A Space Commercialization Model
Ocean Ports And Inter-Modal Transportation

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All figures in this chapter were provided courtesy of Pat Rawlings, SAIC.

Introduction

Extensive literature published over the last 25 years has explored the concept of the commercialization of space, particularly in low-Earth orbit. A significant amount of this literature focuses on content that presents options on the approach – how to do it. Yet another significant segment concentrates on the vehicular aspect – how to get there. Still others center around the 'favorite idea,' where commercialization is the stage upon which to display this 'great idea.'

This chapter will present an alternative to the prescriptive space commercialization approach by focusing on questions instead of the answers – a pathfinder for developing the 'how to' answers and the 'propelled by' questions.

We begin the exploration of 'how to explore the commercialization of space' by a walk-through of a parallel universe, a terrestrial inter-modal transportations system centered upon the ocean port.

Do We Have A Model For The Commercialization Of Space?

The simple answer is no. While there is significant literature on terrestrial commercialization, there appears to be a void in the correlation of space development to the terrestrial successes well documented over the last 300-400 years.

Behind all of this we can postulate a mechanism that links the identified needs of humanity to the capacity to find or create solutions to meeting those needs. It would be speculative and perhaps even specious to call this a 'model' in a rigorously academic sense. But if we expand the definition of 'model' to embrace the concept that a chain of events in an environment, driven by needs being met, constitutes a 'model,' then we have a sufficiently broad definition to explore a model for space commercialization. By linking it to the still-evolving model of ocean based inter-modal shipping, and to commerce through a set of guidelines referred to here as axioms, we can develop a structured 'how to do' instead of a classic 'what to do' model.

Note that 'technology,' which is usually the focus of the literature on the topic of space commercialization, is relegated to a footnote in this approach. That is, it is not technology that drives this model, but rather the needs of humans and the ability to pay an affordable price for the service or goods rendered. Moreover, even the geopolitical events are footnotes. These are attendant conditions, boundary values if you will, in the model. The focus is completely upon the ability to supply goods or services to a market at a price the market will bear. And that certainly includes developing a market for those good or services.

Limits imposed upon the model by the amount of detail to be considered, and where connections to other systems are non-dynamic – sometimes referred to as 'model stubs', are always arbitrary. In this first level of investigation and concept exploration, these stubs will be identified but not explored in detail. The approach will be to draw upon a terrestrial 'parallel universe' and ask open ended questions to promote not only the definition of the model, but also to explore the boundaries of the model.

Solving Earth's Problems – Thinking Through Solutions Above Earth

"You can never solve a problem on the level on which it was created."

- Albert Einstein

Albert Einstein's thoughts spanned not only the realm of physics and our universe, but also the politics of his day. The approach that this comment addresses is precisely what is needed to successfully commercialize space: we must think beyond what it took to commercialize any corner of the Earth from the Earth, and think instead of solutions for space commerce that come from a confluence of physics, commerce, and politics, and be created by a broad consortium of people.

On Earth, risks are bounded by the terrestrial life supportive environment; distances are finite and definable; topology and cartography are manageable; and the relevant physics are clearly understood. Economics are more difficult to define – witness the failures of colonies, expeditions, etc., as well as entire financial systems (e.g., the financial collapse of 2008-2009) but in comparison to space, we live in a benign economic environment.

When we venture into space with the intent to commercialize, we will encounter the same difficulties as history's great explorers, including Columbus, De Gama, Hudson and others. We will also encounter the physics of gravity wells, LaGrange points, closed systems, and a threatening environment incapable of supporting human life, orbital debris and orbit decay, and the fragile physique of the human species in the absence of gravity of exactly 1 g. This set of conditions represents huge risks that are not present on Earth.

We know about these issues; this is not breaking news. What is perhaps a new thought is how this coalesces into an increased level of risk, and what can be done to mitigate it for the sake of economic development. This is where the classic approach to commercialization of space loses traction – to talk about better craft and better rockets, which while needed, is not the central issue. Risk is the central issue. More specifically, the total risk is the barrier to commercial viability.

When the problem is framed as a total risk posture, and is added to the 'exploration' risks, and the financial risks associated with any commercial venture, you have the totality of the problem, the mission, and the business case.

It sometimes seems to be an insurmountable level of risk. It is certainly formidable, and more than 50 years after the first successful orbital flights, commercial space is limited primarily to satellites, while in comparison, aviation progressed from Kitty Hawk and fabric wings to budding commercial applications less than 20 years, and to a global industry in 30.

It is not an insurmountable problem if, and only if, the risk is quantified in terms of the executability, sustainability, and logistical supportability. In this chapter, these measures are explored in comparison to an ocean port, which will be shown to be a fitting analog of a spaceport.

Proposing A Model For Space Commercialization: The Ocean Port

The model of an ocean port will be explored to identify its driving functions, and we will see that the issues and forcing functions are similar for space based commerce, with additional constraints such as the physics of zero gravity, solar effects, and complete vacuum.

What Is A Port?

A port is a place where the mechanical infrastructure needed for large scale exchange of goods, traded for financial gain and to achieve a desired quality of life, is installed. Typically, as shown in Figure 1, the port infrastructure uses technology that is cost effective and robust, not leading edge or risk intensive. It is inter-modal, linking ocean, rail, and vehicular transport. It provides goods that are typically not available locally.[1]

The necessary capital investment is non-trivial, and often is financed either by bonds or a combination of governmental and quasi-governmental agency funding. While a terrestrial port, once built, is used where it is, the space based port is moveable, but moving incurs penalties called delta velocity ('delta V'), or energy to change orbit. This will be touched upon later.

Inter-modal transportation is inherent in the concept of the terrestrially based space port, as shown in Figure 1, and the containers are indistinguishable, uniform and easily handled, translating to lower delivered cost.

Figure 2 illustrates the concept of a terrestrial spaceport and ocean port handling the bulk bundling of commodities in the interest of cost avoidance. This also reflects the need for distribution to occur, although the port is itself not the destination, but merely a stop along the way.

Note that amenities, necessary for people, are absent; they are supplied by the surrounding support infrastructure. Terrestrially this occurs in cities, while in space it is habitat vehicles and modules, with infrastructure that has been bought along for the journey.

If we consider the International Space Station as a rudimentary spaceport, clearly the ability to dock Soyuz, shuttles, and Orion Capsules is a necessary attribute. The 'dock cranes' or Remote Manipulator System (RMS) / docking ports must be equally able to accommodate all of them.

