Commercial Market Assessment for Crew and Cargo Systems

Pursuant to

Section 403 of the NASA Authorization Act of 2010 (P.L. 111-267)

April 27, 2011

Table of Contents

Executive Summary

NASA prepared this commercial market assessment in response to direction in Section 301b of the National Aeronautics and Space Administration Authorization Act of 2010 (P.L. 111-267). The specific requirements of this report are outlined below and are applicable to NASA's current exploration program.

SEC. 403. Commercial Market Assessment

> *(2) COMMERCIAL MARKET ASSESSMENT.—Not later than 180 days after the date of the enactment of this Act, the Administrator shall submit to the appropriate committees of Congress an assessment, conducted, in coordination with the Federal Aviation Administration's Office of Commercial Space Transportation, for purposes of this paragraph, of the potential non-Government market for commercially-developed crew and cargo transportation systems and capabilities, including an assessment of the activities a ssociated with potential private sector utilization of the ISS research and technology development capabilities and other potential activities in low-Earth orbit.*

In performing this assessment, NASA, in consultation with the Federal Aviation Administration's (FAA) Office of Commercial Space Transportation, incorporated the following assumptions:

- A 10-year time horizon was used.
- The assessment was limited to non-U.S. Government markets (i.e., commercial markets and demand from other countries), per the Authorization Act.
- The assessment focused on commercial crew and cargo "systems" defined as systems intended to deliver crew and cargo to the ISS or other destinations, not elements of the system such as launch vehicles and spacecraft, per the Authorization Act. Thus, systems that deliver communications satellites or similar payloads to orbit were not considered.
- NASA and the FAA relied primarily on publicly-available data sources.
- A range of outcomes is provided, with a lower end reflecting historical trends and an upper end reflecting industry inputs on growth.

This report groups likely commercial cargo and crew markets as follows:

- **National Interests**: This category includes countries lacking indigenous human space transportation capability who desire to send astronauts and cargo into space to perform scientific research, acquire technical knowledge, and increase national prestige.
- **Space Tourism**: This category includes spaceflight participants who are not flying under the direct employment or financial sponsorship of a company or government organization.
- **Applied Research and Technology Development**: This category includes customers interested in space-based research activities aboard in-space platforms, such as the International Space Station (ISS). Such research activities may lead to downstream commercial and/or societal application.
- **Other markets**: This category includes satellite servicing, media and entertainment and education markets.

Based on our review, the estimated total aggregated size of these markets, for non- U.S. Government commercial crew and cargo services over a 10-year period, is reflected in Figure 1:

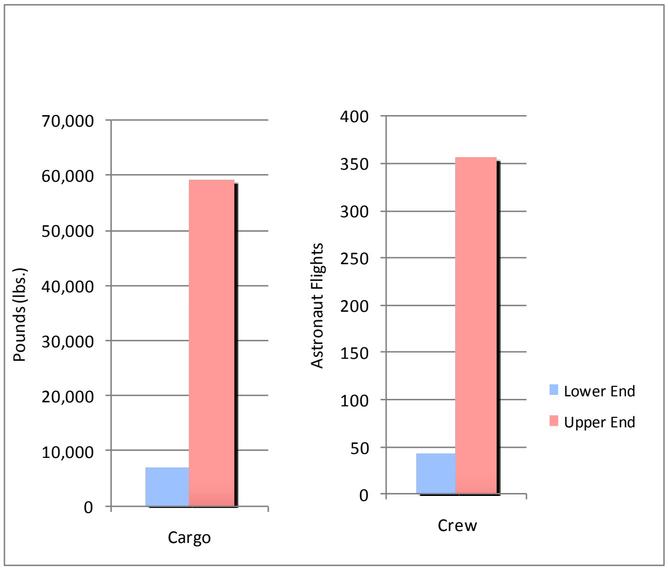

Figure 1: Aggregated Non-U.S. Governmental Markets, Ten Year Total

The “lower end” of the projection is essentially an extrapolation of historical flight rates, assuming there is no change in the historically-demonstrated flight rates for crew and cargo transportation services. The “upper end” of the projection incorporates industry inputs on the potential growth of the markets since industry has done the most analysis on the actual size of the markets and how those markets contribute to their specific business cases. Most likely, the actual flight rates for commercial cargo and crew systems over the next ten years will fall within the lower and upper end of the range. A precise forecast of flight rates would have limited utility at this time because of the major unknowns associated with the systems such as price, availability date, and the technical characteristics of the systems.

To be clear, this report does not characterize the “demand” for commercial cargo and crew services – something that is difficult to quantify at this stage. Instead, this report will show what is best described as “flight rate projections” of cargo and crew systems, constrained in many cases by the available supply and other factors. The actual demand for cargo and crew services could be many times the flight rate projections shown in this report. In addition, these projections do not include NASA ISS crew and cargo needs.

NASA believes that the projections described in this report are more than sufficient to justify Government support for the development and demonstration of commercial cargo and crew systems, especially considering that the U.S. Government has a demonstrated need for commercial cargo and crew transportation to/from the ISS. According to one established aerospace company involved in NASA’s commercial crew efforts, this base Government market alone is sufficient to close its business case. The commercial markets assessed in this report provide a potential upside further strengthening the potential for success. NASA also believes its approach to cargo and crew system development will be more cost effective than a more traditional approach to space system development. (Please see Appendix B.)

NASA’s commercial crew and cargo programs are intended to provide technical and financial assistance to the U.S. industry to develop commercial space transportation capabilities. Additional support is provided by NASA being a long-term customer, providing a market base for commercial crew and cargo services. If successful, these programs will not only help NASA by providing assured access to the ISS and allowing NASA to focus its limited resources on exploring beyond low-Earth orbit (LEO), but it will also help the Nation by strengthening our industrial base, developing a new high-tech industry, and strengthening our economy.

Section 1.0: Introduction

While NASA's commercial cargo efforts have been underway since 2005, and NASA has been purchasing commercial services for robotic spacecraft launches since 1988, NASA is just beginning its Commercial Crew Program. The primary objective of this program is to facilitate the development of a U.S. commercial crew space transportation capability with the goal of achieving safe, reliable, and cost effective access to and from LEO and the ISS. Once the capability is matured and available to customers, NASA plans to purchase transportation services to meet its ISS crew rotation and emergency return needs.

NASA plans to follow an alternative business method that allows U.S. industry more design ownership of their space systems and requires those companies to invest private capital to complement Government funds. This is similar to the approach NASA is using for the commercial cargo effort. NASA plans to award competitive, pre-negotiated, milestone-based agreements that support the development, testing, and demonstration of multiple commercial crew systems with a fixed Government investment. NASA also plans to use a unique Government insight/oversight model featuring a core team of sustaining engineering and discipline experts who closely follow the development of the vehicles. Additionally, NASA plans to use tailored human rating requirements, standards, and processes, with NASA providing the final crew transportation system certification.

This strategy is more of a "commercial like" approach to the development of a crew transportation system than NASA has traditionally pursued. One of the primary benefits of using this approach is its potential for cost effectiveness. NASA has seen the initial signs that this approach does, in fact, reduce costs through the commercial cargo efforts. (Please see Appendix B for a discussion of the cost effectiveness of the commercial cargo activity.)

To reduce the cost to the Government of a commercial program, it is important that the Government not be the only customer. Therefore, NASA is establishing a framework for the commercial crew program that could support multiple customers (e.g., U.S. and international astronauts and personnel, scientists, spaceflight participants) for a variety of reasons (e.g., science, research, station operations, tourism), including NASA personnel as crew or participants. In doing so, the question of other customers becomes important and that is the subject of this report.

Section 2.0: Commercial Crew and Cargo Transportation Systems – Not a New Concept.

The concept of commercial crew and cargo transportation systems has been studied for decades. Through much of the history of the Space Shuttle Program, for example, there have been studies about turning over operations of some or all of the orbiters to the private sector, in order to fly missions for private customers as well as for NASA.

In the mid-2000s, several studies and activities provided new impetus for commercial crew and cargo efforts. The 2004 "Vision for Space Exploration" directed NASA to "pursue commercial opportunities for providing transportation and other services supporting the ISS and exploration missions beyond low

Earth orbit (LEO) …" In 2004, the final report of the President's Commission on Implementation of the U.S. Space Exploration Policy (popularly known as the Aldridge Commission) recommended that the Government take steps to stimulate development of commercial space capabilities, specifically recommending that "NASA recognize and implement a far larger presence of private industry in space operations with the specific goal of allowing private industry to assume the primary role of providing services to NASA, and most immediately in accessing LEO."

In 2005, NASA initiated the Commercial Orbital Transportation Services (COTS) project, an effort to invest financial and technical resources to stimulate efforts within industry to develop and demonstrate safe, reliable, and cost-effective space transportation capabilities, using a fixed Government investment along with industry financial investment to augment the total funding. Under COTS, two companies, Orbital Sciences Corporation and Space Exploration Technologies, Inc. (SpaceX), are actively developing new privately owned and operated cargo transportation systems, including both spacecraft and launch vehicles, which are planned to transport cargo to and from the ISS.

The NASA Authorization Act of 2005 (PL 109-155) directed NASA to study "the means, other than the Space Shuttle and the Crew Exploration Vehicle, including commercial vehicles, that may be used to ferry crew and cargo to and from the ISS." In 2008, the U.S. Congress passed the NASA Authorization Act of 2008 (PL 110-422), which stipulated, "*In order to stimulate commercial use of space, help maximize the utility and productivity of the ISS and enable a commercial means of providing crew transfer and crew rescue services for the International Space Station, NASA shall - - make use of commercially provided International Space Station crew transfer and rescue services to the maximum extent practicable*…"

In 2009, the Review of U.S. Human Spaceflight Plans Committee (commonly referred to as the Augustine Committee) included commercial crew transportation systems in its assessment of options for future human spaceflight activities and found that such systems are "within reach" given industry's current capabilities. "While this presents some risk, it could provide an earlier capability at lower initial and life-cycle costs than government could achieve," the report stated.

In 2010, NASA invested $50 million of stimulus funds under the Commercial Crew Development (CCDev) initiative in five partners to mature commercial crew technologies, concepts, and capabilities (Blue Origin, Boeing, Paragon, Sierra Nevada, United Launch Alliance). On February 1, 2010, the Administration released its Fiscal Year 2011 budget request, which provided $6 billion over the next five years to support the development, testing, and demonstration of multiple commercial crew systems. This was followed in June 2010 by a new U.S. National Space Policy, which directed NASA to "seek partnerships with the private sector to enable safe, reliable, and cost-effective commercial spaceflight capabilities and services for the transport of crew and cargo to and from the ISS."

After considerable debate in Congress, a commercial crew development program was formally endorsed in the NASA Authorization Act of 2010 (PL 111-267), which was signed by the President on October 11, 2010. The law stated, "Congress restates its commitment … to the development of commercially developed launch and delivery systems to the ISS for crew and cargo missions. Congress reaffirms that NASA shall make use of United States commercially provided ISS crew transfer and crew rescue services to the maximum extent practicable."

Section 3.0: A Look at how NASA and the FAA Developed this Report

This study makes a number of assumptions in order to complete a feasible, reasonable market assessment within the time frame of the Congressional language. These assumptions include:

- **A 10-year time horizon**: This report looks out for the next 10 years on the markets. The United States has committed to operating the ISS through 2020, which makes estimates on potential market size extremely uncertain beyond that timeframe. In addition, other uncertainties about the rate of technology development, changes in financial markets, and unforeseen innovations or other disruptions make assessments beyond a 10-year horizon of limited utility. However, potential trends in the markets beyond 10 ten years are discussed later in this report for completeness.
- **Limit to non-U.S. Government markets:** Per the NASA Authorization Act of 2010, NASA is directed to conduct an assessment "of the potential non-Government market" for commercial crew and cargo systems. For the purposes of this report, the term "non-Government" includes commercial users as well as other governments outside the United States.
- **Focus on commercial crew and cargo systems**: The NASA Authorization Act of 2010 specifically mentions "commercial crew and cargo transportation systems", which for this report is interpreted to mean the crew or cargo spacecraft in conjunction with its launch vehicle. In some cases, launch vehicles being developed or upgraded to support commercial crew and cargo systems may have additional applications, most notably satellite launches. Those additional markets are not included in the market assessment, as they do not require the complete crew/cargo system. These markets are discussed later in this report for completeness.
- **Reliance on publicly-available data sources**: Given the 180-day deadline provided in the NASA Authorization Act of 2010, NASA relied on readily available data sources that could be disseminated publicly. Thus, the assumptions and conclusions in this report reflect the current body of knowledge regarding commercial crew and cargo markets as of early March 2011.
- **A range of outcomes is provided:** Because of the uncertainties associated with future commercial crew and cargo markets (described later in this report), the output of this assessment is provided in ranges. The lower ends of the ranges are essentially extrapolations of historical flight rates assuming there is no change in the historically-demonstrated flight rates for crew and cargo transportation services. The upper end of the ranges incorporates industry estimates of the potential growth of the individual markets based on available data, or data willingly shared with NASA for the purposes of this report. Most likely, the actual flight rates for commercial cargo and crew systems over the next 10 years will fall within the lower and upper end of the range.

