AN ANALYSIS OF THE COMPETITIVE ADVANTAGE OF THE UNITED STATES OF AMERICA IN COMMERCIAL HUMAN ORBITAL SPACEFLIGHT MARKETS

Prepared for: The Federal Aviation Administration Office of Commercial Space Transport

By: Futron Corporation, Bethesda Maryland

Greg Autry
Lloyd Greif Center for Entrepreneurial Studies, University of Southern California

Laura Huang
The Wharton School, University of Pennsylvania

Jeff Foust
Futron Corporation

The "Public/Private Human Access to Space" / Human Orbital Markets (HOM) study group of the International Academy of Astronautics (IAA) has established a framework for the identification and analysis of relevant factors and structures that support a global human orbital spaceflight market. The HOM study group has called for analysis at the national level to be incorporated in their global study.

This report, commissioned by the FAA Office of Commercial Space Transport, provides a review of demonstrated and potential Human Orbital Markets and an analysis of the U.S. industrial supply chain supporting commercial human orbital spaceflight. We utilize a multi-method, holistic approach incorporating primarily qualitative methodologies that also incorporates relevant statistical data. Our methodology parallels the National Competitive Advantage diamond model pioneered by economist Michael Porter.

The study reveals that while the U.S. currently possesses significant competitive advantage in commercial human orbital spaceflight, there are several areas of note that present a challenge to the sustainability of this advantage.

INTRODUCTION..4

I. METHODOLOGY AND DATA..5

II. NATIONAL COMPETITIVE ADVANTAGE..6

PORTER DIAMOND COMPONENTS..7
FIRM STRATEGY, STRUCTURE AND RIVALRY..7
DEMAND CONDITIONS..7
FACTOR CONDITIONS..7
RELATED AND SUPPORTING INDUSTRIES..7
PORTER'S STAGES..7
FACTOR-DRIVEN..7
INVESTMENT-DRIVEN..8
INNOVATION-DRIVEN..8
WEALTH-DRIVEN AND THE CURRENT U.S. STAGE..8
LEVELS OF ANALYSIS..9
CLUSTER DATA ISSUES..10

III. DEFINITION OF POTENTIAL HUMAN ORBITAL MARKETS..11

EXISTING MARKET STUDIES..11
HISTORY OF HUMAN ORBITAL MARKETS..12
TOURISM..12
U.S. DOMESTIC CREW TRANSPORTATION..13
ASTRONAUT CORPS OF FOREIGN NATIONS..14
RESEARCH AND DEVELOPMENT..14
MEDIA AND PROMOTION..14
FUTURE MARKETS..14
OTHER MARKETS..15

IV. COMMERCIAL U.S. HUMAN ORBITAL INDUSTRIES..15

GOVERNMENT FUNDED SPACE EFFORTS..15
COMMERCIAL SPACE HISTORY..16

V. FACTOR CONDITIONS AND THE SUPPLY CHAIN..16

RELEVANT U.S. ENDOWED FACTORS..16
HUMAN RESOURCES..16
KNOWLEDGE RESOURCES..18
BASIC EXTRACTIVE RESOURCES..21
CAPITAL RESOURCES..23
INFRASTRUCTURE..24
FACTOR CREATION AND IMPROVEMENT MECHANISMS..25
THE AEROSPACE AND HOM SUPPLY CHAIN..25
THE COMMERCIAL HOM SUPPLY CHAIN..27
U.S. HOM SPACECRAFT..28
U.S. HOM LAUNCH VEHICLES..29
SIGNIFICANT SUB-SYSTEMS AND ASSEMBLIES..30

ROCKET MOTORS / ENGINES 30
STRUCTURES 32
SPACE SPECIALTY INDUSTRIES GROUPING (SSIG) 32
ELECTRONICS INDUSTRIES GROUPING (EIG) 33
NAVIGATION, GUIDANCE, AVIONICS 33
PLUMBING 34
POWER 34
SYSTEMS INTEGRATION 34
U.S. ORBITAL DESTINATIONS 35
FUELS 35

VI. RELATED AND SUPPORTING INDUSTRIES 37

MILITARY AND COMMERCIAL AEROSPACE 37
GOVERNMENTAL SPACE EXPLORATION 37
AUTOMOBILE 38
PERSONAL COMPUTER AND INTERNET 38

VII. FIRM STRUCTURE AND RIVALRY 39

INDUSTRY GEOGRAPHIC CLUSTERS 40

VIII. CHANCE AND GOVERNMENT 41

IX. AREAS OF CONCERN 41

CONCERNS RAISED BY INTERVIEWEES OR NOTED DURING ANALYSIS 41
ITAR AND TRADE RESTRICTIONS 41
SMALL SHOP SUPPLIERS 42
SUPPLY OF SENIOR AEROSPACE ENGINEERS 43
SUPPLY OF SKILLED PRODUCTION WORKERS 43
U.S. MILITARY BUDGET CUTS 43
INCONSISTENT GOVERNMENT SUPPORT 43
GOVERNMENTAL MARKET DISTORTIONS DISRUPT CLUSTERING 44
CRITICAL SUPPLY CHAIN ELEMENTS FROM CHINA 44
SOLID ROCKET MOTORS 46
RP-1 SUPPLY CHAIN 47
CONCERNS NOTED BY OTHER STUDIES 47

X. CONCLUSIONS 48

ACKNOWLEDGEMENTS 49

APPENDICES 50

A. COMMON SPACE ACRONYMS 50
B: NOTE ON CITING OF E-BOOKS 51

REFERENCES 52

Introduction

The International Academy of Astronautics (IAA) has established a "Public/Private Human Access to Space" study group, informally referred to as the "Human Orbital Market study group" or simply the "HOM study group." This group has developed a framework for the identification and analysis of relevant factors and structures that support a global human orbital spaceflight market. It has also called for individual analysis to be conducted at the national level and incorporated in their global effort.

This report, commissioned by the FAA Office of Commercial Space Transport, fulfills that goal by providing a review of demonstrated and potential Human Orbital Markets and an analysis of the U.S. industrial supply chain supporting commercial human orbital spaceflight. We utilize a multi-method, holistic approach incorporating primarily qualitative methodologies that also incorporates relevant archival and statistical data. Our methodology parallels the National Competitive Advantage diamond model pioneered by economist Michael Porter.

The first chapter addresses the study's methodology and data. The second chapter details Porter's approach to the analysis of national competitive advantage. The third chapter considers the various potential HOM markets available to competitors in the near future. Chapter four provides a review of the historical development and relative position of U.S. commercial HOM industries. Chapter five presents an analysis of the supply chain supporting the HOM industries. Chapter six considers the related and supporting industries that benefit firms in the HOM. Chapter seven reviews the structure of HOM firms and dynamics of competition within the U.S. market. Chapter eight addresses the significant external factors of chance and government in regards to the U.S. HOM industrial base. Chapter nine reviews and highlights the areas of concern that this study and others have identified as possible threats to sustained U.S. national competitive advantage. Chapter ten presents our conclusions.

The HOM study group has established a framework for the identification and analysis of factors and structures that support a global human orbital spaceflight market. These factors are broadly defined as: political, legal, capital, historical and cultural. The HOM study group has called for deeper analysis at the national level utilizing the following five analysis phases:

1. Identify the specific human orbital space markets being targeted.
2. Conduct a literature review of relevant reports and articles.
3. Identify relevant political, legal, capital, historical and cultural factors and structures.
4. Identify the set of industries that comprise, support or are related to the identified human orbital space markets.
5. Qualitatively evaluate the likelihood that these industry clusters are sufficient for the eventual natural evolution of human orbital space markets.

While addressing all five phases, this study emphasizes phase one (identifying HOMs), and phase four (identification of supporting and related industries).

I. Methodology and Data

This study utilizes a multi-method, holistic approach consistent with the model pioneered by economist Michael Porter known as the national competitive advantage diamond framework. Qualitative data were gathered from interviews with industry participants and secondary sources. Quantitative data, primarily comparative industry statistics, were gathered from secondary sources.

The scope of this analysis was restricted to the "Commercial" or "New Space" firms engaged in pursuing a competitive, fee-for-service HOM. While the U.S. government remains the largest single consumer of space products and services (Harrison, 2012) and will surely be a major customer of these firms, this study generally eschews primary economic activity occurring under the cost-plus accounting model of the traditional "military-industrial-complex" (MIC) aerospace market. Specifically, this analysis does not substantially address the role of the U.S. National Space Agency's (NASA) Space Launch System (SLS) development project in the HOM.

The foundational primary data for this project were interviews conducted on-site or by telephone with supply chain management at final, downstream, spacecraft and launch vehicle assemblers and operators. These "Tier One" firms included: Orbital Sciences Corporation (Dulles, VA); Space Exploration Technologies (Hawthorne, CA); United Launch Alliance (Centennial, CO) and Sierra Nevada Corporation (Sparks, Nevada). Additional interviews were also conducted with Michael Lopez-Algeria, President of the Commercial Spaceflight Federation (Washington, DC), the non-profit industry association that represents New Space manufacturers and operators.[1] Lopez-Algeria is a former U.S. astronaut with significant flight time and a strong familiarity with a wide variety of spaceflight systems. Follow-up discussions were conducted via email and telephone with each of the participants and/or their staff on both general and specific topics related to the supply chain.

The conclusions of this report remain those of the study's authors and no statement found herein should be attributed to any individual or organization. Participation in this study does not constitute an endorsement of this study nor its conclusions.

These interviews focused on identification of the supply chain for HOM, the related industries that support this supply chain, and areas of concern in the supply chain. By necessity, the qualitative portion of this study has a relatively small sample size, but as a consequence, allows for a richer, more in-depth exploration on the most salient topics related to the supply chain, and empirical validity of the interviews was established nonetheless. With the United States as an international leader in aerospace and New Space, there are still very few U.S. firms capable of successfully conducting human spaceflight operations in the immediate future, and small sample studies risk being anecdotal and inconclusive if responses are found to be significantly divergent. While each firm

[1] One major human spaceflight firm declined to participate and another failed to schedule an interview in the time.

interviewed for this study exhibited a unique approach to supply chain management, there was a general likeness of mind among all the interview subjects, demonstrating validity and reliability in the findings drawn from the method. In particular, a broad consensus was observed in regards to the overall nature and strength of the supply chain as well as on several areas of concern. We therefore feel the conclusions reached here are significant and robust.

II. National Competitive Advantage

This study incorporates the "Porter Diamond" framework for the analysis of national competitive advantage in human orbital spaceflight. In his seminal book entitled *Competitive Advantage of Nations: Creating and Sustaining Superior Performance,* American economist and business strategist Michael Porter established a framework for analyzing national competitive advantage in specific industries. Porter's unit of analysis is the national industry. The diamond framework features four determinants: Firm Strategy, Structure and Rivalry; Demand Conditions; Factor Conditions; and Related and Supporting Industries. Each of these determinants may also reinforce the degree to which the other determinants contribute to a nation's stage of competitive development. Porter's diamond is illustrated in Figure 1.

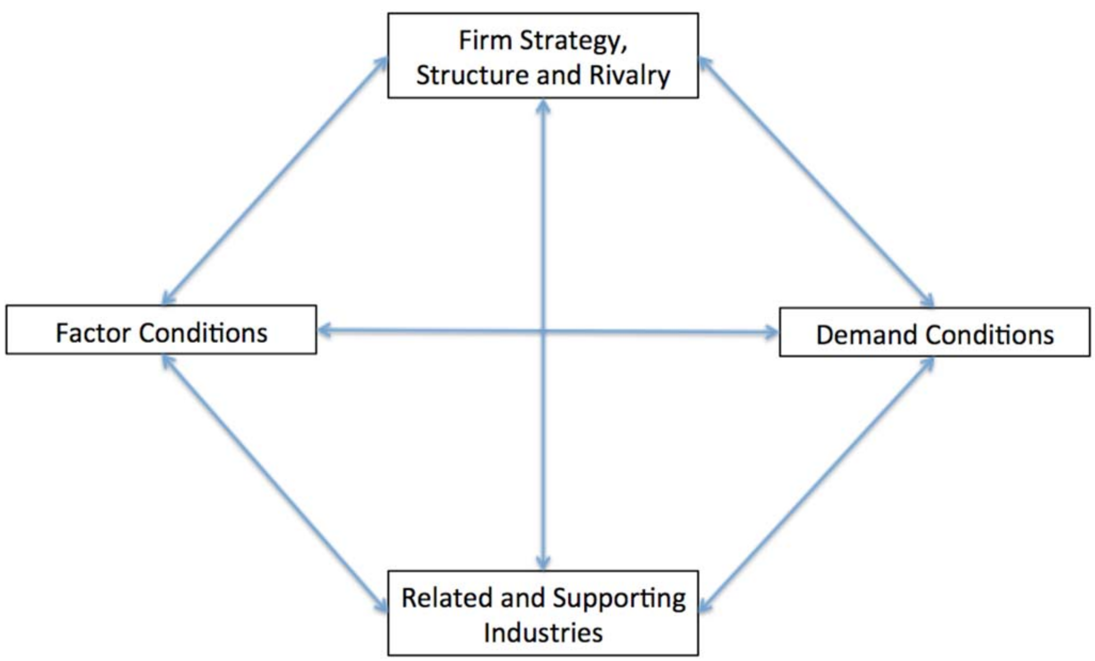

Figure 1. The Porter Diamond

Porter Diamond Components

Firm Strategy, Structure and Rivalry

Firm Strategy, Structure and Rivalry refer to the domestic environment that influences entrepreneurial activity and the operations of existing firms. The legal regime, cultural standards and business norms all impact this determinant, and the match between these factors and the nation's opportunities for competitive advantage determine the level of national success.

Demand Conditions

The demand conditions of the domestic market drive several factors that determine the competitiveness of a nation's industry. These include: the sophistication of the domestic customer, the compatibility of domestic demand with the desires of international consumers, as well as the sophistication and compatibility of the distribution system with international norms.

Factor Conditions

Factors of production are the inputs required of any particular industry. Factor conditions are the environmental determinants that contribute to national competitive advantage. This report will consider both the natural endowment of factors as well as the process of factor creation and enhancement as it relates to commercial human spaceflight.

Related and Supporting Industries

Porter notes that parallel industries can be important to the success of the industry under analysis by providing additional support to the supply chain. A supply chain with more than one client industry to support demand is likely to be more efficient, dynamic and robust. Absent supply constraints in basic input factors, increased demand from parallel industries drives economies of scale in component production, reducing costs for the industry under consideration. Having multiple client industries also protects producers from the cyclical variances in demand and crises in any one industry. This risk reduction constitutes a cost savings that can be passed on to all downstream industries. Incremental improvements and significant innovations that occur in a parallel industry also improve the quality and performance of components from the shared supply chain.

Porter's Stages

Porter's theory defines four stages of competitive development based on a nation's source of advantage: Factor-Driven, Investment-Driven, Innovation-Driven and Wealth-Driven. The first three of these reflect increasing degrees of economic competitiveness based on upgrading of a nation's productive capacity (Porter, 2011: lc. 9643). The last stage reflects drift and decline in competitive advantage.

Factor-Driven

In the *factor-driven stage*, nations derive their competitive advantage from the basic inputs to simple production. Such factors include raw materials, arable land and the nation's labor pool. Nations endowed with significant natural resources often export these for production elsewhere and nations with few resources typically specialize in low cost production of labor-intensive items. There is relatively little value-add in either model and the average standard of living is usually low.

Investment-Driven

Nations in the *investment-driven stage* increase their productivity through investments in larger scale facilities and infrastructure with funds retained from their factor output or foreign investments. While they may improve upon foreign supplied technology, this stage does not reflect significant innovation of basic new technologies or products. Competitive advantage for nations in this stage is based on production efficiencies and incremental improvements in the performance and quality of existing products. Added value is multiplied by investment and drives a rise in living standards.

Innovation-Driven

In the *innovation-driven stage*, nations invest in the education, research and development necessary to create entirely new processes or products. Competitive advantage derives from primary access to valuable, domestically produced intellectual property that adds value to products or enhances productivity. Innovation-driven economies utilize all the determinants of the full Porter diamond model in a wide range of industries. Innovation creates substantial value and therefore standards of living are high in innovation-driven economies.

Wealth-Driven and the Current U.S. Stage

It can be argued that the economy of the United States of America has advanced through the first of these three stages and is currently transitioning from the innovation-driven stage to the *wealth-driven stage*. U.S. consumer demand is high and sophisticated, and the United States ranks high in terms of rule of law and conditions generally conducive to business. The World Bank's "Ease of Doing Business" report for 2013 ranks the U.S. at #4 out of 189 nations[i] and Forbes Magazine ranks the U.S. at #14 out of 145 among "Best Countries for Business" index (though it is trending downward).[ii]

American universities maintain global leadership, with particular strengths in business and technical education. The UK-based 2013-2014 *Times World University Rankings* awarded U.S. institutions 15 of the top 20 spots including the California Institute of Technology University (Cal Tech) at number one. The 2013 Financial Times MBA program rankings place Harvard University at the top, with U.S. schools capturing four of the top five positions, and 12 of the top 20.[iii]

U.S. capital markets are efficient. Sophisticated corporate strategy drives intense rivalry within the U.S. domestic market, pushing up quality, driving prices down and spurring innovation. As many new applications and technologies have spun off of existing industries, there are a wide variety of related and supporting industries that reinforce a dynamic network of national supply chains.

However, it should be noted, that sluggish GDP growth rates, rising national and private debt, non-competitive corporate tax rates, lack of prestige for manufacturing industries, policies that favor and subsidize large established firms, and dropping labor force participation rates raise concerns that the U.S. is relying on past success and putting the engine of innovation at risk. These are indicators of Porter's Wealth-Driven stage that may foretell a decline in national competitive advantage.

Levels of Analysis

Porter worked at the national industrial level of analysis, incorporating whatever diverse set of industries that nation possessed into the cluster data. This study is limited to a specific group of industries involved in and supporting the Human Orbital Spaceflight Markets.