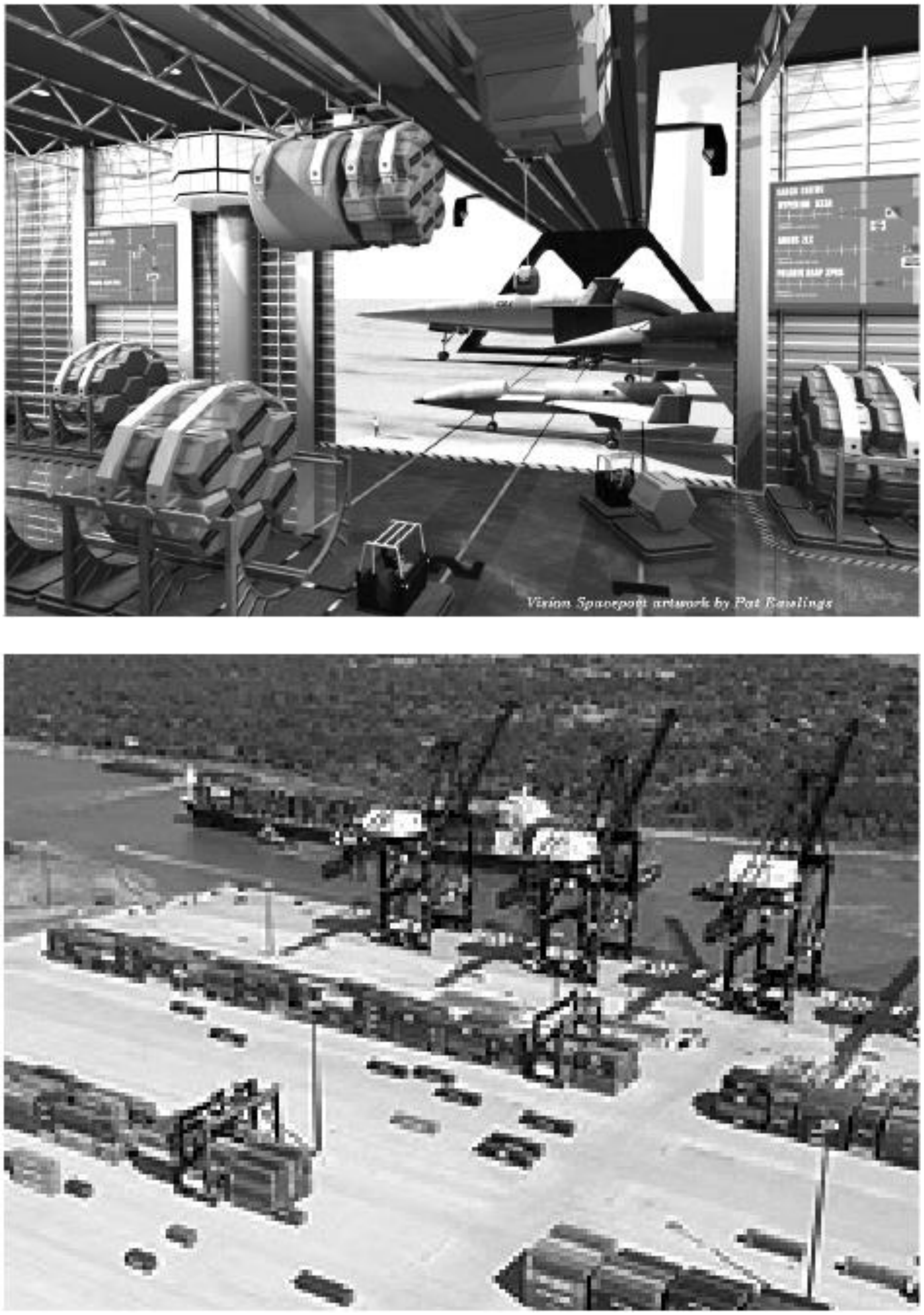

Figure 1
Terrestrial Space Port (above) and Ocean Port (below) share a common heritage, commerce, and technology.

Figure 2
Inter-modal transportation is a common theme for all port infrastructures, whether for space transport (above) or on ocean (below).

Who Owns A Port?

As an initial ownership model for space commercialization, large terrestrial ocean ports have been demonstrated capable of raising enormous amounts of required capital. Traditionally space is a governmental area of expenditure, but to fully expand commercialization into space this must gravitate towards the ocean port model. If we use as an example the Port of Houston and its governing body, The Port of Houston Authority[2] (POHA), we see that port operation and ownership is not an inherently governmental function. This is quasi-governmental agency, with certain powers of a government agency, but since it was funded by public bonds, solvency and profitability must be successfully demonstrated. It simply is not acceptable to lose money 'going frequently where everyone has gone before.' So it appears that a fundamental question to be addressed by the model for space commerce infrastructure is, Can a space-based port commercially interact and integrate with terrestrial commerce, or will it require forever its own niche for standards, processes and cost / risk success criteria?

Nowhere does the size of the rocket ships or the exact product mix going up and coming down from space or across oceans enter the discussion. Whatever is put into space is sent there to produce whatever is sent back, but if it does not provide a profit margin at a risk level that is acceptable, the only way to have even the beginnings of space commerce is government subsidy or government ownership.

Funding for a space commercialization initiative would logically follow the approach used for large terrestrial port construction, involving a complex set of stakeholders. The reader may refer to the Panama Canal as an example of the enormous complexity of such an endeavor [please see the bibliography].

Figure 3 hints at this dilemma. Terrestrial ship traffic is work-a-day dull, while the ground segment of the analog, the launch and processing spaceport, is envisioned as elegant, modern and futuristic.[3] There is clearly a disconnect between the likely reality, and the popular imagery.

In the commercial arena, the port concept is developed into a business case. Let's look at a few historical examples. The Erie Canal, the Pony Express and Air Mail all were innovative ideas in their time, and were in fact operated at a loss for a period. Some eventually made short term profits, but all eventually (and predictably) failed.

How Would A Space Based Port Be Financed?

We assume in this discussion that either a private or public approach can garner adequate financial resources, but there is a decision point here: recognizing the importance of market forces, as we just discussed, and bringing in ROI as a decision making criterion, places this project almost uniformly into the private sector. While governmental policy is frequently consistent, governmental funding rarely is.

Governmental will derived from the electoral process in the United States does not foster unlimited support for indefinite expenditures with undefined benefits, and thus consistent public funding of a concerted space commercialization initiative is not a likely scenario, as it would never enjoy the enduring public support of social programs. The total dollars that NASA received for space activities from its inception in 1958 to the end of FY2008 is \$416B. Adjusted for inflation it comes to \$807B[4]

Figure 3

Can space commerce systems function in synergy with terrestrial commerce systems? We believe so.

The total cost of successful space commercialization will be tallied in the hundreds of billions, and maybe trillions, and therefore it is safe to say that space commercialization must be privately funded to avoid the risk of shifting political winds. To commercialize space, it is mandatory that it is profitable to attract private capital, and public sector monies will only peripherally fund it.

As NASA and the space industry press forward towards the era of space commercialization, clear business case solvency must be demonstrated, and the total system must be built upon private funding.

A truly successful commercialization effort will have lots of financial performance, but not necessarily the 'glamour' that has been associated with the last 40 years of human spaceflight. The day that the vehicles as shown in Figure 5 are beasts of burden on a commercial endeavor, rather than a technology demonstration, is the day that one could legitimately feel that the commercialization of space is succeeding.

Just as these ocean vessels answered commercial needs without government financing to design and build, we must replicate that in space commercialization.

What Is The NASA Role In The Commercialization Of Space?

This leads to the question, 'What should NASA's role in space commercialization be?' Despite being a government agency, there is indeed a key role for NASA to play in this scenario. We suggest that it could and should be a significant source of very high risk, 'game-changing' technologies, as well as the interface between the private sector commercial players and whatever government participation there will be in the commercialization of space.

NASA should develop the capacity to work across contracts, across programs, and even in multiple destinations seamlessly, and of course without regard for profit, to share with the private sector its great depth of experience concerning the physics of space and its highly developed capacity for risk management. The public sector can, in turn, bring forward its best practices across many areas of commercial expertise.

NASA has the unique tool of the Space Act Agreement (SAA), which provides a legislatively-granted mechanism through which to enter into mutually beneficial agreements with companies, universities, start-ups and established firms, and even individuals, whereby NASA receives the right to use a technology while the developer retains full market rights. This mechanism is a key tool in the establishment and maintenance of space commerce through technology development and exploitation by allowing industry, and not the government, to focus on the market.

(Editor's note: Please see Chapter 10, *The Emerging Organizational Framework for the Space Commerce Enterprise* for a more detailed discussion of the Space Act Agreement.)

Another area in which NASA must perform a vital role is the integration of robotics and human elements. Currently, robotic mission technology, operations concepts, mission profiles and destinations share little more in common than being developed under the NASA logo umbrella. Currently there are no 'best practices' defined for human / robotic missions since there have not yet been these types of missions. While tools and techniques vary widely in the mission types, NASA alone has the human, near Earth and deep space experience, tools and corporate knowledge for all these endeavors.

And while there are satellite operators even today that manage constellations of satellites, these are quite limited and do not involve missions requiring humans to venture off the surface of the Earth. The planned transfer of these operations to the commercial sector is a key element that will assure the emergence of space commerce: a keen knowledge of space physics and the knowledge of how to profitably and safely operate complex space systems is absolutely essential.

But NASA should no longer be the exclusive operator of space vehicles, particularly in the realm of space commerce. NASA should continue to conduct the developmental and experimental programs, which are of little commercial value until they are more mature.

Where Are The Space Commerce Components Located – Like Terrestrial Commerce?