As mentioned, the upper ends of the ranges were developed by leveraging primarily industry inputs regarding the potential size of the various markets. Industry, not NASA, will bear the ultimate responsibility for developing the commercial markets described in this report; and private industry, not NASA, is where the expertise for market analysis resides. Government estimates of the future size and growth rate of commercial markets have usually been of very limited value. The U.S. Government can facilitate and help enable these markets to grow. But, private industry will have to make it happen.

It should also be noted that the assessment contained in this report does not characterize "demand" for cargo and crew services. Market demand is extremely difficult to assess. For space tourism, the only professional, publicly-available study of demand was the 2002 Futron Space Tourism Market Study. Instead, the assessment in this report incorporates available data and industry assumptions of supply, demand, and other factors to produce flight rate projections for cargo and crew markets. The cargo market is characterized in terms of pounds of cargo flown to space; the crew market is characterized in terms of astronaut flights, also known as "seats." In some cases, actual "demand" could be significantly higher than the flight rate projections shown in this report because demand for commercial cargo and crew transportation will almost certainly be constrained over the next decade by the limited availability of transportation systems, i.e., supply.

Section 4.0: Definition of a Market

The emergence of a price-based market where firms compete to provide crew transportation into orbit around the Earth to private American citizens and corporations has yet to occur. Nonetheless, American aerospace leaders – including Presidents, Members of Congress, NASA Administrators, corporate executives and aerospace engineers – have long discussed and foreseen the emergence of such a market. The question is not so much whether a non-Governmental market for commercial human spaceflight will emerge, but when and how we should expect such a market to develop. This report assesses the near-term potential for non-Governmental markets for spaceflight capabilities. This section provides a brief discussion of the nature of markets and how the forces of demand and supply interact to create them in the context of spaceflight.

Discussions of non-Governmental markets for spaceflight are complicated in part because the term "market" is itself variable and is often used to refer to quite different concepts. In economic terms, a market is a structure that allows for the exchange of goods and services by buyers and sellers. A critical component of a true market is existence of known prices for the goods and services exchanged within it. A market is also defined by having more than one buyer, and more than one seller.

Markets form because they are an efficient way to connect the demand of buyers with the supply of sellers. A critical question with regard to commercial markets for spaceflight thus pertains to the potential non-Governmental demand for spaceflight. When questions are asked regarding the extent of the market for a product, often the heart of that question pertains to the extent of the *demand* for that product. The demand for a product is most commonly expressed as the amount of a product that buyers would like to purchase at a given price.

We have information on the private demand for a one-week stay on the ISS but only when that week costs approximately $35 million, requires six months of training in Russia and when the supply schedule of flights is extremely constrained. What would the demand be if the price was below $10 million, or if the price were more than $100 million, or with more limited training on American soil, or with a more responsive supply system? These questions cannot be answered definitively until the capabilities exist to provide human spaceflight products with actual prices and features.

However, we know that a significant number of people desire to travel into space and we know that many have expressed a willingness to pay significant prices to do so. Given that there is at least some demonstrated demand for non-Governmental human spaceflight, the current lack of commercial spaceflight capabilities may seem to be evidence that the cost and/or other barriers to entry have thus far been too high. But, the development and supply of spaceflight technologies takes time, and it is worth noting that over the past ten years, beginning roughly around the time of the first commercial flights to the ISS, American entrepreneurs and corporations have invested hundreds of millions of dollars of private capital to develop the technologies, production process, and organizations that they believe can profitably supply a market for space transportation, within an acceptable time horizon to the investors. As the knowledge, technologies, processes and communities capable of spaceflight become ever more widespread and competitive, the emergence of non-Governmental markets for human spaceflight is inevitable.

Factors Affecting the Size of Markets

The potential size of the market for commercial crew and cargo transportation is dependent on a variety of factors, including technical, schedule, financial, regulatory, political, accident rates, and miscellaneous. The uncertainties associated with these factors prohibit a single, quantitative forecast of the demand associated with these markets, which is why the size of the markets is characterized as a range of flight rate projections in this report. A discussion of the uncertainties and how they can help or hinder the development of these markets are addressed in the following sections.

Technical Factors

Technical capabilities, including vehicle capabilities and concepts of operation, will play a major role in addressing potential markets enabled by commercial crew and cargo systems. Companies have proposed or are developing a diverse range of crew and cargo vehicle concepts, and each will have its own unique set of capabilities, pricing, training requirements, passenger profiles, and constraints. In addition, NASA is some years away from selecting specific service providers. All of these uncertainties will affect the actual size and growth of the markets for these systems.

Orbital Platforms and Free-Flying Services

The availability of destinations in LEO for these vehicles, including the ISS as well as other proposed commercial destinations, will also affect the timing and size of non-Government markets. In the near-term, the likely primary destination for commercial cargo and crew spacecraft will be the ISS. In addition to the ISS, the development of commercial orbital habitats has been proposed in recent years, most notably by Bigelow Aerospace of Las Vegas, which has thus far invested $215 million of its own money to pursue this market via the development of a next-generation private sector space station that leverages expandable habitat technology (a technology originally conceived of by NASA but developed and put into practice by Bigelow Aerospace). Bigelow launched and fully tested in space two subscale prototypes of its expandable modules and has proposed a series of increasingly ambitious facilities in Earth orbit and beyond using larger versions of those modules. The company has publically announced its plans to deploy an initial space station as early as 2015, with a larger one to follow as early as 2017, pending availability of commercial crew and cargo transportation systems.

Some services would not require a separate orbital platform to visit, i.e., LEO could be considered a destination itself. Space tourism flights, for example, could be carried out by a crewed vehicle without visiting the ISS or another orbital destination; such free flights would be best suited for short-duration missions. SpaceX has proposed a concept called DragonLab that would turn the Dragon spacecraft into a free-flying laboratory carrying experiments for missions ranging from one week to two years in duration before returning to Earth. The wide range of potential platforms and free flying capabilities could greatly affect the size of the commercial crew and cargo markets.

Schedule Factors

Within the 10-year time period analyzed in this study, the size of the commercial cargo and crew markets are dependent on when services become available. NASA has contracted with both Orbital and SpaceX for initial operational flights to ISS, to occur before the end of 2012. From that point forward, those companies will also have the capacity to provide services to other buyers. Both companies have experienced delays, and if operational dates slip further into the future, the amount of flights that could be provided through 2020 will shrink. Beyond the limits of this study, if the lifetime of the ISS is extended, the market for ISS cargo would continue as well.

The availability date of commercial crew services is less clear. Funding availability and technical progress will both play a very large part in when services will become available.

Financial Factors

A major factor affecting market size is the cost to develop the system and the associated price that will be offered to customers. For commercial cargo, most of the development has been completed for the Falcon 9/Dragon and the Taurus II/Cygnus. Also, the initial price that NASA will pay for cargo transportation services has already been determined via the CRS contract awards.

Development costs for potential commercial crew systems are more uncertain. NASA has not requested detailed cost estimates from industry for commercial crew transportation services and selections are some years away. For example, NASA's Commercial Crew Transportation (CCT) Request for Information published on May 21, 2010, included the request: "What is the approximate dollar magnitude of the minimum NASA investment necessary to ensure the success of your company's CCT development and demonstration effort?" Industry responses were proprietary and cannot be released to the public. However, costs estimates from industry had a range of more than 700 percent from the lowest to the highest estimates. The magnitude of the development costs directly relates to the eventual price for services.

Additional uncertainty exists for commercial crew systems because NASA is planning to require industry to provide investment funds as part of any development agreement. The amount of private capital will vary between partners, and this capital could be provided from sources such as private investment, company revenue or venture capitalists.

All these unknowns (development costs, amount of private capital, ROI levels, and payback periods) contribute to a large range and uncertainty in the eventual price that will be established for commercial crew transportation services, which will have a major impact on the market size.

Regulatory and Certification Factors

Commercial spaceflight presents a number of liability risks to providers addressed to varying degrees by the current regulatory regime. Risks associated with the uninvolved public are already addressed by existing regulations. The regulatory regime is far less certain regarding spaceflight participants. Current U.S. law (the Commercial Space Launch Amendments Act of 2004) does require operators of crewed vehicles to obtain the informed consent of any spaceflight participants to be flown prior to launch. However, informed consent may be insufficient to protect commercial crew vehicle operators from liability claims in the event of an accident. This uncertainty may make it difficult for providers to address this liability through insurance or other means.

Not only is the regulatory regime for human space transportation to LEO in development, but NASA's crew transportation system certification requirements that will be used to certify the systems as safe for transporting NASA and NASA-sponsored personnel to and from the ISS are also in development. In December 2010, NASA released the "Commercial Crew Transportation System Requirements for NASA LEO Missions" document that provides a consolidated set of requirements, standards, and processes that will be applied to the certification of a specific commercial crew transportation system for LEO missions. However, the specific certification requirements applied to systems transporting crew to the ISS are still in work, which contributes to uncertainty in costs, pricing, and ultimately market size.

Accident Factors

An accident involving a commercial crew transportation system, particularly a crewed system, would have an adverse impact on both the vehicle operator as well as the overall commercial spaceflight industry. One potential outcome in the near-term, based on experience with accidents involving crewed government-operated spacecraft, is a stand-down of operations while the accident is investigated and corrective actions implemented. The operator would suffer a loss of revenue because of the lack of flights during the post-accident hiatus, as well as expenses involved in implementing corrective actions as a result of an investigation and repair or replacement of the vehicle involved in the accident. The company could also be liable for accident claims from families of the crew and/or spaceflight participants on the vehicle, or business losses from vehicle customers.

These risks could be mitigated at least in part through regulations, such as laws in some states that immunize commercial spaceflight providers to liability claims from spaceflight participants in the event of injury or death, as well as through insurance. However, it is important to note that every mode of transportation has risk that results in loss of human life. If the U.S. is ever to achieve the goal of routine commercial human access to space, then the industry must be able to respond to accidents likes all the other modes of transportation.

Miscellaneous Factors

Other external factors could also influence the market for commercial crew and cargo systems. One such factor is the development of similar systems outside the United States, subsidized partially or entirely by other governments, competing in the same commercial markets as U.S.-developed vehicles. For example, Russia has sold seats on Soyuz spacecraft to commercial customers. In January 2011, Space Adventures, the American company that markets Soyuz seats to commercial customers, announced that Russia would increase the production rate of Soyuz spacecraft from four per year to five, starting in 2013; this could make additional seats available for flights to the ISS. On the other hand, markets sometimes expand faster when there is more competition which may offset some of the affect of more providers.

Development of commercial crew and cargo markets depend in large part on the existence of the ISS as an anchor customer to support development of systems that can also serve those markets. An accident or other situation that diminishes the capabilities of the ISS, resulting in a reduction in crew and cargo requirements, or the worst-case scenario of the abandonment of the station, would adversely limit the U.S. Government’s need for commercial cargo and crew services. Space environment hazards such as the increase of orbital debris also pose risks that could adversely affect the market for commercial providers if a significant collision occurred.

Section 5.0 Non-Government Markets

As described in Section 3.0, NASA’s study featured analysis of available data sources to identify potential non-Government markets that could be addressed by commercial crew and cargo systems within a 10-year time horizon. This analysis found four market segments most likely to be enabled by such systems in that time period:

- **National Interests**: This category includes countries lacking indigenous human space transportation capability who desire to send astronauts and cargo into space to perform scientific research, acquire technical knowledge, and increase national prestige.

- **Space Tourism**: This category includes spaceflight participants who are not flying under the direct employment or financial sponsorship of a company or government organization.
- **Applied Research and Technology Development**: This category includes customers interested in space-based research activities aboard in-space platforms, such as the ISS. Such research activities may lead to downstream commercial and/or societal application.
- **Other markets**: This category includes satellite servicing, media, and entertainment and education markets.

Therefore, this section provides background and a description of those markets, describes the lower end of the market range based on historical flight rates, describes the upper end of the market range (i.e., market potential), and provides a discussion of unique constraints on the growth of the individual markets that may inhibit the realization of the market potential.

National Interests

Thirty-one nations without indigenous human spaceflight capabilities have sent 96 astronauts into orbit between 1978 and 2010. This total excludes Expedition flights of ISS Partner crew members flown pursuant to the ISS Partner Intergovernmental Agreement\Memoranda of Understanding. "National Interests" have sent astronauts into space on vehicles operated by Russia and the United States primarily through space agency-to-space agency or government-to-government exchanges, but in some cases through cash payments. Countries desire to send astronauts into space to perform scientific research, acquire technical knowledge, and increase national prestige. Historically, astronauts from such nations have performed missions that can be classified into three basic categories: short-duration visits to space stations, short-duration spacecraft missions such as those performed by the Space Shuttle, and long-duration expeditions to space stations. Figure 2 summarizes the historical national interest flights. A more detailed description of these flights is provided in Appendix A.

