exotic materials and fabrics, new "green tech", alternate energy, better internet and communications tools, agricultural tech, water purification and waste recycling new resource exploration and extraction methods, and radical new medical discoveries, will all pay a vital role in ultimately making the exploration and settlement of space a reality. Hence they are now being called "crossover" technologies. My aim is to help already savvy tech investors take their vision to the next level.

One of my favorite examples of the possibilities is a startup company I'm working with in the US. They are creating a magnetic axial flux electric motor, which has only one moving part, and delivers high torque. The developers envisioned this for automotive, wind generation, and regenerative braking uses. The first time I saw this, I visualized it on a Mars rover. My purpose with this paper is to enlighten and inspire investors in many different sectors to take another look at the technologies they are considering investing in (or are invested in already), and think in terms of scalability to new heights.

Conclusion

For years, the space community, from an investment perspective, believed themselves to often be on the outside looking in, in a world where they struggled to find funding in competition against other more compelling and less risky tech-sector opportunities. But that presumed all we were talking about were *launch, tourism, and spaceports*. Clearly that thing we call "space development" is far more complicated than that. As engineers and scientists have known for decades, space exploration is a very *cross-disciplinary* endeavor. It's time to help space advocates, entrepreneurs and investors understand that the same cross-disciplinary approach, with a view to the long goal, makes space utilization an important future sub-market for many terrestrial technologies that are profitable already.

The science fiction author Robert Heinlein once remarked that humans "couldn't go railroading until they were *ready* to go railroading." By that he meant that every integrated component, from the right kind of steel manufacture for the rails, to the right kind of steam engine, sufficient coal mining and delivery infrastructure, track switching systems that could be controlled electrically from a distance, and the telegraph, all had to be in place before railroading could work. One missing component was a show-stopper. The pieces that need to be in place for human settlement of the high frontier are two orders of magnitude above railroading. But by taking the long view, and an overarching problem-solving approach, entrepreneurs and investors can get the job done, within three to five decades. There will be no issue of investors having to be convinced to wait years for their returns, because the returns will always be coming, all along the way.