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## ECONOMIC DEVELOPMENT OF SPACE: EXAMINATION AND SIMULATION

**A.C. Charania\***

SpaceWorks Engineering, Inc. (SEI), United States of America (USA)  
ac@sei.aero

**John E. Bradford†**

SpaceWorks Engineering, Inc. (SEI), United States of America (USA)  
john.bradford@sei.aero

**John R. Olds§**

SpaceWorks Engineering, Inc. (SEI), United States of America (USA)  
john.olds@sei.aero

### Abstract

Given the limited resources of future public outlays in space, long-term space activities have to be envisioned and implemented with the commercial sector in mind. A contribution by SpaceWorks Engineering, Inc. (SEI) to the implementation of NASA's Vision for Space Exploration (VSE) is the Economic Development of Space (EDS): Examination and Simulation project. The EDS project's aim is to examine NASA's utilization of commercial sector assets and evaluate what changes are needed to NASA requirements to promote the commercial development of space. The EDS project involves workshops attended by relevant thought leaders to address both the potential services that can legitimately be provided by the commercial marketplace and the spin-offs from government exploration missions that could be utilized by the private sector. This project also involves the development and application of the Nodal Economic Space Commerce (NESCC) model, a dynamic agent-based market simulation of various future space markets (sub-orbital space tourism, ISS crew/cargo re-supply, space resources, etc.), the resultant financial case of entities that undertake these projects, and the impact of the government actions (technology investment, anchor contracts, tax credits, etc.) upon commercial entities.

### Nomenclature

ABM	agent-based modeling
AST	Administrator for Space Transportation
CE&R	Concept Exploration & Refinement
CEV	crew exploration vehicle
DARPA	Defense Advanced Research Projects

	Agency
EDS	Economic Development of Space
ESAS	Exploration Systems Architecture Study
ESMD	Exploration Systems Mission Directorate
ESR&T	Exploration Systems Research and Technology
ETO	earth-to-orbit
FAA	Federal Aviation Administration
FALCON	Force Application Launch Continental United States
ISS	International Space Station
LEO	low earth orbit
NESCC	Nodal Economic Space Commerce

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\* - Senior Futurist, Member AIAA.

† - President, Member AIAA.

§ - Technical Fellow, Associate Fellow AIAA.

OTA           other transaction authority  
SEI           SpaceWorks Engineering, Inc.  
VSE           Vision for Space Exploration

### **Introduction**

Various motivations exist in Earth's culture for space exploration. Some possible reasons include intellectual (scientific exploration), identity (politics/culture), and economic (profit). The intellectual motivation consists of the development of both general science knowledge and the development of new technologies. Specifically this can include investigation of the solar system, the origins of life, or the weather patterns on earth. This motivation also includes the drive for research and development of new processes and materials that can be applied both in space and terrestrially. Governments have substantial interest in this type of motivation and are clear proponents of the philosophy.

Another motivation listed here is an internal motivation referred to as identity. This includes the human desire (influenced by society and its culture) evident throughout the history of terrestrial exploration and subsequent colonization. These motivations include the need to act against rivals or showcase a society's scientific and military strength (i.e. the late twentieth century Cold War). It could also include the need to work cooperatively with other nations (i.e. the International Space Station). A final motivation is that of commercial, financial reward. This motivation should not be viewed as socially objectionable. Financial rewards drive many new breakthroughs and inspire progress on multiple fronts to make processes more efficient and products more competitive. The history of space exploration is one involving the evolution from one of these paradigms to the other.

Throughout the recent history of man in space, enthusiasts have tried to imagine what will be the ultimate product or service that would revolutionize space exploration. The goal was always to make the dreams in all those pulp novels of ubiquitous space travel possible. Many waited for the government to make it possible for everyone to experience space exploration personally and not by proxy through the world's select cadre of astronauts and cosmonauts; that did not happen. In the most recent past, experts predicted that Low Earth Orbit (LEO) constellations would be the catalyst for a space boom; they were wrong. Now space tourism is seen as one of the only future markets large enough to sustain high flight

rates. Whatever the case may be in the actual future, one point is certain, a constrained government will not be the guarantor of sustained space exploration. Such a sustained presence, if not related to national defense, will ultimately have to emerge from the commercial sector. The history of civilization on Earth is replete with examples of government initiated industries transforming into viable and competitive commercial marketplaces (e.g. railroads, the Internet).

The recent few years have seen a rather curious transformation in the manner space exploration is viewed by the public. The American public now takes human space exploration, as practiced by the government, for granted. The special connection between astronauts and the public inherent in those times of NASA's Apollo mission, a slice of the twenty-first century placed into the twentieth century, may not appear again and possibly for the better. Such connections are difficult to sustain over time as perceptions of "identity" change. Yet the "economic" motivation always remains. In those early years of outer space exploration, governments were the primary driver. Today one can distinguish the gradual evolution to a new paradigm. Even with a lower number of total launches today as compared with time periods of the 1950s-1960s, the modern launch services market is more commercialized. More applications of space and innovations in its use are providing interesting commercial case studies (i.e. satellite television and radio). Additionally, the actual psychological notion of public space travel is just beginning to enter the minds of ordinary people. A myriad of small companies and organizations are proposing to solve various aspects of the space exploration problem. The current drive to develop sub-orbital space tourism vehicles and small payload launch vehicles are examples of this transformation. Any envisioned future with ubiquitous and sustainable space transportation and infrastructure systems will rely on such markets to generate continuous utilization of these assets. This will eventually encourage new launch systems and enable/enhance exploration missions to truly make outer space just another extension of human civilization.

The bureaucratic inertia reinforced by decades of relying on the government to design and develop human exploration products and services must end if sustainability and affordability are goals of such exploration. It is reasonable to assume that a large government entity will be reluctant to allow the

commercial sector to provide such services for the exploration mission. Government planners will greatly benefit if they understand the impact of public technological funding upon the commercialization of space and what areas to commercialize, especially for human exploration and development missions. Past paradigms of space exploration need to evolve to reflect changes within society and the world at large. It is imperative for the government to monitor the commercial marketplace of ideas as well as to fund spin-off activities. Current examples include both the birth of space tourism and commercial-sector investment in inflatable habitats. These influences will have an equal, if not greater impact, upon the ultimate outcome of space exploration than any combination of NASA-specific funded technologies. Such future (and commercially-related) activities could dramatically lower the cost of developing and operating exploration assets. This paper provides an introduction and update to a new project dealing with just such issues of space commercialization. Commercialization as generally addressed in the examination refers to inclusion of smaller, and/or emerging companies beyond the large prime contractor aerospace supply chain.

