Thoughts on Future Space Research and Education

By Jeff Greason

As I am to begin teaching a course at Kepler this summer, I have been asked to share my thoughts on what the needs and opportunities are for space research and education; a dauntingly broad topic, but here they are.

Discussing what is desirable in space inevitably comes back to some questions of values; you cannot talk about improving things without a framework for what good is. That is a value judgement; in my case, I am interested in the well-being and opportunity for advancement by individuals—sapients—persons. At the present time, we only have humans in this category, and I am not expecting either machines or non-terrestrial life forms to become an interest we have to consider in my lifetime. Now, one cannot have human individuals without humanity; one cannot have humanity without life, one cannot have life without a habitable biosphere and an ongoing source of energy to power it, and so on.

I think we in the space movement labor under an intellectual burden that dates back to the beginning of space flight; because it was done by nation-states, for national interests, as part of large, centrally planned programs, we began to think about it, and speak about it, as if it were a designed or planned thing. That is a bit odd. Neither humans nor other life forms have designed their spread into new ecosystems. Both economies and ecosystems are notorious for their incompatibility with central planning. Even large-scale agriculture is not a clockwork mechanism, but a continuous and ever-changing act of fostering desired organisms and discouraging undesired ones. Markets can be influenced, fostered, encouraged, and discouraged, but they are collective, emergent behaviors and not, despite how we talk about them, things to create. We lack a vocabulary for discussing this thing we share, the space enterprise, the space movement, that reflects this organic, evolutionary, market-oriented character, and I will inevitably use design-oriented, mechanistic language here because that is all I have to work with.

Space has had many beneficial impacts on human civilization so far—both psychological and because of valuable information (pictures, communications, navigation, and timing) transmitted from, or through, space. But it has had at most a modest economic effect on the totality of human civilization. For space truly to address the challenges human civilization faces, and to enable the continued growth in the well-being and freedom of action by individuals, it has to enter a period of sustained economic growth. Today, there is essentially NO space-based economic activity. If I visit Antarctica, my visit contributes to the GDP of many nations—Antarctica not being among them. I take nothing from Antarctica but pictures, I leave nothing but footprints, and every product or service I would purchase, I get from somewhere else. Antarctic tourism is a small industry, and one enabled by the existence of Antarctica, but not one that can grow organically. And so it will remain while everything done there is packed in and packed out. Similarly, Apollo, for all it taught us, left no economic improvements behind.

For space to scale to the level where it materially improves the common lot of human individuals, it has to grow substantially, and that means we will need to take steps to enable it to grow organically, without ever-increasing subsidies from Earth. That means that we have to begin to gather the energy and material resources of space and transform them into valuable products and services with at least some of the value-added steps taking place in space, and that these capabilities need to be able to leverage each other to increase their capacity with an ever-decreasing fraction of the required investments coming from Earth. I prefer to talk in these terms of economic development, which is broader than settlement.

Settlement, however, is an inescapable part of the process. For the space sector to add economic value to the Earth, it first has to have things of economic value. A trading relationship requires partners on each side. If the space sector is exporting goods or services to the Earth, then some entity in the space sector has to have owned them before it traded them. It is very difficult to envision that scaling up to significant levels without some people in the space sector—people who live there, work there, and own things there. People have unique properties in an economy. They have desires—not always predictable ones. They are not satisfied forever with the bare minimum of existence—they want other services. They do not work contentedly during every waking hour at assigned tasks—they demand leisure, which creates the possibility that they may do things during that leisure that no planner would predict, including creating new things of value and saving surpluses to reinvest in new activities. People grow their numbers, if the resources permit, allowing the space sector to grow organically. However, people cannot exist for long without other life around them, without bringing a biosphere with them, and so the spread of individual people and the spread of life to currently lifeless areas beyond Earth are inextricably linked.

Having discussed what makes a future scenario more desirable, what needs doing to make desirable scenarios more probable, and how can education and research play a beneficial role?