Site selection for terrestrial ports certainly favors locations that connect people and markets, especially when the port has inter-modal connections for rail and highway. A deep, protected harbor without railheads, pipelines or interstates highways will never become a dominant ocean port.

Figure 6[6] shows the major ocean ports across the United States. There is a predominance of ports on the east coast, some on the west coast, and a small cluster on the Gulf coast.

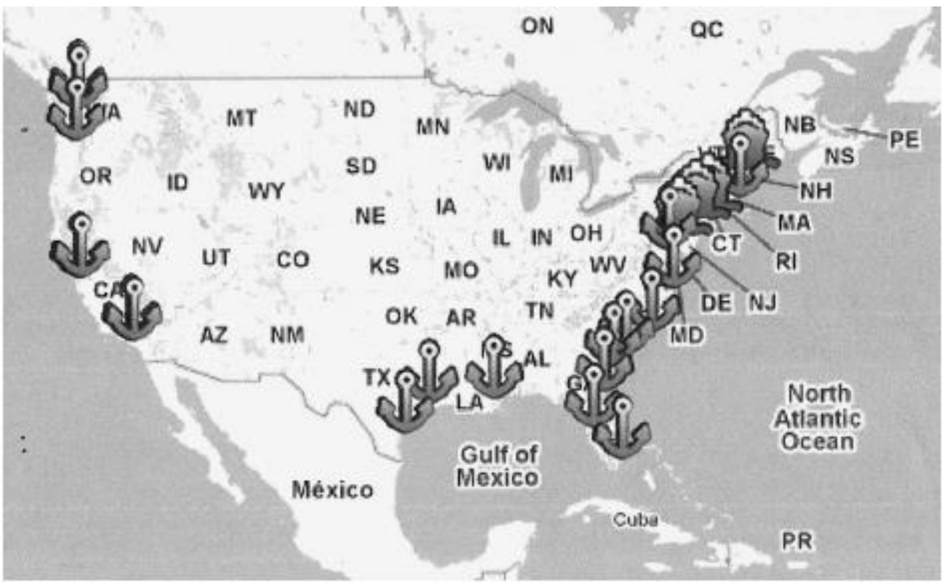

Figure 4
The Major Coastal Ports in the United States.
(Note that Huntington, WV is the 8th largest port at its inland location on the Ohio River.)

While some of this is due to historical roots and interrelationships between the expansion of the United States and the ports, the predominant theme is rooted in the 'connect to the people' concept. The tonnage capacity of the ports, shown in Figure 7 in order of throughput volume[7], shows that seven of the top ten ports, which handled 42% of the total tonnage of all of the ports in the United States in 2008, are located on the Gulf Coast, with one on the east coast and two on the west coast.

This can be simply explained by the conjunction of 'connect to the people' (the need) concept and the 'distance is not a difficulty' axiom. Both east and west coasts and the Midwest heartland is easily reachable from the ports on the Gulf Coast, so it's not surprising then that 72% of the tonnage enters through the Gulf Coast, while the east and west coast share the rest at only 15% and 13% respectively.

A similar pattern will be necessary for space commerce to flourish: space ports must be located on Earth where there is ready access to other means of affordable transport, and in space where there is the need for large volume transportation. Cost in space is also affected by another variable, the relative depth of the gravity well. The shallower the gravity well, the less expensive the transport, because less energy is required to leave orbit and transect to another celestial body (or space station).

Leaving Earth to get to the moon requires leaving Earth's deep gravity well at a high cost in fuel, while transiting from LEO to the moon requires departing from a shallower gravity well and is therefore less expensive.

Rank	Port Name	Total	Domestic	Foreign	Import	Export	Coast
1	South Louisiana, LA, Port of	223	112	111	47	64	Gulf
2	Houston, TX	212	65	146	92	54	Gulf
3	New York, NY and NJ	153	62	91	71	19	East
4	Long Beach, CA	80	12	67	45	22	West
5	Corpus Christi, TX	76	21	55	43	11	Gulf
6	New Orleans, LA	73	36	36	19	16	Gulf
7	Beaumont, TX	69	22	46	41	5	Gulf
8	Huntington – Tri-state, WV	69	69	0	0	0	Inland (Ohio River)
9	Mobile, AL	67	29	38	23	14	Gulf
10	Plaquemines, LA, Port of	63	35	27	8	19	Gulf

Figure 5
2008 Top 10 United States ports by Tonnage
(figures shown in millions of tons)

The most obvious connectivity and accessibility points would be places in the Earth-moon system such as the LaGrange points, gravity neutral points in space that take the least energy to navigate to and from.

The concept of 'support capabilities' versus 'infrastructure capabilities' comes into play here as well. Whether a given operation is performed terrestrially at a port or at another adjacent but removed location is determined by risk, practicality, safety, security, and cost. Crude oil transport is relatively inexpensive via pipeline or ship, so refineries can be located anywhere. But in space, refining the moon's regolith will likely occur on the moon's surface near its sources because it will be much more expensive to transport the raw ore, and much less expensive to transport the refined (and lower mass) products.

While there are other considerations such as disposal of slag, the cost to transport a mass of goods on the surface and in space dominates the business decision.

Hence, a design that seems to work well but requires massive Earth moving (or regolith moving) equipment, equipment weighing several tons and requiring enormous power to transport and operate is a fantasy not a design. Getting the equipment there and fueling it once it arrived would require enormous ‘up mass’ of cargo to be carried to the destination, and the end product would have to be highly valuable for the economics to work.

The same logic applies on Earth. Where orbital energy is a huge penalty in space since mass is the metric of concern, terrestrially volume is the key metric, and therefore for example, remote refining is terrestrially quite practical because movement of mass is relatively easy. Stated as an axiom, then you must satisfy the laws of physics and the laws of markets and commerce simultaneously.

The key points to be made are that a design for any space-based commercialization strategy must include a defined mission, a risk assessment, a forecast positive return on investment (or profit), a life cycle, a maintenance plan, and demonstration of all this through simulation modeling of the entire system.

The robust model will have executibility, sustainability and the logistical supportability necessary to create profit at a level that will attract investment and will result in positive economic impact.

In addition, it must be part of a larger economic ecosystem consisting of elements that all fit together into an economic engine that will very crisply define the constraints, the vehicles, and ultimately the feasibility of the total system.

Figure 8 shows a very small constellation of space-based destinations. Axiomatic design and operations rules concerning the relative merits of these destinations leap off the page.

Example 1

The farther out an asset is, the more difficult and expensive it is to maintain. Therefore, mass should be kept small and design complexity as simple as possible.

Example 2

Little of the ‘local’ in-space (or space-to-space) communication is likely to be hubbed through the Earth. That would be excessively costly and difficult, pointing toward an alternate approach, managing the ‘space frontier’ communication through space-based assets.

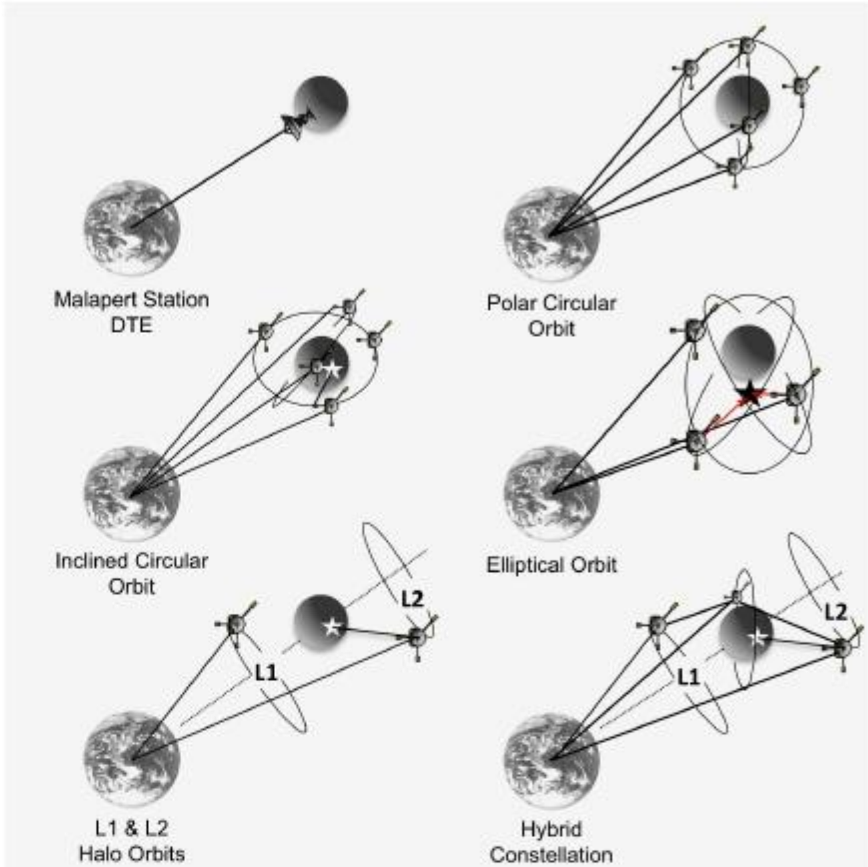

Figure 6
Examples of Possible Asset Locations In Lunar and Near Earth Orbits.