#### **The Government's Current Perspective on Exploration and Commercial Involvement**

Within the United States a major focus of future space policy has been the Vision for Space Exploration (VSE), announced by President George W. Bush on January 14, 2004. As stated in the VSE: "The fundamental goal of this vision is to advance U.S. scientific, security, and economic interest through a robust space exploration program."<sup>1</sup> The VSE has four major objectives:

- 1) Implement a sustained and affordable human and robotic program to explore the solar system and beyond.
- 2) Extend human presence across the solar system, starting with a human return to the Moon by the year 2020, in preparation for human exploration of Mars and other destinations.
- 3) Develop the innovative technologies, knowledge, and infrastructures both to explore and to support decisions about the destinations for human exploration.
- 4) Promote international and commercial participation in exploration to further U.S. scientific, security, and economic interests.

The last objective of the VSE is interesting in its prominence, a top-level policy directive wherein NASA is tasked to seriously consider commercial involvement in space exploration. A recent proponent of this thesis was the President's Commission on Implementation of United States Space Exploration Policy, formed to examine the VSE itself. This commission stressed the imperative of commercial involvement as shown in their following recommendation<sup>2</sup>:

NASA's relationship to the private sector, its organizational structure, business culture, and management processes – all largely inherited from the Apollo era – must be decisively transformed to implement the new, multi-decadal space exploration vision. The Commission recommends: 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 low-Earth orbit. In NASA decisions, the preferred choice for operational activities must be competitively awarded contracts with private and non-profit organizations and NASA's role must be limited to only those areas where there is irrefutable demonstration that only government can perform the proposed activity.

The Commission suggested multiple initiatives NASA should pursue in terms of involving the private sector including tax incentives, regulatory relief, and property rights in space. In the modern era there have been repeated calls from multiple areas within society for such change with only half-hearted initiatives eventually being proposed.

In general, the United States Vision for Space Exploration is to be full-scale human return to the Moon program with Mars follow-on. As of this paper, the NASA Headquarters Office of Program Analysis and Evaluation is engaged in a 60-90 day Exploration Systems Architecture Study (ESAS) to examine many of the larger questions associated with the implementation of the VSE. This study will provide the analytical support for a number of key near-term decisions for NASA, the White House, and Congress and is expected to be released in late summer/fall of 2005. The focus areas of the study include:

- 1) Complete assessment of the top-level Crew Exploration Vehicle (CEV) requirements and plans to enable the CEV to provide crew transport to the ISS and to accelerate the development of the CEV and crew launch system to reduce the gap between Shuttle retirement and CEV IOC.
- 2) Definition of top-level requirements and configurations for crew and cargo launch systems to support the lunar and Mars exploration programs.
- 3) Development of a reference lunar exploration architecture concept to support sustained human and robotic lunar exploration operations.
- 4) Identification of key technologies required to enable and significantly enhance these reference exploration systems and reprioritization of near-term and far-term technology investments.

The ESAS is expected to have large impact as it will be the new NASA Administrator's plan for the architecture components required to implement the VSE.

Unofficial sources have revealed that the study will advocate a large government-led effort in going back to the Moon, relegating commercial industry (and specifically the emerging commercial community) to the crew and cargo logistics support of the International Space Station (ISS). The study is thought to advocate development of a new U.S. government-derived, large payload space launch capability to replace the Space Shuttle, most likely a Shuttle-derived launch vehicle. The in-space human transportation component of the lunar exploration architecture, referred to as the Crew Exploration Vehicle (CEV), will most likely be a capsule or lifting body carried to orbit on an expendable rocket booster, most likely a solid rocket booster with a new upper stage. One major aspect of the VSE is clear: the Space Shuttle is unlikely to fly again after 2010 with a crew in its current configuration. The Space Shuttle's main mission between now and 2010 will be to service the ISS.

There may be potential in the VSE for involvement of non-traditional companies and development of commercially-applicable spin-offs. The challenge is to determine what components of the architecture required to go back to the Moon will be acquired directly from commercial providers versus developed in the traditional industry manner. NASA's concern

is based upon the risk of relying upon the commercial community to develop architecture elements that are in the critical path of the exploration plan. Given this attitude, NASA may look to commercial companies to perform servicing of the ISS after Shuttle retirement in 2010. Over the last few months, NASA Administrator Griffin has repeatedly made the argument for involvement of the commercial space community in this aspect of exploration, the crew and cargo servicing of the ISS. This can be seen in his remarks to the Space Transportation Association in Washington, D.C.<sup>3</sup>:

So it is a real dilemma - it is a real dichotomy: how do we engage competition and position ourselves to take advantage of the successes and accept the failures which inevitable occur in that environment while, at the same time, meeting the goals and objectives that we have as managers? What I've come to, after considerable thinking (with some discussion and modifications to come) - for NASA: the best way to do that is to utilize the market that is offered by the International Space Station and its requirements to supply crew and cargo as the years unfold...So, there will - and there must - be a government-derived capability to service the space station even after the shuttle is retired. But because there must be such a capability does not imply to us that that is the way we would most prefer - to have cargo and crew logistics requirements for the station satisfied. What I would like to do is be able to buy those services from industry...There is a line in our budget called "ISS Crew and Cargo". It is not overly well-funded right now - a couple of hundred million dollars...We plan to use that to get us started on that process...[You can] expect to see the government looking to "make a deal" in a commercial sense. Again, rather than issuing a prime contract focused on process and on very detailed specifications on "how to do" things, [you should] look for a deal-making arrangement where we tell you what it is we want the requested services or good to be able to perform. For those of you that have spent any time in the world of communication satellites - look for that to be the model rather than the CEV procurement...[You should] look for us to conduct such a competitive procurement - and [you should] look for us to pick a "leader" with whom we will get started - and also to fund a couple of "followers" at the study level in case the leader falls off the track. Because, the leader is only going to continue to get his money if

progress continues to be met. We will set up verifiable milestones, agreed upon in the deal, the way that any commercial deal would be done...[You should] look for us to conduct our contracting on a fixed price basis...In exchange for that [you should] look to be required to provide a commitment to sell at a specified price if I provide a commitment to buy - at a specified number...There won't be balloon payments at the end and there won't be "get well" arrangements if you screw up. On the other hand, there will be fairly substantial rewards for people who can deliver.

Additionally, he reaffirmed these points in his opening statement at a House Science Committee Hearing on "The Future of NASA" wherein he stated<sup>4</sup>:

The loss of the Space Shuttle Columbia has made us acutely aware that one of the major impediments in fully utilizing the Space Station's capabilities is that we need a more robust logistics capability for crew and cargo than the United States or our international partners have readily available or on the drawing board. For this reason, we plan to leverage our nation's commercial space industry to meet NASA's needs for ISS cargo logistics and possibly crew support.

Thus there appears to be some genuine admission from NASA itself that the commercial community will be some portion, if perhaps not an integral part, of the implementation of the VSE. Chris Shank, Special Assistant to the Administrator stated at the Space Frontier Foundation's Return to the Moon Conference VI<sup>5</sup>:

We've run the numbers, the budget numbers, and we can't afford this plan—we simply can't—if we follow the business-as-usual approach...NASA needs commercial ISS crew and cargo operations...If we assume CEV was the only vehicle, in a business-as-usual conservative costing approach, that if we didn't take a firm fixed-price approach towards our acquisition practices on how we're going to provide ISS crew and cargo, we could not afford to move on to the Moon.