Short Duration Space Station Visits – Salyut, Mir, ISS[1]	Space Shuttle Flights, excluding Flights to MIR and ISS[2]	Long Duration Space Station Visits - Mir and ISS Expeditions[3]
Total: 26 countries	Total: 13 countries	Total: 2 countries
54 astronaut flights	39 astronaut flights	3 astronaut flights

[1] Space Station visits (first column) were relatively short-duration missions including Soyuz or Shuttle flights to the Salyut, Mir, and ISS with an average amount of time in space of approximately 12 days. These missions are performed primarily to increase national prestige, but may also include modest scientific research and technical knowledge objectives.

[2] Thirteen countries participated in Space Shuttle astronaut flights (second column), excluding Shuttle flights to Mir and ISS. The average duration of a Space Shuttle mission was about 11 days. Space Shuttle flights performed a range of missions. The Space Shuttle represented a unique capability with its large cargo bay and crew carrying capability. In some sense it was a self-contained space station.

[3] Long-duration space station missions consisting of crew that keep a space station operating and perform some utilization are referred to as "expeditions" (third column). By the nature of their long duration in space, expedition members are conducting research on how the human body adapts. In addition, expedition crew members have the opportunity to tend long-duration science and technology experiments. German and French astronauts have served aboard Mir and ISS as Expedition crew members. The average duration of Expeditions missions was about 180 days.

Overall Total Countries: 31
Astronaut flights: 96

Figure 2: National Interests

Based on this historical experience, it is likely that the market for national interests of countries without indigenous human spaceflight capability will consist of at least two client types. The first type will be interested in short-duration missions to LEO, the ISS, or other space station for national prestige and scientific and technical research. A second type may be interested in longer-duration flights ranging from two weeks to six months. This sovereign client may desire to be the primary occupant of a space station or work as part of a mixed crew with astronauts from other nations.

Historical Experience (Lower End of Range)

Figure 3 shows the historical number of astronaut flights for the National Interests market with a trend line:

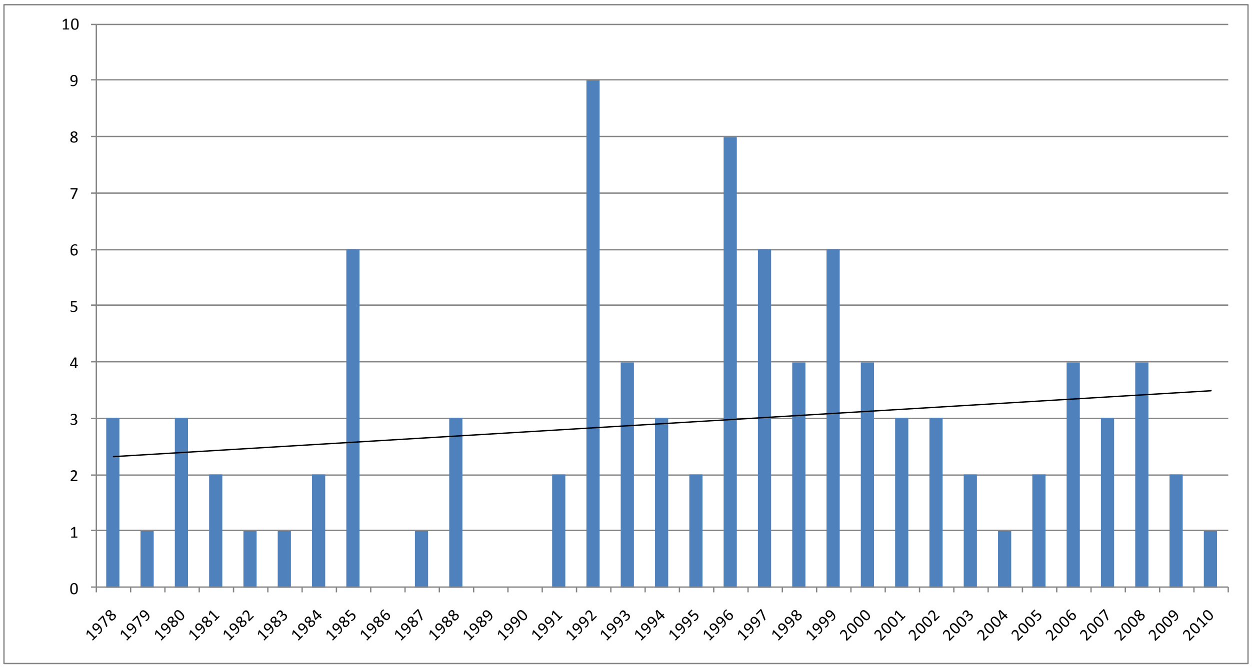

Figure 3: Historical Flight Rate of National Interests (Excluding the United States, Russia and China, and excluding ISS Partner crew members flown pursuant to ISS Partner Intergovernmental Agreement\Memoranda of Understanding.)

In order to establish the "Lower End" of the range for this market, the linear historical growth rate of the number of astronaut flights occurring annually (i.e., the trend line) was extrapolated into the future. This assumes that the historical flight experience will remain unchanged during the next 10 years. Based on this linear growth rate, the number of astronaut flights is projected to be 36 during the assessment period.

Cargo transportation will be required in order to support these astronaut flights. Cargo includes items such as water, food, clothing, personal items, and life support maintenance consumables. It does not include cargo demand required to support other types of space station maintenance, propulsion, or research activity. Basic crew resupply requirements necessary to support a single astronaut can be approximated based on NASA and Russian human spaceflight experience. The generic cargo resupply rate to support astronauts on the ISS is 10.3 lbs/day per crew member.

Based on historical data shown in Figure 2, approximately 97 percent of the projected astronaut flights, or 35 astronaut flights, will be short-duration missions. One astronaut flight will be a long-duration expedition-type mission. Based on a cargo estimate of 10.3 lbs/day per crew member, 35 short-duration missions of 12 days each would generate cargo demand of approximately 4,326 pounds. One long-duration expedition mission of 180 days would therefore generate cargo demand of approximately 1,854 pounds, for a grand total of 6,180 pounds.

Market Potential (Upper End of Range)

The market for nations without indigenous human spaceflight capability to purchase a flight to LEO, time onboard the ISS, or time onboard private space stations builds upon a history of such nations partnering with nations that operate human space transportation systems in order to travel into space. Historically, nations faced a fairly high cost barrier when pursuing human spaceflight. A commercial human space transportation system to LEO, in combination with an affordable space destination, may enable a much larger market for national interests.

The upper end of the range for the National Interests market is based on input provided to NASA for the purposes of this report by Bigelow Aerospace. Bigelow Aerospace is targeting the National Interests market (also known as the Sovereign Client market) as a key part of its business strategy. Bigelow estimates that 30 flights will be accomplished during the assessment period to support its first operational space station. A second, larger space station is planned to be launched two years later and will require 45 - 60 flights will be accomplished to support that station during the assessment period. Each flight is planned to include three to five passengers total.

For the purposes of the upper-end estimation, NASA assumed two of the passengers on each flight are part of the National Interests market segment, this results in a total of 150 to 180 astronaut flights over the assessment period. Adding the lower end of the range of 36 astronaut flights, which represents flights to the ISS for visits or short duration flights to LEO, the grand total for the upper end of the range is 186 to 216 astronaut flights over the assessment period. Using the cargo estimate of 10.3 lbs/day per crew member and assuming 12 day missions, the total for cargo to support the astronaut flights is projected to be approximately 18,540 to 22,248 pounds. By adding the lower end cargo estimate to this projection, a grand total of 24,720 to 28,430 pounds is projected.

A strong positive indicator for this growth is the fact that Bigelow Aerospace has executed seven Memoranda of Understanding (MOUs) with a variety of national space agencies, companies, and governmental entities. These MOUs were signed with organizations in Japan, the United Arab Emirates, the Netherlands, Sweden, the United Kingdom, Singapore, and Australia. These MOUs demonstrate the strong potential for international clientele to utilize such systems, particularly given the current lack of existing commercial crew transportation. Additionally, these MOUs demonstrate that foreign interest is not limited or necessarily tied exclusively to the ISS.

The lower- and upper-end assessments of crew transportation and associated cargo to support the crew over the 10-year period is summarized in Figure 4.

National Interests Market	Number of Astronaut Flights	Amount of Cargo (lbs)
Lower End of Range	36	6,180

Upper End of Range	186 - 216	24,720 - 28,430

Figure 4: Summary of the National Interests Commercial Market (Cumulative over 10-Year Assessment)

Constraints on Market Growth

The market for transportation services to support national interests will be strongly impacted by the availability of an affordable destination and transportation services to deploy astronauts and provisions. Commercially operated space crew transportation systems would be a new mode of operation for these customers. To date, all national interest missions have been conducted by government-operated transportation systems. Nations would need to become comfortable with the use of commercially operated transportation systems in order for commercial operators to grow this market.

Section 5.1: Space Tourism

In the last decade, space tourism emerged as a new and potentially promising commercial spaceflight market. In April 2001, Dennis Tito became the first individual to pay his own way into space, flying on a Soyuz taxi flight to the ISS. Several other people have followed -- each paying tens of millions of dollars to spend a week or more on the ISS.

For purposes of this report, the term “space tourist” refers to a spaceflight participant who is not flying under the direct employment or financial sponsorship of a company or government organization. Spaceflight participants employed or financially sponsored by government organizations, such as national space agencies, for research and other activities are covered under the National Interests section. Space tourists, by comparison, either purchase a spaceflight opportunity themselves or through another private funding source (e.g., as a gift from a friend or family member, or through a sweepstakes). Tourists may engage in a variety of activities on their flights, based on experience from those who have flown in the last decade.

Historical Experience (Lower End of Range)

Figure 5 lists those space tourists who have flown since 2001 and reported prices, based on published accounts of their flights:

Name	Reported Trip Price	Date Launched	Date Returned	Trip Duration
Dennis Tito	$20M	4/28/2001	5/6/2001	9 days
Mark Shuttleworth	$20M	04/25/2002	5/5/2002	11 days
Gregory Olsen	$19M	11/1/2005	11/11/2005	11 days
Anousheh Ansari	$20M	9/18/2006	9/29/2006	12 days
Charles Simonyi	$25M	4/7/2007	4/21/2007	15 days
Richard Garriott	$30M	11/12/2008	11/23/2008	12 days
Charles Simonyi	$35M	3/26/2009	4/8/2009	14 days
Guy Laliberte	$35M	9/30/2009	10/11/2009	12 days

Figure 5: Space Tourists, 2001-2010

The lower end of the range for the space tourist market over the next 10 years is estimated to be eight astronaut flights (i.e., seats), by simply extrapolating the average historical flight rate. For cargo, the same assumption regarding the basic crew resupply requirements necessary to support astronauts on the ISS was used for spaceflight participants (10.3 lbs/day per crew member). Assuming that each flight lasts 12 days (the same as the historical experience), the associated cargo market cumulatively over the 10-year forecast period is projected to be approximately 990 pounds.

Market Potential (Upper End of Range)

The future market for space tourism has engendered much speculation recently. However, most studies conducted to date suggest that market demand above the historical supply rate exists, although the lack of available crew transportation systems has delayed its development. In order to estimate the upper end of the space tourism market, input provided to NASA for the purposes of this report by Space Adventures was leveraged.

Space Adventures, the company which brokered every ISS space tourist flight to date, has developed its own forecast of future space tourist flights, taking into account development of commercial crew vehicles as well as the existence of orbiting space facilities besides the ISS. Their forecast calls for approximately 143 passengers flying through 2020 (including direct sales to individuals, lottery/media, corporate business and research, education and institutions). NASA projects the associated cargo to support those 143 astronaut flights to be approximately 17,700 pounds, based on an average stay time of 12 days and assuming the basic crew resupply requirements to equal those necessary to support astronauts on the ISS (10.3 lbs/day per crew member). Figure 6 provides a summary of the space tourism market projections for crew and associated support cargo.

Space Tourism Market	Number of Astronaut Flights	Amount of Cargo (lbs)
Lower End of Range	8	990
Upper End of Range	143	17,700

Figure 6: Summary of Space Tourism Commercial Market (Cumulative Over 10-Year Assessment)

Constraints on Market Growth

Currently, there are several growth constraints to the space tourism market:

- The availability of crew transportation systems for non-professional astronauts;
- The cost to the customer; and
- The current lack of a destination besides the ISS.

