Economic Development of Space (EDS) Project Update: Examining and Simulating the Space Marketplace
AIAA-2005-6797

Mr. A.C. Charania
Senior Futurist
SpaceWorks Engineering, Inc. (SEI)

Dr. John R. Olds
Technical Fellow
SpaceWorks Engineering, Inc. (SEI)

Dr. John E. Bradford
President
SpaceWorks Engineering, Inc. (SEI)

Mr. Jon G. Wallace
Project Engineer
SpaceWorks Engineering, Inc. (SEI)

Mr. Dominic DePasquale
Project Engineer
SpaceWorks Engineering, Inc. (SEI)
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Introduction
Vision for Space Exploration (VSE)
THE FUNDAMENTAL GOAL OF THIS VISION IS TO ADVANCE U.S. SCIENTIFIC, SECURITY, AND ECONOMIC INTEREST THROUGH A ROBUST SPACE EXPLORATION PROGRAM

- Implement a sustained and affordable human and robotic program to explore the solar system and beyond.
- 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;
- Develop the innovative technologies, knowledge, and infrastructures both to explore and to support decisions about the destinations for human exploration; and
- Promote international and commercial participation in exploration to further U.S. scientific, security, and economic interests.
Building Blocks of the Vision—Under Revision
The ESAS is a 90-day study that is examining many of the larger questions associated with the Vision for Space Exploration (VSE)
- From NASA HQ’s Office of Program Analysis and Evaluation
- Will provide the analytical support for a number of key near-term decisions for NASA, the White House, and Congress

Some of the topics the ESAS is reviewing include the requirements for returning to the Moon and extending human exploration to Mars, as well as possibilities for accelerating the development of the Crew Exploration Vehicle (CEV)

This team is expected to complete its work in July and to start presenting findings

Focus areas
- 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.
- Definition of top-level requirements and configurations for crew and cargo launch systems to support the lunar and Mars exploration programs.
- Development of a reference lunar exploration architecture concept to support sustained human and robotic lunar exploration operations.
- Identification of key technologies required to enable and significantly enhance these reference exploration systems and reprioritization of near-term and far-term technology investments.
In September 2004, NASA made eleven Concept Exploration and Refinement (CE&R) contract awards
- Human lunar exploration architecture studies and Crew Exploration Vehicle (CEV) preliminary concepts
- Lead organizations included both traditional large aerospace companies and smaller aerospace firms.

Suggestions for how the commercial sector (including new and/or smaller firms could contribute)
- 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)
- Commercial industry get domain over ISS resupply after Space Shuttle retirement where NASA would only purchase the service given an abbreviated set of requirements
- 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)

Source: http://exploration.nasa.gov/documents/cer_reports.html
“Emerging” Space
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.

“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.” (Source: Opening Statement by Michael Griffin at a House Science Committee Hearing on The Future of NASA, Tuesday, June 28, 2005)

- Possible reduction of total Shuttle flights before 2010 from 23-30 flights to under 15
- NASA and other USG agencies addressing Iran Nonproliferation Act (INA) of 2000
- Additional commercial purchases for ISS support
  - For crew transport, logistics, and resupply
  - Beyond Progress, Soyuz, Japanese H-II Transfer Vehicle, and European Automated Transfer Vehicles
- NASA is also currently examining alternative configurations for the ISS
  - May 2005, NASA initiated the Shuttle/Station Configuration Options Team (SSCOT)
  - This team is conducting a 60-day study of the configuration options for the ISS and assessing the related number of flights needed by the Space Shuttle before it retires no later than the year 2010
  - Scope include ISS assembly, operations, and use and considers such factors as international partner commitments, research utilization, cost, and ISS sustainability.
  - This team is expected to complete its work in June/July, with those results integrated into the ongoing Exploration Systems Architecture Study (ESAS)
Components of EDS Project
**Objectives**

This study shall examine and simulate potential future scenarios of commercialization of space and how they relate to the United States of America National Vision for Space Exploration (VSE).

**Activities**

1. This activity shall develop specific recommendations on how the National Aeronautics and Space Administration (NASA) can utilize government and commercial products and services to meet the goals of the VSE.

   **OUTPUT: REPORT**

2. This activity shall include the development and use of an economic and market simulation model referred to as the Nodal Economic Space Commerce (NESC) model. The 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.).