In September 2004, NASA made eleven Concept Exploration and Refinement (CE&R) contract awards; in essence the first down payment on the VSE. These studies were to be led by industry teams

to help NASA define the requirements needed in the space exploration architecture to meet the objectives of the VSE. Awards were made at two funding levels: Human lunar exploration architecture studies and CEV preliminary concepts. Lead organizations for these CE&R contracts included both traditional large aerospace companies and smaller aerospace firms. These studies developed suggestions for how the commercial sector, and more interestingly the new and/or smaller firms, could contribute to the VSE implementation. Some specific ideas originating from these studies include:

- 1) Place commercial propellant depots in Low Earth Orbit (LEO) to be available to architecture elements (lunar architecture elements could be launched dry and refuel in orbit).
- 2) Give commercial industry domain over ISS resupply after Space Shuttle retirement where NASA would only purchase the service given an abbreviated set of requirements.
- 3) Open an alternative, non-traditional path for CEV development where there would be one large traditional prime supplier (after a down-select process) but also allow a path for the involvement of a non-traditional supplier. This has been suggested by one of the CE&R contractors Transformational Space (tSpace), an association of non-traditional aerospace suppliers including Scaled Composites (builders of SpaceShipOne).

Additionally, the first set of technology development activities have been started under the Exploration Systems Research and Technology (ESR&T) office within the Exploration Systems Mission Directorate (ESMD), one of the four major enterprises within NASA.

One major new initiative just underway at NASA includes the Innovative Programs Office in the Exploration Systems Mission Directorate (ESMD) at NASA Headquarters. This office contains the NASA program based upon and influenced by the commercial Ansari X-Prize model. Referred to as the Centennial Challenges program, four types of prize categories have been announced: Flagship (1-2/year at US\$10-40M each, major private space mission), Keystone (3-5/year at US\$250K-3M each, subsystem development), Alliance (2-4/year at US\$100-250K each, NASA provides prize purse, others administer

prize), and Quest (up to US\$1M/year, encourage science/technology/engineering/math careers). Current prizes include several US\$10K space elevator prizes, a US\$250K lunar stimulant ground-based oxygen processing prize, and \$250K astronaut glove challenge. Recently, it has been announced that this new office will also be examining non-traditional avenues for engaging the commercial community in exploration. The preliminary outlines of this office indicate that various contract instruments and activities will be utilized (see Table 1) including: service procurements (especially commercial services such as Federal Aviation Regulation Part 12), Other Transaction Authority (OTA) such as funded Space Act Agreements, and prize competitions (especially larger prize purses).

These initial examples of possible involvement through non-traditional means indicate a certain level of acceptance (or at least acknowledgment) of the commercial community and the products and services it may be able to provide.

The VSE (and NASA's implementation of it) is only one part of the larger landscape of changes in government space development budgets. Over the past few years, numerous government Reusable Launch Vehicle (RLV) or space access programs have been cancelled or stalled. These include the X-33, X-34, Space Launch Initiative (SLI), Orbital Space Plane (OSP), and new rocket engine development efforts. With full-scale RLV development and acquisition estimated at US\$15-\$20B, air-breathing / hypersonic space access vehicles remain more than one to decades away from being mature for operational flight. Rocket-Based Combined Cycle (RBCC) and Turbine-Based Combined Cycle (TBCC) systems though are still of interest to the military.

However, various United States Department of Defense (DoD) programs are currently focused on responsive space launch access using both conventional and new technologies. These programs include the Defense Advanced Research Projects Agency (DARPA) Force Application Launch Continental United States (FALCON). The DARPA FALCON program goal is to develop cheaper and faster space access launch vehicles to carry hypersonic test spacecraft as well as the technologies and systems required for a future hypersonic cruise vehicle. For instance under the DARPA FALCON program multiple, small payload (~1Klbs) launch vehicle companies have been given development

funds to advance their concept designs to hardware stage. These programs may stimulate new launch capabilities useful to commercial industry as well as in the implementation of the VSE.

Another important government action that will have a continuing effect is the Commercial Space Launch Amendments Act of 2004 (HR5382) passed by the United States Congress. This bipartisan law has been in work over the previous several years and amends the 1984 Space Launch Act which had no references to manned vehicles. The basic philosophy of the law is that as long as the uninvolved public is not threatened; allow the commercial industry freedom in their designs. Currently in the United States, space tourism vehicles are regulated by the Federal Aviation Administration (FAA) under the Administrator for Space Transportation (AST). This group is responsible for granting licenses and permits for both launch vehicles and launch sites. This new law specifically relates to the authority and duties of this body of the executive branch of government. A major aspect of the new law was to streamline the process for experimental permits to allow unlimited research and development flights (flights not for hire). For flights for hire, as in the case of sub-orbital space tourism operators, the FAA's regulation is limited to traditional informed consent procedures where participants are informed of the risks and waive their rights against the U.S. government. The AST has three years to pass regulation regarding these areas. Future issues that may need to be addressed include export control laws (currently affecting Virgin Galactic's purchase of Scaled Composite's sub-orbital space tourism vehicles), international landing laws, and international liability. However, the nascent sub-orbital and orbital space tourism industry views this new law as a significant milestone that acts as a major step forward in clarifying the role of the government in terms of permitting, licensing, and general regulation.

### **Commercial Sector Involvement**

The Ansari X-Prize, won in 2004 by the Mojave Aerospace Ventures (consisting of Burt Rutan's Scaled Composites and Paul Allen) may be viewed by future historians as a watershed event in the history of space commercialization. By actually providing evidence of the emerging commercial space community's capabilities to perform, it has opened the eyes of both the lay public and government space program managers.

There are currently multiple start-up companies competing for the small-satellite launch market and or sub-orbital tourism market in a post X-Prize environment. For example, the emerging launch vehicle / space tourism companies currently include: Virgin Galactic (Richard Branson of Virgin), Scaled Composites, the SpaceShip Company, SpaceX (Elon Musk from Paypal), Blue Origin (Jeff Bezos of Amazon.com), SpaceDev, Xcor, Microcosm, Armadillo Aerospace (John Carmack of id Software), Rocketplane Limited, TGV Rockets, and the X-Prize Cup (X-Prize Foundation). Additionally, Bigelow Aerospace (Robert Bigelow) is in development of inflatable on-orbit modules based upon NASA-licensed technology. Orbital Recovery, Limited is a new company developing an on-orbit commercial satellite service based upon a stage-adapter from an Ariane-5 launch vehicle. There are also reduced gravity flights being offered by Zero Gravity Corporation. Robert Bigelow has also announced a new US\$50M "America's Space Prize" requiring the following by 2010: a reusable spacecraft capable of taking a crew of no fewer than five people to an altitude of 400 kilometers and completing two orbits of the Earth at that altitude, repeating that accomplishment within 60 days, while demonstrating the ability to dock with Bigelow Aerospace's inflatable space habitat and be able to stay docked in orbit for up to six months. Separate from NASA's VSE and the traditional aerospace industrial base, there are innovative new groups pursuing multiple space services using a myriad of approaches seeking not only government but purely commercial customers (e.g. sub-orbital and orbital tourism).

