Federal Aviation Administration

Report of the Commercial Human Spaceflight Workshop

Hosted by:

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Contents:

Executive Summary:

President Obama's proposed budget for 2011 directs NASA to transition the role of transportation provider for low earth orbit to commercial space companies. In support of this initiative, the Federal Aviation Administration Office of Commercial Space Transportation conducted a workshop on August 4-6, 2010, to collect information on what business environment could allow for the development of a successful commercial human space transportation industry. This report documents the output of that workshop.

The workshop discussions demonstrated that no traditional business case exists that would allow companies to support near term orbital human transportation as fully commercial activities, utilizing company investment and servicing commercial customers, at a price point that can reasonably be expected to generate true commercial sales. This is true because there is insufficient market, including both government and non-government customers, to repay the steep investment required. However, if government interests are considered broadly (including stimulating economic growth and ensuring the health of the vital space industrial base) there may be a non-traditional "business case" that serves both national needs for access to low earth orbit and the needs of the nascent commercial industry.

Despite some optimistic claims to the contrary, there is little evidence of a commercial human orbital market at the current price point of orbital space flight. Although a few individuals have purchased commercial flights on Russian spacecraft, their ticket price only had to cover the marginal cost of a fully developed system supported by a stable government business base. No such system or government business base exists in the US, and when amortization of development costs and fully-loaded operational costs in a new start program are accounted for, the per seat cost soars to a price point which makes a commercial market vanishingly small. However, the workshop identified several approaches and considerations that may bring the price point down to a level where a commercial market can develop.

Because government leaders are not typically expert in business finances, the workshop sought the wisdom and insight of relevant industry leaders. It provided them the opportunity to share their company's view of what will be required to both incentivize their participation and give them a reasonable opportunity to be financially successful. Seven companies participated in the workshop with each given 90 minutes to present its views privately to the panel.

Key findings:

- While a traditional business case (privately funded development with broad commercial and government customer base) could not be found, we believe that given the right assumptions a sufficient case can be built to justify NASA transitioning to the use of commercial human space transportation.
- The workshop participants expressed a general confidence that a commercial human space flight market will develop over time. They had considerably less

confidence in the near term viability of human space flight as a purely commercial enterprise. The more experienced space flight companies unanimously agreed that they cannot see a viable business case for their companies unless specific government actions are taken to reduce the level of corporate investment required, limit financial liability, and guarantee a stable market. They cited consistently over-estimated markets and under-estimated technical challenges in past space flight programs. One entrepreneurial company with limited space flight experience felt optimistic that it could lower its costs to a point where significant government investment would not be required.

- The first principles financial considerations of a satisfactory business case are defined by straightforward mathematics (see appendix C). Analyses performed in the course of this work show that the currently defined market, including both commercial and government customers, is simply too small and speculative to give confidence that privately funded efforts can achieve an acceptable rate of return on the investment. Absent significant government investment in system development or the emergence of a non-government customer significantly larger than NASA, the required price significantly exceeds the cost of purchasing seats from Russia.
- The enormous uncertainties in market size and sustainability further undermine the business case for investment. The current absence of NASA requirements or declared intentions to fly humans in LEO post 2020 is both critical and easily remedied. An assured market limited to ten missions, potentially split between multiple providers, does not provide a sufficient sales volume to repay the significant investment required.
- Industry also has significant concerns about liability, the availability of funding for system development, and the challenge of repaying that investment in a reasonable period at fair market rates of return.
- The commercial aerospace industry possesses the engineering skills and manufacturing capabilities to deliver high quality launch vehicles and spacecraft. However, none of these companies has experience conducting human space flight operations. Thus NASA will want to remain closely involved in operations of complex human missions conducted on its behalf.
- As a result of these issues, 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 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.

The panel believes that moving human space flight to a commercial business model is appropriate and timely, but possible only under three pivotal assumptions:

- That there is a compelling national interest in the government continuing to fly humans to low earth orbit beyond 2020 and that such interest is codified in policy and budget planning.
- That there is a compelling national interest in investing in commercial human space capabilities, even at a cost significantly greater than Soyuz rates initially, or alternatively, with the government bearing a significant portion of the system development costs.
- That the government ensures that NASA requirements and FAA regulations are written to guarantee that flight systems developed for government missions are also acceptable and affordable for commercial customers.

Introduction:

This report documents the product of the Commercial Human Spaceflight Workshop conducted by the FAA on August 4-6, 2010. The purpose of the workshop was to gain an understanding of what is required to achieve a successful commercial human spaceflight industry that can support NASA as it plans for future human space flight activities in low earth orbit.

The panel recognized that there is no single business case that fully describes the interests and capabilities of all parties. Industry sees a business case that is built on the ability to make a profit. The government sees a "business case" that must meet national technical and policy needs consistent with fiduciary responsibilities.