Porter's model conducts its level of analysis at the national industrial level. Porter has previously defined an industry as: *The group of firms producing products that are close substitutes for each other* (Porter, 2008). For this study a national industry is defined as*: the population of firms, in one nation, producing products or services that are similar enough to compete with each other in a market.*

This study will utilize the levels of analysis standards from the literature of community evolution and population ecology as presented in Figure 2. The population of United States firms, which provides for the transportation of humans to and from Earth orbit, constitutes the U.S. Human Orbital Market (HOM) industry. This population is part of the larger community of all New Space / Commercial industries including satellite launch, services and suborbital space tourism. That community belongs to the all-inclusive aerospace field, which incorporates the communities of civilian aircraft industries and those that directly support the military and government space programs.

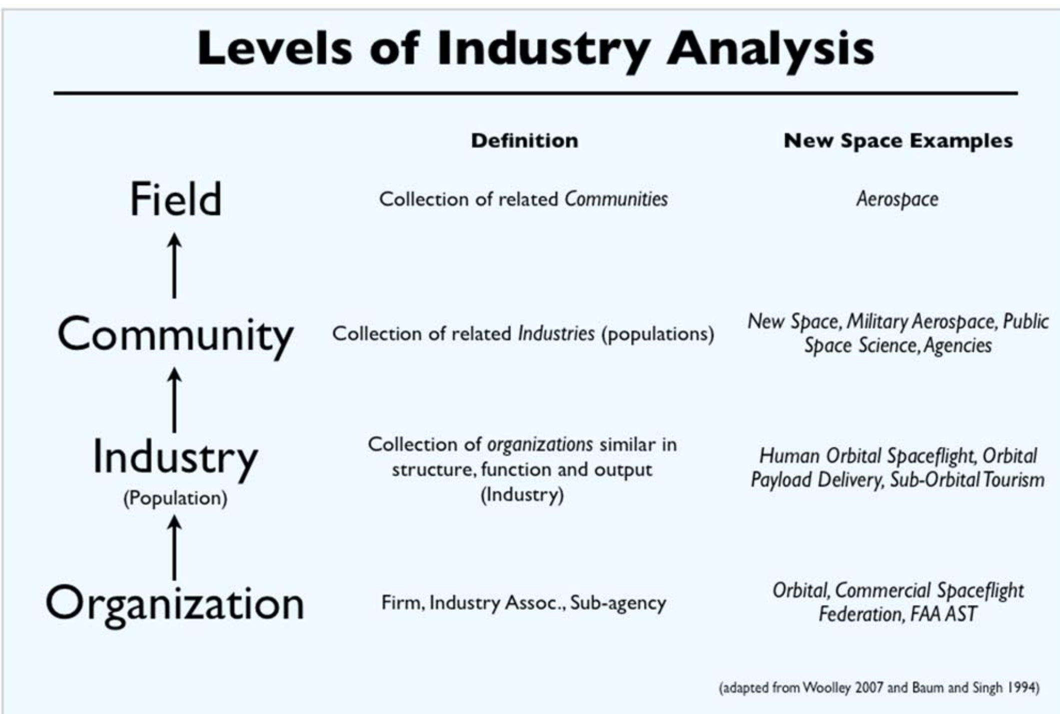

Figure 2. Levels of Industry Analysis

Cluster Data Issues

While this study approximates the Porter methodology it lacks of a homogenous data set for cluster analysis. Porter's cluster analysis utilized the United Nations International Merchandise Trade Statistics (Comtrade) Database. For 1978 and 1985 Porter had access to the SITC 2 classification system to identify specific industries for study. However, for 1971 he suggests that the data set was "much less satisfactory." (Porter, 2011: lc. 13543). We found ourselves in that situation with this analysis. The 3-digit level of SITC classification used by Comtrade in the Yearbook publications is insufficiently refined to isolate the products our interviews determined must be analyzed. Utilizing direct searches of the database with four and five digit codes produced slightly better results but in most cases did not identify the specialized commercial space products under analysis (e.g. rocket fuel or spacecraft environmental systems).

Further, analyzing national competitive advantage via trade flows *presumes that there is generally some level of free trade in those items, resulting in a market driven conclusion of advantage*. This is absolutely not the case in the spacecraft business. Trade in spacecraft and space services is among the most restricted and subsidized of all global products. All operational Human Orbital Spacecraft systems are currently produced and launched by state enterprises. In the broader space market, every non-U.S. launch vehicle manufacturer and operator is state-owned or has significant (40%+) state ownership.[iv],[2]

The nominally private, traditional U.S. launch vehicle manufacturers bear extremely close ties to the military. Employee hiring by private firms on space related projects is micromanaged via the national security clearance process. NASA has heavily subsidized orbital vehicle development by the emerging Commercial / New Space firms and every orbital vehicle launch has been from a governmental facility.

For reasons of national and global security, the U.S. government controls all space technology exports and to a lesser degree imports under the International Traffic in Arms Regulations (ITAR) regime and other laws. U.S. space trade with China and with several aspiring spacefaring nations like Iran, North Korea nations simply does not occur. Exports to the second largest space market, Russia, are extremely limited and imports are also occasionally problematic. New Space firms have complained that even business with traditional American allies, like Britain, is impeded.[v] This significantly distorts trade flows (i.e. U.S. market share in satellite exports does not accurately reflect actual U.S. technological or supply chain advantages in that market).

Though foreign nations are more aggressive in pursuing export opportunities, all other spacecraft and launch vehicle producing nations maintain direct governmental control over space product and service exports, with many similar national restrictions.

[2] The ownership of European Arianespace is complex, but it appears that the government of France controls more than 34% and EADS another 30%. EADS appears to have about 30% state ownership itself.

Consequently, this study concludes that *there is currently no approximation of free trade in space technology*.

If this situation were permanent, an analysis of national competitive advantage would need to assume these governmental subsidies and trade restriction factors as determinants. However, the HOMs are in a transitional state. The U.S. and other nations are realigning their priorities to foster economic development in New Space. This specifically means there are likely to be significant reductions in state control and relaxations of restrictive trade laws, like ITAR, in the near future.[vi]

Our research question is not how the existing factors of National Completive Advantage manifest in current space trade regime, but how they will manifest in the emerging HOMs. *This study presumes the development of relatively freer global HOMs*. Therefore, we find that the utilization of only historical U.N. Comtrade data on traditional aerospace markets to assess national competitive advantage within the HOMs inappropriate.

When encountering insufficient industry data, we have followed Porter's advice, "There was no choice but to make judgments based on inputs from many sources. The alternative, to leave out all industries not showing up in the UN trade statistics, was deemed unacceptable because large groups of important industries in some nations would be ignored" (Porter 2011, lc. 13518).

Therefore, an alternative mixed methods solution was developed. Where the Comtrade data was judge to be irrelevant, we analyzed each industry qualitatively, integrating production and financial data from many sources. We used our own judgment and advice of industry experts to assign a level of national competitive advantage from 0 (none) to 3 (significant) in national competitive advantage for each unit analyzed. These levels are described and symbolized as:

No Advantage -0
Advantage - +
Significant Advantage - ++
Very Significant Advantage - +++

III. Definition of Potential Human Orbital Markets

The HOM study group presumes that the human orbital spaceflight market is global in nature and therefore the analysis is best conducted at the global level rather than national level. This study does not directly survey U.S. market demand. Based on the assumptions of the IAA study and the results of previous surveys we assume that a commercial market for human orbital spaceflight will emerge with sufficient demand to support a number of international players in a generally free market economy.[3]

Existing Market Studies

There have been several market studies and surveys of human spaceflight and related markets.

The most thorough survey to address HOM demand is the 2002 *Space Tourism Market Study* by Futron/Zogby. This study indicated significant demand for orbital

[3] The authors are fully cognizant of the enormity of these assumptions and the historical, economic, and political challenges they suggest.

flights, with 35% of the high net worth individuals being "definitely likely" or "very likely" to participate in orbital travel when price was not a factor. As expected, participation rates dropped with price. At a price of $25 million only 6% were willing to participate. At $1 million the participation rate rose to 30%. Futron noted that an important factor in the development of a successful commercial market was the presence of a commercial destination for tourists (other than ISS). This study projected demand for over 400 tourism only passengers per year by 2020 with industry revenues of $297 million.

The Adventurers Survey of Public Space Travel conducted by Spaceport Associates in 2006 concluded that 47% of self-identified adventure tourists would be interested in orbital flight.[vii]

A 2013 study conducted by students at the University of California, Irvine suggests that 35.3% of respondents would "pay any price they could afford" for an orbital flight, very closely paralleling the earlier Futron results.[viii]

A 2011 statement by Space Adventures, the only firm that has delivered orbital tourism trips, estimated that by 2020 more than 140 private individuals would have made a trip to space.[ix]

NASA's *Commercial Market Assessment for Crew and Cargo Systems* study did not include a survey but did analyze the non-governmental markets addressed in this study. NASA conservatively concluded that the upper-end demand for all non-governmental orbital human flights was approximately 350 over a ten-year period.

History of Human Orbital Markets

Governmental space programs have already demonstrated several commercial markets and have revealed potential demand in others. Figure 3 lists markets identified in this study. The history of other disruptive technologies suggests (e.g. Christensen, 1997) that many applications of commercial human orbital spaceflight have not been identified. It is possible that the market driving application has yet to be identified.

For the purposes of this study, *a demonstrated market* is defined as one in which there have been *re-occurring* (more than once) and *sustained* (still on-going) revenues. A potential market is one in which open interest has been expressed by parties capable of paying the fare and in which limited transactions may have occurred.

The existence of demand for profitable transportation to Low Earth Orbit has been conclusively demonstrated in the markets for Tourism, U.S. Domestic Crew Transportation and Foreign Astronaut Corps flights by the Russian and U.S. government manned space programs.

Tourism

The first paid flight to space by a tourist was the notable case of Dennis Tito. Tito first arranged for a trip to the Mir space station on a Russian Soyuz vehicle via an arrangement with the American firm, Mir Corp. Despite significant opposition from the American space agency, Tito eventually paid $20 million for a trip to the International Space Station in 2001 booked through another U.S. firm, Space Adventures (Dubb. & Paat-Dahlstrom, 2011).

Following Tito's mission there were several additional space tourism flights, including two flights commissioned by Microsoft billionaire, Charles Simonyi. Since 2009 there have been no tourism flights available, as the retirement of the Space Shuttle along with an increased ISS crew standard has resulted in the available supply of Soyuz seats being consumed by NASA astronauts. However, demand remains demonstrated by the $51 million trip to ISS planned by British singer, Sarah Brightman.[x]

	Near-Term (< 10 Years)	Far-Term (> 10 and <50 Years)
Demonstrated Markets	• LEO Tourism • Domestic Gov't Crew Transport • Foreign Astronaut Corps Flight	NA (by definition)
Potential Markets	• R&D • Cis-Lunar Tourism • Cis-Lunar Gov't Crew • Media and Promotion	• Resource Extraction • Energy generation • Deep-Space Vehicle Support Services • Residential Space Station Operation • In Space Construction • Business Travel Service

Figure 3. Identified Human Orbital Markets

Both Space Adventures and British based Excalibur-Almaz have announced plans for circumlunar commercial flights based on updated Soviet space technology. In 2011, Space Adventures announced that one ticket had been sold at a price of $150 million.[xi]

U.S. Domestic Crew Transportation

During the development of the International Space Station project, NASA anticipated utilizing the Russian Soyuz spacecraft for crew transportation and negotiated a bilateral agreement for crew exchanges.[xii] NASA assisted in the specification and funding of modifications to the TMA version of Soyuz designed to accommodate a wider variety of passenger sizes.

Following the loss of the Columbia Orbiter, shuttle launches were suspended (February 1, 2003 - July 26, 2005), and continued concerns with the shedding of foam from the shuttle's external fuel tank precipitated a second suspension (August 9, 2005 - July 4, 2006). These suspensions and a reduced flight schedule required NASA to schedule a number of U.S. astronaut flights on Soyuz. Initially unable to pay Russia directly for space hardware or services due to provisions of the Iran, North Korea, and Syria Nonproliferation Act, NASA made other indirect transfers of considerable economic value, including the clearing of a debt of flight service hours valued at up to $60million.[xiii] Congress provided for direct payments to Russia for spaceflight services with the passage of special legislation in 2005.[xiv]

Following the retirement of the U.S. shuttle fleet (July 21, 2011), NASA negotiated a bulk contract with

Roscosmos for 12 passenger seats at a cost of $753 million ($63 million per passenger). In 2013, it extended this contract with an additional six seats at a cost of $424 million ($71 million per passenger). Following the public announcement of that contract extension, the NASA administrator, Charles Bolden, explicitly expressed support for the President's goal of "American companies launching our astronauts from U.S. soil." [xv]

A market in transporting American astronauts to and from the ISS has been clearly established and a successful U.S. commercial firm could generate several hundred millions in revenue annually from this market.

Astronaut Corps of Foreign Nations

The transportation of astronauts from non-spacefaring nations to low earth orbit has been demonstrated by many flights of foreign nationals aboard both U.S. and Russian spacecraft. The first such flights were the launch of cosmonauts from Czechoslovakia, Poland and East Germany by the former Soviet Union in 1978.[xvi]

Research and Development

In 1984, NASA accepted $40,000 to fly McDonnell Douglas engineer Charles David Walker on STS-41-D so that Walker could operate a space pharmaceutical manufacturing experiment known as the Continuous Flow Electrophoresis (CFES) device. Walker made two further flights in connection with this work. Though the fee was clearly a token economic transfer, it did suggest that firms were willing to pay for human orbital flight in support of research and development. The Challenger disaster of 1986 ended NASA's experimentation with paid spaceflight (Walker, 2006).

Media and Promotion

In 1990, the Tokyo Broadcasting System paid $28 million to fly Japanese reporter Toyohiro Akiyama to Spacestation Mir for a series of one-week television specials. In 1991, Helen Sharman was flown to the Mir as part of a program called "Project Juno." Juno was originated by a consortium of firms intent on creating publicity surrounding the first British citizen in space. Though the consortium failed to deliver the funds, the Soviets flew Sharman anyway (Dubb & Paat-Dahlstrom, 2011).

During her stay on the International Space Station in 2006, Female Space Tourist, Anousheh Ansari became one of the world's most popular bloggers.

This study concludes that while there has been some demonstrated demand for promotional and media-related spaceflight, it is unclear if it is sufficient to support an HOM market.

Future Markets

At least two firms, Planetary Resources and Deep Space Industries, have been founded with the goal of extracting mineral resources from asteroids. Such operations might involve human transport to robotically captured asteroids brought into Earth orbit. NASA has also proposed a demonstration mission of this nature.[xvii]

Since the foundational work of Gerard K. O'Neill in the 1970s[xviii], many proposals have been made to locate populations, power stations and manufacturing plants in Earth Orbit. Such facilities would likely require human assembly and possibly maintenance. With the establishment of significant industry in space it is likely that managers will conduct review visits at space facilities and may eventually establish an onsite presence, driving a future "business travel" market in space. While highly speculative at this time, such a market, being driven by more direct economic returns, would be more robust and sustainable than existing markets.

Other Markets

Other markets, of unknown potential that have been suggested include: zero gravity medical treatment, spiritual-religious travel and end-of-life travel.

IV. Commercial U.S. Human Orbital Industries

Following Porter's framework, a brief historical review of the U.S. Space Launch industry and its related industries is presented.

Government Funded Space Efforts

Although significant research was conduct by Robert Goddard[4] and others before World War II, actual spaceflight started in the United States with the launch of vehicles recovered from the German long-range missile program. Several V2 rockets launched from the White Sands Missile Range from 1946-1952 crossed the Karmen line (demarcated at 100km) into space.

The United States government used domestically produced military hardware for the first American orbital satellite launch in 1958, shortly after the Soviet Union launched Sputnik. Shortly afterward, Human U.S. spaceflight projects were transferred to a newly reformed civilian government agency, the National Aeronautics and Space Administration (NASA). However, rocket development remained closely tied to the military program. The first U.S. human space flights were made in 1961, again closely following that of the Soviets. Since that time, the U.S. has achieved several milestones including docking operations in space, long-term space habitation, lunar exploration and the operation of reusable spacecraft.

The United States was an early entrant in governmental space launches and has more than sixty years of space launch experience, with more human spaceflights (166) than any other nation. The U.S. has also produced a wider variety of human rated spacecraft than any other nation. NASA has flown sub-orbital and orbital launch systems with vehicles capable of transporting one to eight passengers. These spacecraft have used parachutes for land and sea recovery as well as wings. The agency has developed lunar orbital, landing and return vehicles.

Despite this history, the American governmental human spaceflight program is currently entirely dependent on foreign launch vehicles while it awaits the construction of a new domestically produced governmental vehicle and/or an approval of a commercially provided human orbital spaceflight system.

The U.S. governmental human space program has also historically utilized a more commercial supply chain than its competitors, with the majority of development and construction conducted by commercial and often publicly traded firms, albeit with the top tier dominated by a small cohort of large firms closely associated with the U.S. military. The programs of the Soviet Union / Russia and

[4] Goddard's groundbreaking work was heavily backed by grants from the Smithsonian Foundation.

China have been explicitly supplied by military and state-owned enterprises.

Commercial Space History

The United States government has been a leader in the effort to commercialize access to space since the 1980s with legislation aimed at privatization (Autry, 2013). The first private investment in an American New Space firm occurred in 1975, followed by several significant privately funded space projects in the early 1980s, producing the first successful (sub-orbital) commercial, unmanned spaceflight in 1982[5] (Autry, 2013).

Finally, the United States (as of 2013) remains the only nation with a successful privately-funded human space launch project: the three sub-orbital flights made by Scaled Composite's SpaceShipOne in 2004. No nation has attempted an orbital commercial flight, though it would appear that U.S. based Space Exploration Technologies is on track to do so as early as 2015. In fact, it appears that SpaceX is fully capable of making such a launch and recovery at this time and is only delayed by the process of human-rating their system. The ULA+Boeing and ULA+Sierra Nevada projects are also on a very credible track to achieve this goal before the end of the decade. No other nation has a comparably credible commercial HOM effort.