There are several other factors that hamper the orbital space tourism market such as the long training time. While these constraints might be reduced in coming years, it is unlikely that all will cease to be important in the next decade.

The availability of transportation is a significant limiting factor as only the Russian Soyuz is available to service this market and seats aboard the Soyuz are extremely limited. Following the late-2009 flight of Guy Laliberté, the Russian Federal Space Agency, Roscosmos, announced that there would be a hiatus on space tourism because all available Soyuz seats would be used for ISS crew rotations. Additional Soyuz seats may be available for tourists in a few years, as Space Adventures announced in early 2011 an agreement with Roscosmos and RSC Energia to increase the Soyuz production rate from four to five a year and thus offer three seats commercially starting in 2013. On the other hand, if U.S. industry is successful in developing commercial crew transportation systems, the availability of seats for space tourists could dramatically increase.

Cost is another apparent factor limiting commercial human spaceflight, as both customers and launch providers seek to obtain the best value they can. History has demonstrated that buying a ticket aboard an orbital rocket has never been cheap, and so far the only individuals capable of doing so have largely been independently wealthy.

While the prices paid by space tourists to fly short-duration missions on the Russian Soyuz have reportedly increased in recent years, this reported price is lower than what NASA pays primarily because NASA requires services for long-duration missions above and beyond those required by space tourists. With existing ISS demand, Russia has little incentive to open up seats to space tourists. However, as mentioned above, Russian entities have publicly said they could increase Soyuz spacecraft production, pending completion of contracts, potentially freeing up seats for private tourists, provided they are willing to pay an as-yet-unspecified price.

Another constraint on the market is the availability of destinations in LEO that could be visited by tourists. Currently the only destination in LEO with life-support capabilities is the ISS; and, ISS crew aboard is currently limited to six long-duration crew based on crew rescue vehicle (Soyuz) capability. The crew assignments on the ISS are regulated by the ISS Partners, with each ISS Partner allocated a specified amount of ISS crew on the station in accordance with the ISS Partnership agreements. However, Bigelow Aerospace is planning to deploy a series of private facilities that, while oriented toward serving the research and non-U.S. national interests markets, could also host tourists for short- or long-duration stays, thus supporting increased demand beyond what the ISS can accommodate. In addition, the development of crew transportation systems capable of free-flying LEO flights would offset the need for additional LEO destinations.

Section 5.2: Applied Research and Technology Development

Applied research and technology development refers to the use of the microgravity environment and vantage point afforded by the ISS and other in-space platforms to conduct research activities that may lead to downstream commercial and/or societal application. Precursor basic research areas range across the spectrum of biology, chemistry and physics with applied research and technology development opportunities in medicine, materials, remote sensing, and future space technologies demonstration.

In general, research moves along a continuum from basic research activities through applied and translational research to product development and enhancement (see Figure 7). Generally, the continuum begins with research seeking to test a theory or hypothesis (basic research) and concludes with a sustainable and repeatable outcome that creates value in terms of economic or social returns. In practice, research can begin at any phase of the continuum, and can proceed in a non-linear fashion. However, a weak level of investment in the visionary end of the continuum is likely to forestall success in the translational and product end of the pathway. As a scientific investigation moves down the continuum, funding profiles change to include increasing amounts of private and commercial industries until a commercial product may emerge from the investigation – although this does not occur in all cases.

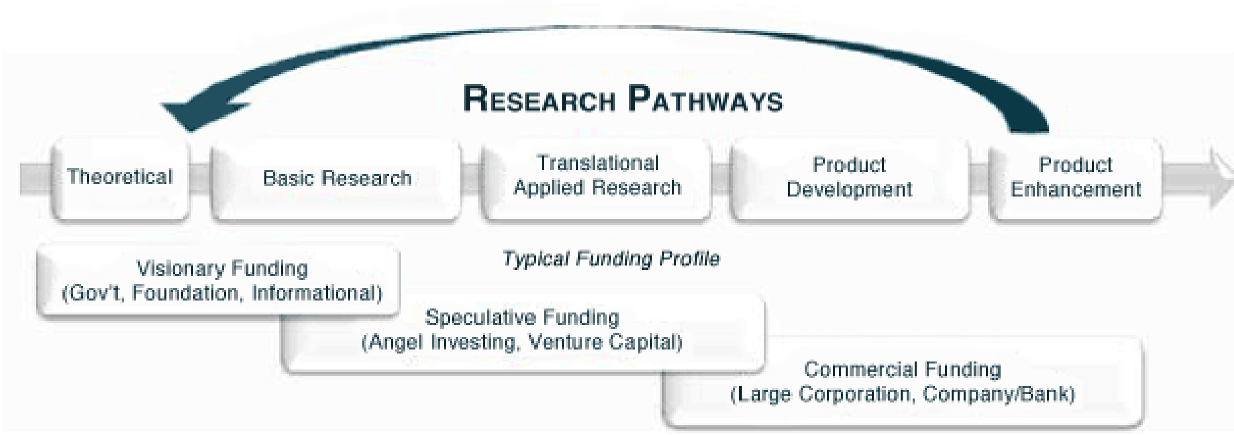

Figure 7: Source ProOrbis 2010

As an example of this pathway, basic research studying the reaction of the bacteria *Salmonella typhimurium* (a strain of bacteria responsible for the incidence of salmonella in humans) exposed to microgravity found increased virulence expressed by the bacteria in the space environment. Subsequent in-space experimentation identified the specific genes responsible for the virulence. Following this result, the private company Astogenetix, Inc. funded a series of experiments on the ISS focused on producing vaccine candidates—an example of preclinical, translational research. As of mid-2010, using results from the ISS experiments, the company is pursuing U.S. Food and Drug Administration approval of a *Salmonella typhimurium* vaccine as an investigational new drug. The company is also pursuing a similar investigation pathway for methicillin-resistant *Staphylococcus aureus*, better known as MRSA.

Research activities onboard the ISS can be classified into four research disciplines. These categories provide a framework for analyzing the types of applied research and development activities that might be conducted in LEO. These categories are:

1. **Biology and Biotechnology:** The space environment (e.g. microgravity) is unique for biological systems, and can offer distinct insights into molecular, cellular, and organismic functions. As a novel environment, space provokes biological processes and responses that cannot be evoked on Earth and, as a result, biology and biotechnology research in the microgravity environment could lead to medical and commercially relevant applications. More than 70 percent of the research performed on the ISS has been in this category.
2. **Earth Observation:** The ISS offers a stage for observation of the Earth, with the added capacity for servicing of onboard instruments should it be necessary. In some cases this may offer operational advantages for the collection of Earth observation data over the use of satellites for the same purpose.
3. **Physical and Materials Science:** The microgravity environment allows scientists to study physical properties, systems, and effects without the complicating factors provided by gravity. Long-term microgravity exposure permits scientific investigations to be conducted in a manner that allows the physical properties of the phenomena being studied to dominate the experiment, rather than the effects of gravity.
4. **Technology Development:** The ISS provides a unique test bed for new technologies for use both in space and on Earth. Technology testing in space allows developers to characterize, optimize, and space qualify hardware performance in space and expands the suite of space-qualified equipment that can then be used to enable other applications.

Historical Experience (Lower End of Range)

To date, virtually all of the funding for experiment development, transportation, accommodation and resources has been provided by government sponsors with few notable exceptions of commercial investment. Commercial investments have been limited to covering the costs of their investigators and incidental expenses. The share of experiments with a commercial interest, as a percent of total experiments performed, has been approximately nine percent.

Figure 8 shows the full breakdown of experiment sponsors, based on the number of experiments conducted onboard the ISS in each of the research disciplines, by all ISS Partners, from December 1998 through September 2010 (Expeditions 0 though 24), a period of time representing the assembly phase of station operations.

ISS Utilization Sponsor	Estimated Distribution of Interests
ISS International Partnership (non-United States)	64%
United States	36%
Commercial	9%
Department of Defense	10%
National Lab – Other Government Agencies	0%
National Lab – Academia	0%
National Lab – Education *(with significant NASA funding)*	17%
NASA Grants	64%
Subtotal (United States)	**100%**
Total	**100%**

Figure 8: ISS Experiment Sponsors, December 1998 to September 2010

In some cases, an experiment conducted on board the ISS by a private, non-U.S. Government entity had its investigator costs paid for by that private entity, but costs of transport and use of the station were covered by NASA. Thus, none of the research included in the "United States – Commercial" category was completely funded by private entities, and it is unclear if any of this research would have been conducted had the government financial contribution not existed. Accordingly, the low end of the range for this market is zero pounds of cargo, even though private entities have contributed financially, in some cases quite substantially, to this research.

Market Potential (Upper End of Range)

NASA planning for ISS utilization requirements breaks cargo upmass and downmass requirements into three categories: mass required to support ISS Systems and Operations, mass required for research on the United States On-orbit Segment (USOS) of the ISS, and mass required for National Lab Utilization. The USOS includes NASA utilization requirements and those of all International Partners except Russia. The National Lab Utilization category includes all U.S. research on the station pursued by entities other than NASA, including research by private firms. In August 2009, NASA developed a *Plan to Support Operations and Utilization of the International Space Station Beyond FY 2015*. This report contained projected cargo upmass (and downmass) requirements for ISS Utilization through 2020, as shown in Figure 9.

Category	Total Projected Cargo Upmass Requirements
Systems/Operations	194,820 lbs
USOS Research (funded)	80,067 lbs
National Lab Utilization (unfunded)	43,266 lbs

Figure 9: ISS Upmass and Downmass Requirements 2011-2020

As mentioned, approximately nine percent of ISS utilization interest has originated from commercial sources. This figure provides an estimate of the level of commercial market interest in Applied Research and Technology Development activities, when the research costs are largely covered by NASA. Accordingly, it can be used to provide the ISS-related portion of the upper end of the range of the Applied Research and Technology Development market. Applying the nine percent to the total projected National Lab Utilization gives an estimate for commercial ISS cargo of approximately 3,900 pounds.

In addition to ISS-related utilization, there will be research and technology related cargo flown to other destinations, such as the Bigelow station or simply to LEO in a DragonLab or other free-flying carrier. For the contribution of this portion to the upper end of the range, the Bigelow flight projection was used: 30 flights during the assessment period for Bigelow Station #1; and 45 - 60 flights for Bigelow Station #2. Bigelow plans to launch major payloads “with the module”; hence, the amount of utilization-related hardware will be relatively small. For the purposes of this assessment, NASA assumed 75 pounds of cargo would be flown on each flight, for a total of 5,600 - 6,750 pounds of commercial non-ISS cargo over the assessment period.

Adding together the ISS and non-ISS related portions provides a grand total of 9,500 - 13,400 pounds for commercial cargo. Figure 10 shows a summary of the projection for the Applied Research and Technology Development market.

Applied Research and Development Market	Number of Seats	Amount of Cargo (lbs)
Lower End of Range	-	0
Upper End of Range	-	9,500 - 13,400

Figure 10: Summary of Applied Research and Technology Development Market (Cumulative Over 10-Year Assessment)

Constraints on Market Growth

The estimates in Figure 11 are constrained by several factors. The historical data used for the range represents a period when ISS activities were conducted under a different concept of the operations than what is in place today: assembly versus utilization. During the period of ISS assembly, resources for completing experiments were relatively limited. Today, the largest modules and research racks have been delivered to ISS, so more launch payload volume and mass is allocated to ISS utilization. Furthermore, more crew time is available for research because there are fewer ISS components to install and assemble. Secondly, the ISS Program notes that “over the past decade funding for research (either from NASA or from private entities) and flight resources have never been available at the same time, and have fluctuated almost independently.” Accordingly, the history-based statistics represented in Figure 11 should not be considered an absolute upper limit.

The American Society for Gravitational and Space Biology, an organization with an interest in expanding research conducted in microgravity, suggests that the following factors limit research activities on ISS:

- Inadequate hardware and instrumentation to support biological and physical sciences experimentation in reduced gravity, including biocontainment work stations and variable speed centrifugation for in-flight gravity controls;
- A lack of frequent and affordable upmass and downmass to and from ISS;
- Absence of designated ground and facilities support for fundamental life and physical sciences flight experiments; and
- Insufficient commercial and basic research entities participating jointly on missions.

Flight rate—*both* upmass and downmass—is a major constraint to development of the market. In the report, "Life and Physical Sciences Research for a New Era of Space Exploration", the National Research Council noted that, "conditioned down mass is of particular importance…" because without it, only basic analyses that do not require experiment or sample return to the Earth's surface can be conducted. Related to flight opportunities are flight costs. The U.S. Government Accountability Office noted in 2009 that launch costs are "prohibitive" to researchers seeking to fund their own way to orbit. An additional significant constraint is that availability of private (non-Government) funding for basic research activities is low, so reaching maturity in absence of government funds will be a challenge. In addition, space-based research techniques remain at risk of being supplanted by ground-based methodologies that offer similar results under more cost-effective conditions.