### **Economic Development of Space (EDS) Project**

A contribution by SpaceWorks Engineering, Inc. (SEI) to the implementation of the Vision for Space Exploration (VSE) is the project entitled: "Economic Development of Space (EDS): Examination and Simulation." This project, begun in April of 2005, is funded exclusively by NASA's Exploration Systems Mission Directorate (ESMD) Research & Technology program under a Broad Agency Announcement (BAA) for the Exploration Systems Research and Technology (ESR&T) office at NASA Headquarters. In early 2004, NASA's ESMD developed a Human and Robotics Technology (H&RT) formulation plan identifying the research and technology goals and objectives for implementing the VSE. Based on this plan, NASA issued a BAA, one of several steps being taken by NASA to develop new partnerships with industry and

academia. From more than 3,700 Notices of Intent submitted to NASA from commercial industry, the field was narrowed to 485 full proposal submissions, and then to a final set of 70 proposals that were selected for an actual award. This project from SEI entitled "Economic Development of Space (EDS): Examination and Simulation" was one of those selected.

The EDS project's aim is to examine and simulate potential future scenarios of the commercialization of space and identify how they relate to the national Vision for Space Exploration. This project is developing specific recommendations on how the National Aeronautics and Space Administration (NASA) can utilize other government and commercial products and services to meet the goals of the VSE. This study involves workshops attended by relevant thought leaders to address what potential services can legitimately be provided by the commercial marketplace in these categories and also what spin-offs from government exploration missions would be utilized by the private sector. The EDS project also includes the development and use of an economic and market simulation model referred to as the Nodal Economic Space Commerce (NESC) model. Markets to be modeled include all current major government and commercial markets as well as overlays of future markets (space tourism, space solar power, etc.). The EDS project team is led by SEI and involves an international team which has expertise in space commercialization, market forecasting and modeling.

From sub-orbital space tourism to new small payload launch vehicles and inflatable space habitats, a myriad of companies and organizations are proposing innovative solutions to the space exploration problem. What is commercial industry doing that could be utilized for the return to the Moon and beyond? What specifically can NASA do to fully allow these innovations to help? What will future space commerce look like? These are the types of questions the EDS project seeks to answer through dialogue with leading thought experts coupled with a high fidelity computer simulation of the future space marketplace.

The project is concerned with two general categories of future economic development of space: human/cargo access to space and space resources. The first category includes earth-to-orbit (ETO) transportation for crew and cargo, commercial and civil, domestic and international. This category

includes development of commercial infrastructure such as on-orbit recovery and space habitats. Specific examples include space tourism, alternate access to the International Space Station, on-orbit satellite servicing, the use of the United States' EELV fleet, commercial habitat development, new commercial launch vehicles, foreign launch providers, European ATV development, and Air Force/DARPA space programs (ARES, FALCON, Orbital Express). The second category involves space material use including In-Situ Resource Utilization (ISRU), Space Solar Power-(SSP), and asteroid mining.

These qualitative and quantitative assessments will help develop a roadmap the government can use to plan the appropriate mix of commercial acquisition and government development required to meet the goals of the VSE. This will help NASA determine which technologies have the greatest potential contribution to the commercialization goals for space exploration. Phase I of the study includes examination of products and services related to human and cargo presence in space such as ETO transportation for crew/cargo and commercial infrastructures such as space habitats. An eventual final report and results from the NESC quantitative model will be presented to managers at NASA Headquarters and other relevant policy makers.

### **EDS Workshops**

One of the major components of the EDS project involves a series of workshops every project year on the topic of space commercialization. Engagement is achieved through relevant presentations and dialogue amongst a diverse set of participants. Two workshops were performed for EDS Phase I with slightly different themes. As a caveat it must be mentioned that the results and discussions from the workshops represent only a small subset of the entire population of space professionals and the interpretations provided here are solely those of the authors. The results here are not given as representative of the entire community but rather as discussion points for further analysis by relevant commercial and government policy makers.

#### **EDS Workshop 1**

EDS Workshop 1 was an invitation-only workshop that took place at the Crystal Gateway Marriott in Arlington, Virginia from Tuesday, May 17, 2005 through Wednesday, May 18, 2005. This workshop was held prior to the National Space Society's 24th

International Space Development Conference (ISDC) which took place at the Sheraton National Hotel in Arlington, Virginia from Thursday, May 19, 2005 through Sunday, May 22, 2005. The purpose of EDS Workshop 1 was to solicit input on how commercial industry can help NASA achieve the objectives embodied in the Vision for Space Exploration (VSE). The workshop included plenary and breakout sessions specifically addressing the following themes:

- 1) "How can the commercial industry help NASA, and specifically the Exploration Systems Mission Directorate (ESMD), achieve its space exploration goals and objectives in the areas related to Earth-to-Orbit (ETO) cargo/human launch and habitats, or access and activities?"
- 2) "What does NASA need to do to change its requirements to facilitate and enable the commercialization of space?"

Selected catalytic presentations were given along with substantial opportunities for interchange between various thought leaders through facilitated group discussion and breakout working groups. There were thirty-six attendees that participated in the workshop, representing various constituencies including:

- 1) Companies seeking to provide space tourism services and to develop that industry
- 2) Companies that provide existing or emerging launch vehicles and the related infrastructure
- 3) Companies providing products that support on-orbit activities, including satellites, on-orbit propulsion, in-space research, and others
- 4) Organizations working to advance or advocate the exploration of space, including NASA
- 5) Companies and organizations engaged in the analysis of space markets, space activities, and the future of space exploration
- 6) Academics and advocacy groups ("other" category, which also includes guest speakers)

The workshop focused on issues that were of considerable interest to smaller entrepreneurial organizations, whose representatives constituted the majority of industry participants. Smaller companies were able to provide insight into their challenges in

working with NASA and in pursuing space activities separately from NASA. The presence of attendees from larger aerospace companies added balance to the mix of viewpoints. The workshop was also balanced between those representing emerging space markets, such as space tourism and on-orbit activities, and those representing more established market segments, such as launch services and industry analysis. This balance allowed for a variety of perspectives and some specific insight from those companies that were once considered emerging and are now thought of as established. Qualitative ranking approaches were used to guide the thoughts of the participants. These approaches included prioritizing a predetermined large set of issues (approximately 15-20 items) into the most relevant. As seen in Figures 1 and 2, two breakout sessions prioritized different types of products and services, namely LEO services (breakout session C) and LEO activities (breakout session D), that the commercial community could provide to the government. The entire workshop group also ranked a list of impediments to working with the government (Figure 3). A weighting process was used to determine the overall ranking of items in each of these categories. The number of participants who gave the same ranking was multiplied by a weighting factor. These "weighted counts" were then normalized by the highest weighted score. The resultant consensus scores (between 0 and 1) as shown in Figures 1 through 4 give an indication of the relative importance of the item in comparison to other items.