V. Factor Conditions and the Supply Chain

The basic factors of national competitive advantage are both endowed and created (Porter, 2011). While the natural endowment of basic factor inputs varies by nation, Porter suggests that, "the factors most important to competitive advantage in most industries, especially those most vital to productivity growth in advanced economies, are not inherited but *are created* within a nation." (Porter, 2011: lc. 2009) The industries that are supported by these created factors tend to add considerably more economic value to the supply chain than the extractive industries associated with endowed factors. The superior value creation of such created factors over endowed factors was keenly illustrated in the second half of the twentieth century by the rapid economic advancement of the relatively resource poor East-Asian nations of Japan, Singapore and Hong Kong. During this same period many resource rich nations in Africa, Central Asia and Latin America struggled with sustaining basic levels of growth.

Relevant U.S. Endowed Factors

Human Resources

The quantity, demographics and quality of the national population are fundamental to national competitive advantage.

Basic factor pools seldom establish competitive advantage in and of themselves, however they serve as the basis for advanced factors that do so (Porter, 2011: lc. 2049). National population constitutes the fundamental factor pool of potential personnel in the necessary specialties to establish competitive advantage in industries with a complex and highly diversified supply chain. A larger population provides the potential for competitive advantage by increasing the candidates available for specialized factors. As of November 2013, the population of the United States was

[5] Space Services, Inc.'s Conestoga I launched from Wallops Island, VA reached 313km where it ejected a 500kg test payload.

317 million[xix] and the nation was ranked as the third most populous sovereign nation on Earth.[xx]

With respect to competing spacefaring nations with demonstrated human spaceflight capacity, the U.S. ranks second, far behind China with 1.3 billion and substantially ahead of Russia at 143 million. There is little reason to presume that hundreds of millions of citizens are required to sustain a successful manned spaceflight program. Several mid-sized nations such as Germany (81 million) and South Korea (49 million) have entered the innovation stage and support extremely complex industries including automobile, ship building, machine tools and electronics sustained by sophisticated and highly specialized national supply chains.

Population growth is a fundamental driver of GDP growth. Entering the second decade of the 21st century, the United State faces a demographic challenge with a steadily declining fertility rate of 1.93 well below the replacement level of 2.1. The rate among college-educated women is even lower at 1.6.[xxi] The primary substitute for domestic birth is immigration. Not only do immigrants contribute to the population directly, but first generation immigrants also have disproportionately higher birth rates. A cultural disposition marked by an acceptance of immigrants has long provided the United States with an advantage in population growth over economic competitors, like Japan. A 2013 Wall Street Journal article suggested that, "immigration has kept America from careening over the demographic cliff."[xxii]

Immigrants and foreign workers have also been noted to exhibit higher rates of entrepreneurial activity (Fairlie, 2012).[xxiii] This is evident within the "New Space" community. The founders of two of the most visible and arguably most viable American spacecraft firms are non-U.S. born. A South African Immigrant, Elon Musk, founded Hawthorne California based Exploration Technologies in 2002. British National, Sir Richard Branson, established Virgin Galactic in 2004 at Mojave, CA.

However, demand for immigration to the U.S. has declined in recent years.[xxiv] For example, net immigration from Mexico to the U.S. has been flat or negative for five years from 2007 to 2012 (Passel, et al, 2012).[xxv]

Population age demographics are an important moderating factor on national human resource endowments. Adults between the ages of 18 and 65 are most likely to be in the labor force. Populations with more workers at the start of their professional careers, between 20 to 30 years of age, have an advantage in lower wage cost. Younger workers also demonstrate increased productivity and mental acuity (Skirbekk, 2004). They are more likely to be skilled in problem solving, learning and math (Skirbekk, 2004). Economies dependent on the skills and entrepreneurship of younger populations are able to sustain their advantage longer. Economies dependent on aging populations face higher social services costs from retirement and entitlement programs. In general, a younger population offers national competitive advantages. This poses a demographic challenge for the U.S. where the mean population age in the United States has risen from 28.1 in 1970 to 37.2 in 2010 (U.S. Census).

Aging has been particularly distinct within aerospace engineering. The majority of our interview subjects expressed concern with this phenomenon, specifically noting a coming "retirement wave" of senior engineers qualified to manage complex projects. It has been remarked that the average engineer at NASA during the Apollo moon mission was in his mid-twenties. As of 2009, this average has risen to the late forties. Notably, the mean age of a *new hire* at NASA is now 41.[xxvi]

The labor force participation rate is calculated as the ratio of those actually working to those of working age who are not institutionalized (Bureau of Labor Statistics). The trends reviewed here would predict a falling U.S. participation rate, and that is indeed the case (fig. 4). However, the actual measure has been falling faster than demographic models predict. A 2006 Bureau of Labor Statistics study (Tossi, 2006) and a 2002 study (Szafran, 2002) both predicted participation rates for 2012 nearly two points higher (approximately 66%) than what has been actually observed (approximately 64%). It has been widely suggested that a lack of economic growth in the United States has resulted in fewer Americans seeking work. This would be supported and in line with Porter's description of the wealth-driven phase (Porter, 2011: loc. 9830).

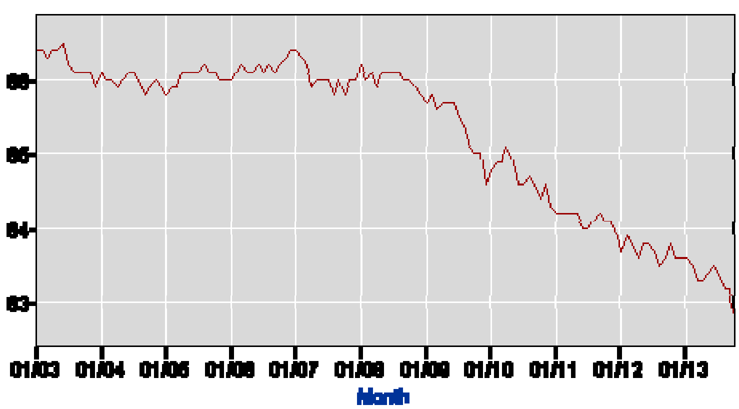

Figure 4. Labor force participation rate: Source: Bureau of Labor Statistics

Knowledge Resources

All HOM careers are anticipated to require a secondary education / high school diploma or equivalent. The majority of HOM careers require post-secondary education in a technical field.

United States spending on education is 7.3% of GDP, well above the OECD average of 6.2% and the OECD reports, "Across all levels of education, annual per-student spending by educational institutions in the U.S. is higher than in any other country, at USD 15,812" (OCED, 2012). Yet, U.S. K-12 public schools are regarded as mediocre by international standards and rank low in comparative statistics among developed nations. On the 2009 PISA assessment of 15-year-olds, the United States performs around the average in reading (rank 14) and science (rank 17), yet below the average in mathematics (rank 25) among the 34 OECD countries (PISA, 2012; OECD 2013). Similar statistics were found in the 2012 assessment (rank 27) among the 34 OECD countries, where American scores remained stagnant, but slipped in absolute ranking because many of the other countries had improved.

The American University system, both private and public, is widely regarded as the finest in the world. U.S. students have a 42% higher education participation rate, which is significantly above the OECD average of 30% (OECD, 2012, p. 2). However, the cost of education in the U.S. higher education remains significantly above average as well and students are often burdened with debt upon their exit from university.

The United States rank 17th in Pearson's Index of Cognitive Skills and Educational Attainment with a score of 0.35 below many European nations (Finland = 1.26, South Korea = 1.23, UK = 0.60) and well above Russia (0.26). China's extremely uneven educational system is not ranked in this index, though the country is noted for high literacy rates and being the largest foreign beneficiary of the U.S. higher education system.[xxvii]

Education (specific – STEM)
Several interviewees echoed the concern often expressed within the national media[xxviii] that America has slipped in Science, Technology, Engineering and Math, the so-called STEM fields. Figure 5a shows U.S. science engineering degrees awarded by year at the undergraduate and graduate levels. Figure 5b shows U.S. undergraduate degrees in Aerospace Engineering, Mechanical Engineering, and Computer Science. The mid-decade decline in enrollments in Computer Science is particularly notable with a 48% drop between 2000 and 2006.[xxix] Data for the last few years suggests that CS enrollment trend is improving.

However, these graphs overlook the dominance of foreign students in advanced computing degree programs at U.S. universities. According to the Computing Research Association, 62.3% of Computer Science and 69.3% of Computer Engineering Masters degrees awarded in 2012 went to non-resident aliens.[xxx] For PhDs, these figures were 51.3% and 55.3% respectively.[xxxi] The U.S. uses its educational system to educate more foreign students than any other nation (OCDED, 2012).

This report concludes that the U.S. educational system is well aligned with the requirements of developing HOM industries. The United States possesses very significant national competitive advantage (+++) in human resources and education.

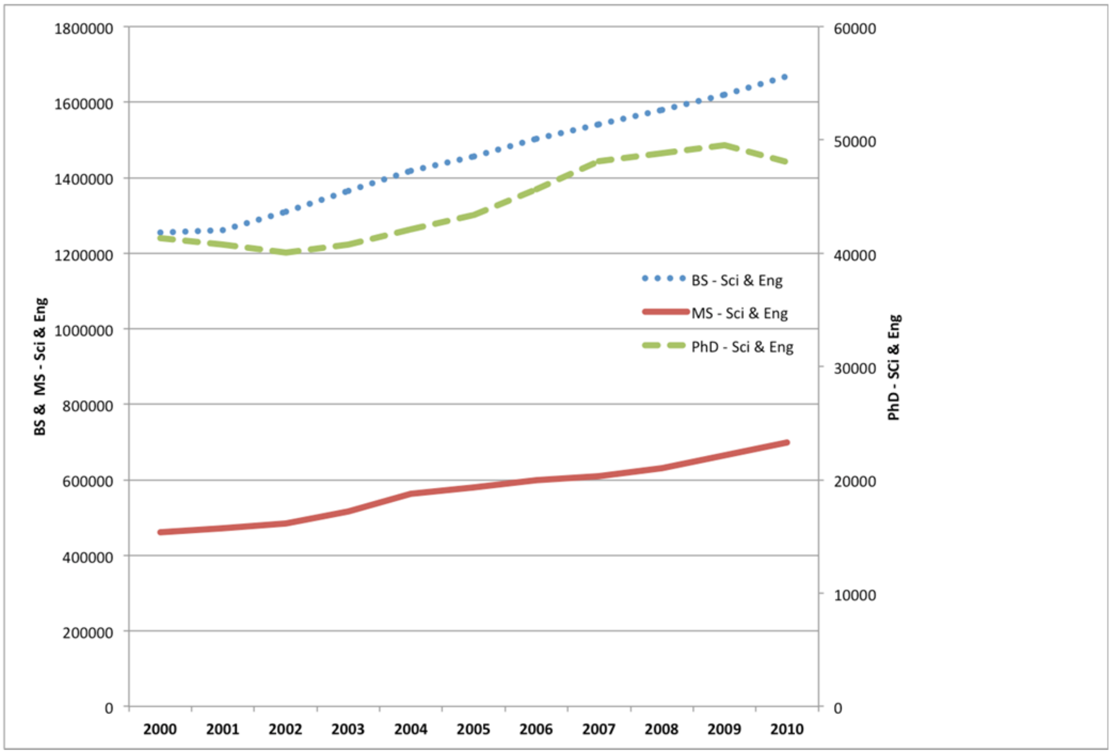

Figure 5a. U.S. Science and engineering degree awards by year, 2000-2010
Source: National Science Foundation

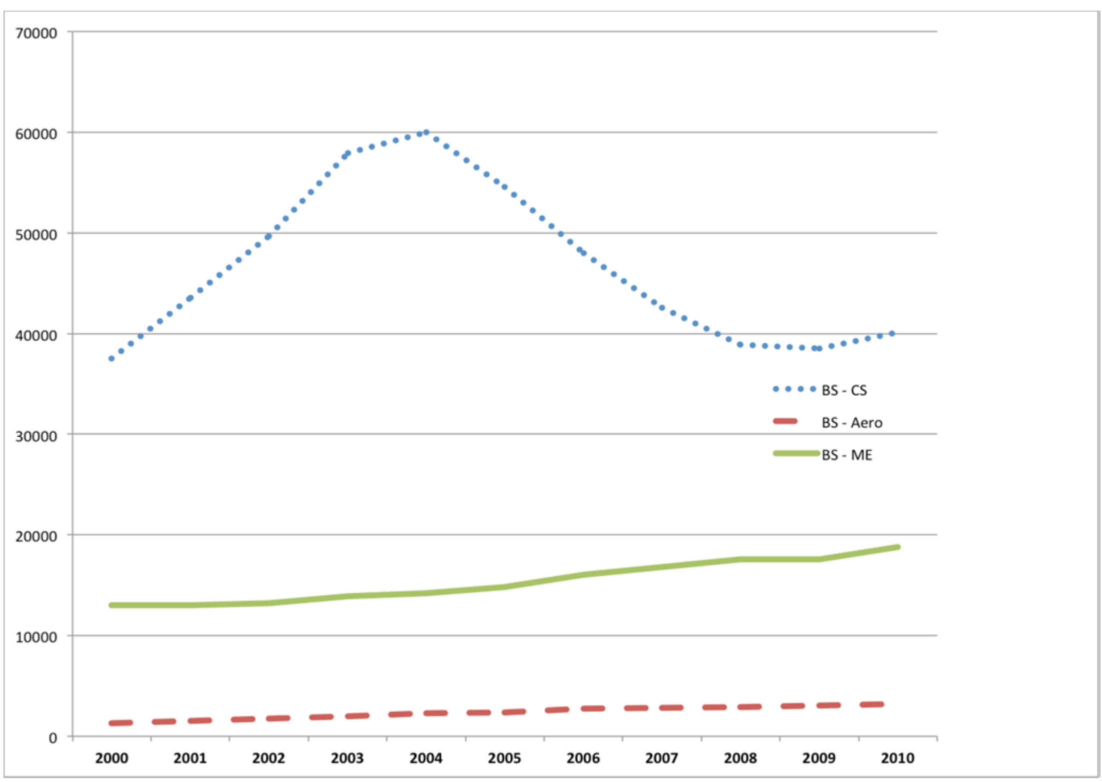

Figure 5b. U.S. Degrees in Computer Science, Aerospace and Mechanical Engineering, 2000-2010
Source: National Science Foundation

Basic Extractive Resources

In reviewing the national competitive advantage of the United States in basic extractive resources, it should be noted that these are generally fully fungible, globally traded commodities. In a relatively free-trade environment, the possession of mineral assets, mining capacity, refining, smelting and production capacity offers little downstream economic advantage. Barring a significant disruption of world trade, basic factor inputs can be assumed to be easily accessible by all spacefaring nations.[6] Possible global disruptions, such as a major war would also surely presumably disturb the demand for global HOM markets. Regional disturbances can create supply constraints in specific factors that are sometimes referred to as "conflict minerals."

With 9.87 million square kilometers of diverse geology, the United States ranks high in mineral reserves and possesses an extensive network of mature and vibrant extraction and refining industries. A brief overview of inputs relevant to spacecraft and launch vehicle production and operation follows.

Petroleum and Petrochemical Refining

The International Energy Agency (IEA) reports that the U.S. is expected to be the world's largest oil producer by 2015 and on track to becoming a self-sufficient supplier.[xxxii] U.S. and global petroleum supplies remain more than sufficient to support the HOM market.

U.S. refining capacity has strained to keep up with the increased domestic production brought on by the commercial success of hydraulic fracturing. U.S. refining capacity peeked in the late 1970s and been constrained by federal and state environmental regulations.[xxxiii] The EIA reports that the last major U.S. refinery was constructed in 1977[xxxiv] and that U.S. is currently operating at above 90% utilization.[xxxv] However much of U.S. oil refining capacity is orientated towards processing imported oil. Both the Council on Foreign Relations[xxxvi] and the EIA[xxxvii] have noted that a mismatch in refining capacity with the volume and quality of domestic oil poses a concern.

This study concludes that the U.S. petroleum production is more than sufficient and that petrochemical refining is sufficiently aligned with the needs of the HOM industries. The U.S. holds significant (++) competitive advantage in petroleum production and petrochemical refining.

Metals and Minerals

The U.S. is a global leader in the extraction of metallic and non-metallic minerals. In total, mining operations contributed $102.6 billion to the U.S. economy in 2011 according to a report by the National Mining Association. Coal accounts for $37.4 billion of this economic activity; non-metallic minerals contribute $36 billion with metals contributing $29.2.[xxxviii]

According to the 2010 British Geological Survey (BGS), the U.S. is a major producer of many metals including Iron/Steel, Copper, Bauxite/alumina/aluminum, Silver, Gold, and Uranium.[xxxix]

There are some specific minerals, essential to the aerospace industry and technology in general, in which the U.S. currently lacks

[6] Other than aspirants subject to sanction regime such as Iran or North Korea.

either sufficient known reserves or production capacity.

Titanium alloys are noted for their lightweight tensile strength and corrosion and fatigue resistance which make them an extremely important basic input for specialized spacecraft components used in structures and motors as well as being used as a pigment (Ti02) in the brilliant white paint most commonly associated with spacecraft. While not a significant source of ore, the U.S. does produce a moderate amount of titanium materials. The U.S. Geological Survey (USGS) reports that the nation "has become highly dependent on imports of the minerals used to make titanium and TiO2." However these materials come primarily via very stable trading relationships with Australia and Canada."[xl] Russia and China are major producers of titanium with source material from the Ukraine and Australia respectively. Nonetheless, during the Cold War, the U.S. DOD maintained a National Defense Stockpile (NDS), which included strategic reserves of sponge titanium metal for the aerospace industry.

Cobalt is important in a number of space related materials including high strength alloy drill bits, powerful magnets, and rechargeable batteries. It is also a catalyst material used in chemical production reactors. The United States is not a significant producer of cobalt and imports much of the material from Africa, though BGS reports that it does have a high quality deposit underdevelopment in Idaho.

The U.S. is not a significant producer of chromium, which is used in the production of stainless steel, a significant input to spacecraft and launch vehicles. The U.S. also lacks reserves of tantalum, an important input for electronics. Tantalum has been constrained in recent years resulting in rising prices.[xli]

The New York Times reports that "The United States depends fully on foreign gallium and indium and is 80 percent dependent on imported germanium"[xlii] all of which are important in specialized electronics.