Most research activities conduced in LEO or onboard ISS to date have been basic research in character. Over the forecast period a gradual shift from basic to translational research could occur if the Government invests in proof-of-concept experiments that stimulate private interest. If the Government does not invest in this early stage research, it will impede the development of commercial applications.

As an example of proof-of-concept activities that might be enabled by in-space technology demonstration activities, Bigelow Aerospace and NASA have discussed connecting a Bigelow Expandable Activity Module (BEAM) to the ISS. Connecting a BEAM to the ISS would provide a demonstration of Bigelow's technology. The demonstration would also provide both NASA and Bigelow with data on the performance of inflatable space habitation modules in orbit. With a successful demonstration of the ISS's technology development capabilities, other users may follow.

Section 5.3: Other Markets

Other markets may be enabled by development of commercial crew and cargo transportation systems. These other markets include: satellite servicing, media and entertainment, and education. Historically, for example:

- Two commercial satellites have benefited from human-tended rescue performed by the Space Shuttle during a single mission in 1984: Palapa B2 and Westar 6.
- A number of companies have used spacecraft, particularly the Russian space station Mir and the Russian segment of the ISS, for advertising and other media projects (the first non-Government funded spaceflight participant was funded by a television broadcasting company).

- A commercial firm is preparing the first Science, Technology, Engineering, and Mathematics (STEM) mission that does not require NASA funding, for 16 school districts.

Satellite Servicing

Rescue of satellites stranded in an incorrect orbit is a relatively advanced capability that could be supported by commercial crew transportation spacecraft. To date, all human-tended servicing missions to date have been conducted by Government-funded missions performed by either the United States or Russian Governments. In addition, most commercially operated satellites in LEO are not valuable enough to justify a human-tended rescue mission. Thus, this market has not seen much historical activity.

However, there are two historical examples cited above, the Palapa B2 and Westar 6. In addition, between 1997 and 2009, approximately seven satellites lost greater than 50 percent of their lifespan due to being stranded in an incorrect orbit and could potentially have been candidates for servicing had the transportation capability been available.

Media and Entertainment

Mir, along with its cosmonauts, was a platform for companies such as Pepsi and MTV to launch promotional activities. This included an ad filmed on Mir that aired in September of 1997 during the MTV Music Awards. In 1999, Pizza Hut spent $1 million for the rights to plant a large logo on the side of a Proton launcher headed for the ISS. The following year, Pizza Hut worked with Russian food scientists to deliver oven-ready pizzas to ISS incumbents. Shortly after, Kodak paid to have their logo and a slogan placed onto a material that was to be tested for durability in space on the outside of the ISS. In 2001, Radio Shack & Popular Mechanics also worked out deals with the Russians for advertising on the ISS.

More recently, Bigelow Aerospace carried out a "Fly Your Stuff" promotion through their Genesis I and Genesis II. Photos taken within the Genesis I reveal banners and logos from different companies lined against the module's interior walls. In addition to images and logos, Bigelow Aerospace allowed the public to send small items to space. Once in space, the items were photographed floating in Genesis II and those images were made visible on the Bigelow website.

Also, IMAX Corporation and NASA have developed a long-standing partnership which has enabled millions of people to virtually travel into space through a series of award-winning films. A list of those IMAX films is provided in Figure 11.

Title	Production Year
Hail Columbia	1981
The Dream is Alive	1985
Blue Planet	1990
Destiny in Space	1994
Cosmic Voyage	1996
L5: First City in Space	1996
Mission to MIR	1997
Space Station 3D	2002
Magnificent Desolation	2005
Hubble 3D	2009

Figure 11: NASA IMAX Movies

While past media and entertainment efforts have largely involved the use of government crew members on vehicles, one private spaceflight participant has flown as part of a media project. In 1989, Tokyo Broadcasting System (TBS) paid the Soviet Government to fly one of its journalists, Toyohiro Akiyama, to the Mir space station. Akiyama flew on Mir for one week in December 1990, providing reports for TBS. Since then, there have been several proposals to fly journalists, actors, or other media and entertainment professionals into space.

Education

As most people are aware, almost all shuttle missions and ISS expeditions have an education outreach component, whether that being astronauts talking with school children or filmed activity on Shuttle/ISS for educational purposes. Although the shuttle program will be ending, NASA's education efforts will continue to utilize the inspirational people, resources and facilities at its disposal, including the Astronaut Corps and the International Space Station, to assist the Nation to inspire a new generation of scientists and engineers.

An education-related market may develop in the future, thanks to lower cost research opportunities enabled by concepts such as NanoRacks. The approach of NanoRacks is to use increasingly sophisticated and powerful small space systems, along with a no-frills business model that drives down user cost. In 2010, the National Center for Earth and Space Science Education partnered with NanoRacks to perform the Student Spaceflight Experiments Program (SSEP). This program allows 16 microgravity science experiments, developed by grade 5-12 students, to be sent into space onboard the space shuttle. The 16 experiments were chosen from 447 proposals. SSEP is the first pre-college STEM education program to be both a national initiative and implemented as a commercial venture. Future SSEP missions will leverage the National Laboratory capability of the ISS in which NASA would provide the transportation and host the NanoRacks experiment platform.

Size of Other Markets

During our analysis for this report, we found no detailed studies of the demand for satellite servicing, media and entertainment, and educational activities on the ISS or elsewhere in LEO that can be enabled by commercial cargo and crew vehicles, beyond the anecdotal evidence cited above. This suggests that these other markets will not be drivers for the initial commercial demand for cargo and crew transportation systems. Hence, lower and upper ranges are not provided. However, given that there has been some historical activity shown to exist and the fact that, over time, activity in these markets may expand, they have been included in this report.

Section 5.4: Market Aggregation

Figure 12 combines the estimated projected sizes of the markets addressed in the previous section, for both the lower and upper ends. At the lower end, the overall market is dominated by national interests, a market with a decades-long track record of interest from nations seeking human access to space. The remainder of the market at the lower bound comes from tourism, another market with a lengthy record of interest that is expected to continue. Tourism becomes more of a driver at the upper end of the range, given the surge in demand expected by industry sources in the coming decade.

Market Segment	Cargo (lbs)		Crew	
	Lower End	Upper End	Lower End	Upper End
National Interests	6,180	24,720 - 28,430	36	186 - 216
Tourism	990	17,700	8	143
Applied Research and Technology Development	0	9,500 - 13,400	-	-
Other Enabled Markets	-	-	-	-
Total	**7,170**	**51,920 - 59,530**	**44**	**329 - 359**

Figure 12: Aggregated Non-Government Markets – 10-Year Total

A key factor in this analysis is that the market for crew transportation drives the overall market. That is, in the case of the lower end of the cargo market, 100 percent comes from supplies needed to support the crew during missions. For the upper end of the assessment, cargo to support the crew is still by far the biggest component to the overall projection, with the Applied Research and Technology Development market the only cargo market (i.e. experiments and support equipment) which does not also have a crew component. This suggests that the development of commercial crew transportation systems is essential to enabling the overall market growth for commercial space transportation capabilities in LEO.

Section 6.0: Other Relevant Considerations

Any discussion of commercial crew markets would not be complete without mention of U.S. Government needs. The U.S. Government provides the foundational market from which the commercial markets can grow and expand. Also, components of the systems, such as the launch vehicle and spacecraft, have commercial potential beyond just transporting crew and cargo to LEO. This section provides a top-level overview of the commercial potential for components of crew and cargo systems. In addition, the outlook for commercial crew and cargo systems beyond 10 years is also relevant to this report and is included in this section.

Section 6.1: U.S. Government Market for Commercial Crew and Cargo Capabilities

While the commercial markets described above are real and potentially large, NASA’s need for commercial crew and cargo services is clearly the foundational market from which additional non-Government markets can be established. With the decision to extend the life of the ISS to 2020 or beyond, there is now a long-term, sustainable market for commercial human space transportation services.

Some potential commercial crew providers have indicated that the U.S. Government/NASA market is sufficient *in and of itself*. Per Boeing's voluntary, non-proprietary input to NASA for this report: "Although we can close our business case on NASA services alone, it is the potential upside generated by a commercial market that offsets the investment and risk inherent with a commercial crew LEO transportation development effort."

The most significant, and currently the only planned and funded, U.S. government mission for commercial crew and cargo services is ISS crew transportation and cargo resupply. The other missions listed in this section are entirely notional and are not currently planned or funded. They are potential U.S. Government missions that may arise in the future.

NASA ISS Mission

For the ISS mission, NASA requires safe and reliable crew rotation capability for up to four U.S. or U.S.-sponsored crewmembers per flight, two flights per year. This also includes providing an assured crew return/rescue capability for these crewmembers while the commercial spacecraft is docked to the ISS. Assuming services begin in 2016 and go through to 2020, there will be a need for up to 40 astronaut flights during the assessment period.

Regarding cargo, NASA is already under contract to purchase 132,000 pounds (60 MT) of cargo resupply services for the first half of this decade. In addition, NASA anticipates requiring an additional 132,000 pounds of cargo delivery to the ISS from 2016 - 2020. The cargo complement is composed of oxygen, water, food, clothing, medicine, spare parts, new science technology developments, etc. Cargo usage is annually assessed and changes based on the latest information on key cargo requirement drivers. Figure 13 shows a summary of NASA's projected needs for commercial crew and cargo transportation for the ISS during the assessment period to meet total ISS crew and cargo needs.

NASA ISS Crew and Cargo Market	Number of Astronaut Flights	Amount of Cargo (lbs)
Estimated Amount	Up to 40	264,000

Figure 13: Summary of Applied NASA Market for ISS Crew and Cargo

It should be noted that any flights above NASA's needs for commercial crew and cargo transportation to the ISS (i.e., all the non-U.S. Government projections shown in Figure 13) could have a profound impact on the business case for commercial services. As the Augustine report noted, *"…if there were only one non-NASA flight of this system per year, it would reduce the NASA share of the fixed recurring cost by 33 percent."*

More importantly, Figure 13 only shows NASA's needs for commercial crew and cargo transportation during the assessment period. NASA has already purchased over 40 crew seats on the Russian Soyuz system for ISS crew transportation and rescue services at a cost of well over $1 billion. Had commercial crew transportation been available to NASA, those 40+ crew seats could have been purchased from U.S. aerospace companies. Additionally, every year that there is a delay in the availability of commercial crew transportation (either because of budget cuts or other delays), some of the seat opportunities shown in Figure 13 will be transferred to Russia for the purchase of even more Soyuz seats.

Commercial Space Station Mission

A commercial space station mission would entail providing NASA crew access and/or cargo transfer to a commercially sponsored space station in LEO, which is functioning as a science platform. NASA-sponsored crew could participate in science experiments onboard a commercial space station. Cargo could include NASA science experiments which would require access to unique scientific equipment aboard a commercial space station.

Rescue Mission

This would entail a rescue mission to an inhabited space station operating in LEO, to rescue and return to Earth a crew whose spacecraft is no longer safe for return. In this scenario, a major malfunction would have to occur to the crew return spacecraft while it was docked to an orbiting space station. The crew would then remain on the station awaiting launch of a rescue vehicle.

Exploration Crew Transportation Mission

For this mission, NASA would require safe and reliable crew access (and potentially cargo transfer) to a NASA-developed Exploration Spacecraft System (ESS) loitering in LEO. Upon transfer of crew members to the ESS, an uncrewed (or minimally crewed) crew transportation system spacecraft would separate from the ESS. The ESS would depart LEO without the crew transportation system and would perform a deep space mission, providing its own Earth return capability once the deep space mission was completed. The crew transportation system would de-orbit and land at an appropriately chosen landing site.

Satellite Servicing Mission

The objective for this mission would be to provide servicing of NASA satellites (or potentially satellites owned by other Government agencies and serviced by NASA crew) in LEO. In general, each satellite servicing mission would have a unique inclination and altitude and unique servicing needs. Cargo carrying capability for these servicing missions would have to include all hardware and tools necessary to perform the servicing and return any items required for post-flight analysis.

Repair missions of the Hubble Space Telescope (HST) in 1993, 1997, 1999, 2002 and 2009 are perhaps the most well-known examples of on-orbit servicing. In addition, the NASA Solar Maximum Mission (SMM), launched in 1980, operated until 1981 when the attitude control system failed. The Space Shuttle Challenger successfully serviced the SMM satellite in 1984 during mission STS-41C, fully restoring functionality.

Propellant Refueling Mission

One space architecture concept that has garnered interest is the propellant depot. Such depots would store propellants in Earth orbit or other locations, such as Earth-moon Lagrange points, for use by commercial or government spacecraft for various applications, from human exploration missions to refueling commercial satellites. Depots would allow spacecraft to be launched “dry”, or without any propellant on board, increasing the amount of useful mass that can be launched on a single vehicle; the spacecraft would then obtain its necessary propellant at the depot.