Broadly speaking, if we want economic growth in space, we have to make it worthwhile for individuals, singly or collectively, to do things. That means lowering the costs of going there and doing things and improving the benefits to be gained. There are also existing benefits we get from space, in the form of non-tangible psychological benefits, a sense of available space (which may overlap with the Overview Effect), and in terms of scientific knowledge. Not only are those valuable in their own right, but they also have existing stakeholders who will fight to protect them, and we have to attend to their interests if we wish to proceed. Broadly, then, the main areas seem to me to be:

1) lowering the cost of access to, and through, space;
2) growing the market for space services, especially human services, and the infrastructure that provides them;
3) increasing the returns from space development; and
4) expanding the zone of human exploration and science.

While space is a technological endeavor, many of these require approaches that touch on domains far from those of engineers and scientists.

Lowering the Cost of Access

Lower cost of access to space has long been recognized as the foundational requirement for economic development of space—you have to be able to get there, and the cheaper getting there is, the more things are worth doing. Not so widely recognized is that this is primarily a problem of low existing *demand* for space transportation. Worldwide space launch traffic is on the rough order of 1,000 metric tons/year (roughly ten 747 flights' worth). It was this, and not any lack of technological vision, that held back investment in newer space transportation technology—governments and companies both recognized that existing markets did not justify further investment.

Because space has been so expensive, most things done in space are things we cannot do any other way—if we could, we would. The converse of that is that the elasticity of the market is very low—if space were 20% cheaper, would we launch 20% more communications satellites, or weather satellites, or GPS satellites? So far, the answer has been no.

On the other hand, with very large changes in price (an order of magnitude), it is easy to think of new things we would do—tourism, manufacturing, energy collection, and some in-space assembly of satellites.

This suggests the existence of a "U-shaped" market elasticity curve (Figure 1; the values on the charts below are my own and are highly speculative).

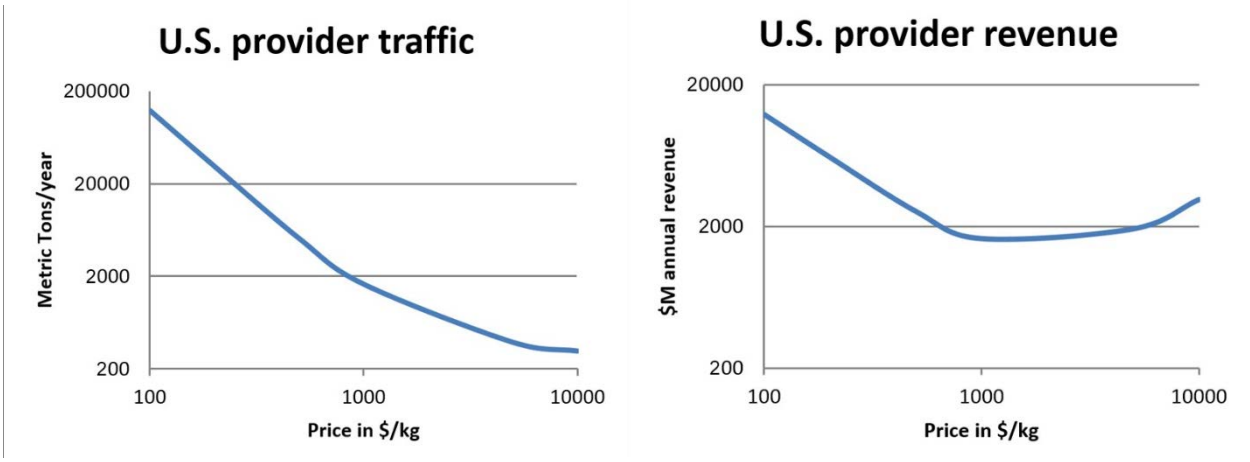

Figure 1. Market elasticity in space

In the last ten years, large speculative investments have been made by private entities (most notably SpaceX and Blue Origin, but also by many smaller firms) in improving space transportation capabilities. This has resulted, for the first time, in published pricing and direct price competition between providers, and a substantial drop in price to roughly $2,000/kg. Since it takes about $1 billion/year to keep a launch company in business, and since the highest volume company sells about 20 launches/year at a price around $60

million, and there are four large and scores of small companies competing in this market, it is clear that what we need is an increase in demand.