A 2012 report by American Resources Policy Network suggests that the U.S. is highly dependent on foreign sources for: antimony, arsenic, bauxite, cobalt, fluorspar, gallium, hafnium, lithium, manganese, nickel, platinum, rhenium, strontium, tantalum, tellurium, tin, vanadium, and zinc.

U.S. supplies of silicon, essential to the production of electronics, are ample. The United States is the leading producer of crystalline silica, the essential input to the production of optical glass, ceramics and in support of oil production (used in fracking).

Rare Earths

The group of exotic metals known as the "Rare Earth Elements" (REEs) includes 15 Lanthanides together with Yttrium and Scandium. These metals are generally found together in sedimentary deposits and must be extracted using sophisticated refining techniques. Small quantities of these minerals are essential to production of a number of high-technology products commonly utilized in spacecraft. These include LCD screens, high-performance batteries, solar panels, powerful magnets and navigational systems.

The United States possesses significant proven reserves of rare earths. In fact the U.S. possesses the world's second largest concentrated deposit at Mountain Pass, California. However, production at the mine was halted in 2002 and though the mine has been undergoing upgrades, a return to full production has been delayed.[xliii]

This study concludes that the U.S. metal and mineral extraction and refining industries are sufficiently aligned with the needs of the HOM industries. The U.S. holds significant (++) competitive advantage in metals and minerals.

Capital Resources

Access to private capital is one of the most critical resources for the development of any new technological industry (Porter, 2011: lc. 2022). Porter notes that the "globalization of capital markets" has tended to homogenize national conditions. However, the national security implications of spaceflight drive highly regulated and constrained aerospace capital flows, making available endogenous capital significantly more powerful.[7] A nation with captive, private domestic capital available for space investment therefore has significant national competitive advantage.

The United States is the world's wealthiest country. According to the International Human Dimensions Programme on Global Environmental Change the "inclusive wealth", a measure of a "country's capital assets, including manufactured, human and natural capital" in the United States is $118 trillion, more than twice that of second ranked Japan at $55 trillion.[xliv] The U.S. is ranked just seventh in mean wealth per individual according to the 2012 Global Wealth Report by Credit Suisse and even lower in median wealth indicating uneven wealth distribution.[xlv]

However, high net worth individuals are particularly important to the financing of unusual and risky business endeavors. From this perspective, the noted trend of increasing income and wealth disparity in America [xlvi] drives an advantage in investable wealth concentration. The Credit Suisse report reveals that the U.S. has more than 35,000 "Ultra high net worth individuals"[8], with China placing second at under 5,000. Entry into the first tier of the HOMs requires hundreds of millions of dollars of investment, necessitating either billionaire-class angel investors. The Forbes' 2013 ranking of 1,426 billionaires lists 442 as being U.S. citizens, including 13 of the top 20.

The American banking system is mature world leading industry with sophisticated and transparent governance. The U.S. system did attract significant criticism following the 2007-2009 financial crisis, but the regulatory reaction to the crisis was relatively responsive and robust. However, Bloomberg places only one U.S. institution on its 2012 list of 20 "World's Strongest Banks."[xlvii]

American entrepreneurs enjoy direct access to the world's most vibrant network of angel investors and venture capitalists with an interest in high-technology companies. While traditional investors have been hesitant to embrace space startups, the U.S. possesses a significant potential advantage in capital resources.

However, despite these advantages in

---

[7] e.g. It is unlikely that a U.S. investor could make a significant investment a Chinese space firm due to restrictions placed on such an investment by both nations' governments. Similar domestic ownership restrictions in regards to aerospace firms are also favored by Russia and European nations.

[8] Defined as possessing $50 million or more.

assets and capital the United States has been rapidly accumulating public and private debt. According to the USDebtClock.org the total unfunded liabilities[9] of the United States are over $127 trillion, far exceeding the value of all national assets.[xlviii] This represents a significant long-term concern for the U.S. economy and capital markets.

This report concludes that while the growing public and private debt remains a concern, the U.S. private capital markets and financial sector are very well aligned with the requirements of developing HOM industries. The United States possesses very significant national competitive advantage (+++) in finance.

Infrastructure

As a leading developed nation the U.S. has a robustly developed infrastructure that has boasted world-class utilities, communications and transportation systems for several generations. The U.S. was the global leader in implementation of most modern systems including telephony, electric power, automobile highways, airports and air traffic control, and the Internet.

Space Specific Infrastructure

The United States space infrastructure is unparalleled. The U.S. has no less than five governmental launch facilities that have placed payloads into orbit: Cape Canaveral, Florida; Vandenberg Air force Base, California; Wallops Island, Virginia; Kwajalein Atoll, Marshall Islands; and Kodiak Island, Alaska.

A number of private spaceports primarily focused on suborbital flights are now in operation or in review. Operational facilities include the Mojave Air and Spaceport, California; Spaceport America in New Mexico; and the Mid-Atlantic Regional Spaceport (MARS), Virginia.

A commercial orbital launch was made at MARS by Orbital in 2013. Vertical suborbital launches have been conducted at Spaceport America[xlix]. Likewise, Paul Allen's Stratolaunch program proposes operating out of horizontal runway facilities like Mojave to conduct orbital air launches as far as 1500 miles away. Such a system could conceivably launch HOM vehicles from any major airport.[l]

The U.S. government aerospace economy has always been cyclical. Currently the industry is in a long-term downturn related to deep budget cuts in defense and years of declining investment in the civilian space program. This situation has resulted in substantial excess capacity in several areas. The cancelation of the Space Shuttle program and its replacement Constellation program has left NASA without a manned spaceflight program. The NASA centers in Houston and at the Cape have a number of facilities that are entirely mothballed or underutilized. These include R&D labs, wind tunnels, launch pads and astronaut training facilities.

Much of this excess capacity in governmental facilities is being made available to commercial spaceflight operators, including potential HOM participants. NASA has opened its R&D facilities and labs for the testing of commercial spacecraft including running models of the Sierra Nevada Corporation's Dream Chaser spacecraft in the hypersonic wind tunnel at the Langley Research

[9] The unfunded liabilities consist of commitments to government income and medical entitlement programs for retired workers – social security and Medicare.

Center in Hampton, VA.[li] In a notable operational example of privatization, NASA recently transferred operation of their 39A launch complex to SpaceX at no charge.[lii] LC-39A was used to launch manned spaceflights from the 1960s Apollo program through the final Space Shuttle in 2011. Houston's Johnson Space Center has been renting out its extra-large swimming pool, the Neutral Buoyancy Laboratory, to private training firms wishing to simulate zero gravity conditions for commercial HOM astronauts and spaceflight participants.

The twentieth century U.S. investment in commercial aviation, military aerospace and the national space program has also produced significant excess facility capacity among commercial contractors. The primary production facility for Space Exploration Technologies in Hawthorne California is a former Northrup factory used for many years to produce aircraft and components for both military and commercial aviation.[liii]

Oceanic Support Capabilities

Prior to the Space Shuttle, the U.S. traditionally utilized a "splash down" technique to recover manned space capsules from the sea. Though planning to move to a land-based solution, SpaceX has, so far, recovered their Dragon capsules at sea as well. Recovery and search and rescue operations for future HOM vehicles may take place at sea. The United States is well equipped in this regard, with significant coastline. According to the Central Intelligence Agency's World Factbook, the U.S. has 19,924 miles of coastline on two major oceans. The U.S. also operates the world's largest Navy from directly controlled or allied ports across the globe. 393 vessels are registered in the U.S. merchant marine fleet, though U.S. interests own many more.[liv]

Factor Creation and Improvement Mechanisms

Non-endowed factors can often be artificially established and existing factors can often be improved. Porter notes, "Well-functioning mechanisms that create and upgrade factors provide the foundation for high-order advantages" (Porter, 2011, lc. 9878). This applies to infrastructure as well as human and knowledge resources. The actual competitive advantage derived from factors depends on how effectively they are deployed (Porter, 2011, lc. 2049).

Over the last decade, slow economic growth and federal budgets strained by entitlement and defense commitments have resulted in reduced infrastructure investment by both private and public sector agents. Much concern about America's "crumbling infrastructure" has appeared in the media[lv] and it has been the subject of Congressional hearings.[lvi] Interviewees indicated that, despite appreciating this concern, the current U.S. infrastructure is entirely suitable for the needs of their HOM firms.

This report concludes that the U.S. infrastructure is very well aligned with the requirements of developing HOM industries. The United States possesses a very significant national competitive advantage in infrastructure.

The Aerospace and HOM Supply Chain

The MIC aerospace supply chain has traditionally been viewed as a series of "Tiers", the exact number of which varies depending on the detail of the model. The Tier 1 supplier is the final or "Prime Contractor" (or just "the prime") responsible for complete systems integration and delivery of a complete and operational spacecraft to the governmental client: a national space agency or military force.

The Tier 1 firm then subcontracts major subsystems, such as engines, recovery systems or navigation systems, to various Tier Two suppliers. Tier two suppliers require assemblies and subcomponents such as motors, pumps, wiring harnesses from Tier Three and Four suppliers, who acquire basic hardware like gears, blades, circuits and fasteners from even lower tier suppliers.

The New Space, commercial firms have, in general, retained this structure[10] and utilize most of the traditional supply chain in parallel with the MIC. Figure 6 depicts the current state of the Space Supply Chain with examples of output products produced at each tier.

Until the emergence of the New Space industries, innovation in the U.S. aerospace supply chain had been limited by governmental regulation aimed at achieving extremely high degrees of reliability. Requalification costs have resulted in systems that are essentially unchanged and unimproved in either performance or efficiency for many decades which makes differentiation on any criteria other than cost difficult. Cost advantages in mature products are generally achieved by scale and the natural result is a market rife with Monopoly, Oligopoly and Monopsony (Davidian, 2012). Such a market lacks threats of new entrants, sufficient competition and motives for cooperation as well. While detailed specifications ensure a baseline of quality, innovation and delivery speed suffer from the lack of credible threats. A similar situation is presumed to exist in all governmentally dominated space industrial bases.

While we have not identified any specific surveys of the commercial human orbital supply chain, there have been a few reports that are close parallels. A 2012 report produced by the Tauri group of Alexandria Virginia, analyzed the U.S. military satellite supply chain. Tauri's report was prepared as part of a sector-by-sector, tier-by-tier (S2T2) survey of the U.S. industrial base for the Deputy Assistant Secretary of Defense for Manufacturing and Industrial Base Policy (MIBP). This report importantly identified 17 "at risk" technologies in the military satellite supply chain. A summary of these concerns are included in this study under "areas of concerns."

[10] It is notable that Scaled Composites christened the development program that resulted in the first commercial human spaceflight as "Tier One" in homage to this convention.

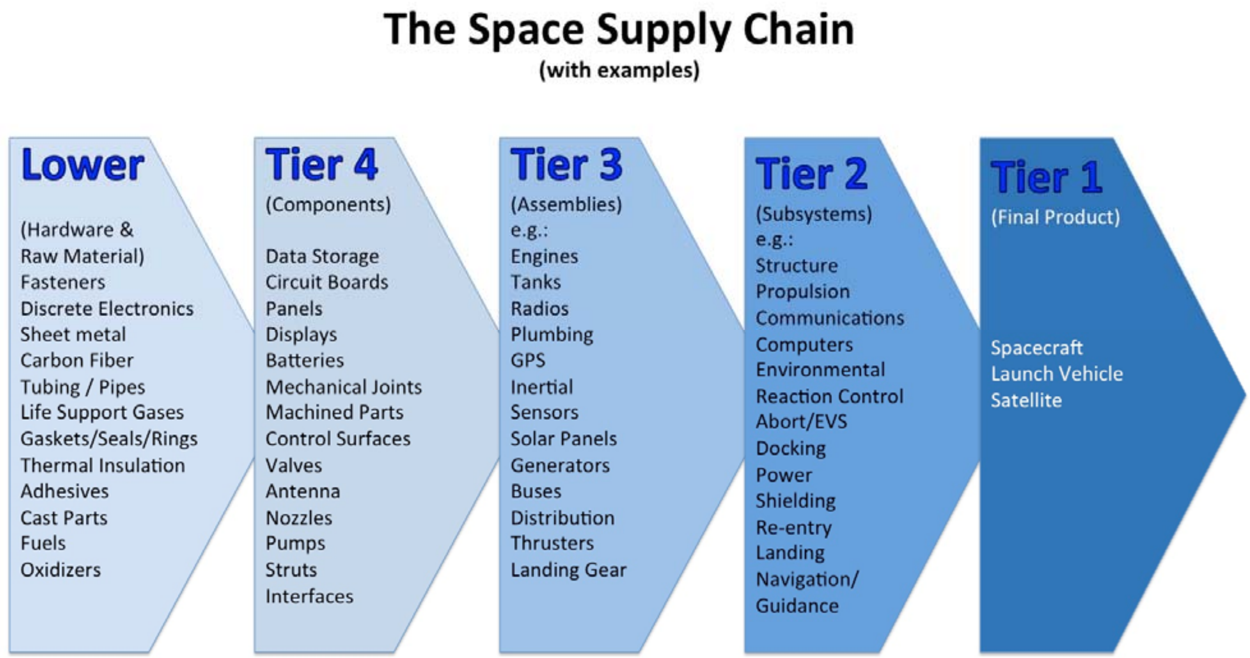

Figure 6. The Space Supply Chain

The Commercial HOM Supply Chain

The commercial space / New Space supply chain varies from the traditional aerospace chain by removing the detailed qualification requirements. This is achieved either by removing the government as a client entirely or by requiring the government to assume the role of a traditional consumer of services rather than that of a system designer. In an immature market, lacking a dominant designs and standard organizational forms, a wide variance of strategies are likely to be observed in supply chain management as firms search for satisfactory efficiencies.

Of the three primary launch vehicle manufactures we see one that is extremely vertically integrated (SpaceX) and two have aggressively pursued outsourcing (ULA, Orbital Sciences).

At the moment the number of orbital space launches per year is measured in the dozens and the number of human rated spacecraft is a mere handful. Supply chain managers find that insuring the timely delivery of highly specialized components with exacting tolerances at these very low volumes is a challenge. Vendors are hesitant to prioritize such low volume work at any reasonable price.

In an effort to control quality and delivery rates Space Exploration Technologies, has brought more and more development in-house and produces the vast majority of their own major assemblies themselves. The Hawthorne California startup develops engines, fuel tanks, capsules, rocket bodies, fairings, recovery systems, electronics, software and even spacesuits for its Falcon 9 launch vehicle and Dragon spacecraft in-house.

Conversely, United Launch Alliance, a consortium founded by aerospace giants Boeing and Lockheed Martin to operate their legacy Delta and Atlas launch vehicles has sought to aggressively reduced costs via outsourcing. ULA outsources a significant portion of their Atlas V launch vehicle, including the entire first stage RD-180 engine system from RSC Energomash.

Orbital Sciences has also sought cost advantage through outsourcing its first and second stage engines to specialists Aerojet and ATK respectively.

U.S. HOM Spacecraft

The U.S. currently possesses no operational, flight demonstrated human rated spacecraft, either commercial or governmental. There are three major commercial systems under development as part of NASA's CCDEV/ CCiCap program and one well-funded independent effort.

Dragonrider

SpaceX has made significant progress on Dragonrider, a spacecraft based on its successful unmanned dragon cargo vehicle.

Dream Chaser

Sierra Nevada Corporation is currently flight-testing the Dream Chaser, a reusable orbital spacecraft designed to surmount any number of vertical launch system, immediately the ULA Atlas V. SNC has has also announced cooperation with European Space Agency and may launch Dream Chaser from the Ariane launch vehicles.[lvii] The Dream Chaser is directly derived from the NASA HL-20 lifting body, which was a prototype Crew Emergency Return Vehicle inspired by the design of the Russian BOR-4 prototype.[11]

CST-100

Boeing's commercial space group is developing the CST-100 orbital capsule for vertical launch vehicles. In their CCiCap proposal, Boeing has specified the ULA Atlas V and noted its proven track record. They have also indicated the capsule could be launched by the SpaceX Falcon 9 in the future.

The Boeing capsule features a clamshell design for easy crew and materials loading and a customizable configuration. It will be capable of transporting a crew of seven to the International Space Station or a Bigelow habitat.

Orion/ Multi-Purpose Crew Vehicle (MPCV)

Under the SLS program, NASA has continued development of the Orion deep space spacecraft originally slated for the cancelled Constellation program. The current iteration is known as MPCV and is scheduled for an unmanned, orbital test flight in 2014 after launch from a ULA Delta IV heavy rocket.[12]

Other Spacecraft Projects of Note

Blue Origin is reportedly plans to develop an orbital human spaceflight system as a follow-up to their New Shepard sub-orbital craft currently under development.

U.S. based Virgin Galactic has a well-developed sub-orbital spaceplane program and has conducted several successful drop and powered atmospheric flight tests of its SpaceShipTwo craft from its fully operational WhiteKnightTwo carrier vehicle. It currently plans to conduct spaceflights in 2014 and has additional vehicles in production at its subsidiary, The Spaceship Company. Virgin has publicly

[11] The BOR-4, itself was inspired by earlier U.S. lifting body prototypes such as project Dynasoar.

[12] The Delta IV is not human rated and is being utilized for unmanned testing of the craft until the Space Launch System is available.

stated its intent to pursue the orbital market in the future.

XCOR Aerospace of Midland, Texas is currently manufacturing its first Lynx sub-orbital space plane and plans flights by 2015.

This study concludes that the U.S is developing a number of strong, commercial competitors in the spacecraft manufacturing business. While the Russian Soyuz and the Chinese Shenzhou (a Soyuz derivative) remain proven vehicles, their core design is antiquated and they are not likely to be technically or economically competitive with the modern, reusable designs emerging from U.S. producers. The commitment of these nations to state-owned solutions limits the likelihood that an innovative, competitive market for spacecraft will emerge in those nations.

Despite the immediate lack of an operational vehicle, it appears that the United States will very soon attain a very significant national competitive advantage (+++) in human rated orbital spacecraft.