The results indicate that workshop participants felt that the commercial community could most likely provide products and services in the near term. The top contributions in terms of space access were those of consumable supply and ISS crew rotation. These are more near term, potential markets than orbital space tourism or high-value (e.g. government exploration-related) cargo. Similarly for space activities, the most promising contributions were deemed to be telecommunications and ground processing, above farther term markets such as space tourism habitats (space hotels). It can be inferred that the group did not perceive far term markets such as tourism to be beyond the reach of commercial industry, but just not the most immediate contribution by the commercial space community.

There was general agreement that NASA does not take the commercial space community seriously. However, there was acknowledgement that this perception has been changing over the years. The

participants from the commercial space community still felt there was a large risk in working with NASA, both in terms of the collective administrative burden placed upon a company and the inherent uncertainty of dealing with ever-shifting government requirements. The commercial participants in the workshop do realize that some companies may not be sufficiently capitalized to take on such ventures as well.

Specific observations from the discussions in EDS Workshop 1 include the following:

- 1) A mistaken perception of relative risk should not preclude use of the emerging commercial space community (or "new space") in exploration activities. There is a perception that NASA still views the companies in this community as non-credible. Space is risky and there may be a need to have both critical and non-critical paths for exploration. The emerging space community may have a very legitimate role to play in these non-critical paths as potential off-ramps for development. There may even be a need to review the nature of government exploration, currently managed as a program rather than nurturing an industry.
- 2) Bureaucracy and inconsistency (i.e. changing requirements, non fixed-priced contracts, etc.) are large barriers to commercial sector involvement with the government. Allowing commercial industry freedom to design a solution may be important. The precise organizational structure of NASA (realignment, re-branding, etc.) may also be up for evaluation.
- 3) NASA's historical role may still be applicable today and it has core missions that the commercial industry cannot replicate (i.e. planetary exploration). NASA can still act as a champion for exploration in general. NASA could also utilize commercial expertise in the promotion of the VSE.
- 4) NASA should not develop ETO launch services but buy where appropriate. NASA may have to reexamine its preference for owning and operating systems. This does not preclude pure technology development for future RLVs to X-vehicles (which may be encouraged) or development of large,

heavy lift services which may not be available from the commercial industry by itself. LEO access is one of the primary market opportunities in the near term for space commercialization. Cargo launch (and specifically propellant supply) and crew transfer are important capabilities the commercial space community can provide in terms of LEO access. There is interest from multiple commercial entities (traditional and non-traditional alike) and government should not interfere in this development.

- 5) The government should continue the use of prizes but be careful in their applicability. Prizes may be limited in terms of applicability to longer term, large-scale robotic and human exploration goals. Prizes are better suited for more near term goals (such as near earth, LEO activities). Prizes for activities with excessive risk will not be attractive for commercial companies.
- 6) Telecommunications and ground services can be immediate areas of commercialization, separate from tourism.
- 7) The government should encourage partnerships between the emerging / "new space" community and the traditional aerospace industrial base.
- 8) The government, along with industry, should reexamine existing International Traffic In Arms regulations. Partnerships between multiple companies (non-aerospace/aerospace, small/large, domestic/foreign etc.) will be important in the future.

## **EDS Workshop 2**

EDS Workshop 2 was an invitation-only workshop that took place at THEhotel at Mandalay Bay in Las Vegas, Nevada on Wednesday, July 20, 2005. This workshop was held prior to the Space Frontier Foundation (SFF) Return to the Moon VI Conference which took place at the Flamingo Hotel in Las Vegas, Nevada from Thursday, July 21, 2005 through Saturday, July 23, 2005. The purpose of EDS Workshop 2 was to solicit input on how commercial industry can help NASA achieve the objectives embodied in the Vision for Space Exploration (VSE). The workshop included plenary sessions specifically addressing the following themes:

- 1) Presentations and discussion of products and services related to Earth-to-Orbit (ETO)

cargo/human launch and habitats in the near, mid, and far-term.

- 2) Presentations on modeling the space marketplace, specifically the Nodal Economic Space Commerce (NESC) model.
- 3) Discussion of various government technology investments that could be beneficial to the commercial industry.

Selected catalytic presentations were given along with substantial opportunities for interchange between various thought leaders through facilitated group discussion and breakout working groups. There were approximately twenty-three attendees that participated in the workshop, representing various constituencies, similar to EDS Workshop 1.

There was specific discussion of potential future space companies in the year 2010-2020 that consisted of refining fictitious profiles of multiple companies as derived by the EDS project team prior to the workshop. Several company profiles were examined in depth at the workshop including: a small cargo electric propulsion-based delivery company (operating in the year 2010), two suborbital passenger flight companies (operating in the 2010), and a lunar oxygen production company (operating in the year 2020). These business profiles will be used to develop the company agents in the NESC model.

Similar to EDS Workshop 1, qualitative ranking approaches were used to guide the thoughts of the participants. These approaches included prioritizing a predetermined set of technologies (approximately 15-20 items) into the most relevant in terms of those technologies the government should fund that will best contribute to the business success of the commercial space community (including the emerging space community). The participants felt that better fuel cell technology would be near the top in terms of possible government investment that could assist the commercial space community. It was also speculated that this technology would have application to multiple concepts within aerospace and also benefit other industrial areas beyond aerospace. Surface nuclear power sources, a very expensive but potentially power rich technology, was also ranked very highly. Propellant storage technologies (tanks and in-space storage) both also scored highly amongst the possible technology options. These technologies all have similar characteristics in requiring large investments, something industry may still want or even need the government to perform. It is interesting to note, that a consensus opinion from

EDS workshop 1 was that the government still has a role to play in the development of space, commercial industry (even the emerging community) recognizes this role. In EDS Workshop 2, the role, in terms of technology development, was deemed to be in the area of expensive but potentially enabling technologies.