Depots have the potential to significantly increase the market for commercial launch vehicles developed for or adapted to commercial crew and cargo technology systems by launching propellant to the depots. Crew and cargo vehicles could also be adapted to support these vehicles by serving as tugs to transport propellant modules or spacecraft to be refueled to and from the depots. Specific launch and spacecraft requirements for depots would depend on a number of factors, including the orbit the depot is in and the types of propellants it would host.

Market for Components of the Commercial Crew and Cargo Systems

Pursuant to the language in the NASA Authorization Act of 2010, this study assesses the markets for complete commercial crew and cargo systems. However, individual components of these systems, particularly the launch vehicles, can address markets beyond those analyzed in this report.

Launch of Commercial Spacecraft

A major, existing market for commercial space transportation is the launch of commercial satellites intended to serve markets such as communications and remote sensing. In addition, some non-U.S. Governments without indigenous launch capabilities procure launch services on the commercial market. Over the last 10 years there have been an average of approximately 21 commercial launches per year globally, primarily consisting of commercial communications satellites operating in geosynchronous orbit. The *2010 Commercial Space Transportation Forecasts* by the FAA's Office of Commercial Space Transportation and its Commercial Space Transportation Advisory Committee projects an average of over 27 commercial launches per year from 2010-2019, again dominated by commercial geosynchronous orbit communications satellites.

New launch vehicles developed for commercial crew and cargo systems, or existing vehicles adapted to for use in those systems, could be used for commercial satellite launches as well. SpaceX has already demonstrated some success in this area, selling a number of commercial satellite launches on its Falcon 9 vehicle developed as part of the COTS program. Commercial satellite launch demand, along with that from crew and cargo launch markets, can allow launch services providers to amortize fixed costs over a larger number of missions, reducing per-launch costs and making them more competitive on the global launch market.

Launch of U.S. Government Spacecraft

Launch vehicles developed for or adapted to commercial crew and cargo transportation systems can also be used for the launch of U.S. Government civil and national security spacecraft. This is already the case for the Atlas V and Delta IV vehicles, developed originally for those missions and more recently proposed by a number of companies as the launch vehicles for their commercial crew transportation systems. The additional demand for commercial crew and cargo launches for NASA and commercial applications can help support the industrial base by increasing production rates and thus lowering per-unit costs.

Outlook Beyond 10 Years

This assessment examined potential markets for commercial crew and cargo vehicles out to a ten-year horizon, primarily because of the long-term uncertainties inherent in any market assessment as well as the expected operational life of the ISS. However, it is possible to qualitatively assess the outlook for these and other markets associated with such vehicles beyond 2020.

One major factor in the long-term outlook for such services is the lifetime of the ISS. The Governments of Japan and the Russian Federation have approved continued ISS operations beyond 2016. The NASA

Authorization Act of 2010 extended ISS operations until at least 2020. In March 2011, the European Space Agency Council approved continued ISS operations to at least 2020. The Canadian Space Agency is working with its Government to reach consensus about the continuation of the ISS. However, ISS operations beyond 2020 are uncertain. Continued use of the ISS beyond 2020 will depend on both technical issues with the station, as some core elements of the station approach the end of their design life, and the perceived utility of the station by the ISS Partner nations. Should technical considerations permit and ISS Partners find that government and commercial uses of the ISS have sufficient merit, ISS operations may continue well into the 2020s, extending the market for commercial crew and cargo services.

Even after the ISS reaches the end of its life, there will likely be continued human spaceflight operations in LEO. NASA's mission of space exploration is written into law in the National Aeronautics and Space Act, and it has been repeatedly authorized by multiple Congresses over the years. Thus, NASA is expected to be in the business of human spaceflight for the foreseeable future. New spacecraft developed and/or operated by Government agencies either as a direct successor to the ISS or in preparation for human spaceflight activities beyond Earth orbit can be projected. Government agencies may also choose to buy or lease commercially-developed orbital facilities, while other such facilities are used by commercial entities for tourism, research, and other markets.

Many of the markets studied in this assessment have growth potential that is likely to continue beyond this study's 10-year horizon. Tourism, for example, is likely to grow provided there is sufficient supply of transport spacecraft and orbital facilities to host them. Commercial research and development activities may grow at a significant rate, particularly if there are success stories from research activities in the next 10 years that demonstrate the value of space research to commercial customers. Media and entertainment, which is not foreseen to be a leading market in the next 10 years, may be able to leverage the capabilities developed for other markets and grow considerably beyond the ten-year horizon of this forecast. As in all cases, though, disruptive developments, both positive and negative such as accidents, economic downturns, or the development of new technologies could affect the long-term outlook for commercial cargo and crew transportation systems.

Section 6.2: How Government Interest/Action Can Help Spur Markets

Another major factor, perhaps the largest, that will affect the development of commercial crew and cargo markets is U.S. Government action. If the Government takes no action, many of the markets described in this report will likely not emerge to any significant degree in the next decade. The Augustine Committee stated, "…*unless NASA creates significant incentives for the development of the [commercial crew] capsule, the service is unlikely to be developed on a purely commercial basis.*" This conclusion was largely echoed by the final report of the FAA Workshop on Commercial Human Spaceflight, which concluded, "*The workshop participants expressed a general confidence that a commercial human spaceflight market will develop over time. They had considerably less confidence in the near-term viability of human space flight as a purely commercial enterprise*."

NASA's Commercial Crew Program is specifically designed to reduce the risk for private industry by providing significant financial and technical assistance for the development of these systems. Once these systems are proven to be safe and mature, NASA plans to be a reliable, long-term customer for crew transportation services. NASA believes that by providing both assistance in the system development and demand for the service, the "business case" for commercial human spaceflight providers can close for one or more U.S. aerospace companies.

Historical Examples

There are several historical examples where the U.S. Government, through direct financial and technical assistance, deliberately contributed to the development of new or expanded commercial transportation markets. The enabling legislation for the funding of the other transport industries clearly referenced the U.S. Government's strategic interest in seeing such a market develop for reasons that include but were never limited to the development of commerce. In other words, a frequently cited reason was the U.S. Government's interest in the further development of national capabilities in new technical realms. A similar situation exists today where commercial spaceflight capabilities can contribute to building new or expanding existing industries, but also support a Government interest of access to LEO for crew and cargo.

- **Railroads**

  Transcontinental railroad construction in the United States was initially enabled by the Pacific Railroad Acts approved in the mid-1800s. These acts authorized the issuance of Government bonds and the grants of land to railroad companies. From 1850-1871, the railroad companies received more than 175 million acres of public land, an area more than one tenth of the whole United States and larger in area than the state of Texas.

  The first transcontinental railroad was completed on May 10, 1869, establishing the possibility of travel from New York to San Francisco in six days. The commitment of consistent investment in railway development by the Government also supported and attracted related investment by the private sector in the United States and abroad. With both Government and private funding sources available, railroad mileage grew strongly, expanding from 9,000 miles in 1850 to over 129,770 miles in 1890. Government support for railways continued well into the era of airline travel as well. By year-end 2007, U.S. railroads operated 160,627 miles of track with 167,000 employees and generated $54 billion in annual operating revenues.

- **Airmail**

  Similarly, in the mid-1920s, legislation sponsored by Congressman Clyde Kelly of Pennsylvania, Chairman of the House Post Office Committee, authorized the Postmaster General to contract for domestic airmail service with commercial air carriers. The bill, which became known as the Air Mail Act of 1925, or the Kelly Act, also set airmail rates and the level of cash subsidies to be paid to companies that carried the mail. By transferring airmail operations to private companies, the U.S. Government effectively created the commercial aviation industry.

  Harry S. New, Postmaster General under President Calvin Coolidge, awarded contracts to the largest commercial companies with the largest aircraft, which could accommodate more passengers as well as the mail. Mr. New anticipated that increasing revenues from passengers, who at the time numbered only a few hundred each year, would eventually lead to more profit for the airlines. Additional airline profits would, in turn, directly reduce the burden of subsidy for airmail paid by the Post Office.

  Over time, the domestic airlines have grown steadily. Today, the commercial airline industry, initially derided as a fad, is recognized as a fully mature and fundamental part of the nation's infrastructure generating over $106 billion in 2009 revenues by the U.S. commercial passenger airlines.

Section 6.3: Government Catalyst for Commercial Cargo and Crew

Initiated in 2005, the COTS program has been making steady progress in the development of commercial cargo systems to resupply the ISS. A notable milestone occurred in December 2010 when SpaceX successfully completed its first demonstration flight under the COTS program by launching the Falcon 9 launch vehicle to orbit, separating the Dragon space capsule, completing two full orbits of the Earth, safely landing in the Pacific Ocean, and recovering the Dragon capsule.

While COTS cannot yet be considered a full success since no cargo has been delivered to the ISS, the COTS cargo project has already made a significant difference to NASA and the U.S. space industry. The following situation existed as recently as 2008:

- With the pending retirement of the space shuttle, NASA was facing a shortfall in ISS cargo resupply capability of some 60 metric tons in the first part of the decade which would have significantly curtailed the productivity of this laboratory in space;
- With the pending phase-out of the Delta II, there would have essentially been no mid-sized satellite launch capability for NASA science missions forcing those missions to either squeeze into a small launch vehicle or grow the size and cost of the payload to fit an Evolved Expendable Vehicle class launch vehicle; and
- The U.S. market share of commercial launch contracts was averaging less than 15 percent.

Today, NASA has contracts with two U.S. commercial providers for ISS cargo delivery services which, along with our International Partners, provide a robust portfolio of ISS resupply capabilities. Mid-sized NASA science missions can again be planned with the addition of the Falcon 9 launch vehicle into NASA's stable of vehicle options and potentially the addition of the Taurus II. In addition, SpaceX was recently awarded the largest commercial launch vehicle contract in history to launch a new constellation of Iridium satellites. All this, for a very modest U.S. Government investment and within a very short period of time compared to historical spaceflight development efforts. Thus, COTS has already proved successful in meeting one of its primary objectives which was to "create a market environment where commercial space transportation services are available to U.S. Government and private sector customers."

NASA's pending Commercial Crew Program, as proposed in the President's FY 2012 budget request, would significantly reduce the technical, programmatic, and financial risk associated with the development of crew transportation systems. FAA's report of the Commercial Human Spaceflight workshop which summarizes additional roles the U.S. Government could take in supporting commercial spaceflight:

> *"…industry and the panel agree that if policy makers decide that a transition to commercial launch services is in the national interest, the government must take more aggressive measures to support the development of the industry, such as the following:*
>
> *a. Act as the anchor tenant customer for the foreseeable future, including guaranteeing a market greater than five years of ISS support.*
>
> *b. Invest in system and/or infrastructure development to limit capital requirements and shorten payback periods. Several companies required that the government fund at least part of the development of the human system as a condition of their participation.*
>
> *c. Offer or facilitate limitations on liability.*
>
> *d. Provide mature, stable requirements, including human rating requirements, as soon as possible.*

e. *Ensure that NASA and the FAA agree on a coherent set of requirements and regulations that enable fielded systems to serve both government and non-government customers.*

f. *Insulate commercial providers from financial penalties associated with schedule impacts that may arise from conservative decisions required to operate safely*."

<u>Section 7.0: Conclusion</u>

This report assessed the market for commercial crew and cargo services, ranging from space tourism to research and development to national interests. Over time, the commercial markets identified in this report hold the strong promise of significantly more customers, more flights, and potentially lower prices to the U.S. Government. Even at the lower end of the range, which assumes absolutely no growth in the markets above what has already been experienced historically, the non-U.S. government market for crew transportation matches the U.S. Government market projection. At the upper end of the range, commercial markets drive the overall market and, in some cases, dwarf the U.S. Government projections for crew transportation.

From the Augustine Committee report:

> "*Given the appropriate incentives, this [commercial space] industry might help overcome a long-standing problem. The cost of admission to a variety of space activities strongly depends on the cost of reaching LEO. These costs become even greater when, as is the circumstance today, large sums are paid to develop new launch systems but those systems are used only infrequently. It seems improbable that order-of magnitude reductions in launch costs will be realized until launch rates increase substantially. But this is a 'chicken-and-egg' problem. The early airlines faced a similar barrier, which was finally resolved when the federal government awarded a series of guaranteed contracts for carrying the mail. A corresponding action may be required if space is ever to become broadly accessible. If we craft a space architecture to provide opportunities to industry, creating an assured initial market, there is the potential -- not without risk -- that the eventual costs to the government could be reduced substantially*."

The clearly identifiable market of the ISS for regular cargo delivery and return, and crew rotation provides the "corresponding action" referred to in the Augustine report and provides a foundation for private sector development efforts to succeed. With the fully operational ISS, there exists for the first time a strong, identifiable market for "routine" transportation services to and from LEO. This base market provides sufficient justification, in and of itself, for at least one established aerospace company to project that it can close its business case.