U.S. HOM Launch Vehicles

The U.S. currently produces four commercial operational, flight demonstrated launch systems that are capable of lofting a human into orbit. Two of these vehicles are in the process of obtaining human rating from NASA. The U.S. space agency is also developing a government-designed system, which may potentially compete in the HOM market.

ULA Atlas V

United Launch Alliance is currently pursuing a human rating for the Atlas V in response to demand from the commercial spacecraft market. Boeing has chosen the Atlas as the primary launch vehicle for their CST-100 capsule. Sierra Nevada has also selected the Atlas as the inital launch vehicle for their Dream Chaser spacecraft. Bigelow Aerospace has selected the ULA for the launch of its space habitats.[lviii] Previously Orbital Sciences had proposed utilizing the Atlas V for their proposed Prometheus spacecraft.[13]

SpaceX Falcon 9

Space Exploration Technologies is currently pursuing a human rating from NASA for their Falcon 9 launch vehicle as wells as for their DragonRider capsule under the NASA commercial crew (CCDev / CCiCap) program. The Falcon 9/DragonRider capsule configuration is slated for final testing of its pad abort / LES systems in 2014. Human flights are anticipated in 2015.[lix] SpaceX has stated their intention to make the Falcon 9 a reusable system with fully recoverable first and second stages making controlled, vertical landings after launch.

ULA Delta IV

United Launch Alliance is not currently pursuing a human rating for the Delta IV or Delta IV heavy. NASA has stated that the CBC and RS-68 engines would require a number of modifications for human rating. These include controlling the hydrogen "fuel rich environment" at liftoff that could pose a risk to human occupants.

Orbital Antares

Orbital Science Corporation is not currently pursuing a human rating for the Antares two-stage launch vehicle. They have demonstrated the ability to deliver their Cygnus capsule to the International

[13] Prometheus was developed as a proposed HL-20 derived lifting body for NASA's CCDEV program. Development was shelved when Orbital did not secure a funded slot in the CCDEV program.

Space Station as part of NASA's COTS program. The Cygnus payload capacity and capsule size suggest Antares could be capable of launching a human orbital vehicle. Orbital has noted that their system meets "stringent human-rated safety requirements for ISS operations."[lx]

Space Launch System

While the scope of this analysis is restricted to the commercial HOM market, it should be noted that NASA is moving forward with development of a new manned launch vehicle based on shuttle-derived technology. The "Block I" SLS first stage is slated to use four RS-25 LH2/LOX engines with two strapped on solid boosters. Future plans for liquid motor boosters are under consideration. The second stage will initially use a single RL-10 LH2/LOX engine, while development continues on a new JX-2 motor (also LH2/LOX). Although delays and budget overruns plagued its predecessor, Constellation the current projected launch date for an unmanned SLS mission is in 2017 and the first human SLS mission is set for 2021.[lxi]

This study concludes that the U.S possesses a number of strong, commercial competitors in the space launch vehicle manufacturing business. While the European Ariane, Russian Soyuz and the Chinese LongMarch rockets are well proven launch vehicles their state-owned / dominated producing firms have never operated in an unsubsidized manner. They already face significant economic disadvantages against the satellite launch pricing model SpaceX is currently utilizing.[lxii] It is hard to imagine any disposable launch vehicle competing against a future reusable launch system on cost. A competitive domestic market has SpaceX, ULA and Orbital highly motivated to constrain costs.

Despite the immediate lack of a human rated vehicle, it appears that the United States will very soon attain a significant national competitive advantage (++) in human rated orbital launch vehicles.

Significant Sub-Systems and Assemblies

The following list of 20 significant sub-systems, assemblies and supplies for Spacecraft and Launch Vehicles was developed in the interview process. Those followed by "*SSIG*" were analyzed together in the Space Specialty Industries Grouping and those followed by "*EIG*" as the Electronics Industries Grouping.

Abort / EVS - *SSIG*
Communications - *EIG*
Computers - *EIG*
Docking System - SSIG
Electronics (general) - EIG
Engines (propulsive) / Rocket Motors
Environmental & Life Support - *SSIG*
Consumable Fuels and Gasses
Landing System - *SSIG*
Navigation & Guidance / Avionics
Payload Deployment System - *SSIG*
Plumbing and Tubing
Power Systems
Pressure and Spacesuits - *SSIG*
Propellant and Environmental Gas Tanks
Reaction Control and Maneuvering - *SSIG*
Reentry System - *SSIG*
Sensors - EIG
Shielding (In Space) - *SSIG*
Structure / Airframes - *SSIG*
Thermal Control System - *SSIG*

Rocket Motors / Engines

Rocket engine production has a long history in the United States, beginning with the fundamental work of the American physicist and inventor, Robert Godard, in the early twentieth century. Godard demonstrated the first liquid fueled rocket engine in 1926. Significant production of rocket engines began in the U.S. following the Second World War. Development of engines applicable to HOM was driven by the demands of the military strategic missile program, civilian space program and the launch market for telecommunications and other commercial satellites.

Current U.S. producers of liquid fueled rocket engines suitable for the HOM include SpaceX and Aerojet-Rocketdyne. XCOR Aerospace is working with ULA to produce an innovative piston pump motor that could be used in the upper stage of the Atlas V. Current U.S. producers of solid fuel rocket engines include ATK and Aerojet.

Space launch vehicles and rocket engines have traditionally been single use, non-recoverable assets. Engines that are able to restart after stage or spacecraft separation and control the descent of a reusable launch vehicle stage promise a significant cost reduction. Several U.S. firms are currently developing restartable and reusable rocket motors and launch vehicles for both sub-orbital and orbital applications. These firms include: XCOR Aerospace, Masten Space Systems, Armadillo Aerospace, Blue Origin Systems, and SpaceX.

First Stage Engines

The SpaceX Falcon 9 uses nine Merlin 1D engines powered by RP-1 and LOX. The Merlin engine is developed and produced in-house by SpaceX.

The United Launch Alliance Atlas V first stage is a RD-180 liquid motor powered by RP1 and LOX. ULA has outsourced the first stage engine in the Atlas V to Russia's RSC Energomash.

The ULA Delta IV first stage known as the Common Booster Core (CBC) utilizes RS-68 produced domestically by Aerojet Rocketdyne. The Delta IV heavy utilizes three CBC first stages in a configuration with two as side mounted boosters. The RS-68 utilizes LH2 and LOX as the oxidizer.

Orbital Sciences, Antares uses a single AJ26 RP-1/LOX engine in its first stage. These engines are 1970s vintage Soviet produced NK-33 motors remanufactured by Aerojet.[lxiii]

Upper (2nd) Stage Engines

The U.S. has a long history in multistage rockets. Robert Godard patented the first design for multistage launch vehicle in 1914.

The SpaceX second stage utilizes a single Merlin RP-1/LOX engine.

The Atlas V second stage utilizes one or two RL-10 LH2/LOX engines. ULA has been in development with XCOR Aerospace to utilize an XCOR piston pump in a new upper stage engine.

The Delta IV second stage uses a single RL-10 LH2/LOX engine.

The Orbital Sciences Antares second stage is a Castor 30 solid rocket motor produced by ATK.

Much of the U.S. rocket motor supply chain is dependent on Russian imports. Nonetheless, we see that domestic firms are currently developing and deploying a unique line of low cost, modern rocket motors featuring innovations like restarablility and reusability. SpaceX's Merlin engine appears to have already successfully lowered spaceflight costs and XCOR's piston pump technology promises to lower costs on ULA's upperstages. SpaceX proposes to build a more powerful engine, capable of competing with Russia's higher performance closed-loop Kerolox motors. U.S. rocket engines from firms like SpaceX also have the advantage of advanced gimbal control[lxiv] for navigation, whereas the Russian and Chinese human launch vehicles utilize older vernier rockets[lxv] for inflight course correction.

This study concludes that the U.S. currently lacks significant national competitive advantage in rocket motors, but is well positioned to attain a significant competitive advantage (++) in the next few years.

Structures

The U.S. has significant experience with the production of launch vehicle structures. A number of firms have produced launch vehicle structures for the military ICBM and space launch markets as well as for NASA human exploration programs since Project Mercury.

Currently New Space firms ULA, SpaceX and Orbital produce and/or integrate domestically manufactured first and second stage launch vehicle structures using state of the art forming, construction and welding technologies. SpaceX (and possibly Blue Origin) are developing reusable the first reusable launch vehicle structures.

This study concludes that the U.S., with its comparatively diverse and competitive market, possesses a competitive (+) advantage in terms of launch vehicle structures.

Space Specialty Industries Grouping (SSIG)

The United States possesses a diverse and growing network of space specialty industries, composed of tier two, three and four firms producing a wide variety of space related systems, assemblies and components for satellites, launch vehicles and spacecraft. These include satellite busses, docking systems; reentry and landing systems, spacesuits, environmental and life support systems, and emergency crew escape and abort systems. The scope of this study does not permit an in-depth analysis of each product and service individually. We have grouped them under the heading Space Specialty Industries Grouping (SSIG).

The Manta business directory website lists 206 firms under "U.S. Space Research and Technology Companies."[lxvi] This is clearly not a comprehensive listing as the Colorado Space Coalition website company directory currently lists 435 space technology firms in that state alone.[lxvii] The California Space Authority lists 121 member firms.[lxviii]

Many of these companies are very small, privately owned consulting firms and job shops that produce products or provide services on contract for firms in the tiers above them. While no comprehensive database of all space related manufacturing and services firms was located, it is the opinion of this study's authors, supported by interviews with industry experts, that the U.S. has significantly more space manufacturing and service firms than any other nation.

Interviewees suggested these small firms are often extremely effective for short-run, specialized manufacturing. However, some interviewees expressed concern about the ability of these small firms to transition from one-off manufacturing to a rate-of-production model sufficient to support a rapidly growing New Space industry. Challenges facing smaller suppliers include their lack of access to financing, lack of experience in scaling production, and lack of experience in managing rapid growth.

This study concludes that the U.S. possesses significant competitive advantage (++) in space specialties.

Electronics Industries Grouping (EIG)

The United States possesses a diverse and developed network of electronic design and assembly firms making space-rated electronics gear for satellites, launch vehicles and spacecraft. These include sensors, computers, and communications systems. No comprehensive industry database dedicated to space-rated electronics was found, though interviews and online searches suggest that there are hundreds of U.S. firms operating in these industries.

The broader commercial and consumer electronics industry supports the space specialty supply chain. The UN Comtrade database reports that for the United States exported $41 billion in electronic components (SITC 776) and $42 billion in telecommunications equipment (SITC 764) in 2012. The U.S. imported over $212 billion of electronic components (776) in the same year. This trade imbalance reflects significant loss of U.S. electronics manufacturing to Asia over the last two decades. Continued erosion of domestic capability threatens the supply chain for space specific electronics. Comtrade reports China's 2012 export of electronic components (776) was $82 billion, or roughly double that of the U.S.

This study concludes that the U.S. possesses competitive advantage (+) in space-rated electronics.

Navigation, Guidance, Avionics

The United States is a world leader in space-navigation, guidance and avionics systems.

The U.S. military developed Global Positioning and American firms built and deployed the first GPS constellation. The United States GPS remains the standard for global navigation and the most robust operational navigational satellite constellation. Additionally U.S. firms have expertise in inertial navigation[lxix],[lxx], magnetic navigation, stellar navigation and guidance systems[lxxi]. U.S. firms, like Microsemi, have years of experience producing space-rated, radiation-hardened solutions specifically for satellite and spacecraft in both the governmental and commercial sectors.[lxxii]

These systems combined with communications gear and user interfaces constitute the avionics package for an aircraft of spacecraft. The military and commercial aircraft avionics business is a supporting industry for space-rated navigation and communications systems. U.S. firms like General Electric and Honeywell[lxxiii] are world leaders in this field, often through the acquisition of smaller innovating firms, both domestic and foreign[lxxiv].

This study concludes that the U.S. possesses significant competitive advantage (+++) in Navigation, Guidance and Avionics.

Pressure Tanks

The United States possesses a mature and diverse pressurized storage, transport and fuel tank industry. IBIS world reports that the industry had 2012 revenues of $7.8 billion.[lxxv] The commercial and military aerospace supply chain contains many firms capable of producing metallic, lined composite and more recently fully composite fuel and oxidizer (or monopropellant) tanks suitable for HOM launch vehicles.[lxxvi] Pressure tanks are also used for the storage of environmental gasses aboard spacecraft and space stations. The UN Comtrade database reports the U.S. as the third largest exporter of metal containers for storage or transport (SITC 692) with 8.6% of global trade volume in 2012.

This study concludes U.S. possesses competitive advantage in pressure tanks (+).

Plumbing

The U.S. possesses a sophisticated network of industrial pipe and tubing fabricators. Again, the commercial and military aerospace supply chain contains many firms capable of producing the specialized and complex tubing needed for fueling and cooling HOM launch vehicles.

The general industrial supply chain of metal and plastic tubing supports these specialized producers The United Nations International Merchandise Trade Statistics (Comtrade) database reports the U.S. is the 2nd global exporter of plastic tubes and fittings (SITC 581) with 11.2% of world trade in 2012. In metal tubes (SITC 679) the U.S. exported 7.2% of the global volume.

This study concludes that the U.S. possesses significant competitive advantage (++) in launch vehicle and spacecraft plumbing.

Power

America has significant experience in spacecraft power systems and several U.S. firms provide power generation and distribution systems.

Fuel cells and Solar Photo Voltaic (PV) panels and have been the standard for power generation on human orbital spacecraft. U.S. research and manufacturers pioneered both technologies. America maintains a significant presence in fuel cell manufacturing.[lxxvii]

U.S. firms such as Boeing-Spectolab and Emcore produce high performance and reliable space rated solar panels. However, the U.S. manufacturing base for commercial ground-based solar panels, which is important to supporting the overall solar PV material supply chain, has been nearly lost in recent years.[lxxviii]

Lithium-ion (L-ion) batteries are increasingly the short-term power storage medium of choice for spacecraft and launch vehicles. The U.S. lacks domestic productive capacity for these batteries in the commercial and consumer market.[lxxix]

As a whole, this study concludes that the U.S. holds a competitive advantage (+) in power systems.

Systems Integration

The combination of spacecraft, launch vehicles, payloads and facilities into routine HOM spaceflight operations presents an important engineering, logistical and business challenge.
U.S. firms have significant expertise in systems integration for manned and unmanned vehicles. With more human launches and a greater variety of vehicles than any other nation, U.S. firms have

gained more experience in real world integration. A number of New Space integration firms have also emerged to provide payload integration services in the sub-orbital rocket industry.

As a whole, this study concludes that the U.S. holds a significant competitive advantage (++) in systems integration.

U.S. Orbital Destinations

The HOM market implies that human spaceflight participants transported to orbit would have a destination. The U.S. currently operates the International Space Station (ISS, or "station") in conjunction with the governments of Russia, the European Union, Japan and others. As noted, several space tourists have visited the ISS.

Bigelow

Bigelow Aerospace is developing inflatable human rated orbital habitats based on technology acquired from NASA. Bigelow has launched unmanned scale models of their structures for testing and NASA has agreed a $17.8 million contract with Bigelow to implement a Bigelow Expandable Activity Module (BEAM) on the International Space Station.[lxxx]

Bigelow plans to launch independent inflatable space stations for markets including space tourism, R&D, and foreign astronaut corps.[lxxxi] Bigelow has reserved launch space on both SpaceX and ULA launch vehicles and has been partnering with Boeing on using their CST-100 for human transport to the station.

Although having only a single competitor in the U.S. orbital destination industry is suboptimal there are no similarly credibly supported ventures outside the United States. This study concludes the United States has significant competitive (++) advantage in orbital destinations.

Fuels

Bipropellant Liquid Fuels

Rocket Propellant 1 (RP-1) Rocket Propellant 1 is a highly refined kerosene fuel derived from petroleum. Removal of impurities, particularly sulfur, is important to its purity. The U.S. oil production and refining industry is mature and as noted earlier is robustly expanding.

RP-1 production is similar to jet fuel production and related to automobile gasoline production. Interviewees report no concern with the domestic production capacity of RP-1. However, it appears that all operators obtain their RP-1 from the Defense Energy Support Center (DESC), a division of the U.S. government Defense Logistics Agency. A review of GSA awards for RP-1 supplies suggests that Johann Haltermann, Ltd.[lxxxii], AKA Haltermann Solutions, holds a monopoly on this production. Haltermann is located in Houston, Texas and is a division of Monument Chemical. Monument is a privately owned firm headquartered in Indianapolis, Indiana.

Liquid Hydrogen (LH2) Hydrogen gas can be produced and manufactured by several methods and then liquefied. The most efficient and most common manufacturing method is the steam/catalytic reforming of methane (natural gas). This process is associated with gas produced as a by-product of the refining process.[lxxxiii] Refiners are also a growing consumer of hydrogen, utilizing the gas to comply with EPA requirements to reduce sulfur emissions.[lxxxiv]

The U.S. has abundant supplies of natural gas. The U.S. Energy Information Administration (EIA) ranks the U.S. fourth in proven gas reserves at 334 trillion cubic feet.[lxxxv] The commercial success of hydraulic fracturing has greatly increased American supplies (from 224 trillion ft^3 in 2009) and driven down the costs. This promises abundant American supplies of hydrogen and declining costs.

Hydrogen is traditionally transported from large production facilities by truck, which increases economic costs and creates a potential supply bottleneck. A new generation of small steam reforming generators facilitates the production of Hydrogen at consuming facilities.[lxxxvi]

Hydrogen can also be extracted from water via electrolysis where sufficient supplies of electricity are available. Sustainable hydrogen can be produced with solar or wind generated electricity. Techniques to extract hydrogen from biomass have also been demonstrated by U.S. based researchers.[lxxxvii]

The EIA reports that U.S. hydrogen production capacity exceeds 3billion cubic feet per day[lxxxviii], which is sufficient to fill over 56,000 U.S. Space Shuttle external tanks daily.[14] Production is growing rapidly. Air Liquide reports they more than doubled their U.S. production between 2004 and 2009.[lxxxix]

Bipropellant Oxidizers

LOX is the only oxidizer used by identified suppliers of the HOM market. More exotic oxidizers have been identified in the satellite launch business and Nitrous Oxide (N2O) has been utilized in hybrid engines for the suborbital market. N2O is commonly used in a variety of industrial and consumer applications and there are no apparent supply constraints. This analysis will be restricted to LOX.