### **Nodal Economic Space Commerce (NESC) Model**

The Nodal Economic Space Commerce (NESC) model is a dynamic, agent-based market simulation tool of the space marketplace. Each agent in the model is a representation of various entities within the space industry (consumers, producers, and the government) that provide or demand different products and services (Earth-to-orbit launch, habitats, resources, etc). Each agent has certain behaviors and interacts with other agents, possibly resulting in competition between firms and entrance of new competitors. The NESC model contains various future space markets (duopoly, pure competition, etc.) and simulates the financial case of entities that undertake these projects. NESC is of higher fidelity than existing models utilizing more advanced financing, acquisition, and overall decision-making strategies throughout the full supply chain of space products and services (from vehicle developers to operators to consumers). Sample future markets that NESC will simulate include sub-orbital space tourism, orbital space tourism, commercial and government spacecraft, government exploration (ISS, moon) cargo/crew services, and future resources (mining, Space Solar Power, etc.). Agent-based modeling (ABM) allows one to simulate the impact of decisions before applying them in the real world. These choices include behaviors such as end-user price changes, product differentiation, insurance charges, and vehicle cost increases. Additionally, the impact of government actions can be incorporated (price elasticity, technology investment, anchor contracts, tax credits, regulation, etc.). The NESC model is still in development and the content of this paper is intended to inform the reader to the basic premise of the NESC model. The NESC philosophy allows for a more realistic and dynamic simulation of traditional and emerging space markets.

The complex world consists of many interactions of multiple groups. These groups consist of individual entities each with certain behaviors. As conditions around these entities change, so do their reactions based upon their behaviors. In terms of modeling the economic relationship between entities, multiple

paths can be chosen for such modeling. Typical, spreadsheet-based models strain to model the complexity both within these individual entities and their interaction with other entities. Additionally, spreadsheet models may require more computation time for optimization and probabilistic analyses for very advanced models. Also the complex financial calculations for an adequate model require more processing than typically handled in such environments.

Agent-Based Modeling (ABM) in a programming language can provide a solution by allowing the modeling of such dynamic interactions. The benefits of ABM include<sup>7</sup>:

- 1) ABM captures emergent phenomena: Emergent phenomena result from the interactions of individual entities. The whole is more than the sum of its parts because of the interactions between the parts. For example, a traffic jam, which results from the behavior of and interactions between individual vehicle drivers, may be moving in the direction opposite that of the cars that cause it
- 2) ABM provides a natural description of a system: The model seems closer to reality. For example, it is more natural to describe how shoppers move in a supermarket than to come up with the equations that govern the dynamics of the density of shoppers
- 3) ABM is flexible. It provides a framework for tuning the complexity of the agents: behavior, degree of rationality, ability to learn and evolve, and rules of interactions. There is an ability to change levels of description and aggregation (e.g. aggregate agents, subgroups of agents, and single agents, with different levels of description coexisting in a given model)

In the simulation here, the companies are represented in the model by “agents.” Each agent decides for itself which actions to perform at what time, based on external conditions and private internal aspects (current beliefs, desires, etc). Agent-based software provides the framework for creating agent-based models. Over 20 different software programs were evaluated by the authors until the Recursive Porous Agent Simulation Toolkit (RePast) ultimately was selected due to available libraries, maturity, and ease of use. RePast is an open-source software framework for creating agent-based simulations using the Java

programming language. The first implementation of NESC is based in RePast.

### **Sub-orbital Space Tourism Implementation**

The first example market that was modeled in NESC was the sub-orbital space tourism market with companies competing for customers with the goal of maximizing revenues (see Figure 5). In this version of NESC (version 0.3) for the sub-orbital space tourism market, each company autonomously decides its pricing strategy given its unique capacity, costs, and vehicle characteristics. NESC outputs the financial health of each company (cash flows, Net Present Value, market share, etc.) and can be used to explore various scenarios including supply vs. demand effects, customer preferences, and company strategies (including product differentiation and cost leadership).

### **ISS Re-supply Market Implementation**

The second major implementation of NESC is the modeling the future ISS cargo/crew re-supply market with agents representing demand (NASA, commercial space) and supply (NASA CEV, European ATV, Japanese H-II, Soyuz, Progress, emerging alternate U.S. providers). This market has been chosen because of recent government policy to allow commercial companies to provide ISS re-supply services in anticipation of a reduction in Space Shuttle availability.

### **Future Work**

The EDS project, as proposed to NASA, is a two year long project to qualitatively and quantitatively examine the trends and forecast the future in terms of space commercialization. The NESC model is currently in prototype form and is being heavily modified from the development model shown at EDS Workshop 2. At the end of Phase I (project year 1) a fully functional NESC model is anticipated to be complete that will include multiple case studies (company agents).

Future markets to be modeled in NESC include orbital space tourism, space activities, space solar power, lunar/asteroid resources, etc. Additional financial methods to be implemented in NESC will allow for determination of company initial price points, allowing companies to enter and exit the

market, and allowing companies to use higher fidelity financing tools (stocks, warrants, debt financing). The strategies available to company agents will also be expanded to allow company agents to estimate the actions of their opponents and make production decisions to increase fleet size. New agents will also be added to the model, including expressing demand through individual customer agents or groups of customers with unique desires and behaviors (beyond simple market elasticity curves), vehicle production agents, and government agents (with the power to provide tax incentives, anchor tenancy, etc.).

Phase II of the project (project year 2) involves examination of space resource markets and a probabilistic examination of the NESC markets from Phases I and II. Phase II also involves two more workshops. Publicly available final reports are anticipated for all EDS activities. The NESC model will eventually be made available to funding agencies such as NASA and be available for use by SpaceWorks Engineering, Inc. (SEI) for any interested customers.

### **Conclusions**

EDS Workshops 1 and 2 were successful in engaging both EDS team and external representatives of commercial space companies ranging from traditional entities to the emerging/ “new space” community. There has been a very positive start on the development of the Nodal Economic Space Commerce (NESC) agent-based model in the RePast framework. Multiple lessons have been learned from initial development of the NESC model that will help guide future development. NESC has the potential for dynamically modeling the space marketplace in an agent-based software framework. In such an environment there is autonomous decision making by agents, communication between agents, and various price setting strategies. EDS Workshop 2 provided an opportunity to disclose the first aspects of the NESC model (even in beta form). There was genuine interest on the part of government and industry in the potential of this activity. The timeliness of this activity cannot be understated given the initiatives from commercial industry (e.g sub-orbital space tourism) and new programs within the government to utilize this community (e.g NASA’s new Innovative Programs Office and the potential NASA ISS re-supply Broad Agency Announcement).