It may be that at the current price, new markets will emerge that kick us over to the positive-elasticity region of the curve, and that space transportation will begin a self-reinforcing cycle of higher traffic and lower prices. It is also possible that one or more providers will eventually drop out of the market and that what we have now will be the best we get for a while.

For a technological solution to work at the current market, we would need either a space launch system that shared its costs with non-space markets, or one that allowed a much smaller company to provide comparable launch services. Those are both ripe fields for invention, both of new business models and of new, non-rocket technologies, and both are beginning to be explored.

But the surest way to get to lower prices, for any technology, is to grow the market.

Grow the Market for Space Services, Especially Human Services

A big change in space activity that increases the demand for launch would, by itself, essentially kick us over to an organic growth curve. Any new market, or aggregation of new markets, that required 5,000 tons/year or more of payload and made a profit doing it would probably be enough. This is an area with not enough attention paid to it, and not enough business cases being dreamed up to explore it.

This is especially interesting, because even if the present space launch situation turns out to be a speculative bubble, propped up by a combination of individual and national interests prompting over-investment, the result will doubtless be price competition in launch—which means there is going to be a lot of cheap launch capacity around for a while. And if people find uses for all that cheap launch capacity that make money, the temporary situation will become permanent, and launches will stay cheap and keep getting cheaper, as people keep struggling to win market share in a growing traffic model.

We are not used to thinking in terms of thousands of tons in space. We should be thinking bigger. The challenge of course is that right now, any given space venture essentially has to create the entire value chain—make its own power, bring its own structures, design its own spacecraft, etc. That is a daunting task on Earth, and it is worse in space.

One approach is to find markets that are lucrative enough that they pay for all of that, a sort of boom-town model. Another approach is to design market-aiding mechanisms. I have toyed with the concept of a futures market in space services, allowing people to trade in things like rocket propellant FOB a storage node, with insurance hedges to ensure that someone depending on the product can get it when they need it, even if speculative future services do not materialize. The same could be extended to items like electrical power supplies or transportation services. This is an area of great promise that does not need a billionaire to solve.

The biggest step change in market dynamics would be for human beings in space to switch from being a cost center to a profit center. If launching people to space made

money, we would launch a lot of them. Today, there is no way to pay for labor in space. It is, literally, priceless. The emergence of market pricing in launch and in satellite components has been revolutionary in introducing competition, and there is every prospect that the same would be true in space. But then, the people doing that work have to be free to do it—not constrained by their government contracting agreements from doing it. Early applications for human labor in space may not all be noble or high-minded things—they might include filming commercials, making movies or other media products, or doing research in competitive fields where company secrets are important.

Any innovation, technical or business, that lowers the cost of keeping people in space improves the cost/benefit ratio. That covers infrastructure, improved life support, lower mass radiation shielding, more cost-effective habitat designs, new ideas for gathering energy, improved use of in-situ resources. Even the simplest questions are surprisingly poorly studied. Do plants need illumination during a lunar night of 14 days—and if so, how much? That can be studied in a greenhouse on Earth—and yet data is hard to come by.

There is no question in my mind that people can be economically valuable in space. A large part of the expense of satellites is in the actuators that unfold a satellite from a compact and rugged package for launch to a large and rather fragile useful form. A technician in a suitable facility who did nothing other than plug modules together and unfold solar panels could probably generate tens of millions of dollars a year in economic value. The challenge is again one of minimum volume. Putting up a habitat, servicing it, and transporting people to it at present prices is an expensive enterprise. The first for-hire astronaut in space is expensive. The tenth, not so much. If we could think of something that needed ten people in space that made money, they would be affordable.

Ample thought has gone into what we would do with hundreds or thousands of people in space habitats, perhaps not enough has gone on what we would do that made economic sense with ten.

There is no doubt that the long-run promise of energy and materials from space is there; I save them for the last because what has made them difficult is, again, the need to create an entire end-to-end value chain, including some of the in-space transportation services. If someone can think of a way to make even modest profits from them by exploiting thousands of tons of cheap launches, those business cases should be discussed, debated, and vetted, and investment sources could be educated about them. There are huge psychological barriers to making those investments today, simply because no one wants to be laughed at for making them. We need to find ways to make the laughter stop.