Liquid Oxygen (LOX) Commercial oxygen manufacturing via atmospheric extraction is a mature U.S. industry. Liquid oxygen is isolated from air via cryogenic distillation. Oxygen is used in a large number of industrial processes in the U.S. including ceramics, metallurgy, welding and chemical production. The medical and environmental control (wastewater, coal gasification) industries are also major consumers of oxygen.

Combined U.S. oxygen and hydrogen production generated $8.5billion in revenues for 2012.[xc]

Monopropellant Solid Fuels

Solid fuel rockets motors (SRMs) have commonly been used as strap on boosters to liquid fueled first stages. Both the Space Shuttle and the proposed Space Launch System utilize this configuration.

Though no commercial HOM vehicle is currently planned to utilize solid fuel boosters, the Orbital Antares launch vehicle uses a solid motor in its second stage to boost the Cygnus capsule to the ISS. The SLS design initially calls for solid boosters. It is reasonable to conclude that solid boosters could be included in future HOM commercial launch vehicles.

The U.S. has a long history of producing solid rocket motors. The market is dominated by ATK Corporation, which appears to hold a monopoly on orbital class boosters. Ammonium Perchlorate (AP) is the most common solid rocket fuel and

---

[14] The Space Shuttle Super Lightweight Tank had a capacity of 52,881 $ft.^3$

currently the only producer of AP is WECCO of Utah. This single source issue is a notable area of concern.

Hybrid Solid Fuels – Currently there are no orbital launch vehicles or spacecraft in production that use hybrid (solid + liquid/gas) motors, though such motors have been utilized in the suborbital manned spaceflight market and they could conceivable be used as boosters in an HOM vehicle. The typical fuels are synthetic rubber or hydroxyl-terminated polybutadiene (HTPB). These materials do not appear to be constrained.

Inert Ullage Gasses – Chemically nonreactive gases, such as helium and nitrogen are pressurized to force liquid fuels into the combustion chamber and to fill vacant space in the fuel tank. Nitrogen is the most common commercial gas produced in the U.S. Helium is produced in large quantities for a number of commercial and consumer products. Both are available in quantity from a number of competitive domestic sources. These gasses are not supply restrained.

This study concludes that the United States possesses competitive advantage (+) in the production of fuels and oxidizers.

VI. Related and Supporting Industries

For firms in the commercial human orbital market, related and supporting industries are particularly important. With only a handful of manned space launches occurring in a given year, HOM vehicles represent relatively small demand yet have very specialized production requirements. Adding in unmanned launches, the market has remained limited to less than a hundred orbital flights per year for the last two decades. Supporting markets are required to sustain their supply chain.

Military and Commercial Aerospace

All interviewees agreed that the military aerospace industry and the commercial aviation and satellite industries are critical to the existence of their suppliers in the commercial spacecraft industry. The United States aerospace industry stands far above all other nations in breadth and depth of its development. A 2010 OECD report on the global aerospace market ranked the U.S. #1 in "value added by aerospace industry" at $66 billion. The UK and Germany came in second and third with just over $8 billion each. Half of the top 20 firms listed in the report were American, including three of the top four firms.[xci]

U.S. aerospace contributes very significantly to national competitive advantage (+++) in the HOMs.

Governmental Space Exploration

The United State Governmental Space Exploration program under NASA has been a major driver of basic research and development, education, infrastructure development, aerospace employment and aerospace manufacturing capacity. Since its establishment in 1957 NASA has spent approximately $500 billion.[xcii] This is far in excess of any other national space program. The 2012 NASA budget allocation was $17.7 billion. The increased Russian space budget announced for 2013 is $7.9 billion, ahead of China and on parity with Europe.[xciii]

U.S. governmental space exploration contributes very significantly to national competitive advantage (+++) in the HOMs.

Automobile

The automobile industrial supply chain was also mentioned by the majority of interviewees as being critical to the commercial space business – either directly for commercial spacecraft or as a bigger client for their suppliers. The automobile supply chain supports the production of many basic materials including metals, electronics, fabrics, pressure hoses and chemicals. It additional provides some direct components to New Space firms.

The U.S. has a mature, robust and competitive automobile industry. U.S. firms produce over 17 million vehicles per year. According to the International Organization of Motor Vehicle Manufacturers, the United States was the second largest producer of motor vehicles by count in 2013. General Motors is the world's second largest automobile manufacturer by volume and Ford ranked fifth.[xciv] Significant quality competitors exist in Japan and Europe and Chinese firms have captured a large piece of the very low-end market volume.

The U.S. automobile industry contributes to national competitive advantage (+).

Personal Computer and Internet

Entrepreneurs from the Personal Computer and Internet industries have demonstrated a particular enthusiasm for establishing and funding New Space commercial ventures. Billions of dollars of wealth generated from previous success in the PC and Internet industries has flowed into New Space. Continued revenues from those industries are important to the continued growth and development of these firms.

Significant New Space entrepreneurs and their PC/Internet firms include:

SpaceX: Elon Musk, PayPal
StratoLaunch: Paul Allen, Microsoft
Blue Origin: Jeff Bezos, Amazon.com
Planetary Resources: Eric Schmidt & Larry Page, Google

U.S. multinational firms such as Apple, Microsoft, HP and Dell have dominated the global personal computing business since its inception in the late 1970s. Economically significant foreign competitors remain generally limited to Asian firms competing on price in the commodity computer market and specialized software firms from Europe and Asia.

HP, Dell and Apple accounted for 61% of U.S. domestic PC shipments in 2013 and 32% of global shipments. American PC firms are focused on the higher-end of the market capturing disproportionate revenues and profits. A 2013 report by Asymco notes that U.S. based Apple, is by far the most profitable PC manufacturer in the world, capturing a full 45% of global PC profits for itself in 2012. Dell and HP added another 20%, bringing the U.S. total to at least 65%.[xcv]

While, production of nearly all U.S. PCs has been outsourced to Asia, the advantage of the supporting relationship in this specific case is returns on investment not manufacturing capacity. Such returns generally accrue to stockholders regardless of production location and disproportionally benefit the U.S.

Despite the significant growth of Chinese Internet firms within the "Great Firewall" of their domestic market, U.S. firms such as Google, Amazon.com, and Facebook continue to dominant global Internet markets. In a 2013 calculation of market value U.S. companies Google, Amazon, and eBay were top ranked. U.S. firms enjoyed a combined market value of more than three times that of their global competitors.[xcvi]

The U.S. has very significant national competitive advantage (+++) in the PC and Internet industries.

Figure 7 summarizing this analysis of the U.S. HOM related industries in a modified Porter style cluster chart.

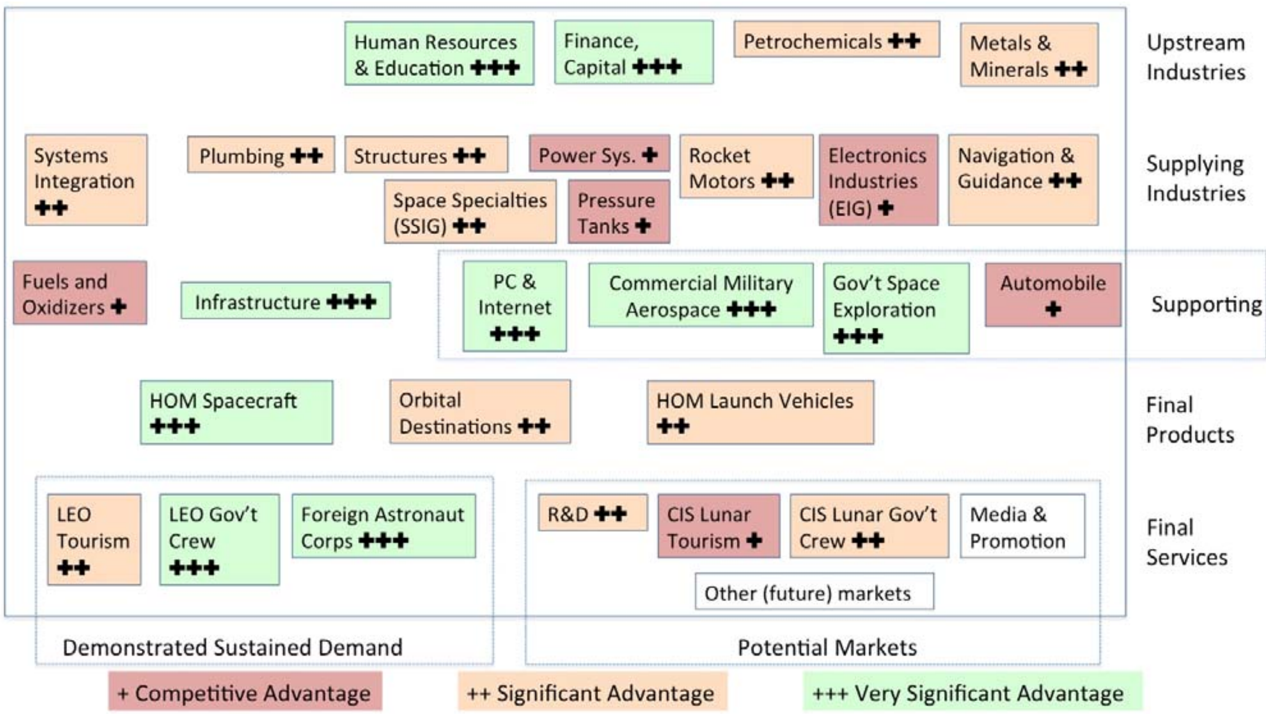

Figure 7. HOM Cluster Chart

VII. Firm Structure and Rivalry

As noted earlier, firms in the United States enjoys substantial economic freedom and the U.S. business climate is ranked as relatively competitive. The government is stable and the rule of law is secure. Business formation is relatively easy and the American model of corporate governance has long been the standard for the world. Access to capital and debt financing is robust.

Space exploration and success in aerospace has been important to U.S. national prestige since the 1950s. The U.S. government has demonstrated a sustained commitment to the privatization of space activities and development of a commercial launch industry.

While the space market is far from perfectly competitive, the U.S. market is nearly free of the state owned enterprises that dominate competing nations. Our interviews suggest a growing sense of healthy market rivalry pervades the domestic New Space industries.

Industry Geographic Clusters

Industry clusters spur innovation through ready exchange of ideas, materials, facilities and personnel. As the technology industry matures into manufacturing, production efficiency is improved by shorting supply chains. Figure 8 shows nascent New Space industry clusters in the U.S. The map depicts total and failed firms of significance. The Southern California cluster, with a concentration around Mojave, California and the greater Los Angeles area, now comprises at least 13 significant live firms. This includes leading HOM competitor SpaceX, in Hawthorne.

Denver Colorado has long been the center of a very significant cluster of space suppliers associated with the University of Colorado and Colorado State University. A growing cluster of New Space firms has developed in the area and efforts are underway to create a spaceport near Denver International Airport (DIA). [xcvii]

Several firms, including Orbital Sciences, are also located near the Washington DC area for access to NASA HQ, DOD, MARS and potential government clients.

Texas has a long history as a governmental space center. The state and municipal governments of Texas has been aggressively recruiting New Space firms from California and Colorado. SpaceX conducts engine and low altitude flight-testing there. Blue Origin has established its flight operations in the state. There is also an effort to establish a spaceport outside of Houston.[xcviii]

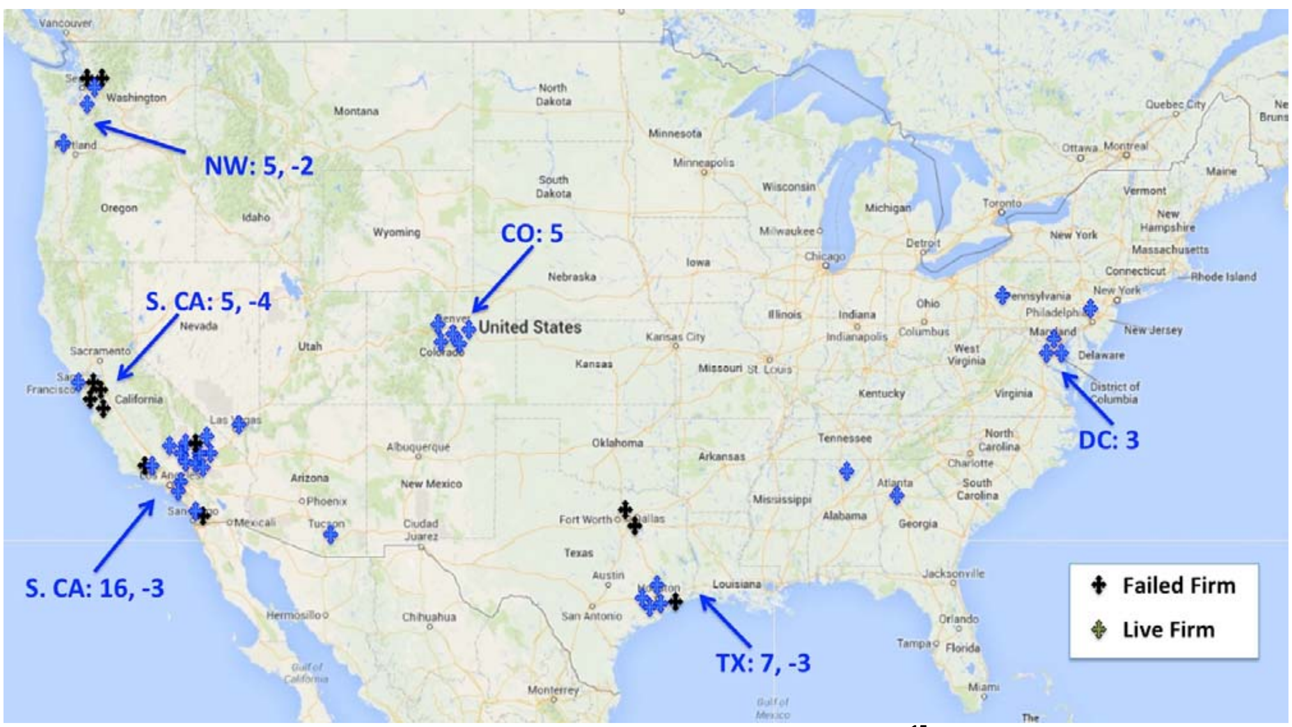

Figure 8. New Space Clusters (Total, Failed Firms) [15]

---

[15] The designation of firms as "New Space" or "significant" is invariably a matter of judgment on the part of the authors. The criteria applied were that that firms or corporate divisions operate in a fee-for-service (not cost plus) market and possess revenue, employees or a permanent physical location.

VIII. Chance and Government

Porter identifies two forces external to the diamond model that influence industry competitiveness: *chance* and *government*.

Chance
The future outcomes of chance are by definition unquantifiable. The past influence of chance includes the already documented distribution of basic resource endowments. It might also be noted that the commercial HOM market is developing at a time that appears to be most fortuitous for American firms. However, this is highly coincidental with the increasing capabilities and media attention garnered by the success of these emerging firms.

Government
The U.S. government has officially supported commercial activity in space since the enactment of the Commercial Space Launch Act of 1984[xcix], which was intended to "facilitate commercial space launches" and to limit the regulation of launches in compliance with international treaties, insurance of public safety and the interests of national security. This act directed the Department of Transportation (DOT) to establish an executive agency to handle all commercial space launch licensing and activities. The FAA's Office of Commercial Space Transportation currently maintains this role.

Congress has repeatedly reinforced its support for commercial space launch. The 1990 Launch Services Purchase Act[c] required the use of commercial vendors when appropriate. The 1998 Commercial Space Act[ci] sought "to encourage the development of a commercial space industry in the United States". Human flight was addressed with the 2004 Commercial Space Launch Amendments Act[cii] designed "to promote the development of the emerging commercial human space flight industry."

Several U.S. states and municipalities have sought to facilitate commercial space operations in their jurisdictions by limiting liability or extending tax waivers or other subsidies.

The government has also been a repeated impediment to U.S. private firms. National security and public safety interest have created an extremely regulated business environment. A general sense developed among New Space firms that this market turns the norms of U.S. governance on its head, in that, space launch activities are assumed to be prohibited unless they are explicitly permitted. Cooperation with international customers, partners and suppliers has been troubled by government trade restrictions. (See the section on ITAR).

IX. Areas of Concern

The following are issues impacting U.S. national competitive advantage noted by interviewees as concerns, identified during industry analysis, or noted in previous reports.

Concerns Raised by Interviewees or Noted During Analysis

ITAR and Trade Restrictions

No area of the space industrial base is more controversial than the export restrictions on U.S. space technology under the International Traffic in Arms Regulation regime (ITAR). Calls for ITAR reform have been proliferating for years.[ciii] Based on anecdotal observation, the vast majority of commercial space executives feel that ITAR unduly punishes U.S. firms in the global market place and stimulates foreign competitors, particularly in regards to satellite manufacturing. It has also been cited as a complication in accessing the global supply chain. In particular, this has involved the need for sharing design information to facilitate the integration of major foreign assemblies into U.S. vehicles.

In regards to ITAR, a 2012 Aerospace Industries Association paper states, "If we continue on this path, without implementing the right reforms, our nation risks the scenario of a weakened space industrial base that is unable to fully meet U.S. national security needs or sustain our technological edge against foreign competitors."[civ]

U.S. space firms are generally very supportive of genuine national security and defense interests. We heard a call for a more practical interpretation of what technologies are truly strategic and actually protectable under the unilateral control of U.S. policy as well as for differentiating more clearly between hostile and non-hostile foreign suppliers and customers.