The communication system presented in Figure 9 shows how the total system design could affect the culture of the space community. All control assets today for space communication are located on Earth. As no nation has conducted a manned space venture beyond 400 NM from Earth since Apollo, Earth connected (hubbed) communication is logical. But from a cultural perspective this may be difficult to achieve since 'it's always been done this way,' (i.e., controlled from Earth) although the commercialization of space demands that assets are treated like the super tankers on the ocean: 'Call when you need help, or we'll see you in the next port of call.'

There is nothing radical in this thinking from a technology perspective, but as a side note, having control and communications not tied to an Earth-based management system may present a significant cultural challenge, and thus a cultural aspect of space commercialization may be needed as an axiom of the space commercialization model since commerce itself is about people and their real and perceived needs.

(*Editor's note:* Please see Chapters 5 and 6 for a discussion of the Cisco IRIS system, a space-based internet router that enables space-to-space communication, and eliminates the need for communication to be hubbed through Earth stations.)

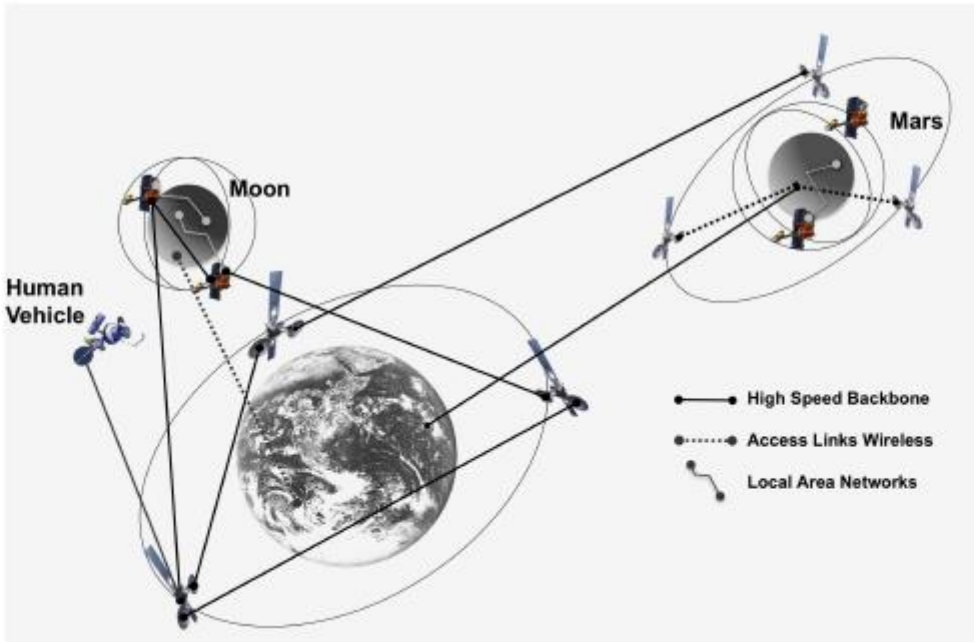

Figure 7
Space Commerce Communication Network
Potential asset-centric space communication system, rather than an Earth-centric system.

While data on the sustainability of the active ports in the United States is available, perhaps the most convincing argument that sustainability is vital is shown in Figure 10[8]. The business case for the Panama Canal era exemplifies the concept of sustainable operations. If the Canal were to operate at a loss, and then look to expand, financial backers would be few. The canal is currently undergoing an upgrade to enable larger ships to pass through, and as it happened, the profit of the current system enables capital to be available for the design and construction of the upgrade.

Any space-based commercial system that succeeds will have to pass this type of litmus test for solvency: that is, it will have to operate profitably at a base level before expansion can be considered.

Total System Evolution Of Both Terrestrial And Space-Based Assets

Hence, the total system will evolve piece by piece, and in a somewhat predictable way, analogous to a terrestrial ocean port. A contemporary example will be used to illustrate this facet of the model: the migration from the Panamax ship to the Post-Panamax ship.

The Panama Canal is currently undergoing a major upgrade to the lock system to relieve the constraint on size of an ocean going ship that can pass through the canal. The current lock system is based on a 1900 design and was constructed 1903-1914. Shipbuilding and ocean freight economics have been growing into the current Panamax size. ('Panamax' is the term for the maximum size a ship can be to transit the canal. 'Post-Panamax' refers to any ship larger than that, which includes many of today's largest cargo and tanker ships. Figure 11[12] gives the definition of both configurations.)

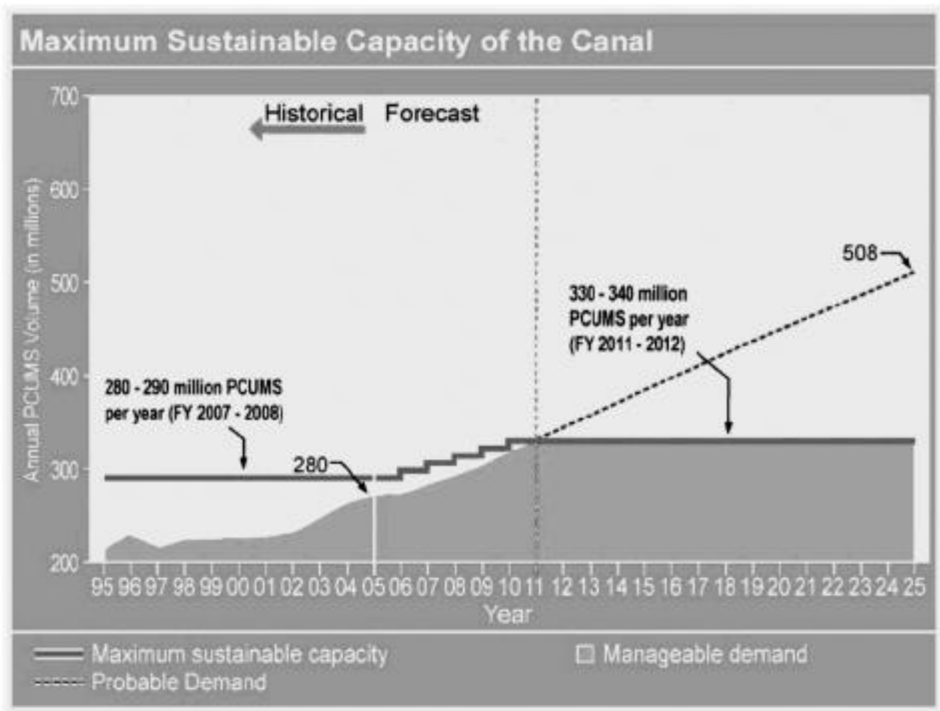

Figure 8
Historically Based Future Projection of Post Panamax TEU Performance.

Currently, the Panama Canal can accommodate a vessel 1000 ft long by 100 ft beam. This is roughly 50% more length and beam than any ship of the 1900 era. As an example, the Pruessen (The 'Prussian') sailing ship launched in 1902 was roughly 450 by 50 ft, and the 1918 'Carolinian' launched in Britain was roughly 360 by 50 ft.[10,11] Hence, there was considerable accommodation built into the canal for future expansion of ship size in the original design.