Finally, once there is even one material product or human-provided service that is profitable in space, all the others will be dramatically easier to introduce to the market, because the second entrant will not have to provide all the end-to-end pieces of the value chain and infrastructure. The marginal cost of introducing a second product is nearly negligible compared to the investment to get the first one. Space economics scale up well; it is the initial barriers which are daunting.

Increasing the Returns from Space Development

While space suffers from this planning mindset and vocabulary, the expansion of human presence and even human-supporting ecosystems to uninhabited niches is an integral part of the human experience, though that experience is mostly prehistoric. People reached Australia by some form of watercraft roughly 50,000 years ago, and that was an ecosystem as alien to them as any planet depicted on *Star Trek* might seem to us. The Thule/Inuit people learned to live and work in the frozen regions of the Northern hemisphere ~1,000 years ago, by invention of new techniques including the use of carnivores as draft animals. The Polynesian and their predecessor Lapita cultures spread across reaches of the Pacific, which must have been nearly as daunting to them as space seems to us today, and they learned to bring not just the people, but also their ecosystem of domesticated animals and plants with them to a host of new island environments, adapting their tool-making technology to the resources available in each. The settlement of Iceland has some records, though they are fragmentary, and the settlement of Ascension Island, including the successful transformation of the environment to one that would feed its population, is well documented.

Because of the fragmentary record, nothing one can say about early human settlement efforts is free from controversy. But as best I can tell, there are common threads in many of them, which usually include at least two of the following:

- a drive to gain access to new energy resources (hunting or agricultural land being primarily an energy resource) because the existing population in an area desired more than was available;
- a beneficial property interest by those at home, who stood to gain by contributing the resources to those who went—what, today, we might call real-estate speculation;
- a strategic location that made those at home willing partially to underwrite the sending of those who went to create a new trade route, port of call, or defensible frontier;
- a desire for independence or sovereignty—the Polynesian and Viking societies having evolved a voyaging culture in part because it is cheaper to send out boats filled with a would-be-chief and his followers than it is to have the civil war that results when two would-be-chiefs have their eye on the same throne.

Because of the Cold War framework in which we began the Space Age, we took measures to remove two of the most powerful of these incentives—real-estate property interest and a desire for independence—from the incentive structure. That is a policy issue, and it is something that can be corrected in the policy domain. There are many possible approaches to solving it, and they do not all require an international framework—for example, agreements among a few market-oriented spacefaring nations for a method of title valid within those nations might be sufficient. We ignore the need for a framework for some kind of independence at our peril—who can doubt that if there were a framework to achieve that, people would be gathering the resources to claim it?

These are questions informed as much by history and by economics as by science and technology. A great deal of the discussion in this area is by academics who are far

removed from practical realities, and there is a great hostility to market economics among many actors in international organizations. The problem of wanting to design or plan things centrally rather than structuring a framework in which they can evolve is very strong here. Evolving a new vocabulary, a new framework for thinking about these questions, not in terms of design, but in terms of market dynamics and evolutionary processes, is a fruitful domain for education and research by and for practical workers in the field

I believe that a framework for independence, or at least partial sovereignty, can be rooted, ethically, in the right of self-determination. If people are living in a space habitat, or on a planetary body, surely, it is first and foremost up to them to decide how to live their lives, and not to those on some other planet. If we fail to recognize that and prepare for it, we are decreasing incentives for economic development in space and sowing the seeds of future conflict.

A point I think needs much broader recognition and dissemination is that it is clearly not true that by raising barriers to property ownership or sovereignty, we are somehow preventing them. We are simply raising the price. It is unlikely that nation states that have blatantly disregarded other international agreements, such as the Law of the Sea Treaty, will let the Outer Space Treaty stop them from making territorial claims in space. Multibillionaires who do not need the approval of broad investor bases are also not likely to be restrained from making, and defending, property claims. The absence of legal structures for these things simply means they will be the preserve of those willing to use older tools, like force. The only people restrained from acting in space by these structures are those in relatively free, market-oriented countries with a strong rule of law. There, we have grown used to financing only with clear, defensible title, and acting in smaller groups than nation-states. Creating a structure for property rights and sovereignty democratizes space and makes it available to smaller actors in free societies.