While this report does not document a guaranteed approach to enabling commercial human industry, it captures the major points that the industry and government teams conclude are key enablers and/or obstacles to industry success. The panel also concluded that, given a very specific set of assumptions, a sufficient business case could be constructed that meets the needs of industry and the government.

Problem Statement:

President Obama's 2011 budget directed NASA to begin the transition from the agency's traditional approach of developing human space transportation systems to one utilizing commercial suppliers for access to low earth orbit destinations, specifically the International Space Station. This significant change has generated concern from many people who support human space exploration. Their reasons for concern include many issues, with one of the most common being the difficulty in articulating a business case that works.

This workshop collected inputs from industry on what they see as the minimum acceptable circumstances that enable a workable business case. The product is a description of necessary elements which might be assembled to enable companies to successfully operate commercially to transport humans to and from low earth orbit.

A related issue surfaced during preparation for the workshop. It was noted that all three of NASA's fatal spacecraft accidents were linked to schedule pressure. Following each accident additional measures were put in place to attempt to insulate key decision makers from cost and schedule pressure and thus ensure good decision making. The panel feels it important to ensure that the business case take into consideration the potential effect of business factors on decision making to ensure that they do not exacerbate pressure that can reasonably impact judgment.

Workshop Process and Product:

Each company was provided 90 minutes to describe the business case as they see it for their company. While a short list of questions was provided to stimulate thinking on

several key points, the presenters were encouraged to go beyond the list to address areas of unique concern to them.

Following the interviews, the panel met to discuss the results and identify key points of agreement as well as unique concerns. These points were summarized and out-briefed to the participants on the afternoon of the 3rd day. The panel then undertook the preparation of this written report.

This report is provided for the use of the NASA Administrator, the FAA Associate Administrator for Commercial Space Transportation, and other government entities involved in the use of commercial human orbital transportation. It attempts to present a balanced and comprehensive picture of the elements of such a business case and key considerations to make it work.

Industry Overview:

General:

The United States has a long and distinguished history of accomplishment in human and robotic space flight. This history reflects the contributions of both the government and commercial communities. Due to the high risk and cost of early space efforts, the government has been the principal customer and operator and has developed deep and specialized capabilities to support a long term commitment to space. Meanwhile, industry has developed the ability to engineer and manufacture high quality products while rapidly adjusting to changes in requirements and demand.

While some portions of the industry (such as communications satellites) have evolved to be largely commercial, to date all orbital human space flight activities remain exclusively under close government leadership. Industry has participated extensively as contractors under government direction, but the key decisions and final responsibility have remained with the government.

For its part, the government conducts programs to meet national imperatives for national defense, scientific investigations, technological leadership, and/or international cooperation. But while the government creates the demand, it rarely builds the hardware or software for which it depends on private companies.

This has led some to suggest that the space program of the past, including the human missions flown by Mercury, Gemini, Apollo, Shuttle, ISS, and others, were accomplishments of commercial space companies similar to that being proposed in the budget. This is partially true insofar as these companies conducted the majority of the detailed system design, test, and manufacturing of the hardware. However, it is not true in that for all US human spaceflight programs the government has held the critical leadership role for system requirements, acceptable design implementation, risk management and acceptance, and execution of operations. The level of effort provided by the government (as measured in dollars) has typically been roughly equal to that spent on hardware providers.

This split of roles and responsibilities has produced a highly effective synergy between industry's flexibility and manufacturing capacity and the government's deep technical expertise, corporate knowledge, and operations capability, including expensive, highly specialized facilities.

A New Paradigm

To date, the high cost and risk of human space missions have required the government accept the financial, technical and programmatic risk. This made the government the funder, customer, and overall manager. Key questions arising from the planned commercial human program are, 'What has changed to enable true commercial programs now? What has lowered the risk to make it appropriate for commercial companies?'

The answers lie in the fact that NASA is proposing to approach human space flight differently than in past programs. Whereas previous programs incorporated cutting edge technology and challenged systems to achieve very high levels of technical performance, the proposed commercial program is focused on relatively simple systems to provide routine access to low earth orbit at acceptable levels of safety. The more aggressive programs of exploration and cutting edge technology expansion will remain the domain of the government, while commercial companies focus on orbital flight using mature technology and conservative designs.

For example, NASA has a tendency to design missions of high cost and consequence such that mission success is a very high priority. While aborts are designed into the system to address severe failures, multiple layers of redundancy are included to increase the probability of mission success with aborts as a last resort. The resulting additional redundancy and pressure to achieve mission success complicate the vehicle design and operational decision making.

NASA's proposed approach may offer commercial companies the opportunity to optimize design priorities for safety and economy rather than brute performance. This might allow them to, for example, produce a system with less redundancy but with a greater emphasis on survivable aborts as the means to ensure occupant safety. The use of a reliable launch vehicle with active systems monitoring and management, a robust escape system, and mission design to protect abort options may substantially mitigate mission risks.[1] These factors should contribute to controlling costs as well.