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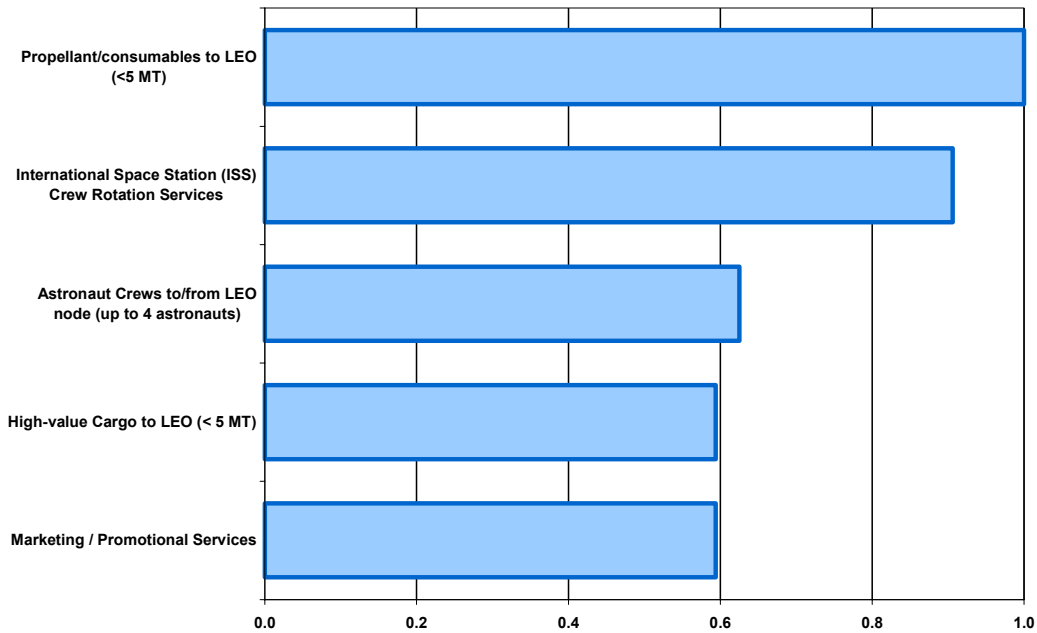
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**Table 1. Example Areas of Transaction by NASA Innovative Programs Office.<sup>6</sup>**

Mission	Government Transaction Type	Potential Application
1) Sub-orbital launch	Services	i. Micro-g experiments ii. Astronaut training
	Prizes	i. Altitude and reusability for science instruments ii. Vertical-Take-Off-Vertical-Landing (VTVL) and speed for lunar lander proxy
2) Low cost ETO launch	Services	i. Unflown payloads ii. Technology payloads
3) Proximity operations	Services	i. Unpressurized Space Station cargo delivery ii. Pressurized Space Station cargo delivery
	Services	i. Space Station cargo return
4) Reentry	OTA	i. Return vehicle development
	Prizes	i. Return vehicle flight
	Services	i. Space Station crew transfer ii. CEV crew transfer
5) Crew transport	OTA	i. Crew vehicle development
	Prizes	i. Crew vehicle flight
	Services	i. Lunar mission provisioning
6) In-space propellant provisioning	Prizes	i. In-space propellant storage and transfer demonstration
	Services	i. Small missions ii. Surface payloads
7) Small lunar transport	Prizes	i. Data/demo menu ii. Small soft lander

**Breakout Session C - ACCESS**



**Figure 1. Consensus Score of Top Contributions by the Commercial Space Community (Including Emerging Companies) to Exploration [Related to LEO Access]**

### Breakout Session D - ACTIVITIES

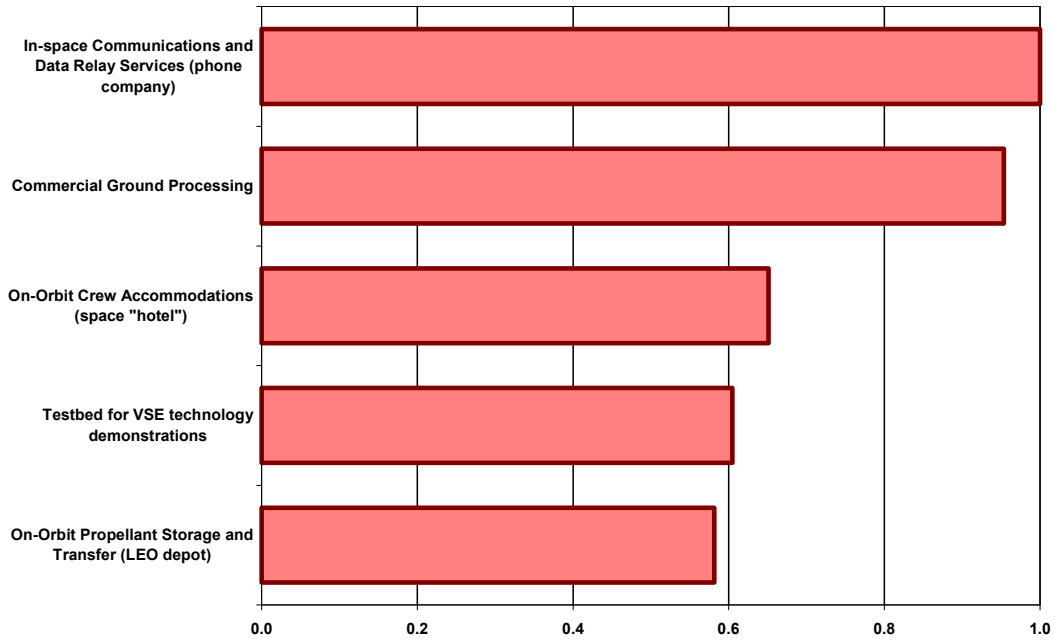


Figure 2. Consensus Score of Top Contributions by the Commercial Space Community (Including Emerging Companies) to Exploration [Related to LEO Activities]

### Breakout Session E - BARRIERS

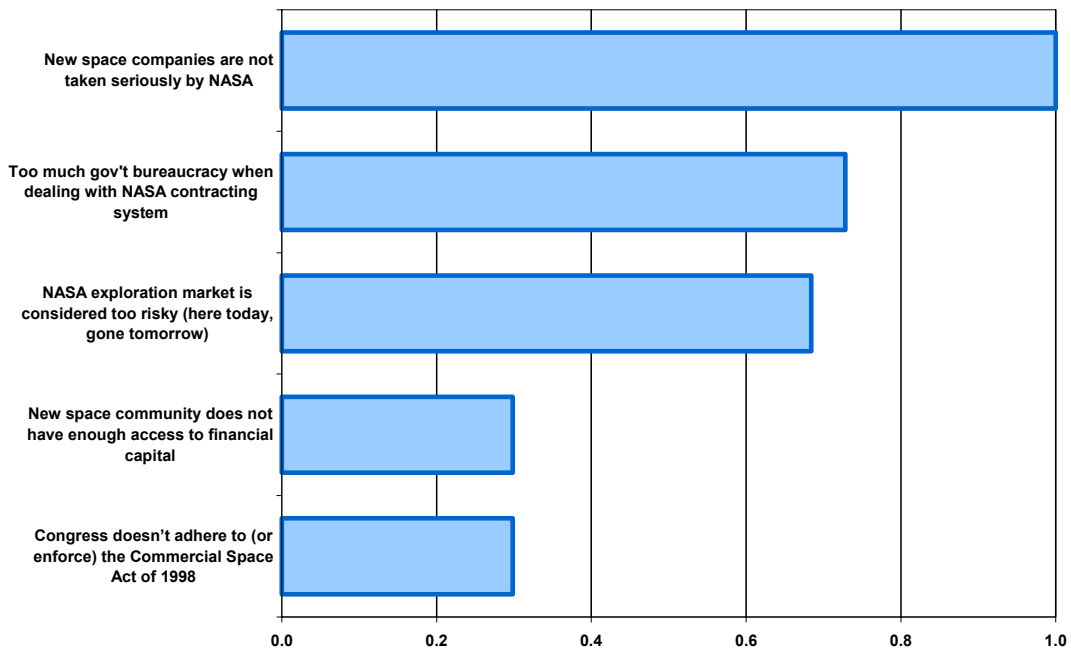


Figure 3. Consensus Score of Top Government Barriers to Commercialization of Space