If successful, NASA's Commercial Crew Program will provide assured access to the ISS. It will end the gap in U.S.-provided human access to space and ensure we do not cede the U.S. leadership role in space. It will also allow NASA to concentrate its limited resources on exploration beyond LEO, enabling NASA to go further faster in the exploration of the solar system. It benefits U.S. private industry by strengthening the U.S. industrial base, enhancing our capabilities, and capturing market share of a new high technology industry. In addition, it benefits the Nation with more jobs, economic growth, and opportunities for human spaceflight for a variety of people (e.g., astronauts, international partner personnel, scientists, spaceflight participants) for a variety of reasons (e.g., science, research, ISS operations, tourism).

For these reasons, it is important that the Congress support NASA's commercial cargo and crew efforts. Delays in the availability of commercial spaceflight capabilities negatively affect the markets described in this report and degrade the business case for commercial providers. Catalyzed by a successful

Commercial Crew Program, a stable commercial non-Government market is likely to emerge. Without this catalyst, prospects for such a market emerging are considerably lessened. New potential suppliers are poised to try, and now is the time to open this new vista for American industry.

Bibliography

American Society for Gravitational and Space Biology (ASGSB), "The American Society for Gravitational and Space Biology Calls to Reestablish American Leadership in Space Sciences," Whitepaper submitted to the NRC Decadal Survey on Biological and Physical Sciences in Space, 2009.

Astrogenetix, Inc. "Astrogenetix Performs Drug Development In Microgravity," May 26, 2010, http://www.astrogenetix.com/news-and-events/news/astrogenetix-performs-drug-development-in-microgravity (accessed February 16, 2011).

BBC, "Mir actor remains grounded," March 16, 2000, http://news.bbc.co.uk/2/hi/entertainment/679935.stm (accessed February 15, 2011).

Blumberg, Baruch S., et al, "Report of the Workshop on Space Biology on the Early International Space Station" NASA Ames Research Center, Moffett Field, CA, March 14-15, 2002.

Boeing communication with NASA on space tourism demand, released January 2011.

Boyle, Alan, "NBC launching 2001 space odyssey," MSNBC.com, September 12, 2000, http://www.msnbc.msn.com/id/15424344/ns/technology_and_science-space/ (accessed February 15, 2011).

Cantwell, Betsy, "Life and Physical Sciences for a New Era of Space Exploration." (presentation at the American Astronautical Society National Conference: ISS - The Next Decade, Cape Canaveral, Florida, November 16-17, 2010)

Carreau, Mark, "$30 million buys Austin resident a ride of Soyuz mission," *Houston Chronicle*, October 10, 2008, http://www.chron.com/disp/story.mpl/front/6052360.html, (accessed February 11, 2011).

Clark, Stephen, "Boeing space capsule could be operational by 2015," Spaceflight Now, July 21, 2010, http://www.spaceflightnow.com/news/n1007/21boeing/ (accessed February 7, 2011).

Commercial Space Launch Amendments Act of 2004 (Public Law 208-492), December 23, 2004, http://www.faa.gov/about/office_org/headquarters_offices/ast/media/PL108-492.pdf (accessed February 7, 2011).

David, Leonard, "International Space Station Could Get Private Inflatable Room," SPACE.com, January 26, 2011, http://www.space.com/10686-nasa-bigelow-module-international-space-station.html (accessed February 16, 2011).

DeLucas, Larry, et al. "A Major Initial Market: Activity in Low Earth Orbit. Creating a Business Case for Protein Crystallization," (presentation at Space Investment Summit, April 17 ,2007).

de Selding , Peter B., "DLR Takes Step Toward In-orbit Servicing Demonstration," *Space News*, February 24, 2010, http://www.spacenews.com/civil/022410-dlr-takes-step-toward-in-orbit-servicing-demo.html (accessed February 4, 2011).

Eilertsen, Baard, "Market Interest in Fleet Management on Orbit Services – a Commercial Approach," Swedish Space Corporation, March 24, 2010, NASA On-Orbit Servicing Workshop Presentation.

FAA Office of Commercial Space Transportation, *2010 Commercial Space Transportation Forecasts*, May 2010, http://www.faa.gov/about/office_org/headquarters_offices/ast/media/2010_launch_forecast_report.pdf (accessed February 16, 2011)

FAA Office of Commercial Space Transportation, *Report of the Commercial Human Spaceflight Workshop, August 4-6, 2010*, report published April 2011.

Futron Corporation, *Space Tourism Market Study: Orbital Space Travel & Destinations with Suborbital Space Travel*, October 2002, http://www.futron.com/upload/wysiwyg/Resources/Reports/Space_Tourism_Market_Study_2002.pdf (accessed February 16, 2011).

Goldstein, Jeff, "STS-134 Experiments Selected, STS-135 Opportunity Announced," Student Spaceflight Experiments Program Press Release, December 22, 2010, http://ssep.ncesse.org/2010/12/ssep-national-press-release-sts-134-experiments-selected-sts-135-opportunity-announced/ (accessed February 22, 2011).

Government Accountability Office (GAO), "International Space Station: Significant Challenges May Limit Onboard Research," November 2009.

Griffin, Michael, "Remarks to the Space Transportation Association," June 21, 2005, http://www.nasa.gov/pdf/119275main_Griffin_STA_21_June_2005.pdf (accessed February 11, 2011).

Halvorson, Todd, "Space, Inc. Part 1: Robert Bigelow, a hotel mogul working to build private space stations." *Florida Today*, November 15, 2010, http://www.floridatoday.com/article/20101114/NEWS0204/101115027/Space-Inc-Part-1-Robert-Bigelow-hotel-mogul-working-build-private-space-stations (accessed February 16, 2011).

Halvorson, Todd, "Space station production plant could bring 2K jobs to Brevard," *Florida Today*, February 3, 2011, http://www.floridatoday.com/article/20110203/BUSINESS/102030309/1007/news02/CEO++Space+station+plant+could+bring+2K+jobs+to+Brevard (accessed February 7, 2011).

Harper, Lynn, et al, "The Biotech Revolution in Space." (paper presented at the AIAA Space 2006 Conference, San Jose, California, September 19 – 21, 2006).

Kundrot, Craig E., et al., "Microgravity and Macromolecular Crystallography," *Crystal Growth & Design* Vol, 1, No. 1: 87-99.

Miller, Barry, "On-Orbit Satellite Servicing – Is There A Business Case That Makes Sense," Lockheed Martin, March 24, 2010, NASA On-Orbit Servicing Workshop Presentation.

Morring Jr., Frank, "NASA, Roscosmos Seeking More Soyuz Seats," *AviationWeek.com*, February 10, 2011, http://www.aviationweek.com/aw/generic/story_channel.jsp?channel=space&id=news/asd/2011/02/10/07.xml&headline=NASA,%20Roscosmos%20Seeking%20More%20Soyuz%20Seats, (accessed February 11, 2011).

NASA Authorization Act of 2005 (Public Law 109-155), December 30, 2005, http://legislative.nasa.gov/PL109-155.pdf (accessed February 21, 2011).

NASA Authorization Act of 2008 (Public Law 110-422), October 15, 2008, http://legislative.nasa.gov/PL%20110-422.pdf (accessed February 21, 2011).

NASA Authorization Act of 2010 (Public Law 111-267), October 11, 2010, http://legislative.nasa.gov/PL%20111-267.pdf (accessed February 7, 2011).

NASA, "NASA Deputy Administrator Visits Nevada Innovation Sites", February 4, 2011, http://www.nasa.gov/home/hqnews/2011/feb/HQ_11-033_GarverNevada.html (accessed February 15, 2011).

NASA, International Space Station Program-provided data, February 2010.

NASA, "Plan to Support Operations and Utilization of the International Space Station Beyond FY 2015, pursuant to The NASA Authorization Act of 2008," August 6, 2009, http://www.nasa.gov/pdf/472057main_CORRECTED_ISS_Beyond_2015_Report_sec_601_FINAL_8_14_09.pdf (accessed February 22, 2011).

NASA Marshall Space Flight Center, "Orbital Space Plane Fact Sheet", May 2003, http://www.nasa.gov/centers/marshall/news/background/facts/ospfacts.html (accessed February 11, 2011).

NASA, CSA, ESA, JAXA, and Roscosmos, "The Era of International Space Station Utilization, Perspectives on Strategy from International Research Leaders" 2010.

National Research Council, "Life and Physical Sciences Research for a New Era of Space Exploration: An Interim Report." 2010.

National Space Policy of the United States of America, June 28, 2010, http://www.whitehouse.gov/sites/default/files/national_space_policy_6-28-10.pdf (accessed February 21, 2011).

Orbital Sciences Corporation, "Cygnus™ Advanced Maneuvering Spacecraft," http://www.orbital.com/NewsInfo/Publications/Cygnus_fact.pdf (accessed February 7, 2011).

Orbital Sciences Corporation, "Orbital Submits Proposal for NASA's Commercial Crew Development Program," December 14, 2010, http://www.orbital.com/NewsInfo/release.asp?prid=756 (accessed February 7, 2011).

President's Commission on Implementation of United States Space Exploration Policy, *A Journey to Inspire, Innovate, and Discover*, June 2004, http://govinfo.library.unt.edu/moontomars/docs/M2MReportScreenFinal.pdf (accessed February 11, 2011).

ProOrbis, LLC, "Reference Model for the International Space Station U.S. National Laboratory." 2010.

Review of U.S. Human Spaceflight Plans Committee, *Seeking a Human Spaceflight Program Worthy of a Great Nation*, October 2010, http://www.nasa.gov/pdf/396093main_HSF_Cmte_FinalReport.pdf (accessed February 11, 2011).

Robinson, Julie A. "International Space Station: Research Capabilities in Life and Physical Sciences Early Utilization Results" (presentation to the NRC Decadal Survey, May 7, 2009).

Rogers, Everett M. *Diffusion of Innovations*, 5th Edition, Free Press, 2003.

Shiryaevskaya, Anna, "Space Adventures, Russia Agree to Expand Tourist Trips in 2013," Bloomberg Businessweek, January 12, 2011, http://www.businessweek.com/news/2011-01-12/space-adventures-russia-agree-to-expand-tourist-trips-in-2013.html, (accessed February 11, 2011).

Sierra Nevada Corporation, "Virgin Galactic Joins in Sierra Nevada Space Systems Dream Chaser Orbital Space Vehicle Program," December 15, 2010, http://www.sncorp.com/news/press/pr10/snc_vg.shtml (accessed February 7, 2011).

Space Adventures, "Space Adventures Concludes Agreement to Offer Commercial Spaceflight Opportunities to the International Space Station," January 12, 2011, http://www.spaceadventures.com/index.cfm?fuseaction=news.viewnews&newsid=817 (accessed February 11, 2011).

Space Commercial Laboratory Applications Working Group. 2010. https://sites.google.com/site/spacecommerciallabworkinggroup/ (accessed February 3, 2011).

SPACEHAB, "Enterprise Module and Space Station Internet Media Company Will Take Space Commerce to New Heights," December 10, 1999, http://www.spaceref.com/news/viewpr.html?pid=269 (accessed February 15, 2011).

SpaceX, "Dragon Overview", http://www.spacex.com/dragon.php (accessed February 7, 2011).

SpaceX, "DragonLab," http://www.spacex.com/downloads/dragonlab-datasheet.pdf (accessed February 7, 2011).

SpaceX, "Iridium and SpaceX Sign Major Commercial Launch Contract", June 16, 2010, http://www.spacex.com/press.php?page=20100616 (accessed February 16, 2011).

SpaceX, "Taking the Next Step | Commercial Crew Development Round 2", January 17, 2011, http://www.spacex.com/updates.php (accessed February 7, 2011).

Stodieck, Louis S., "ISS National Laboratory: Commercial and Educational Research." (presentation at the American Astronautical Society National Conference: ISS - The Next Decade, Cape Canaveral, Florida, November 16 – 17, 2010).

Thumm, Tracy, et al, "The Era of International Space Station Utilization Begins: Research Strategy, International Collaboration, and Realized Potential" (paper presented at 61st International Astronautical Congress, Prague, Czech Republic, September 27 - October 1, 2010).

Uhran, Mark, "Positioning the International Space Station for the Utilization Era," (presentation at the 49th AIAA Aerospace Sciences Meeting, January 4-7, 2011).

ViviSat, "ViviSat Launched: New Venture Will Provide Satellite Life Extension Services", January 13, 2011, http://www.vivisat.com/?page_id=70 (accessed February 16, 2011).

Wilford, J.N., "Space Salvage: Lost Satellites are the Prize," *New York Times*, November 6, 1984.

Webber, D. and Reifert, J. "Filling in Some Gaps", Executive Summary of the Adventurers' Survey of Public Space Travel, September 2006.