Thus a pattern emerges. The government remains the funder and customer for high risk programs while commercial companies take over the mature technology and operations. Over time the technology and operations experience for more aggressive programs will mature to the point where they can be successfully undertaken by commercial providers.

This pattern only predicts the convergence of capabilities and risk levels. It predicts nothing with regard to markets. It is hoped that the President's budget, if implemented, will provide the market and other facilitations to provide critical early support for the industry, stimulate innovation and cost reduction, and thus cause the creation of a broad and economical commercial human capability.

Market Outlook:

The commercial space flight market is defined by the "space goods, services, or activities provided by private sector enterprises that bear a reasonable portion of the investment risk and responsibility for the activity, operate in accordance with typical market-based incentives for controlling cost and optimizing return on investment, and have the legal

[1] Whether or not this reliability will meet a specific goal is unknown at this time. Current loss of crew goals under consideration by NASA appear within range of this approach, but only detailed design analyses can assess performance.

capacity to offer these goods or services to existing or potential nongovernmental customers.[2]"

Due to the high cost of entry to the market and high recurring cost of human space flight, no real commercial market has yet to emerge. Commercial markets begin to expand when sufficient demand meets available supply creating a virtuous cycle which allows producers to achieve economies of scale and lower prices further. This process requires early customers who are not price sensitive to bear the very high cost of the small production rates. As prices drop, additional demand is expected to enter the market. In some scenarios the market never grows beyond that small core group due to inherently high cost or technological limitations. In the case of human space flight, it is likely that the cost will remain very high for the foreseeable future simply because of the technical challenge and inherent risk of the enterprise. Nevertheless, there is hope that by creating a consistent demand for commercially attractive products a truly commercial market can be stimulated.

The human space flight industry may be a case study of how government can facilitate turning specialized, high cost services into commercial products. The nature of the prior government-only demand for human space flight created processes, systems, and infrastructure designed solely around U.S. government requirements and not suitable for commercial markets. Without true commercial involvement, these systems are sub-optimized for true commercial markets and the industrial base. A prime example of this is the Space Shuttle, which is an extremely capable spacecraft but one with extreme demands for unique infrastructure, high levels of engineering support, and operations optimization. The result is a system that is capable of superb technical achievements but at a cost that is unsuitable for commercial applications.[3]

Another example of this can be seen in the development of the business case for the Evolved Expendable Launch Vehicle (EELV). Here, support for two EELV launch providers during the 1990s and early 2000s was predicated on a launch market far greater than what materialized. The collapse of the business case for low earth orbit communications networks left both Boeing and Lockheed Martin competing for far fewer launches than they had anticipated. As a result, neither company could remain profitable in the new, less robust commercial launch market.

Fundamentally, then, the key deterrents to new entrants into the commercial space flight market are that the technical, financial and economic barriers to market entry are very high and the market is both small and uncertain. However, these disincentives do not necessarily translate into a consensus among potential market entrants that there is no commercial space flight market.

[2]As defined in the National Space Policy released in June 2010.
[3] The Space Shuttle also fell victim to extreme optimism in predicting market size. The actual flight rate has averaged roughly 10% of the rate cited in justifying the program during its development.

Industry Feedback:

Market viability:

As just described, in general, the companies that participated in the workshop share a vision of a healthy commercial human spaceflight market in the future and would like to participate under the right circumstances. However, the participants exhibited an inverse relationship between the experience level of the companies and their willingness to invest large amounts of company capital. This appears to reflect several characteristics of the experienced companies, including their generally more conservative culture and a corporate memory of (and some painful experience with) over-estimated markets (both commercial and government) from previous programs. They are also not inclined to underestimate the challenges of making space systems sufficiently reliable to carry humans.

Industry made it clear that the size of the initial investment and the lack of a predictable market of sufficient size to repay investments are the two largest obstacles to achieving a viable commercial human space industry. Government can do much to address both of these obstacles by investing in the development of the spaceflight systems and by serving as the anchor tenant customer for a period of time sufficient to payback the investment.

Several companies expressed confidence that they can operate successfully if expenditures are limited to recurring costs without a large debt burden. They believe that over time they can achieve efficiencies that can lower the recurring costs to include new market sectors. They feel constrained by the small known market and resulting uncertainty of investment payback.

Budget:

The companies agreed that as of the date of the workshop, the President's budget proposal was the most reasonable and supportive of a commercial human industry of those under active consideration. The proposal in the Senate seemed to provide substantially less support than the President and the House was seen as not supportive of the commercial industry at all.