   **OUTPUT: MODEL**

**Funding Source**

Broad Agency Announcement (BAA) in 2004
Exploration Systems Research and Technology (ESR&T) Office
Exploration Systems Mission Directorate (ESMD)
National Aeronautics and Space Administration (NASA)

Note: Out of 3500+ Notices of Intent, 500 went to full proposal, only 70 were funded, including the EDS Project
Components and Project Phases

- Examination
  - Experts in the field of space tourism, space market assessment, and space resources will be utilized to help develop future scenarios of the economic development of space. Case studies and modeling issues will be discussed through project workshops, seminars, and meetings of commercial, government, and international organizations.

- Simulation
  - The Nodal Economic Space Commerce (NESC) tool will model various future space markets (duopoly, pure competition, etc.) and simulate the financial case of entities that undertake these projects.

- Phase I:
  - Phase I of the proposed study will last twelve months. It will consist of examination and simulation of future commercial products and services that could be used in future exploration architectures as well as NASA technologies that would benefit the economic development of space. The study will include workshops, reports, and initial development/utilization of the NESC tool in a deterministic manner. **Specific attention will be paid to Category A related products and services (Human and cargo presence in space, or access and activities).**

- Phase II:
  - Phase II of the proposed study will last twelve months. It will consist of examination and simulation of future commercial products and services that could be used in future exploration architectures as well as NASA technologies that would benefit the economic development of space. The study will include workshops, reports, and initial development/utilization of the NESC tool in a deterministic manner. **Specific attention will be paid to Category B related products and services (Space resources such as space solar power, ISRU, mining).**
<table>
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<th>Organization</th>
<th>Team Members</th>
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<tr>
<td>SpaceWorks Engineering, Inc. (SEI)</td>
<td>A.C. Charania (Principal Investigator)</td>
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<tr>
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<td>Dr. John R. Olds</td>
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<td></td>
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<td>Dominic DePasquale</td>
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<td></td>
<td>Jeff Whitfield</td>
</tr>
<tr>
<td>The Tauri Group, LLC</td>
<td>Carissa Bryce Christensen</td>
</tr>
<tr>
<td></td>
<td>Elaine Gresham</td>
</tr>
<tr>
<td></td>
<td>Carie Mullins</td>
</tr>
<tr>
<td>Shimizu Corporation (Japan)</td>
<td>Dr. Hiroshi Kanamori</td>
</tr>
<tr>
<td>CSP Japan, Inc. (Japan)</td>
<td>Hideki Kanayama</td>
</tr>
<tr>
<td>Spaceport Associates</td>
<td>Derek Webber</td>
</tr>
<tr>
<td>Keio University (Japan)</td>
<td>Dr. Robert Alexander Goehlich</td>
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<tr>
<td>Teal Group Corporation</td>
<td>Marco A. Caceres</td>
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<tr>
<td>X-Prize Foundation</td>
<td>Gregg Maryniak</td>
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<tr>
<td>NASA Johnson Space Center (JSC)</td>
<td>Dr. Wendell Mendell</td>
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**Team Members**
## Economic Development of Space (EDS) Project Roadmap

### Milestones / Objectives
- Workshop 1
- Workshop 1 Report
- Workshop 2
- Workshop 2 Report
- Preliminary NESC Model
- Phase I Final Report
- Deterministic NESC Output
- NESC Model Delivery
- Workshop 3
- Workshop 3 Report
- Workshop 4
- Workshop 4 Report
- Phase II Final Report
- Probabilistic NESC Output
- NESC Model Delivery

### NASA Meetings
- NASA HQ Progress Review Presentation (PRP)
- NASA HQ Progress Review Presentation (PRP)
- NASA HQ Project Continuation Review (PCR)
- NASA HQ Progress Review Presentation (PRP)
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- NASA HQ Project Continuation Review (PCR)
- NASA HQ Progress Review Presentation (PRP)
- NASA HQ Progress Review Presentation (PRP)
- NASA HQ Final Project Review (FPR)

### LEGEND
- Study Activities
- Meetings
- Tool Delivery
- Recommendations & Results Delivered
EDS Workshops
EDS Workshop 1 Overview
Overview of EDS Workshop 1

Crystal Gateway Marriott Hotel, Washington, D.C. USA

17-18 May 2005 (1 ½ Day Workshop)

Presentations, Facilitated Group Discussion, Breakout Working Groups

Non-Traditional Aerospace, Government, Academic

Primary Goal

Develop a series of recommendations representative of the combined voice of the emerging, non-traditional commercial space industry, to NASA based on responses to the following major questions:

Major Question No. 1 - “How can the commercial industry help NASA, and specifically the 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?”