The analysis of this study also notes that there is a potential upside in restrictions on foreign suppliers and partnerships in fostering a nascent industry and developing strong domestic customers. Reserving the world's largest space customer (the U.S. government) and most significant commercial market will produce short-term competitive advantage for domestic firms. Similar industry specific trade protections (formal and informal) have been very successfully implemented by many developing nations, notably the "Asian tigers" to secure footholds in strategic industries formerly dominated by the U.S and Europe. The collapse of many U.S. strong technology industries (e.g. electronics manufacturing, chip fabrication, solar panel production) competing under a free trade model in the face of heavily protected foreign competitors should not be understated. The traditional trade correction mechanisms (bilateral negotiations, counter-sanctions, WTO complaints) have been too slow and non-responsive to defend U.S. firms. Success with U.S. complaint filings often comes long after the American firm has either collapsed or offshored its production to the competing nation.

Porter acknowledges this success of the protectionist strategy in cases, but strongly cautions that *sustained protection* of domestic industries engenders dependency, stifles innovation, makes domestic products less compatible with the global market and produces weaker competitors in the long-term (Porter, 2011: lc. 13361).

Small Shop Suppliers

The bottom tiers of the aerospace supply chain contain many small, independent shops that produce items including machined metal parts and wiring assemblies. This model has worked well for an industry that produces relatively few copies of unique, custom pieces.

Interviewees expressed concern with the ability of their small parts suppliers to meet production schedules and maintain quality in the transition from low-volume specialty production to a rate-based model.

Engineers and machinists with experience in very large aerospace firms often establish these small businesses. Limited access to capital and debt as well as lack of experience with the management of high-growth, mid-size businesses can be a challenge in scaling these operations effectively.

Supply of Senior Aerospace Engineers

Interviewees expressed concern with the supply of management-qualified engineers. The cyclical nature of the space and defense industries has created an aerospace workforce that is notably mature.[cv] Many engineers began their career during the heyday of the space race in the 1960s and early 70s. They are now approaching retirement. The layoffs of the post-Apollo period induced relatively few younger engineers to replace them. While new engineers are now joining the industry there is a gap in engineers aged 30 to 50 who would normally fill management positions.

Supply of Skilled Production Workers

Interviewees expressed some concern that a general decline in U.S. manufacturing capacity driven by offshoring of such work has resulted in a lack of experienced young machinists, CNC operators and production engineers.

U.S. Military Budget Cuts

The military aerospace industries are extremely important to the shared aerospace supply chain that feeds the HOM and other New Space industries. The volume of demand from immature New Space firms alone is insufficient to support the operation of many lower tier suppliers. These suppliers require additional customers and for most of them, military projects are their mainstay business. Continually shrinking federal budgets have placed significant pressure on the U.S. Department of Defense. A permanent decline in the defense aerospace industries is assumed. This is a growing concern for the supply chain.

Additionally, military R&D has long been an important source of innovation for commercial aerospace businesses. Jet engines, radar and the global positioning system are examples of many spinoffs from military investment that are critical to the commercial sector. The military also provides New Space firms with important infrastructure including the GPS constellation and launch sites.

Inconsistent Government Support

Many New Space advocates have noted that political conflicts and apparent regional favoritism have resulted in unpredictable budgeting for programs executed under the Commercial Space Act Agreements. Specifically, while the President has advocated full funding of the CCDev / CCiCap programs, forces in the U.S. Congress have sought to derail that funding each year, often to maintain work at NASA centers or production facilities in their districts or states. Budget negotiations drag on for months, and place New Space firms in an environment of demand uncertainty. This uncertainty creates business risk that is likely to dissuade investment in U.S. space firms (Autry, 2013).

It was also noted that development of the SLS system effectively establishes a state-owned launch services enterprise that will capture government crew opportunities that private firms might otherwise exploit. Worse, with the SLS lacking a specific mission goal and facing ever tighter federal budgets, the program may choose to fill its manifest and justify its overhead by competing with the private sector for the commercial launches in the HOMs. Introduction of a large governmental competitor into a nascent market creates an extremely undesirable economic situation.

Governmental Market Distortions Disrupt Clustering

The U.S. political system has long favored spreading NASA Research Centers, grants and contract awards, across multiple states. A major reason for this is the effort to secure broad congressional support for federal space programs through the creation of local jobs. This has resulted in a space infrastructure that is inefficiently distributed across the United States with long supply chains and logistical inefficiencies. It has also impeded the natural formation of industry clusters, which as noted earlier are important sources of national competitive advantage.

In the New Space environment, the variation in state regulatory environments and the intentional use of state and municipal subsidies to lure New Space firms into new areas impedes the organic organization of firms into natural clusters.

A notable example is the planned relocation of XCOR Aeropsace from the major New Space cluster in Mojave, California to an isolated location in Midland, Texas. XCOR's development at Mojave was an outcome of natural clustering, being one of the firms benefiting from the distribution of employees of the failed Rotary Rocket. XCOR CEO, Jeff Greason, has cited both California's burdensome regulatory environment and incentives from Midland as influential to this move.[cvi]

A number of states and municipalities across the country have set their sights on capturing New Space firms to their technology development zones or proposed spaceports with tax incentives or outright subsidies. While potentially beneficial for these jurisdictions, the distributive effect reduces overall U.S. national competitive advantage.

The significant variation between states in regards to labor, environmental and safety regulations also threatens to disrupt cluster formation. California, the location of the dominant New Space cluster, is often listed as among the least "business" friendly states in the Union.[cvii] It has been noted as possessing particularly inflexible emissions regulations, which impede engine testing and a Division of Occupational Safety and Health (Cal-OSHA) that duplicates the burden of the Federal agency (OSHA).

While the United States enters the New Space era with a significant nascent cluster in Southern California, the U.S. is at a competitive disadvantage in sustaining cluster growth when competing against nations possessing more homogenous tax and regulatory regimes and those that strategically plan industry clustering. Specifically, China[cviii] has implemented government-directed industry clustering with great success and obtained world dominating competitive advantage in several industries (Navarro, 2011). It should be presumed that if China chooses to pursue a commercial approach to the HOM industries it would follow a similar strategy.

Critical Supply Chain Elements from China

This study has identified two critical supply chain components in which the U.S. is dependent on China: REEs and Solar Panels. China has already demonstrated its willingness to disrupt the flow of REEs to trading partners in response to a minor dispute involving a single fishing vessel impounded by Japan. This incident impacted the Japanese electronics and auto industry supply chains (Navarro & Autry, 2011).

Given China's increasingly competitive geopolitical position vs. the U.S. and the potential for either bilateral trade disputes or counter-entanglements in several growing regional territorial conflicts[16], the situation poses the risk of a supply chain interruption for lower tier U.S. HOM spacecraft suppliers in a number of assemblies. This places U.S. HOM manufacturers at risk.

Rare Earth Elements

Until the late 1990s, the Mountain Pass mine in California produced more than 80% of the world supply of REEs. Extremely aggressive extraction and pricing by Chinese state owned firms in the early 2000s resulted in closure of the Mountain Pass. American industry is now entirely dependent on imported REE supplies (Navarro & Autry, 2011). Current mine owner, Molycorp, reports that it is nearly ready to resume production at Mountain Pass under its Project Phoenix Phase I effort. However, the full production, Phase II effort, appears to be stalled due to declining REE prices.[cix]

With more than 90% of global REE market held by China, U.S. HOM firms are subject to a supply chain risk with variety of electronic and navigation assemblies as well as components utilizing high powered magnetic coupling, sensors and specialized metal alloys.

Solar Panels

Domestic or allied producers of specialized, space grade, solar panel assemblies require a robust supply chain, which their relatively small industry does not support. This supply chain is significantly supported by the related commercial, land based solar panel manufacturing business. The majority of that industry and much of its related supply chain relocated to China. In 2012, the U.S. produced 3% of commercial PV solar modules while China produced 64%.[cx] Eventually multinational firms are likely to move solar R&D investments closer to the source of production, putting the American technological advantage at risk.

Counterfeits and National Security

The dominance of China as a supplier for electronic components is an issue for reasons of quality control and national security. Counterfeit or compromised components have found their way into the military and space supply chains.[cxi],[cxii] Fearing quality or security compromises in from components, interviewees noted they make special efforts to maintain a "China free" supply chain.

Russian Engine Supply

The U.S. and Russia have enjoyed several decades of successful cooperation in space, including construction, operation and supply of the ISS. Russia is currently the only source of crew transport services for NASA and has increasingly sought business supplying U.S. space manufacturers with a variety of proven materials, components and assemblies developed by the Soviet and Russian space agencies.

[16] The U.S. and China have engaged in varying levels of direct and proxy conflict regarding the Korean Peninsula and the Taiwanese Straights since the 1950s. Tension has also developed in the East and South China Seas. U.S. and allied naval vessels have had recent incidents with China in international waters and in areas claimed by Japan and the Philippines.

Russian built, closed-loop Kerolox engines have long provided higher performance in a smaller package than comparable U.S. Kerosene based engines.[cxiii] RD-180 rocket motors – produced by state-owned NPO Energomash under a joint partnership with Rocketdyne called RD-AMROSS – have proven to be a very reliable first stage engine for the ULA Atlas V and have significantly reduced costs for that vehicle. However, advocates of a fully domestic or allied military supply chain have expressed skepticism of this model.

Since the rise of the Putin regime, tensions have occasionally flared between the U.S. and Russia. On August 27, 2013 Russia's RT News reported that Russia's Security Council was considering halting the export of RD-180 engines.[cxiv] Though no official connection was made, the timing was highly coincidental given the low point in U.S. - Russian relations at the time[cxv] (tensions over Syria and Edward Snowden.)

Buffering against a supply interruption or delay, ULA maintains a significant inventory of engines. Two or more years has been suggested in news reports.[cxvi] The eventual domestic production of RD-180 type engines has also been discussed as a solution. ULA is also prepared to transfer unmanned launches to its Delta launch vehicle. While the Delta is not human rated, it could conceivable acquire this rating.[cxvii]

A similar issue may exist with the Aerojet AJ26 motor currently used in the first stage of the Orbital Sciences Antares launch vehicle. The AJ26 is based on remanufactured Soviet NK-33 motors shipped from Russia. With a limited supply of these engines, Orbital has sought access to the RD-180 supply as well as requesting resumption of production of the NK-33 in Russia.

This engine dependency on Russia poses a potential risk of a major supply chain interruption for U.S. HOM launch vehicle manufacturers.

Solid Rocket Motors

Some interviewees noted there has been general concern with the Solid Rocket Motor (SRM) supply chain. Several DOD and Congressional reports have also highlighted the shrinking SRM industrial base. Specifically, reduced opportunities in the large SRM (40in. +) market due to the lack of development of a new U.S. launch systems. U.S. ICBM programs have not seen a new missile developed in decades (Minute Man III circa 1968 and Trident D5 circa 1987). Additionally cancellation of the kinetic interceptor program, retirement of the Space Shuttle and cancellation of NASA's Ares launch vehicle reduced opportunities for SRM producers. Between 1995 and 2004, the number of prime contractors for SRMs shrank from six to just two firms, with only ATK and Aerojet currently producing SRMs in the U.S.[cxviii]

Further, the only North American manufacturer of Ammonium Perchlorate (AP), the primary SRM fuel, is a WECCO plant in Utah.[cxix] WECCO, a division of American Pacific Corporation (AMPAC) had a fatal explosion at this site in 1997. In 1988 the PEPCON division of AMPAC was completely destroyed in a major AP production accident that killed 3 and injured over 300.[cxx] Despite WECCOs improved safety record over the last decade, dependence on a single domestic plant represents a significant supply chain risk for HOM firms that utilize SRMs.

In this regard, the NASA manned exploration program, which continues use of the Space Shuttle derived SRM boosters in SLS, constitutes a significant supportive industry for the commercial space supply chain.

RP-1 Supply Chain

RP-1/LOX appears to be emerging as the "fuel/oxidizer combination of choice" for commercial orbital launch vehicles, particularly in first-stage engines. SpaceX, ULA and Orbital have all standardized on this propellant mix.

The national supply chain for RP-1 appears to be both a distribution and production monopoly. Our review indicates that the Defense Energy Support Center (DESC), a division of the U.S. government Defense Logistics Agency, is the sole distributor and Johann Haltermann, Ltd. a division of Monument Chemical, is the only producer. It appears that there is only one production facility, located in Houston, Texas.

Monopolies present a supply risk, a national security risk, repress innovation and decrease economic inefficiency through lack of competition. Industries that develop in domestic monopolies are less competitive in international markets (Porter, 2011).

In a free global trade regime, this monopoly would reduce U.S. national competitive advantage in HOM. However, it should be noted that RP-1 supplies in competing nations likely to be governmental monopolies of both production and distribution.

Concerns Noted by Other Studies

Tauri Group Report on Space Industrial Base

Several "technology risk areas" were noted in a 2012 paper entitled *Trends and Dynamics in the Lower Tiers of the U.S. Space Industrial Base* presented to the AIAA SPACE 2012 Conference by Dolgopolov, Maliga & Smith of the Tauri Group. That paper reported on the insights from a significant study produced for Deputy Assistant Secretary of Defense for Manufacturing and Industrial Base Policy (MIBP) by Tauri. The Tauri report lists both new risk areas and those identified by proceeding studies.

Although the scope of the Tauri study was broader (encompassing the entire U.S. space industrial base), with alternate focus (specifically examining satellite launch systems and military objectives), interviewees agreed that the overlap of technology in launches systems and spacecraft is significant enough to rank these as areas of concern for U.S. national competitive advantage in HOM.

Tauri concerns included the items listed below.

◆Space qualified Solar Cell Glass covers and Solar Optical Reflectors

◆High-energy radiation detectors (Cadmium zinc telluride)

◆Ammonium Perchlorate for solid fuel rocket motors (previously detailed)

◆Space qualified electronic subcomponents including potentiometers, optical encoders and traveling wave tubes

◆Space qualified mechanics for launch vehicles including: Harmonic drive transmission, torque rods, and slip rings.

◆Rayon based carbon cloth phenolic

Additional details can be found in the aforementioned Tauri publication (Dolgopolov, Maliga & Smith, 2012) and the *2012 Department of Defense Annual Industrial Capabilities Report to Congress*, which incorporate the findings of that study. Further information can be found in the 2011 presentation entitled *U.S. Industrial Base Analysis for Space Systems* presented at the 2011 Defense Manufacturing Conference.[cxxi]

X. Conclusions

The conclusion of this study is that the United States holds a very significant competitive advantage in Human Orbital Spaceflight Markets. Rarely has a nation held such a richly appropriate combination of resources, skill, experience and infrastructure in the face of new industry emergence.

The four determinants of the Porter diamond model are mutually reinforcing in the U.S. HOM industries.

U.S. firms have the advantage of a captive customer in the government crew transportation business, which constitutes the single largest opportunity in the HOM market. Further, U.S. firms enjoy a "home field" advantage in domestic demand from the largest national market of corporate and individual consumers, as well as substantial national credibility in the global market.

As this study has shown, the U.S. is endowed with nearly every appropriate natural resource required to support a vibrant HOM industrial base. Access to others is at hand through global markets with friendly trading partners. The U.S. already possesses technological superiority in nearly every significant spacecraft technology[17] and is poised to gain in several areas. The U.S. higher education system is capable of supporting the demands of the HOM industries.

The United States has an entirely sufficient national infrastructure for HOM activities as well as a uniquely diverse set of valuable space specific facilities and assets. The U.S. federal government is supportive of making these facilities available for private use. State and local governments are actively developing supporting infrastructure for New Space operations.

The American business environment is well suited to developing strong HOM competitors. Capitol and financing are abundant; presuming investors and lenders can be convinced of the viability of the HOM industries. The U.S. has a strong advantage in a number of industries that support the HOM supply chain.

Porter might suggest that the United States is actually too well endowed, lacking the sort of *selective factor disadvantages* that drive innovation through the attempt to overcome some important yet surmountable shortcoming. (Porter, 2011: 2218). At present the absence of such a challenge does not appear to be impeding America's space entrepreneurs.

[17] With the noted exception of rocket engine performance held by Russia's closed-loop kerolox systems.

Acknowledgements

The authors wish to thank the following organizations: *Commercial Space Flight Federation, Orbital Sciences Corporation, Sierra Nevada Corporation, Space Exploration Technologies, United Launch Alliance, and XCOR Aerospace.*

(This acknowledgement does not attribute any specific statements or positions, nor does it imply an endorsement of this study or its conclusions by any organization, firm or individual.)

Appendices

A. Common Space Acronyms

AP – Ammonium Perchlorate, a primary solid rocket fuel
CBC – Common Booster Core (RS-68 engine / 1st stage Delta IV)
COTS – Commercial Orbital Transport Services, a program funded by NASA to spur reliable private re-supply services to the ISS. SpaceX, Orbital Sciences are funded COTS participants which have completed demonstration flights.
CCDEV – Commercial Crew Development Program, a NASA program supporting the development of independent fee for service orbital spaceflight firms capable of transporting government crew to and from the ISS. Blue Origin, Boeing, Paragon, Sierra Nevada, ULA.
CCiCap – Commercial Crew Integrated Capabilities, the 3rd phase of the CCDev Space programs under the Space Act Agreement. Sierra Nevada Corporation, Boeing, and SpaceX have are participants.
CCtCap – Commercial Crew Transportation Capability Contract, A FAR (traditional Federal Acquisitions Regulation contract) based extension to CCDev/CCiCap.
ISS – The International Space Station
ITAR - International Traffic in Arms Regulation regime, export controls on munitions including most rocket and space technology
LES – Launch Escape System
LH2 – Liquid hydrogen used as a rocket fuel.
LOX – Liquid oxygen used as an oxidizer in rocket engines.
N2O – Nitrous Oxide used as an oxidizer in hybrid rocket motor for suborbital flight.
RP1 – Highly refined kerosene used as a rocket fuel.
SLS – Space Launch System, the current NASA manned spacecraft and launch vehicle development program.
SRM – Solid Rocket Motor
ULA – United Launch Alliance, the assembler and operator of the Delta and Atlas launch vehicles.