Acquisition Considerations:

All companies agreed that it made sense for both industry and the government to invest in the NASA Commercial Crew Development. There were varying opinions on how much the companies should invest, although all agreed NASA should provide a majority of the investment. There were inputs received regarding experiences with various acquisition mechanisms and again there were varied opinions on their practicality. There was no consensus for or against the use of Space Act Agreements (SAA). In general, all agreed it made sense for some use of SAA's to allow the commercial industry to be a true partner and provide the Government the most flexibility. However, there was caution

expressed about using SAAs for high value investments since it limits government control over that investment as in a traditional 'FAR-based' contract.

Most all companies commented on the fact that the use of fixed price contracts or agreements (including SAA's) is best suited for fixed requirements and mature technology. Constantly changing requirements will lead to higher company investments that were not planned for. Since change is inevitable in any major development activity, it was recommended that the acquisition mechanism provide for equitable adjustment for technical changes and/or any additional risk mitigation.

Most companies cautioned against NASA allowing Orion and Soyuz to compete for the government sector of this market. They recognized the value of risk mitigation but were concerned about the effect on capital availability. They were also concerned with the potential of creating an unfair advantage that may result for any company that would be awarded full government funding to develop systems for transporting NASA crew to ISS, specifically, Orion.

Several companies warned the government about using incentives or holding back on payments in an effort to encourage commitments to safety. In fact, many of the companies said this action could lead to the opposite effect since the lack of funds may cause them to cut corners or do things differently because funds are delayed.

Liability and Indemnification:

It was clear that all commercial providers would require indemnification from excessive liability caused by commercial human operations. This may include financial support for insurance against any damage inflicted in the conduct of the enterprise as well as extension of the current indemnification regime.

Risk Management:

All commercial providers understand the risk of human space exploration and clearly showed they have the ability to identify and manage its risk. They further demonstrated they understood NASA's approach to managing risk to maximize mission success and achieve acceptable safety. What was not clear is whether the less experienced companies have incorporated lessons learned from early programs. NASA may need to provide significantly more insight and oversight to ensure sufficient identification and management of key risks.

Technical Requirements:

The government should provide stable, high level (performance) requirements and avoid being overly prescriptive. The Government should consider using commercial standards and tools whenever practical and should provide a simple methodology for evaluating and accepting/rejecting these standards. All agree appropriate use of commercial processes can help reduce the cost of spaceflight. How great a reduction varies by

company; with younger and more entrepreneurial companies being more optimistic than the more experienced ones.

When determining mandatory requirements, NASA should tailor existing ones to the greatest extent possible and ensure they are achievable. Many were concerned NASA would impose requirements they have 'on the books' that have not been met for any current or future human spaceflight system (i.e., Shuttle, Soyuz, Constellation). Many companies suggested the human rating requirements should be developed jointly between NASA, FAA and industry during the next year (FY11). This would help create a stable set of requirements that all parties can have time to validate.

When the need arises to make requirements changes, the government should apply a stream-lined approach for reviewing and accepting changes. All companies agreed that the commercial provider(s) should own the design to enable timely changes and resulting actions without the burden and bureaucracy of the government. In addition, development requirements and processes should allow for flexibility such that evolutionary changes (within reasonable costs) are attainable.

Regulatory Considerations

The companies suggested that NASA, FAA and NTSB (for mishap investigation) should develop and implement clear and common requirements and regulations. All desire FAA involvement in the NASA design and development phase since their business models require other commercial FAA licensed activity in the services phase. They are very concerned about having commonality between the two agencies. In addition, the government needs to address the gap in FAA regulations for human space flight. For example, currently passengers (spaceflight participants) are not covered. When supporting NASA missions, NASA astronauts should be considered as crew, yet the current regulations were not written to address government crews on-board the commercially licensed vehicles. Finally, several companies recognize the importance of considering operations as well as development in the regulations.

Insight/Oversight

Most companies understand the need for the Government to have both insight and oversight as part of the Commercial Crew Development and Services effort. Most showed a general willingness to use NASA expertise and some of the less experienced companies expressed a genuine need to tap into NASA's experienced workforce to be successful. There was less agreement regarding the amount of insight and oversight believed to be necessary and appropriate. Some were very clear that they only wanted a handful of NASA personnel in their plants and only when they asked for their assistance. Others recognized the importance of having day-to-day Government insight as long as it could be limited. General consensus existed amongst these companies that as long as the insight members were literally part of the team knowledgeable enough to help produce

products and not 'watchers/checkers' they would be welcomed[4]. As far as oversight, all were concerned about the level that would be sought and the approval processes the government would impose. A major concern was the time penalty as NASA became involved to review/approve decisions. Although they recognize the importance to safety of the oversight role, many suggested NASA create stream-lined approval processes that limit the number of boards/panels NASA requires and where possible, dove-tail into their processes. Many commented that the NASA insight/oversight whitepaper written by Frank Bauer and Wayne Hale was a good start on a model.