But current ship capacity exceeds what the canal designers envisioned. The technology that enabled growth in ship size includes arc welding (which replaced plates and rivets), metallurgy (yielding stronger and lighter metals), power systems (significant increases in horsepower performance), and control systems, none of which could have been anticipated or planned for. Nor could the coupled and multiplicative effects of these technologies be estimated, and in addition, computers and software tools for simulation and system engineering had not yet become a part of the ship designer's toolset. Finally, the advent of containerization, a profound innovation-revolution, has fundamentally changed both the economics of ocean freight operations, and the design of the ships themselves, as well as the process of port operations and in fact all intermodal transportation.

The current project to expand the capacity of the canal, scheduled for completion in 2014, constitutes a design upgrade to a system that is now 100 years old. 100 years of effective working life is an outstanding achievement for any technical or technological system, and this was achieved largely because the original designers sized the canal to accommodate ships that were double the size of those in operation at the time.

Based upon containerized shipping format, the Panamax vessel is no longer the optimum vessel configuration from an economics perspective. And it is the economic considerations that lead to the need for a canal expansion, that is, the need to accommodate extremely large vessels. But in the commercial world, the key factor is not size per se, but unit cost per unit shipped.

The standard measure of terrestrial cargo capacity is a function of volume, designated as the 'TEU', the 'twenty-foot equivalent unit,' 20x8x8 feet. A standard 40 ft container unit is two TEUs.

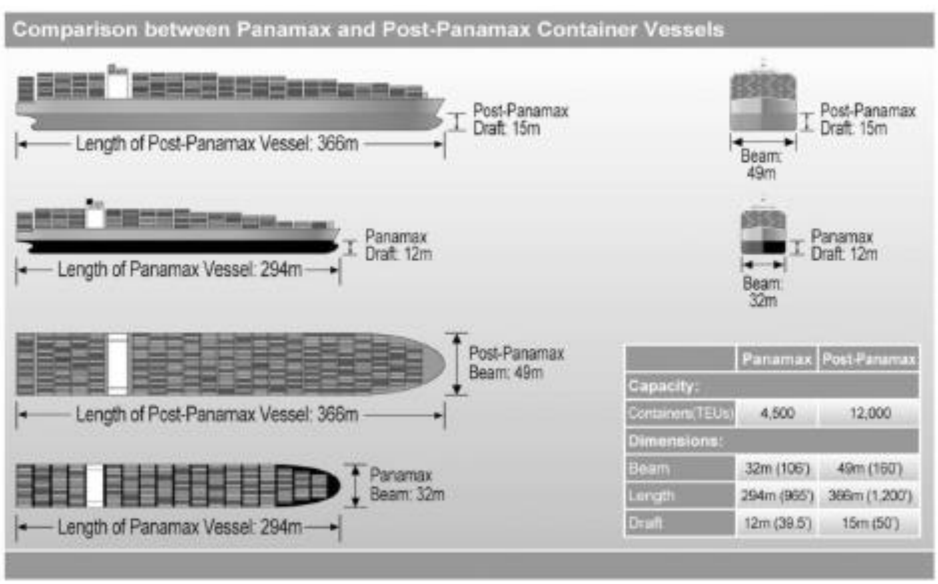

Figure 9
Comparison of Panamax to Post-Panamax ship dimensions.

For a spaceport, the TEU equivalent will not be a volume measurement, but rather a measurement of mass, likely notated as 'MT to

LEO,' or metric ton to low Earth orbit. (A metric ton is 1,000 kg (2,204.62262 lb), or approximately the mass of one cubic meter of water at four degrees Celsius. The nominal LEO orbit is defined here as 120 nautical miles (NM) or 222 km above the Earth's surface.)

How important is this change for the Panama Canal, and what is the effect on shipping cost, and therefore for delivered goods? Figures 12[13] and 15[13] show that the Post-Panamax system drives the shipping cost down for transport between existing ports (fuel and labor costs on operations are considered constant for the exercise), and the subsequent rise in total shipping volume is significant.

Comparison of Tonnage Growth per Segment			
PCUMS Tons Per Market Segment*	Year 2005	Year 2025	
		Canal without an expansion	Canal with an expansion
Containers	98	185	296
Dry Bulk	55	49	73
Liquid Bulk	34	19	28
Passenger	10	13	19
Car Carrier	36	40	58
Refrigerated Cargo	19	15	22
General Cargo	7	3	4
Others	20	6	8
Total PCUMS Tons	**279**	**330**	**508**
*Millions of PCUMS tons			

Figure 10
Panama Canal Growth Projections, 2010 – 2025.

Perhaps the most striking projection is that the importance of the canal to shipping, expressed in TEU / year, is relatively flat without the canal expansion (growth through 2025 is only 18%), while it is 82% (nearly doubled) with the expansion. With the venture into space commercialization, one could reasonably expect to see this kind of growth in commerce, and in wealth creation, if the lessons from terrestrial commerce are reframed by the laws of space physics.

For any transport system undergoing a change, the shift to Post-Panamax is not instantaneous, nor does it need to be completed quickly. The old canal assets will not soon fall into disuse, and the smaller ships will not disappear from service, as shown in Figure 13[14]. Based upon projections, the old locks will be as busy for the near future as they are today, because not all routes or commodity needs require a Post-Panamax ship configuration.

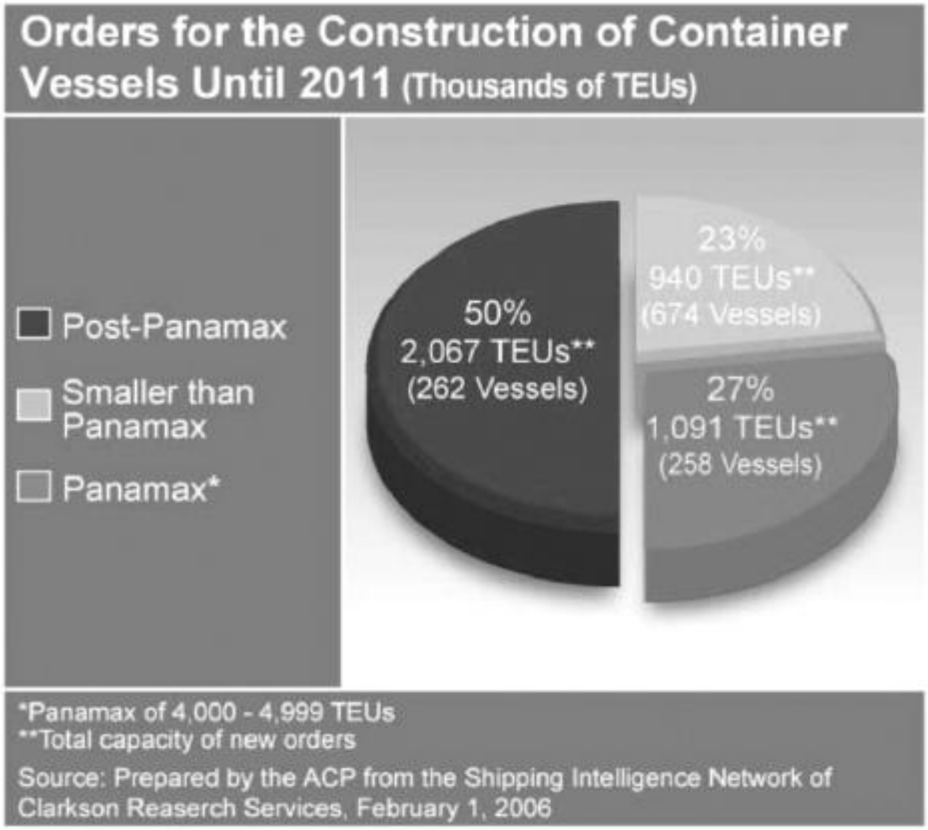

Figure 11
Shipbuilding Orders: Mixed Fleet Is Best For Profit Margin.