Expanding the Zone of Human Exploration and Science

There is no question that how we think about space constrains what we do with it. It took Apollo for the Moon truly to become a place in our thoughts. It took the analysis of the samples brought back to start to understand some of the resources it might hold—and we missed arguably the most important one, the polar volatiles, which took another generation for people to think of it, look for it, and send several missions to gain ever-greater confidence in their existence. It was not until those resources were found that people began serious consideration of Luna as an economically valuable location.

It is an important part of the process of human expansion to new niches that we must first explore, and then we can settle and begin economic activity. One of the great psychological benefits of space is that, for those who have truly internalized it, it opens the system—we recognize that we are not facing scarcity, but abundance: “it’s raining soup, grab a bucket.” To continue to provide that benefit, there must always be a next destination, a next goal post.

Mars and the asteroids beckon, and beyond them, the outer solar system. We can already guess at some things future generations will think valuable out there. As the population of the Solar system grows off the Earth, nitrogen becomes valuable—abundant in the

outer system. As we shift to a fusion-powered economy, the ice giants, Uranus and Neptune, are rich in fusion fuels (deuterium and helium-3). The outer solar system is essentially full of ice.

Furthermore, we are living in the great era of discovery of planets in other solar system; thousands and climbing. It is only a matter of time before we find one about which science and popular sentiment alike cries out, “why can we not send a probe?”

In less glamorous but more fundamental pursuits, science itself is showing signs of stagnation; the great questions are reaching the limits of earthbound laboratories. We need bigger and higher flux particle accelerators. We need to know what dark matter is made of—or if, indeed, there is any such thing. There are alternative theories that we need to test that we can only test in space away from the sun, or by sending instrumented packages to higher speeds. The quantum-mechanical treatment of gravitation eludes us; we might not understand it without observing ultra-dense matter—and the nearest white dwarf is 8.6 light years away. The universe is a great laboratory awaiting experimenters.

To unlock those frontiers, we absolutely require better propulsion. The limits of chemical rockets have been reached (as was clear to all that they would be, as far back as Tsiolkovsky). The field of possible options is very rich. Very few realize how rich it is. It is hard for the general public to understand that we have spent less on improving propulsion in the last few decades than we have spent on any one of the missions that would benefit from improved propulsion. Mars in months, the outer solar system in a year rather than a decade, even missions to send probes to other stars in the time that the Voyager spacecraft have been flying are all things we can see ways to do.

On a less lofty note, in the decades during and since World War II, Big Science has become an interest group, or lobby, of significant political power. This has produced some notable accomplishments, but it also creates the danger that when there is a large, powerful group involved in studying something, it does not look favorably on alternative approaches. For example, we have spent more on studying the effects of microgravity on humans than it would take to provide artificial gravity for humans. There is a strong view among the space science community that humans should not visit Mars—or at least not until the scientists are done studying it. If we want to expand the sphere of human economic activity, we have no choice but to keep the supply of scientifically interesting questions replenished, or else we will create a conflict between interests, resulting in both less science and less economic activity than we otherwise could have.

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About the Author: Jeff Greason is an entrepreneur and innovator with 22 years' experience in the commercial space industry. He is the chief technologist at Electric Sky, developing long-range wireless power for propulsion and other purposes; and Chairman of the Tau Zero Foundation, developing advanced propulsion technologies for solar system and interstellar missions. He has been active in the development of commercial space regulation and served on the Augustine Commission in 2009. Jeff was a cofounder of XCOR Aerospace, and he served as CEO from 1999 to early 2015. Previously, he was the rocket engine team lead at Rotary Rocket, and an engineering manager in chip technology development at Intel. He holds 25 US Patents. He is also a Governor of the National Space Society.

Editors' Notes: Jeff Greason has been recognized for years as one of America's outstanding Space experts. He has contributed to both government agency and commercial Space company policy and study efforts. Kepler Space Institute's (KSI) academics will benefit greatly by his joining the faculty. In this essay he includes a host of Space subjects that will need more research and inclusion in the *Journal of Space Philosophy*. ***Bob Krone and Gordon Arthur.***