Market Outlook

When asked about the reality of a market, there was no consensus on either the size or when it might mature. Some provided an optimistic outlook that included space tourism and 'other than government' interest in space technology development and experimentation. Some believe the vitality of the market also depends on the demand for and compatibility with the other market-base of non-human services to LEO including satellite launches and cargo transport. There was agreement that the Government's actions will drive the initiation of the market and its growth rate. NASA's defined market for crew transport to and from the International Space Station (ISS) will not allow a return on investment if the companies have to fund the development themselves. Most models indicate the Government must provide a majority or all of the development funding.

There was a general consensus that the current and future market estimates must be realistic. The companies that participated in the EELV Program urged the government to be careful of excessive optimism when estimating the commercial market and encouraged caution and due diligence.

[4] This approach may complicate the NASA governance model as it has the potential to compromise the independence of the oversight team.

Panel Observations:

Acquisition Considerations

The panel observed several concerns over the use of fixed price instruments. There was a consensus that fixed price acquisitions can work fine when requirements remain fixed, there is appropriate government insight and oversight, and milestone reviews occur successfully. In addition, the panel agrees that using fixed price mechanisms increases the risk that some technical changes and additional risk mitigation may not be implemented for cost reasons. Since this can increase risk, the government should ensure an appropriate mechanism of equitable adjustment is provided for circumstances that warrant these kinds of expenditures.

NASA's current approach for acquiring a commercial capability for cargo delivery to the ISS was discussed with all of the participating commercial providers. This approach was generally referred to as the "COTS/CRS model". Implicit in this COTS/CRS model is a fixed government investment in the commercial system's development with a minimum (or at least a reduced amount) of government oversight in the provider's system development process. A fixed price basis for the post-development cargo delivery services is also implied. Nearly all of the workshop participants (5 of 7) liked the COTS/CRS model and accepted (or recommended) its use for commercial crew delivery to ISS. One participant was ambivalent about this model, believing that any contracting/acquisition mechanism could be used and that any/all terms and conditions can be worked out. The final participant believed that the COTS/CRS model is a good model, but that this program was simply too large and therefore precluded its use. They believed that the commercial provider needed to invest greater than 50% of the program funding in order to make this model successful, and that no company can afford such a large investment (especially considering the small size of the follow-on crew delivery market).

There was also considerable discussion among the participants on the level of NASA oversight required for a commercial crew transportation system development. These discussions revealed a wide range of what the companies consider an appropriate level of oversight. One participant noted that when the government has a considerable amount of investment in a program, there should indeed be strong oversight. Other than that, most of the participants accepted that there should be government insight and oversight and some welcomed government (NASA) participation in the commercial provider's development process as a valuable risk mitigation. The common concern, however, was that the government oversight would lead to requirements or design changes, for which some equitable adjustment mechanism was absolutely required.

Risk

The acceptance of risk is one of the fundamental characteristics of commercial enterprise. Companies accept significant risk as they raise capital, divert resources, and commit their reputations to new markets. In exchange for this risk they anticipate the potential to

make significant returns on their investments. Sometimes these risks are rewarded with success. Sometimes they result in technical and business failure. In some cases the failures result in the collapse of the company.

These risks are normal and appropriate for companies as their owners and managers are responsible for managing them to whatever level they feel appropriate. In addition, most taxpayers expect the government to make decisions that appropriately manage the large risks associated with high priority national objectives. Particularly when major national investments are at risk, they expect to see planning and decisions that protect those investments. Certainly providing support for the International Space Station is of such a stature.

The panel feels that NASA should undertake the use of commercial human space transportation services only with a full appreciation for the risks involved. These include technical risk (that the companies may not be able to achieve full mission objectives), programmatic risk (that the cost may be significantly higher than predicted) and business risk (that the companies may not be willing or able to continue).

Full and responsible acceptance of these risks requires the use of appropriate risk mitigation strategies. These might include selecting more than one commercial company for funding, and/or designing a government owned system (such as Orion) that is capable of doing the low earth orbit transportation mission at some cost of efficiency.[5]

The panel also believes that NASA should maintain some level of independent technical authority for programs involving human safety. In order that the commercial providers own their designs and have responsibility for their performance, that authority should not be able to direct design changes but rather advise NASA program management of their concerns and recommendations.

Liability

Liability arising from a mishap is an issue of great importance to the workshop participants. They recognize that despite the best efforts of design and operations, an accident is inevitable. Limiting the liability of such an accident is fundamental to enabling the industry to develop and will certainly require government involvement.

The current indemnification regime protecting commercial launch activities is a good model for the additional protections required. It is not clear whether it will be sufficient. Several workshop participants expressed a desire that the government provide payment for liability insurance and /or broad indemnification against liability.