Since commercial space systems must obey the laws of physics and the laws of economics simultaneously, we can anticipate many different kinds of transport needs. We should expect to fly a mixed fleet of booster and cargo vehicles, including a Saturn V-like booster, a shuttle-like transport, a Delta IV Heavy-like system, and an Atlas V-like system, even while experimenting with the Single Stage to Orbit (SSTO) technology[15] and even the Space Elevator.[16] We expect NASA to be closely involved in designing and building the prototypes of the 'next gen' vehicles to assure a cost effective 'mixed fleet' of booster and cargo system vehicles.

No single government agency has control over the production of this vast an array of launch and vehicle equipment, nor does any entity in the private sector. Therefore, it is clear that only the private sector, and many pieces of it working together, could attempt the grand scale of enterprise that the commercialization of space will require, while the public sector must participate heavily in technology development.

An interesting parallel on the units of measure of the vehicles arises out of Figure 14.[17] The lift capability of the arsenal of lift systems shown is but a sample of what is available or might be available internationally. To get large masses out of Earth's gravity well to LEO requires a large system. The shuttle and Ares I are both roughly 25MT to LEO, Ares V is 180MT, and Saturn V is 120MT.

There is ample evidence as seen in Figure 15[17] to show that the 'flex' in the port / ship system has a very profitable future planned by size tailoring of vessels and missions, or needs. Non-canal ships like the *Eugen Maersk*, the world's longest ocean freighter at 1,300 feet, are already at sea, so technology is not a limiting consideration in size determination, nor is government funding. Economics surely is. It is clear that an armada of tools, and mass transfer (lift systems) will be necessary for the commercialization of space.

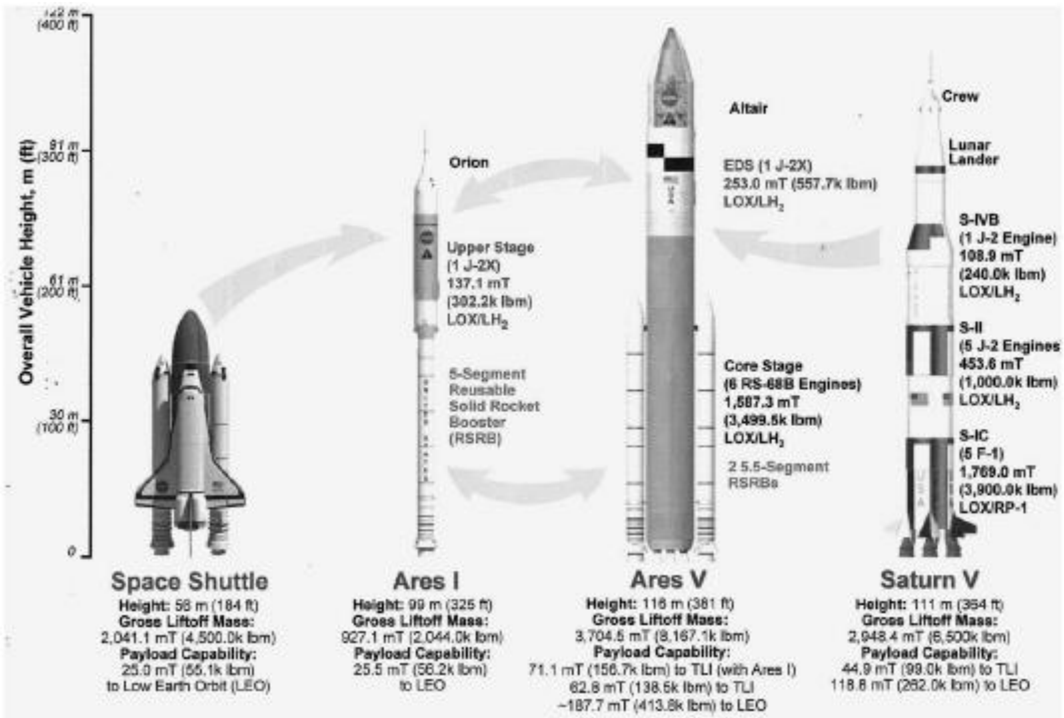

Figure 12
Booster Systems: Mass-To-LEO Baseline Today.

Available records over the history of the Panama Canal are also required to anchor the future estimates in the reality of actual performance and to manage the risks, but this is a problematic area for the space-based commercialization argument. We have only had government-funded, institutionally-controlled human space flight projects to date, and therefore much of the available literature and 'data' are wildly suspect.

The 50 shuttle launches per year, the 10 year shuttle program, the Space Station Freedom, the X-33, the X-34, the Single Stage to Orbit (SSTO) and the latest, the Constellation Program, have no collective success history with which to form the basis of a projection for the succeeding step. This may be the largest impediment in the successful modeling and the actual commercialization of space – accurate cost projections and therefore Return on Investment (ROI) that are needed to secure the necessary capital for such large undertakings.

This is why developing a successful commercialization model is so critical. If you cannot model it and show success, you can be assured that it will be even worse in the physical entity because of all the factors that you omitted in your model.

Note that to date, this has been the quintessential argument for government alone engaging in space-based forays – no one else has the resources available or is willing to commit these resources given the extreme uncertainties. But this is no longer true. Henceforth, space commercialization belongs to the private sector, with assistance in limited areas from the government.

The shipping industry has hundreds of years of data and many years of the current technology upon which to develop new models. Commercial shipping cost changes, assuming fuel and labor are relatively similar, show why it is an attractive option to build a larger canal and sail larger ships hauling identical cargo.

The Post-Panamax era also has other impacts on ocean commerce, which are potentially larger than the cost savings growth factor shown in Figure 15, particularly on the ports of call. Let's examine an example. Focusing the discussion on just ports in the United States, several trends emerge. First, tonnage is expected to increase by 60% (close to the 82% of the canal itself), and the bulk of that will be through the Gulf Coast, particularly the Port of Houston. Why? In Figure 6 we saw that the Gulf Coast services the central states and can nearly equidistantly reach either coast. If a planner for the Port of Houston Authority were looking at just local data and events, this huge positive impact would be obscured from sight, and the resulting business decisions would be poor. The confluence of the cost decrease from post-Panamax ship size, the upward growth of tonnage independent of the expanded Canal, the reduced shipping time due to the expanded canal, and the pre-planned expansion of the inter-modal transportation links and pipelines at the Port of Houston all converge to decisively impact future tonnage traffic into Houston.

The resulting axiom is: Change impacts to facilities and destinations are not limited to just first order effects on commerce in an immediate area; they include second and even third order effects that include reduced time, favorable unit of measure / unit economics and even global geopolitical considerations.

One additional axiom must be stated regarding estimating the impacts. Continuous and rigorous planning is required for space commerce to succeed, and such planning must be at a far greater depth and scope than is currently done for ocean ports.

Percentage Cost Savings per TEU per Voyage - Post-Panamax Vessels (Compared with a Weekly 4,000 TEU Panamax Vessel Service)		
Route	6,000 TEU Vessel	8,000 TEU Vessel
Asia - U.S. East Coast	8%	16%
Asia - U.S. West Coast	8%	17%
Asia - U.S. East Coast through Suez	7%	17%
Source: Transpacific Vessel Deployment Options with an Expanded Panama Canal, R.K. Johns & Associates Inc. 2004		

Figure 13
Comparison of Panamax and Post-Panamax ships.
Cost of Operations as a Function of TEUs.

In space, the divergent nature of destinations, product mixes, the high risks, and the extremely capital intensive nature of space commerce demands this degree of planning. This planning, like that for the terrestrial ports, must recognize a limited span of control, and interfaces to geopolitical stimuli, as well as evolving technology and other important parameters. Here is yet another example of executibility, sustainability and logistical supportability being the interrelated criteria, not just technology or simply the cost.

Security: Difficult On Earth – Impossible In Space?

What better place to engage in terrorism than where there are very high valued assets and absolutely no law enforcement capability within 250,000 miles? This is the reality for space commerce. It potentially admits outright terrorism, pirate hi-jack of both assets and vehicles, and theft of high value commodities. Moreover, the assets that are infrastructure, the processing bases, the fueling stations, etc, are all vulnerable as well. To date, there have been no human spaceflight incidents of this nature in LEO or in the moon missions that are verifiable. (This excludes 'test' destruction of satellites.)