### Government Technology Investment for Space Access and Activities

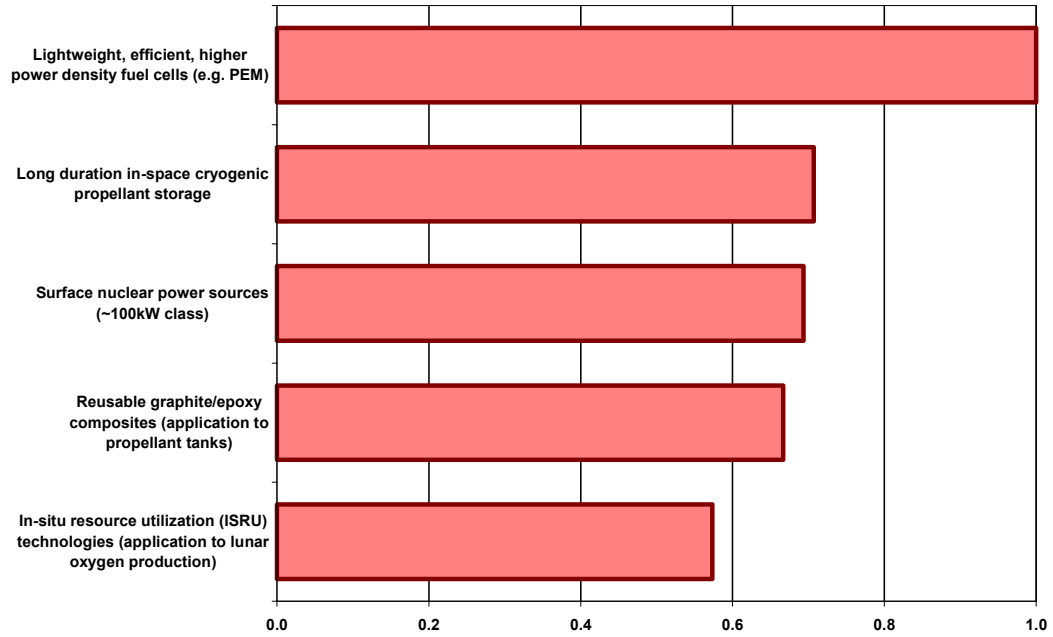


Figure 4. Relevant Government Technology Investment as Viewed by Commercial Enterprises

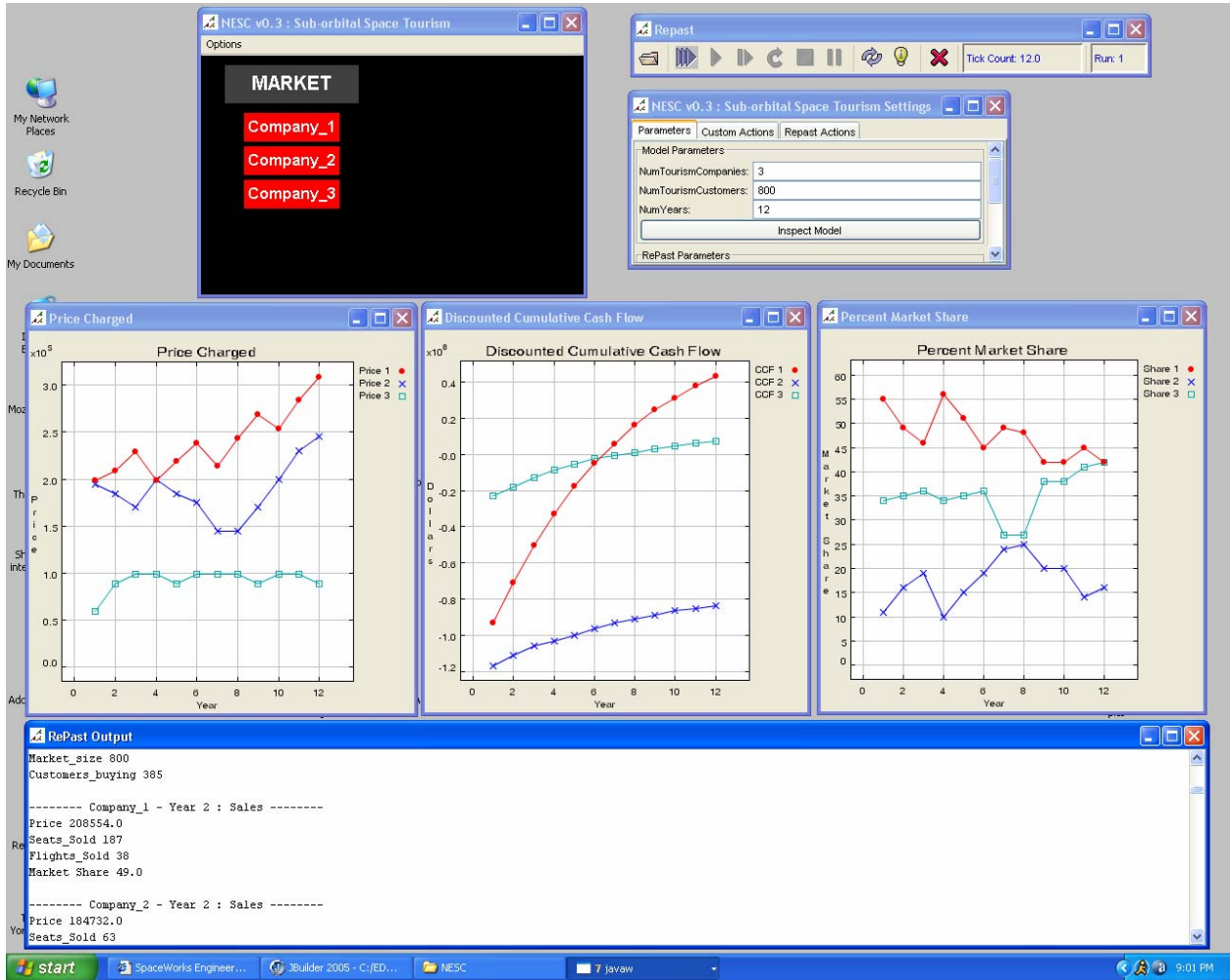


Figure 5. NESC v0.3 Formulation (Sub-orbital space tourism market) in RePast Framework on PC Desktop