[5] Workshop participants stressed the need for the government to not be an active competitor in the market. Should the Orion be obviously designed and developed as a system optimized to do the same job as the commercial providers' systems, it would significantly depress the interest of investors. Such behavior would exacerbate the already low confidence in the stability of the commercial market.

If the government is the ultimate provider of insurance resources, this increases its stake in the operations of the companies and further legitimizes its right and responsibility to oversee industry operations. As insurer of last resort, the government has a responsibility to not only maintain insight into industry operations but also oversight with some level of "veto power" over critical decisions.

Conclusions

The panel recognizes its limited mandate in conducting this workshop and does not feel it appropriate to offer recommendations to NASA. At the same time, we do feel it is appropriate to assemble and communicate conclusions we have drawn from our work.

Summary

The panel and the industry participants all envision a future state in which low earth orbit is filled with vibrant commercial activity and NASA is engaged in a bold program of exploration beyond. Achieving such a vision requires that the government take steps to transition routine functions to private providers at an appropriate point. The end of the Shuttle Program offers an opportunity to choose between another government-funded earth to orbit transportation system for which it must pay all costs in perpetuity, or the development of a commercial industry that can provide transportation services to all users while realizing economies of scale and other benefits of commercial operations.

While appropriate, the move to transition human space transportation to the private sector is a high risk undertaking. If made, its risk means the government must recognize the full set of consequences and incorporate appropriate risk management in its planning and execution. It also means that the industry's growth can be accelerated substantially by the wise use of government policies and acquisition strategies.

Existence of a business case

The development and execution of an effective business case for commercial human space transportation is a complex undertaking with many elements and options. The panel feels that the workshop illuminated the fact that no traditional, wholly commercial business case exists at this time, nor is one likely to arise for many years without government involvement. On the other hand, the panel is confident that, given the right mandate and government involvement, there is an opportunity for industry to successfully provide these services to government and commercial customers as they arise. We also believe that commercial suppliers can provide equivalent services at lower cost than government.

Risk Management

The many high risk elements of this decision require appropriate risk mitigation efforts. Areas of risk include requirements definition, system design, test, and operations, as well as the potential for business setbacks such as delays in the arrival of a commercial market. Risk mitigation steps that should be considered include the use of multiple commercial providers, the architecture of a future government system to provide fall back capability to service low earth orbit, the full availability of government facilities, personnel, and lessons learned, and the appropriate roles and responsibilities between the government and industry.

To the maximum extent possible, government planning should implement the operational concept of "make before break" in which a new capability is demonstrated to be safe and effective before relinquishing an existing capability.

Grow the Market

As demonstrated through financial analyses performed for this report, the currently defined market for commercial human space transportation is likely to produce insufficient revenue to warrant significant private investment. A satisfactory business case requires either a significantly higher price point or significantly greater traffic from a combination of both government and commercial customers, and compatible requirements so that common systems can achieve economies of scale. At this time the predicted market is too small and speculative to close the business case at a price point that could stimulate a significant commercial market. The identified NASA market is relatively high confidence but far too small.

Perhaps the most logical step is for NASA to define its own long term market for access to low earth orbit. It seems intuitively obvious that NASA will have an ongoing requirement for access to low earth orbit essentially forever, and yet the agency has limited its defined market to five years and ten flights. Committing to a much larger, long term market would have enormous impact on the viability of the commercial industry.

Some concepts of additional market opportunities for NASA include:

Expanded Utilization of the ISS

The ISS utilization is currently based on a permanent ISS crew of six astronauts with crew rotations performed on relatively long periods of stay. This limits the "market" for crew transportation to the ISS to just a couple missions per year. By increasing access to the station the agency has the opportunity to increase the mix of long and short duration astronaut missions to ISS. This could provide specialized crew training for complex tasks and the potential for non-NASA astronaut visits. Also, the addition of some visiting research facilities (nodes or research equipment) could allow for additional opportunities. These facilities could be provided from either government or commercial sources and could be made available through either NASA or commercial sources.

Short Term Space Research

The early flights of Space Shuttle provided short term (7 to 12 day) missions dedicated to space research. These missions utilized the Spacelab and Spacehab modules (as well as the Shuttle Orbiter itself) to conduct scientific and engineering experiments in the space environment. Such short term research missions can be conducted using a variety of manned and unmanned space systems, which could include commercially provided on-orbit research facilities (such as the Bigelow modules) and commercially provided astronaut/researcher transportation to LEO.

On-Orbit Servicing

On-orbit servicing of space-based assets (such as the Hubble Space Telescope) is still possible after the retirement of the Space Shuttle. Missions as complex as servicing Hubble would just require more than one launch per mission. If NASA continues to field on-orbit serviceable space systems, there would be an increased market for crew transportation missions to LEO.

Development of Exploration Infrastructure

Many people believe that exploration beyond low earth orbit will require the development of an orbital space infrastructure to assemble vehicles, create fuel depots, and stage mission operations. Such missions will certainly require routine access for crews and supplies.