However, while the Cold War is over, it is but a reminder that conflict can readily grip competing power structures. Extraterrestrial Terrorism (the new 'E.T.') might well be the cause of 'Cold War Part II,' or World War III, because of the enormity of the stakes, the risks, and the sheer amount of capital required to undertake this adventure. Whether such exposure is a stabilizing influence (an unthinkable act), or is in fact vulnerability with apocalyptic consequences, presents an interesting sidebar discussion that is not pursued here. At a minimum, though, space commercialization must prepare some contingency and recovery plan for addressing this issue. Without a rigorous enforcement capability, terrorism cannot be outlawed in practice, and it will not go away of its own accord.

It is unclear that the mission scope of the United States Air Force, which has the Missile Command and stewardship for the GPS system among other space assets, would extend itself or be authorized to extend into 'outer space,' which would include LEO, lunar, geosynchronous, and eventually beyond. Perhaps this might be yet another inherently governmental function, protecting the commerce lanes as the Coast Guard does on the high seas and ports.

Recall the timid beginnings of the American Navy. Only after pirates raided ships and were strangling commerce, did the Congress of 1794 decide to build the United States, the Constellation, the Constitution, the President, the Congress and the Chesapeake.[26] In that era, the US was a self sufficient nation, unlike today, as we could not now sustain our standard of living without strong, secure commercial operations extending globally. But even when the six ships were approved, waffling occurred in the funding the last three. As there were no other warships in the ocean flying the colors of the United States of America, the concept of privateering was born, and was supported by, among others, Thomas Jefferson:

> *"...every possible encouragement should be given to privateering in time of war with a commercial nation... Our national ships are too few in number...to retaliate the acts of the enemy. ...by licensing private armed vessels, the whole naval force of the nation is truly brought to bear on the foe."*[27]

Space security might therefore be yet another industry spawned by the commercialization of space: policing the commerce routes in and beyond LEO. This is a germane topic to address because it is a required support function that has no placeholder in a terrestrial ocean port plan, yet without it there may be a fatal risk flaw in spaceport commercialization. The recent adventures of Somali pirates attacking international shipping lanes, and the solutions found therein, should be watched and analyzed carefully.

> *(Editor's note:* Please see Chapter 20, *The US Space Guard: Institutional Support to Space Commerce*, for a more detailed discussion of this issue.)

Jurisdiction: It Is An Issue Terrestrially – What About In Space?

NASA has standard agreements with the FAA[20] and STRATCOMM[21] to allocate US airspace on ascents and entries of space vehicles, and to do collision analysis for avoidance of space debris in the on-orbit phase. While these pertain neither to laws of physics nor to laws of commerce, they are real constraints and must be addressed by any space commercialization initiative. This set of functions would fall under the category of support infrastructure.

This function set has analogs in the ocean port model too, as traffic control may be rather pedestrian, but is nevertheless a critical issue. In fact, it is not an option to not have this support, but as yet there are no commercial services companies that perform it. That might be a business opportunity at some future date, but for the immediate discussion of space commercialization there are no non-governmental service providers.

One option would be to negotiate an arrangement with the military regarding airspace. For the near future, the FAA has jurisdiction in the civilian arena for the United States airspace below 400,000 feet altitude.

Perhaps more interesting is the concept of international partners in the space commercialization team that perhaps brought an exo-atmospheric vehicle to operational status, such as the atmospheric skimmer, or the SSTO like Skylon[22] shown in Figure 14

A Skylon is a conceptual, hydrogen-powered aircraft that would take off from a conventional runway, accelerate to Mach 5.4 using atmospheric air, and switch the engines to use the internal liquid oxygen supply to take it to orbit. The British company Reaction Engines developed this concept.

The point for us is that a definition of the infrastructure must encompass functions that might not be readily apparent. This forms then, a corollary to the existing axiom regarding fully identifying the costs for support infrastructure required for space commercialization success: forecast the future through planning.

One parenthetic thought on the Skylon type vehicle: If this were to be developed for cargo and expanded to handle human passengers it would be an entirely disruptive technology that would be a forcing function in the commercialization planning. The basic cost of mass to LEO might be reduced by a factor of 5 or 10, and as was seen as a result of the completion of the Panama Canal, breakthroughs in transportation costs completely change the commerce game. Carrier sizes change, times to port change, and most importantly, what was not feasible often becomes commercially feasible.

To frame this problem with numbers of vehicles and destinations, the Port of Houston receives more than 8000 ships per year making port, or roughly 25 per day.[23] The number, size, and requirements for this mixed fleet of ‘visiting vehicles’ dictate dock space, traffic control, and on-shore TEU handling capacity.

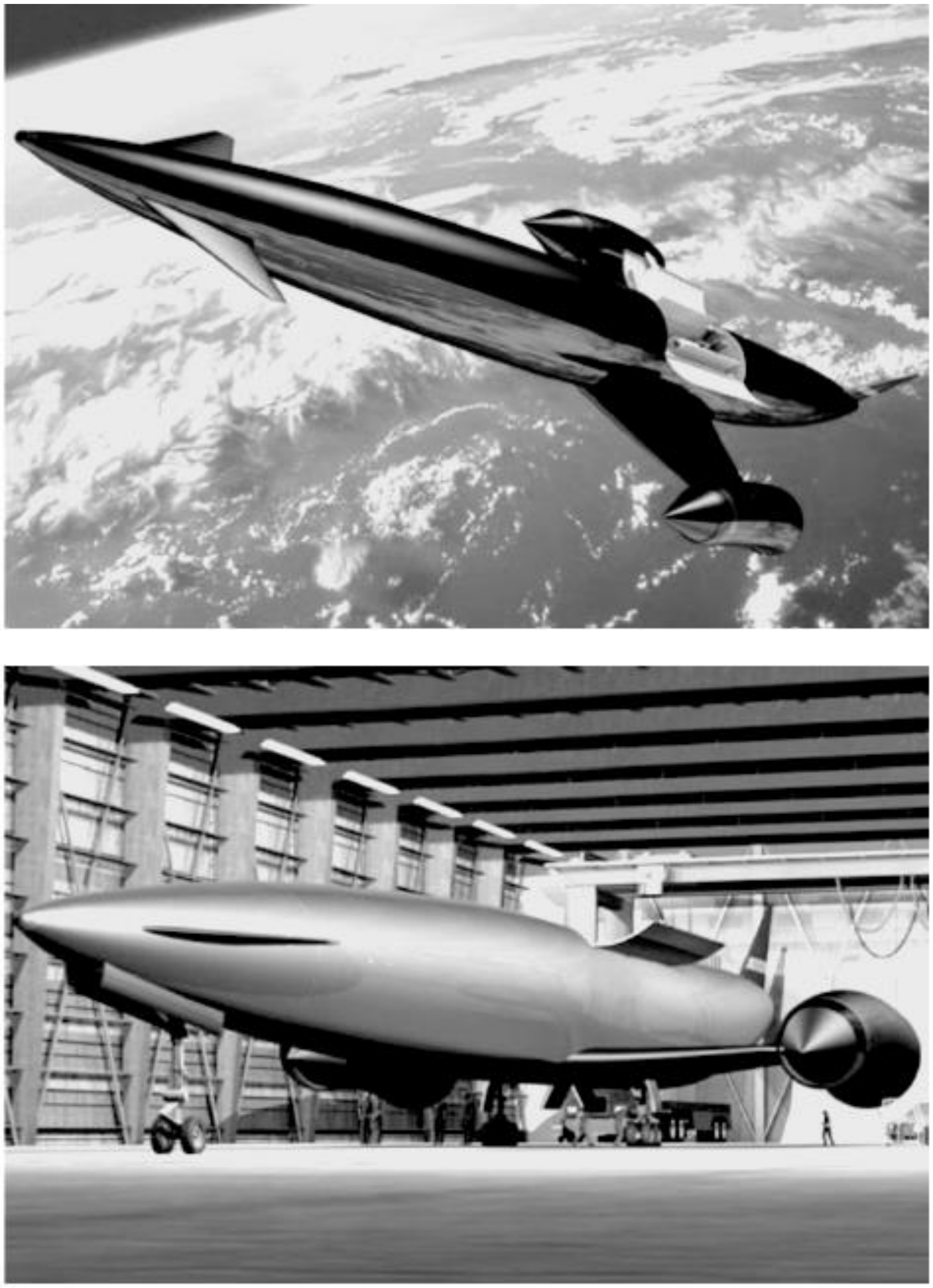

Figure 14
Deployment and flight configuration for Skylon SSTO vehicle concept.