B: Note on Citing of e-Books

Electronic books (e-books) have been referenced in this paper. Following what are believed to be current best practices in a developing field, and in keeping with recommendations from the Modern Language Association (MLA), guidelines 5.7.18[18]*, specific e-book references have been cited with chapter numbers rather than page numbers (e.g. Corbin & Strauss, 2008: Ch. 9). Additionally, where possible, Kindle Location notes have been added to chapter notations (e.g.Corbin & Strauss, 2008: Ch. 9, Lc. 2707, indicating Chapter 9 and Kindle location 2707).*

[18] http://www.mla.org/style/handbook_faq/cite_an_ebook

References

Autry, G. (2013). *Exploring New Space: Governmental Roles in the Emergence of New Communities of High-Technology Organizations*. PhD dissertation, University of California, Irvine.

Bureau of Labor Statistics Glossary, online, accessed 10/20/13, http://www.bls.gov/bls/glossary.htm#L

Christensen, C. (1997). *The innovator's dilemma: when new technologies cause great firms to fail*. Cambridge: Harvard Business Press.

Davidian, K. (2012) *Space Industrial Base.* Presentation to NASA Institute for Rocket Propulsion Studies, Senior Steering Group Meeting June 12-13.

Davidian, K., & Di Pippo, S. (2013). *An Outline of the Study Group 'Public/Private Human Access to Space'*. IAC.

Dolgopolov, A., Maliga, K., & Smith, P. (2012). Trends and Dynamics in the Lower Tiers of the U.S. Space Industrial Base. *AIAA SPACE 2012 Conference & Exposition*. Pasadena: AIAA.

Dubbs, C. & Paat-Dahlstrom, E. (2011). *Realizing tomorrow: The path to private spaceflight. Lincoln*, NE: University of Nebraska Press

Fairlie, R. W. (2012). Immigrant Entrepreneurs and Small Business Owners, and their Access to Financial Capital. *Washington: U.S. Small Business Administration*.

Futron Corp. (2002). *Space Tourism Market Study: Orbital Space Travel & Destinations with Suborbital Space Travel*.

Harrison, Glennon J. (2012). *The Commercial Space Industry and Launch Market*. Congressional Research Service Report for Congress. R42492

Navarro, Peter & Autry, Greg. (2011). *Death by China: Confronting the Dragon, a Global Call to Action.* Upper Saddle River, New Jersey: Prentice Hall

Porter, M. E. (2008). *Competitive advantage: Creating and sustaining superior performance.* New York: Simon and Schuster.

Porter, M. E. (2011). *Competitive Advantage of Nations: Creating and Sustaining Superior Performance*. New York: Simon and Schuster.

Szafran, R. F. (2002). Age-adjusted labor force participation rates, 1960-2045. *Monthly Lab. Rev.*, *125*, 25.

Tauri Group. (2012) *Suborbital Reusable Vehicles: A 10-Year Forecast of Market Demand*

Passel, J. S., D'Vera Cohn, G. B. A., & Gonzalez-Barrera, A. (2012). *Net Migration from Mexico Falls to Zero--and Perhaps Less*. Pew Research Center.

PISA, L. F. (2010). *Strong Performers and Successful Reformers in Education.*

PISA (2012). *What Students Know and Can Do: Student Performance in Mathematics, Reading and Science.*

OECD (2013) *Education at a Glance, Unite States Country Note.*

Skirbekk, V. (2004). Age and individual productivity: A literature survey. *Vienna yearbook of population research*, 133-153.

Walker, C. D. (2006, November 7). Interview with Charles D. Walker. (S. Johnson, Interviewer) *NASA Johnson Space Center Oral History Project*.

---

[i] http://data.worldbank.org/indicator/IC.BUS.EASE.XQ

[ii] http://www.forbes.com/lists/2011/6/best-countries-11_land.html

[iii] http://rankings.ft.com/businessschoolrankings/global-mba-ranking-2013

[iv] http://www.spacenews.com/article/civil-space/34107arianespace-chief-likely-to-take-french-space-agency-helm (accessed 12/31/13)

[v] http://www.thespacereview.com/article/375/1 (accessed 1/10/14)

[vi] http://www.usnews.com/news/articles/2013/01/31/regulation-reform-may-help-commercial-spaceflight (accessed 12/31/13)

[vii] http://www.incredible-adventures.com/space-survey/space-adventurers-survey.pdf (accessed 1/2/14)

[viii] Aggarwal, Barnum, Emigh, Nguyen, Tinker, Werner survey conducted by MBA students working with this study's author. Results available on request to gautry@uci.edu

[ix] http://www.spaceadventures.com/index.cfm?fuseaction=news.viewnews&newsid=827 (accessed 1/4/14)

[x] http://www.dailymail.co.uk/tvshowbiz/article-2212535/Sarah-Brightman-outbids-NASA-join-space-expedition.html (accessed 12/31/13)

[xi] http://web.archive.org/web/20100102213413/http://astronautix.com/craft/dsealpha.htm

[xii] http://www.spacenews.com/article/end-soyuz-deal-near-nasa-explores-limited-options

[xiii] http://www.nbcnews.com/id/6640347/#.Un_1DKWLc8M

[xiv] http://www.spaceref.com/news/viewpr.html?pid=18128

[xv] http://blogs.nasa.gov/bolden/2013/04/30/post_1367334429451/

[xvi] http://news.google.com/newspapers?nid=1817&dat=19780826&id=OkggAAAAIBAJ&sjid=-p0EAAAAIBAJ&pg=5039,6208016

[xvii] http://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0CCgQFjAA&url=http%3A%2F%2Fwww.nasa.gov%2Fmission_pages%2Fasteroids%2Finitiative%2F&ei=19a-UtOPIszrkAevwoHIDA&usg=AFQjCNFAcSftgUILqm7V4zcq6MOf537mCA&bvm=bv.58187178,d.eW0 (accessed 12/28/13)

[xviii] http://www.nss.org/settlement/physicstoday.htm (accessed 12/27/13)

[xix] U.S. Census Population Clock accessed 11/10/13 http://www.census.gov/popclock/

[xx] Central Intelligence Agency accessed 11/10/13 https://www.cia.gov/library/publications/the-world-factbook/rankorder/2119rank.html

[xxi] http://online.wsj.com/news/articles/SB10001424127887323375204578270053387770718

[xxii] http://online.wsj.com/news/articles/SB10001424127887323375204578270053387770718

[xxiii] http://www.sba.gov/advocacy/7540/141841

[xxiv] http://refugeeandimmigrantnetwork.wordpress.com/2012/08/02/358/

[xxv] http://www.nytimes.com/2012/04/24/us/mexican-immigration-to-united-states-slows.html

[xxvi] http://www.popularmechanics.com/science/space/nasa/4318625

[xxvii] http://www.pbs.org/newshour/rundown/2013/11/chinese-students-boost-us-universities-to-all-time-high-foreign-enrollment.html

[xxviii] http://www.cnn.com/2012/02/09/opinion/bennett-stem-education/

[xxix] http://ieeexplore.ieee.org/xpl/login.jsp?tp=&arnumber=5752953&url=http%3A%2F%2Fieeexplore.ieee.org%2Fxpls%2Fabs_all.jsp%3Farnumber%3D5752953

[xxx] http://cra.org/uploads/documents/resources/taulbee/CRA_Taulbee_CS_Degrees_and_Enrollment_2011-12.pdf

[xxxi] http://cra.org/uploads/documents/resources/taulbee/CRA_Taulbee_CS_Degrees_and_Enrollment_2011-12.pdf

[xxxii] http://www.voanews.com/content/iea-us-worlds-biggest-oil-producer-by-2016/1788573.html

[xxxiii] http://www.rand.org/content/dam/rand/pubs/monograph_reports/MR1707/MR1707.ch3.pdf

[xxxiv] http://www.eia.gov/tools/faqs/faq.cfm?id=29&t=6

[xxxv] http://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=MOPUEUS2&f=M

[xxxvi] http://www.cfr.org/oil/case-allowing-us-crude-oil-exports/p31005

[xxxvii] http://www.eia.gov/conference/2013/pdf/presentations/powell.pdf

[xxxviii] http://www.nma.org/pdf/economic_contributions.pdf

[xxxix] http://www.bgs.ac.uk/downloads/start.cfm?id=1574

[xl] http://minerals.usgs.gov/minerals/pubs/commodity/titanium/stat/

[xli] http://agmetalminer.com/2013/04/03/why-us-tantalum-imports-and-prices-are-skyrocketing/

[xlii] http://www.nytimes.com/gwire/2009/06/09/09greenwire-imported-minerals-metals-fuel-us-shift-to-home-57275.html

[xliii] http://seekingalpha.com/article/1106271-molycorp-the-pain-is-here

[xliv] http://www.ihdp.unu.edu/article/iwr/

[xlv] http://www.thefinancialist.com/wp-content/uploads/2012/10/2012-GlobalWealthReport-.pdf (accessed 12/26/13)

[xlvi] http://www.forbes.com/sites/dalearcher/2013/09/04/could-americas-wealth-gap-lead-to-a-revolt/ (accessed 12/26/13)

[xlvii] http://media.bloomberg.com/bb/avfile/rxfIKJLQ7yMA (accessed 12/26/13)

[xlviii] http://www.usdebtclock.org/# (accessed 12/25/13)

[xlix] http://spaceportamerica.com/press-release/nasas-sl-8-rocket-flight-becomes-spaceport-americas-20th-launch/

[l] http://www.stratolaunch.com

[li] https://www.google.com/#q=nasa+wind+tunnel+test+dreamchaser (accessed 12/26/13)

[lii] http://www.nbcnews.com/science/spacex-wins-nasas-nod-take-over-historic-launch-pad-39a-2D11741834

[liii] http://www.wired.com/autopia/2012/05/the-rocket-factory-spacex-builds-them-from-top-to-bottom/ (accessed 12/26/13)

[liv] https://www.cia.gov/library/publications/the-world-factbook/rankorder/2108rank.html (accessed 12/26/13)

[lv] e.g. http://www.huffingtonpost.com/2011/07/27/transportation-infrastructure-cost_n_911207.html

[lvi] http://www.jec.senate.gov/public/index.cfm?p=Hearings&ContentRecord_id=0a406522-5fdd-4bc6-bda0-a0741e5a3d24 (accessed 11/25/13)

[lvii] http://www.parabolicarc.com/2014/01/08/esa-outlines-cooperation-sierra-nevada-dream-chaser/ (accessed 1/8/13)

[lviii] http://www.sunshinestatenews.com/story/nevada-aerospace-company-aims-florida

[lix] http://www.nasa.gov/press/2013/july/nasa-commercial-crew-partner-spacex-completes-two-human-critical-reviews/#.UqoI_qWLfRo

[lx]http://www.orbital.com/NewsInfo/release.asp?prid=869

[lxi] http://www.nasa.gov/exploration/systems/sls/eft1_ksc.html

[lxii] http://www.spacenews.com/article/spacex-undercut-competition-clinch-head-turning-iridium-deal (accessed 12/29/13)

[lxiii] http://spaceflightnow.com/news/n1003/15nk33/

[lxiv] http://www.nasa.gov/offices/c3po/partners/spacex/index_prt.htm (accessed 1/2/14)

[lxv] http://www.spaceflight101.com/soyuz-fg.html (accessed 1/2/14)

[lxvi] http://www.manta.com/mb_34_G0295_000/space_research_and_technology (accessed 12/29/13)

[lxvii] http://www.spacecolorado.org/companies-projects/directory.aspx (accessed 12/29/13)

[lxviii] http://www.californiaspaceauthority.org/membership/membership-list (accessed 12/29/13)

[lxix] http://virtualskies.arc.nasa.gov/navigation/4.html (accessed 1/2/14)

[lxx] http://www.honeywell.com/sites/aero/Inertial_Navigation_Products3_CC2561849-4833-AC45-9714-E381D2C8E291_H2F689D55-70D9-172D-9672-4BEB35100A5B.htm (accessed 1/2/14)

[lxxi] http://www.spacewar.com/reports/Northrop_Grumman_Stellar_Navigation_System_Makes_Its_First_Flight_On_RC_135_Aircraft_999.html (accessed 1/2/14)

[lxxii] http://www.microsemi.com/documents/products/Microsemi_Space_Solutions.pdf (1/4/14)

[lxxiii] http://www.honeywell.com/sites/aero/Avionics_Electronics.htm (accessed 1/4/14)

[lxxiv] http://www.geaviation.com/press/other/other_20070504.html (accessed 1/4/14)

[lxxv] http://www.ibisworld.com/industry/default.aspx?indid=633 (accessed 12/30/13 via UCI VPN)

[lxxvi] http://www.compositesworld.com/articles/the-markets-pressure-vessels-2012 (accessed 12/22/13)

[lxxvii] http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/2012_market_report.pdf (accessed 12/30/13)

[lxxviii] http://www.washingtonpost.com/business/the-global-market-for-solar-cells/2011/12/16/gIQATywQyO_graphic.html (accessed 12/30/13)

[lxxix] http://www.fas.org/sgp/crs/misc/R41709.pdf (accessed 12/30/13)

[lxxx] http://www.nasa.gov/mission_pages/station/news/beam_feature.html (accessed 1/2/14)

[lxxxi] http://www.space.com/19291-inflatable-alpha-station-bigelow-aerospace.html (accessed 1/4/13)

[lxxxii] https://www.fbo.gov/index?s=opportunity&mode=form&id=d776bfdf8afabea49f5a2c2847c88519&tab=core&_cview=1

[lxxxiii] http://www.eia.gov/oiaf/servicerpt/hydro/appendixc.html

[lxxxiv] http://business.highbeam.com/industry-reports/chemicals/industrial-gases

[lxxxv] http://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm?tid=3&pid=3&aid=6

[lxxxvi] http://www.us.airliquide.com/en/brochure-and-video-library/on-site-hydrogen-production-1.html

[lxxxvii] http://www.vtnews.vt.edu/articles/2013/04/040413-cals-hydrogen.html?utm_campaign=Argyle%2BSocial-2013-04&utm_content=shaybar&utm_medium=Argyle%2BSocial&utm_source=twitter&utm_term=2013-04-04-08-30-00

[lxxxviii] http://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=8_NA_8PH_NUS_6&f=A

[lxxxix] http://www.us.airliquide.com/en/rss/california-air-liquide-starts-up-hydrogen-unit-for-cleaner-fuels.html

[xc] *IBISWorld Industry Report 32512Oxygen & Hydrogen GasManufacturing in the U.S..* Retrieved via http://www.ibisworld.com/industry/default.aspx?indid=459

[xci] http://www.oecd.org/sti/futures/space/48301203.pdf (accessed 1/4/14)

[xcii] http://www.theguardian.com/news/datablog/2010/feb/01/nasa-budgets-us-spending-space-travel (accessed 12/24/13)

[xciii] http://www.spacenews.com/article/civil-space/35638russia-boosting-space-budget-to-surpass-china-equal-europe (accessed 12/24/13)

[xciv] http://www.oica.net/wp-content/uploads/2013/03/worldpro2012-modification-ranking.pdf (accessed 12/30/13)

[xcv] http://www.asymco.com/2013/04/16/escaping-pcs/ (accessed 12/30/13)

[xcvi] http://www.statista.com/statistics/277483/market-value-of-the-largest-internet-companies-worldwide/ (accessed 12/30/13)

[xcvii] http://spaceportcolorado.com (accessed 1/14/14)

[xcviii] http://mashable.com/2013/09/11/houston-spaceport/ (accessed 1/4/14)

[xcix] https://www.govtrack.us/congress/bills/98/hr3942/text (accessed 11/22/13)

[c] http://archive.spacefrontier.org/commercialspace/lspalaw.txt (accessed 11/22/13)

[ci] http://www.nasa.gov/offices/ogc/commercial/CommercialSpaceActof1998.html (accessed 11/22/13)

[cii] http://www.faa.gov/about/office_org/headquarters_offices/ast/media/PL108-492.pdf (accessed 11/22/13)

[ciii] http://csis.org/files/media/csis/pubs/021908_csis_spaceindustryitar_final.pdf (accessed 12/27/13)

[civ] http://www.aia-aerospace.org/assets/CompetingForSpaceReport.pdf (accessed 12/27/13)

[cv] http://www.popularmechanics.com/science/space/nasa/4318625 (accessed 1/4/13)

[cvi] http://www.thespacereview.com/article/2120/1

[cvii] http://www.forbes.com/sites/mikepatton/2013/03/31/the-most-and-least-business-friendly-states/ (accessed 12/27/13)

[cviii] http://blogs.worldbank.org/developmenttalk/china-s-special-economic-zones-and-industrial-clusters-success-and-challenges

[cix] http://www.molycorp.com/about-us/our-facilities/molycorp-mountain-pass/

[cx] http://www.greentechmedia.com/articles/read/Yingli-Gains-Crown-As-Top-Producer-in-a-36-GW-Global-PV-Market

[cxi] http://www.levin.senate.gov/newsroom/press/release/senate-armed-services-committee-releases-report_on-counterfeit-electronic-parts/ (accessed 12/30/13)

[cxii] http://www.hq.nasa.gov/office/codeq/trismac/apr08/day2/hughitt_NASA_HQ.pdf (accessed 12/31/13)

[cxiii] http://www.spacenews.com/article/launch-report/36232space-propulsion-development-of-us-closed-loop-kerolox-engine-stuck-in

[cxiv] http://rt.com/news/russian-rocket-engine-ban-039/

[cxv] http://www.thespacereview.com/article/2384/1 (retrieved 12/29/13)

[cxvi] http://www.spacenews.com/article/military-space/37962military-quarterly-ula-finding-its-stride-in-rocket-production (accessed 1/14/14)

[cxvii] http://www.spacenews.com/article/opinion/37019sn-blog-report-of-possible-rd-180-ban-could-mean-many-things-including-nothing (accessed 1/14/14)

[cxviii] http://www.acq.osd.mil/mibp/docs/presentations/DMC_SRM_brief_Dec_09.pdf (accessed 12/29/13)

[cxix] http://apfc.com/CORP/wec.php (retrieved 12/29/13)

[cxx] http://www.lasvegassun.com/news/1997/jul/31/cedar-city-explosion-kills-one-brings-back-memorie/

[cxxi] previously retrieved from http://www.taurigroup.com/files/U.S._Industrial_Base_Analysis_for_Space_Systems.pdf (no longer an active link) Contact the Tauri Group, 6361 Walker Lane, Suite 100Alexandria, Virginia22310.