Closing Thought

Everyone involved in the workshop believes it is time to begin the development of the commercial human space transportation market. They generally believe that this is the greatest single step available to reduce costs and increase access to space.

But the panel believes strongly that it is an important decision that will require the government accept high initial risk and cost as anchor tenant, mentor, and initial investor. If successfully implemented, the payoff will be huge - more robust access to space, increased interest in space among the populace, and the development of a new and vital industry within the United States with the potential to be as important to our nation in the future as aviation has been in the past.

Appendix A

Assumptions:

All issues and observations contained in this report were provided under the following assumptions:

US Access to Space: The national interest of the US is best served by the nation having an indigenous capability to transport crew to and from low earth orbit, and that national interest is sufficient to justify incurring costs above those of purchasing seats on vehicles owned and operated by other nations.

Exploration: It is the policy of the United States to carry out human space exploration by developing the capability to move humans beyond low earth orbit. This is recognized as a high risk mission that will be conducted with dedicated vehicles developed and operated by NASA.

Commercial Space Policy: It is the policy of the United States to expand economic activity into space by shifting the provision of routine human access to low earth orbit to commercial providers. The US government will obtain its capability to transport crews to and from low earth orbit through these commercial providers.

International Space Station: The United States will continue to support its obligations to the ISS at least through 2020. This will require continuous servicing of human crews at least through that time. The US is committed to provide transportation for at least three crew in vehicles flown twice per year, or a total of six crew per year.

Soyuz and Progress: NASA will continue to negotiate services with the Russians to provide launches of Soyuz and Progress to provide cargo and human transport to the ISS in the period between now and the development of alternate capabilities.

Investment: It is the policy of the United States to support the development of a healthy national commercial human space industry. NASA procurement of services from commercial providers is intended to stimulate the growth of commercial markets beyond NASA's needs.

Appendix B

Stakeholders:

NASA

NASA is the primary purchaser (market) for orbital human space transportation and human space operations for the U.S government. NASA has historically also been the developer and operator of all U.S. manned space systems.

NASA's Primary Interests/Objectives:

- Safety and Mission Success – safety of the flight crew (and the accompanying mission success) are paramount to NASA's human spaceflight programs.
- Capability to Deliver Crew to LEO (and beyond) – providing highly reliable and available access to space for NASA's astronauts, for Low Earth Orbit and eventually beyond LEO.
- Cost of Operations – developing and operating affordable manned space systems, and conducting cost effective manned space missions.

Commercial Providers

Commercial providers (the aerospace industry) are the primary suppliers of design and manufacturing for civil, military, and commercial space systems. For human space systems, these resources have all been provided under government funded and managed contracts; with the recent exception of suborbital systems being developed for commercial operations. Commercial providers have successfully developed and operated un-manned orbital systems and a suborbital manned launch system (e.g. Virgin Galactic).

Commercial Provider's Primary Interests/Objectives:

- Profitable Business Case – a profitable business case for human spaceflight and any related business activities for both the near term and far term
- Sustainable and Predictable Market – a sustainable and predictable market, in order to establish the acceptable level of investment and risks
- Performance of Company Operations – reliably safe and profitable performance of the company's own operations

FAA

The FAA is the U.S. government regulatory agency for commercial space transportation; which includes space launch and re-entry systems (manned or un-manned), as well as commercial space launch facilities (spaceports). The FAA issues permits and licenses to the commercial providers who build and operate systems.

FAA's Primary Interests/Objectives:

- Public Safety – protection of public safety and property during space launch and reentry operations
- Development of a Commercial Space Industry – encourage, facilitate, and promote the commercial space industry, to include both manned and unmanned, suborbital and orbital missions

Appendix C

Business Case Analysis:

Although sophisticated models exist for analyzing business cases, they include many variables unique to companies and opportunities. However, the irreducible minimum relationship for a business with a positive cash flow is captured by:

$$\text{Annual Revenue} \geq \text{Investment Payback} + \text{Recurring Costs}$$

$$(P \times Q) \geq (I + (I \times R) \times T)/T + (Rc \times Q)$$

Where P = market price per unit
Q = quantity of units sold annually
I = Required investment
R = interest rate (cost of funds)
T = payback period for funds in years
Rc = recurring cost per unit

Revenue (the product of price and quantity sold) **must** exceed the cost of investment (repayment of principle and interest) and the recurring cost of hardware and operations. When the investment is large and the quantity of units to be sold is small, the price must be very high. If investment is reduced or eliminated, the required cost per unit is far less.

Investors expect to make a profit in addition to paying back simple interest on the investment. Such profit is in addition to the minimum described here.