The same situation, substituting mass for volume, would hold true for a space commerce infrastructure.

The payload mass capability of a booster system is more like an airliner than an ocean vessel. Out of the major airport adjacent to the Port of Houston, Houston Intercontinental, there are 1400 arrivals and departures per day,[24] and roughly 156,000 per day across the entire United States.[25] While the number of launches from and entries to the Earth is not likely to ever reach this level, the Skylon or a similar hypersonic, exo-atmospheric craft might not 'launch' like a rocket, but rather 'depart' like an airplane. Or perhaps they will blend into events called 'laun-parture' or an 'ent-rival' numbering more in the airport realm of events than ships docking at port.

This would hasten the infrastructure to change radically, requiring the axiomatic concept of space-based communications and control. This is also an excellent example why there must be system of system simulations in the business model, as non-connected elements may have first order effects on each other, in addition to more subtle but far-reaching second and third order effects on the system as a whole. Engaging in this type of simulation is a necessary part of the planning process.

Do We Have Enough Information And Understanding To Initiate The Commercialization Of Space?

The short answer is no. But then, we never will if certainty or near certainty is required. This is and always will be a risk intensive business, even with superior planning. If the level of risk is commensurate with the potential ROI, then let the commercialization of space begin.

But how much of the cost of space operations has to do with providing a human habitat off the planet? Consider, then, the potential 'game changing' nature of robots. Newer robots have both dexterity and strength, and we must ask, 'At what point do we outfit a station or a waypoint with robotic 'inhabitants'?

In such case, what is the role of a human, and when is the human too costly or the risk of loss of life too great? Here is a potentially multiplicative technology confluence, where the technologies together offer leverage much beyond than their additive sum.

There are no clear answers to this conundrum, which is why the need for continuous planning and assessment is not only cost effective, but is in fact the only strategy suited to preventing being overcome by events, particularly technology driven changes.

This example also nicely demonstrates need for continuous planning to be the final axiom of the model. We won't get 100 years of use out of the access portal to space like we have from the Panama Canal. The technology that kept the Panama Canal on the cutting edge of technology for so many years, useful and cost effective until the present day, was a very slow to change, an open system that has been in use for centuries: water lift.

The dawning era of space commercialization begs the question of when and how emerging technologies will either be incorporated, or will entirely disrupt things, such that it effectively resets to a ‘start again mode,’ requiring an entirely restructured initiative. We recall that Ferdinand De Lesseps tried but utterly failed to build a lock-less canal system in Panama for 10 years, from 1879 to 1889. It took breakthroughs in medicine to overcome malaria, and in technology (in the form of steam shovels), and ten additional long years of work to realize the vision.[19]

If this seems bold, recall that the ‘Space Age’ was ushered in back in 1957, and by about 1992 it was universally declared that we are living in the ‘Information Age.’ Over 35 years, we went from dreaming of inhabiting Mars to watching Mars movies on 3D TV. The ‘half-life’ of the Information Age will no doubt be shorter than the Space Age, and maybe we are already into another age after just 20 years, the cusp of the ‘Age of Space Commercialization’?

Conclusion

We have explored the laws of physics and the laws of commerce to derive a set of axioms that we believe will be useful as for evaluation of the ‘readiness’ of a space commercialization proposal.

Such axioms include the need to define the total system, model and simulate the system of systems, and carefully examine all associated assumptions. From that body of work will come the defining technologies, the cost estimates for infrastructure, and most importantly the evaluation of executibility, sustainability and logistical supportability of the entire system of systems. Once this is completed, a concept can also be assessed against a very successful and applicable reference system, the ocean port and container ship commerce model.

Our set of axioms, given below, will no doubt require further tuning and refinement as we incrementally move toward that next great adventure of the Commercialization of Space. These are the criterion cornerstones against which any proposed approach to space commercialization could be judged at a system level, particularly in the absence of any prior history of a successful space commercialization initiative.

Axioms Of The Space Commercialization Model

1. To commercialize space, it is mandatory that a plan has long-term profitability that is demonstrable through system modeling.
2. Only the private sector has the resources, potential to obtain financial backing, and the experience available on the grand

scale required to plan space commercialization and execute that plan. A 'plan' is defined as including defined mission, risk, return on investment, life cycle, and maintenance plan, and these can be demonstrated through simulation modeling of the entire system.

3. Space based commercialization must address viable missions, managed risks, adequate return on investment, life cycle design, thorough maintenance plans, all through effective simulation and modeling that demonstrates the executibility, the sustainability and logistical supportability of the system of systems.
4. Space vehicles are just beasts of burden, not technology 'wunderkind.' Terrestrial shipping and space shipping have analogous attributes that can inform plans for space commercialization.
5. NASA must be a catalyst, but not in the prime operations manager. The 'heavy lifting' of operations must shift to the commercial sector.
6. The location of space-based assets is not defined by a mission, an adventure, or a need to explore, but by the imperative to connect supply to the need, as in any free market.
7. Clear understanding of the significance of 'distance from Earth' must be demonstrated for a concept to be proven executable, sustainable and logistically supportable. When is distance from Earth a critical factor, and when is it inconsequential?
8. Compliance with the laws of physics simultaneously with the laws of capital generation, investment and ROI are non-negotiable.
9. The application of new technology cannot disrupt a commercial revenue stream. Technology is only attractive to solve a need, not for its own sake inserted into space commercialization. Technology also cannot add substantial risk; rather, it must be applied to decrease risk.
10. Mass to space commerce is as volume is to terrestrial commerce. This will drive design considerations for the artifacts and the business cases for space commercialization.
11. Research, development and art in and of themselves have no commercial value to operations in space commerce.
12. Only the private sector has experience, the relevant historical data and culture to create, manage, and operate a functional commercialization system.

13. Success builds upon success. Since there is very limited history and certainly only a weak pattern as yet of commerce and human manufacturing in space, incipient efforts at space commerce must be managed with the expectation and preparation for significant degrees of failure for the near future. Contingency plans are consequently mandatory.
14. Due to the sheer size and complexity of the total system model for any space commercialization concept, the second and third event order effects must be understood, and incorporated into the system model, and into the physical system when it is built.
15. Continuous, rigorous, and inter-disciplinary planning is required for space commercialization to succeed and continue. This planning must be more robust, integrated and in depth than is routinely done for terrestrial initiatives.

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Tom Diegelman

Tom Diegelman has been in the aerospace community for over 35 years, involved in the research, development and operation of training simulators, ground based flight control installations and facility operations. Tom started his career with Cornell Aeronautical Laboratory as a research engineer, working on early versions of shuttle handling quality study simulations and shuttle shock tunnel testing.

Tom moved to Houston in the late 70's to join Singer / Link Flight Simulation and worked in the Shuttle Mission Training Facility (SMTF) as a model developer, and later a manager of simulation projects. In 1988, Tom joined NASA to lead the $170M redesign of the SMTF. Assignments at NASA / JSC include projects in advanced mission control technology, technology development, and facility operations control. He served as Facility Manager for Mission Control for 3 years before accepting an account manager position in the Technology Transfer Office, developing partnerships and Space Act Agreements.

The design of the training facility for the Constellation Program culminated his nearly 30 years of experience at JSC in Jake Garn astronaut training facility. Tom was elected to Seabrook City Council in 2006, and served two terms, during which he worked closely with the Port of Houston Authority on the Seabrook / Bayport Terminal Facility issues. Tom is a member of Baytran, a non-profit organization promoting inter-modal transportation solutions in the Houston / Bay Area, and continues to be involved in local, state and federal government on behalf of the space technology community.

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Ken is coeditor of this volume, and also coauthor of Chapters 1 and 24. He has been the leader of ATWG since it was established in 1990.

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