Appendix A – Historical Astronaut Flights by National Interests

Astronaut	Nation	Launch Date	Flight Up	Flight Back	Flight Time (days)
Remek, Vladimir	Czechoslovakia, now Czech Republic	3/2/1978	Soyuz 28	Soyuz 28	7.93
Hermaszewski, M	Poland	6/27/1978	Soyuz 30	Soyuz 30	7.92
Jaehn, Sigmund	Germany	8/26/1978	Soyuz 31	Soyuz 29	7.87
Ivanov, Georgy	Bulgaria	4/10/1979	Soyuz 33	Soyuz 33	1.96
Farkas, Bertalan	Hungary	5/26/1980	Soyuz 36	Soyuz 35	7.86
Tuan, Pham	Vietnam	7/23/1980	Soyuz 37	Soyuz 36	7.86
Mendez, Arnaldo	Cuba	9/18/1980	Soyuz 38	Soyuz 38	7.86
Gurragcha, J	Mongolia	3/22/1981	Soyuz 39	Soyuz 39	7.86
Prunariu, D	Romania	5/14/1981	Soyuz 40	Soyuz 40	7.86
Chretien, Jean-Loup	France	6/24/1982	Soyuz T-6	Soyuz T-6	7.91
Merbold, Ulf	Germany	11/28/1983	STS-9	STS-9	10.32
Sharma, Rakesh	India	4/3/1984	Soyuz T-11	Soyuz T-10	7.90
Garneau, Marc	Canada	10/5/1984	STS-41-G	STS-41-G	8.22
Baudry, Patrick	France	6/17/1985	STS-51-G	STS-51-G	7.07
AlSaud, Sultan	Saudi Arabia	6/17/1985	STS-51-G	STS-51-G	7.07
Furrer, Reinhard	Germany	10/30/1985	STS-61-A	STS-61-A	7.03
Messerschmid, Ernst	Germany	10/30/1985	STS-61-A	STS-61-A	7.03
Ockels, Wubbo	Netherlands	10/30/1985	STS-61-A	STS-61-A	7.03
Neri Vela, Rodolfo	Mexico	11/27/1985	STS-61-B	STS-61-B	6.88
Faris, MA	Syria	7/22/1987	Soyuz TM-3	Soyuz TM-2	7.96
Alexandrov, Alexander	Bulgaria	6/7/1988	Soyuz TM-5	Soyuz TM-4	9.84
Mohmand, A	Afghanistan	8/29/1988	Soyuz TM-6	Soyuz TM-5	8.85
Chretien, Jean-Loup	France	11/26/1988	Soyuz TM-7	Soyuz TM-6	24.76
Sharman, Helen	Britain	5/18/1991	Soyuz TM-12	Soyuz TM-11	7.88
Viehboeck, Franz	Austria	10/2/1991	Soyuz TM-13	Soyuz TM-12	7.93
Bondar, Roberta	Canada	1/22/1992	STS-42	STS-42	8.05
Merbold, Ulf	Germany	1/22/1992	STS-42	STS-42	8.05
Flade, Klaus-Dietrich	Germany	3/17/1992	Soyuz TM-14	Soyuz TM-13	7.91
Frimout, Dirk	Belgium	3/24/1992	STS-45	STS-45	8.92
Tognini, Michel	France	7/27/1992	Soyuz TM-15	Soyuz TM-14	13.79
Malerba, Franco	Italy	7/31/1992	STS-46	STS-46	7.97
Nicollier, Claude	Switzerland	7/31/1992	STS-46	STS-46	7.97
Mohri, Mamoru	Japan	9/12/1992	STS-47	STS-47	7.94
MacLean, Steve	Canada	10/22/1992	STS-52	STS-52	9.87

Astronaut	Nation	Launch Date	Flight Up	Flight Back	Flight Time (days)
Schlegel, Hans	Germany	4/25/1993	STS-55	STS-55	9.99
Walter, Ulrich	Germany	4/25/1993	STS-55	STS-55	9.99
Haigere, Jean-Pierre	France	7/1/1993	Soyuz TM-17	Soyuz TM-16	20.67
Nicollier, Claude	Switzerland	12/2/1993	STS-61	STS-61	10.83
Mukai, Chiaki	Japan	7/8/1994	STS-65	STS-65	14.75
Merbold, Ulf	Germany	10/3/1994	Soyuz TM-20	Soyuz TM-19	31.52
Clervoy, Jean-Francois	France	11/3/1994	STS-66	STS-66	10.94
Reiter, Thomas	Germany	9/3/1995	Soyuz TM-22	Soyuz TM-22	179.07
Hadfield, Chris	Canada	11/12/1995	STS-74	STS-74	8.19
Wakata, Koichi	Japan	1/11/1996	STS-72	STS-72	8.92
Cheli, Maurizio	Italy	2/22/1996	STS-75	STS-75	15.74
Guidoni, Umberto	Italy	2/22/1996	STS-75	STS-75	15.74
Nicollier, Claude	Switzerland	2/22/1996	STS-75	STS-75	15.74
Garneau, Marc	Canada	5/19/1996	STS-77	STS-77	10.03
Thirsk, Robert	Canada	6/20/1996	STS-78	STS-78	16.91
Favier, Jean-Jacques	France	6/20/1996	STS-78	STS-78	16.91
Haignere, Claudie	France	8/17/1996	Soyuz TM-24	Soyuz TM-23	15.77
Ewald, Reinhold	Germany	2/10/1997	Soyuz TM-25	Soyuz TM-24	19.69
Clervoy, Jean-Francois	France	5/15/1997	STS-84	STS-84	9.22
Tryggvason, Bjarni	Canada	8/7/1997	STS-85	STS-85	11.85
Chretien, Jean-Loup	France	9/26/1997	STS-86	STS-86	10.81
Doi, Takao	Japan	11/19/1997	STS-87	STS-87	15.69
Kadenyuk, Leonid	Ukraine	11/19/1997	STS-87	STS-87	15.69
Eyharts, Leopold	France	1/29/1998	Soyuz TM-27	Soyuz TM-26	20.69
Williams, Dafydd	Canada	4/17/1998	STS-90	STS-90	15.91
Mukai, Chiaki	Japan	10/29/1998	STS-95	STS-95	8.91
Duque, Pedro	Spain	10/29/1998	STS-95	STS-95	8.91
Haigere, Jean-Pierre	France	2/20/1999	Soyuz TM-29	Soyuz TM-29	188.85
Bella, Ivan	Slovakia	2/20/1999	Soyuz TM-29	Soyuz TM-28	7.91
Payette, Julie	Canada	5/27/1999	STS-96	STS-96	9.80
Tognini, Michel	France	7/23/1999	STS-93	STS-93	4.95
Clervoy, Jean-Francois	France	12/20/1999	STS-103	STS-103	7.97
Nicollier, Claude	Switzerland	12/20/1999	STS-103	STS-103	7.97
Thiele, Gerhard	Germany	2/11/2000	STS-99	STS-99	11.24
Mohri, Mamoru	Japan	2/11/2000	STS-99	STS-99	11.24

Astronaut	Nation	Launch Date	Flight Up	Flight Back	Flight Time (days)
Wakata, Koichi	Japan	10/11/2000	STS-92	STS-92	12.90
Garneau, Marc	Canada	12/1/2000	STS-97	STS-97	10.83
Hadfield, Chris	Canada	4/19/2001	STS-100	STS-100	11.90
Guidoni, Umberto	Italy	4/19/2001	STS-100	STS-100	11.90
Haignere, Claudie	France	10/21/2001	Soyuz TM-33	Soyuz TM-32	9.83
Vittori, Roberto	Italy	4/25/2002	Soyuz TM-34	Soyuz TM-33	9.89
Perrin, Philippe	France	6/5/2002	STS-111	STS-111	13.86
DeWinne, Frank	Belgium	10/30/2002	Soyuz TMA-1	Soyuz TM-34	10.87
Ramon, Ilan	Israel	1/16/2003	STS-107	STS-107	15.94
Duque, Pedro	Spain	10/18/2003	Soyuz TMA-3	Soyuz TMA-2	9.86
Kuipers, Andre	Netherlands	4/19/2004	Soyuz TMA-4	Soyuz TMA-3	10.87
Vittori, Roberto	Italy	4/15/2005	Soyuz TMA-6	Soyuz TMA-5	9.89
Noguchi, Soichi	Japan	7/26/2005	STS-114	STS-114	13.90
Pontes, Marcos	Brazil	3/30/2006	Soyuz TMA-8	Soyuz TMA-7	9.89
Reiter, Thomas*	Germany	7/4/2006	STS-121	STS-116	171
MacLean, Steve	Canada	9/9/2006	STS-115	STS-115	11.80
Fuglesang, Christer	Sweden	12/9/2006	STS-116	STS-116	12.86
Williams, Dafydd	Canada	8/8/2007	STS-118	STS-118	12.75
Shukor, Sheikh Muszaphar	Malaysia	10/10/2007	Soyuz TMA-11	Soyuz TMA-10	11.00
Nespoli, Paolo	Italy	10/23/2007	STS-120	STS-120	15.06
Eyharts, Leopold*	France	2/7/2008	STS-122	STS-123	48.25
Schlegel, Hans	Germany	2/7/2008	STS-122	STS-122	12.77
Doi, Takao	Japan	3/11/2008	STS-123	STS-123	15.76
Yi, So-Yeon	South Korea	4/8/2008	Soyuz TMA-12	Soyuz TMA-11	10.00
Hoshide, Akihiko	Japan	5/31/2008	STS-124	STS-124	13.76
Wakata, Koichi*	Japan	3/15/2009	STS-119	STS-127	137.63
DeWinne, Frank*	Belgium	5/27/2009	Soyuz TMA-15	Soyuz TMA-15	187.86
Thirsk, Robert*	Canada	5/27/2009	Soyuz TMA-15	Soyuz TMA-15	187.86
Payette, Julie	Canada	7/15/2009	STS-127	STS-127	15.70
Fuglesang, Christer	Sweden	8/28/2009	STS-128	STS-128	13.87
Noguchi, Soichi*	Japan	12/20/2009	Soyuz TMA-17	Soyuz TMA-16	167.00
Yamazaki, Naoko	Japan	4/5/2010	STS-131	STS-131	15
Nespoli, Paolo*	Italy	12/15/2010	Soyuz TMA-20	In progress	In progress

* These flights were covered by the ISS Partner agreements. For the purposes of this report, these flights are not part of the National Interest market.

Appendix B – Discussion of Cost Effectiveness of Commercial Cargo Effort

NASA recently conducted a predicted cost estimate of the Falcon 9 launch vehicle using the NASA-Air Force Cost Model (NAFCOM). NAFCOM is the primary cost estimating tool NASA uses to predict the costs for launch vehicles, crewed vehicles, planetary landers, rovers, and other flight hardware elements prior to the development of these systems.

NAFCOM is a parametric cost estimating tool with a historical database of over 130 NASA and Air Force space flight hardware projects. It has been developed and refined over the past 13 years with 10 releases providing increased accuracy, data content, and functionality. NAFCOM uses a number of technical inputs in the estimating process. These include mass of components, manufacturing methods, engineering management, test approach, integration complexity, and pre-development studies.

Another variable is the relationship between the Government and the contractor during development. At one end, NAFCOM can model an approach that incorporates a heavy involvement on the part of the Government, which is a more traditional approach for unique development efforts with advanced technology. At the other end, more commercial-like practices can be assumed for the cost estimate where the contractor has more responsibility during the development effort.

For the Falcon 9 analysis, NASA used NAFCOM to predict the development cost for the Falcon 9 launch vehicle using two methodologies:

1) Cost to develop Falcon 9 using traditional NASA approach, and
2) Cost using a more commercial development approach.

Under methodology #1, the cost model predicted that the Falcon 9 would cost $4.0 billion based on a traditional approach. Under methodology #2, NAFCOM predicted $1.7 billion when the inputs were adjusted to a more commercial development approach. Thus, the predicted the cost to develop the Falcon 9 if done by NASA would have been between $1.7 billion and $4.0 billion.

SpaceX has publicly indicated that the development cost for Falcon 9 launch vehicle was approximately $300 million. Additionally, approximately $90 million was spent developing the Falcon 1 launch vehicle which did contribute to some extent to the Falcon 9, for a total of $390 million. NASA has verified these costs.

It is difficult to determine exactly why the actual cost was so dramatically lower than the NAFCOM predictions. It could be any number of factors associated with the non-traditional public-private partnership under which the Falcon 9 was developed (e.g., fewer NASA processes, reduced oversight, and less overhead), or other factors not directly tied to the development approach. NASA is continuing to refine this analysis to better understand the differences.

Regardless of the specific factors, this analysis does indicate the potential for reducing space hardware development costs, given the appropriate conditions. It is these conditions that NASA hopes to replicate, to the extent appropriate and feasible, in the development of commercial crew transportation systems.