Appendix D

Cost and Schedule Pressure vs. Safety:

As previously noted, NASA has suffered three fatal accidents involving crew in spacecraft that clearly involved schedule pressure. With each accident, provisions were added to attempt to insulate critical decision makers from pressures that could lead to bad decisions. Subsequent accidents have shown that these processes were insufficient to address all cases.

NASA program management and flight operations teams have gone to extraordinary efforts to protect safety related decisions. Multiple boards concur on every change to design or operations planning and independent oversight panels review key design decisions. The agency's governance model has formalized the decades old practice of elevating to senior Agency leadership any issue that is not fully resolved at lower levels. The ethic of safety at the working level is outstanding.

But many safety critical decisions are the product of judgment that cannot be measured or tested a priori. Judgment is by its very nature subjective and therefore introduces risk. Such judgment based decisions essentially represent a subjective weighing of probabilities and consequences.

Human space flight is a high risk activity. The cost of operating safely in space includes the need for relentless attention to the smallest design detail and performance anomaly, which in turn requires a large engineering support effort. Unfortunately, even that level of attention has been insufficient to protect against all judgment errors.

There are opportunities to make this problem better or worse. The decision of the Space Shuttle design team to not include a crew escape capability created an extraordinary burden on the later engineering and operations teams. The entire system must be essentially flawless each time it is flown, and the crew and flight control teams must be ready to take critical action with very short response times. Our experience with the Shuttle has shown that this is extremely difficult and expensive.

By transferring the responsibility for human space transportation to commercial companies, NASA is putting the responsibility for critical safety decisions into the hands of people with simultaneous responsibility for business issues that are not all aligned with safety. Contracts must be met, and employees paid. Time and money are critical issues to be tracked and controlled. Several newcomers to the space business have publicly stated that "NASA needs to learn that schedule <u>does</u> matter."

All of the company officials who participated in the workshop clearly indicated that they understand the need to operate safely in order to stay in business. But it is clear that unless special steps are taken to protect against it, commercial operators will face even more severe pressure to perform to cost and schedule targets than their government

counterparts. Since companies are required to make a profit or at least maintain enough cash flow to pay employees and creditors, their decisions are evaluated against a different set of risks and consequences. Specifically, the conditional possibility of an accident will have to be weighed against the certain consequences of delays. This is the perfect set up for bad decision making.

All of the commercial providers who participated in the workshop emphasized their clear understanding of the importance of safety for the survival of their company and the industry as a whole. All promised that they would utilize the very highest integrity in their decision making. None allowed that they would intentionally accept a significant increase in safety risk to protect cost or schedule milestones because the future of their company depends on operating safely.

Several companies seemed to place the majority of their investment in safety in their design approach. They implied they were going to "design a safe system" and that the rest would be relatively easy. The panel notes that there are four components to operating safely - system design, manufacturing, test, and operations – and that design only captures one of them.

Experience has shown that it is extremely difficult to ensure perfect decision making in real life. If the company is in extremis regarding cash flow and faces liquidation, the potential for adverse consequences from a less conservative decision may seem like an acceptable risk. This does not imply anyone would intentionally act irresponsibly, but that what is believed to be a low probability of an accident may seem like a reasonable risk to accept when the alternative is the certainty of liquidation.

The panel believes that the government must make explicit provisions to protect commercial providers from adverse consequences of technical and operational decisions required to operate safely. Clearly, if a company presents a continuing series of difficult decisions requiring additional cost and schedule protection it may indicate a poor design or ineffective operator. That may result in a failure to renew a contract or other adverse action, but it should be the result of a history of performance, not an individual decision or two.

Multiple options exist on how this might be accomplished. One example might be to adjust the production and processing flow of vehicles to ensure that there is always one in storage ready to replace one with a unique concern. While this does not eliminate issues with generic design issues, it can be effective with serial number specific concerns or processing errors.

The panel views this as one of the most challenging tasks that lie before NASA and industry in order to achieve the safe and productive future all hope for.

Appendix E

Panel Members:

The government panel consisted of individuals familiar with yet independent of the commercial space industry. Individual expertise included business case development, current NASA plans and constraints for commercial crew services, human space flight operations, human rating of space systems, and executive management of both government and commercial space system organizations.

Organization	Name	Role
FAA / AST	James Van Laak	Chair
NASA / Commercial Crew Initiative	Maria Collura	Member
FAA / AST	Jim Duffy	Member
Consultant	Angelo (Gus) Guastaferro	Member
FAA / AST	Dr. George Nield	Observer
FAA / AST	Rene Rey	Observer
FAA / AST	Larry Scott	Recorder

Industry Representatives:

The following companies participated in the workshop. They were selected on the basis of their demonstrated capabilities and interest in participating in the commercial human space transportation industry and are listed in alphabetical order.

Bigelow Aerospace
Boeing
Lockheed Martin
Orbital Sciences
Sierra Nevada
SpaceX
United Space Alliance