Major Question No. 2 - “What does NASA need to do to change its requirements to facilitate and enable the commercialization of space?”

Results

Presentations were given by SpaceWorks Engineering, Inc. (SEI), NASA Headquarters (Chris Moore and Doug Comstock), Erik Lindbergh (X-Prize Foundation), Gregg E. Maryniak (X-Prize Foundation), and Marco Caceres (Teal Group). Four breakout meetings and three plenary sessions were held in total during the one and half days of the workshop. One-on-one interviews were conducted of selected invitees related to the NESC model development. Results were documented for future use. A final CD was given out to all participants. A short face-to-face all-hands meeting for the team occurred after the end of the workshop on Day 2. **A final report will be publicly available soon.**
Location

Sheraton National, NATIONAL SPACE SOCIETY (NSS) INTERNATIONAL SPACE DEVELOPMENT CONFERENCE (ISDC 2005) 19-22 May 2005

Crystal Gateway Marriott EDS WORKSHOP NO. 1 17-18 May 2005

Ronald Reagan International Airport Washington, D.C.
<table>
<thead>
<tr>
<th>Statement</th>
<th>Breakout Sessions Consensus</th>
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<tbody>
<tr>
<td>1. It is too risky to involve the new space community in the critical path of a high-profile national program like the Vision for Space Exploration (VSE). NASA should primarily depend on traditional aerospace primes and suppliers to accomplish the human exploration program.</td>
<td>Disagree</td>
</tr>
<tr>
<td>2. NASA should be restructured into a more NACA-like aerospace technology development organization that supports, rather than competes with emerging space industry.</td>
<td>Strongly Agree</td>
</tr>
<tr>
<td>3. The first 100 miles (i.e. access to and from LEO for cargo and crews) should be the exclusive domain of the emerging commercial industry. NASA should not be in the business of developing and operating space access vehicles.</td>
<td>Agree</td>
</tr>
<tr>
<td>4. NASA’s historical role in leading and managing the Apollo effort of the 1960’s and 70’s is not applicable today given emerging commercial space capabilities.</td>
<td>Neutral</td>
</tr>
<tr>
<td>5. NASA should offer an X-Prize-style prize for sending and returning humans to the moon by 2020 and let private industry and private investors respond to this challenge.</td>
<td>Agree</td>
</tr>
<tr>
<td>6. NASA must provide low cost, reliable access to and from LEO as a prerequisite that will enable commercial industry to develop new businesses and activities in cis-lunar space.</td>
<td>Strongly Disagree</td>
</tr>
</tbody>
</table>
NOTE: Based upon qualitative rankings of participants

### Breakout Session C - ACCESS

- **Propellant/consumables to LEO (<5 MT)**
- **International Space Station (ISS) Crew Rotation Services**
- **Astronaut Crews to/from LEO node (up to 4 astronauts)**
- **High-value Cargo to LEO (< 5 MT)**
- **Marketing / Promotional Services**

### Top 5 Contributions to Space Access

Economic Development of Space (EDS)
SpaceWorks Engineering, Inc. (SEI)
www.sei.aero
NOTE: Based upon qualitative rankings of participants

Breakout Session D - ACTIVITIES

- In-space Communications and Data Relay Services (phone company)
- Commercial Ground Processing
- On-Orbit Crew Accommodations (space "hotel")
- Testbed for VSE technology demonstrations
- On-Orbit Propellant Storage and Transfer (LEO depot)

Top 5 Contributions to Space Activities
NOTE: Based upon qualitative rankings of participants

Breakout Session E - BARRIERS

- New space companies are not taken seriously by NASA
- Too much gov't bureaucracy when dealing with NASA contracting system
- NASA exploration market is considered too risky (here today, gone tomorrow)
- New space community does not have enough access to financial capital
- Congress doesn't adhere to (or enforce) the Commercial Space Act of 1998

Top 5 Barriers (Draft Results)
Risk should not preclude use of the emerging commercial space community (or “new space”) in exploration activities.

Government bureaucracy and inconsistency (i.e. changing requirements, non fixed-priced contracts, etc.) are large barriers to commercial sector involvement.

NASA should not develop native ETO launch services but buy where appropriate.

The government should continue the use of prizes. Prizes for activities with excessive risk will not be attractive for commercial companies.

The government should encourage partnerships between the new space community and the traditional aerospace industrial base.

The government, along with industry, should reexamine existing ITAR regulations.
**Location**
Las Vegas, NV USA

**Date**
20 July 2005 (1 Day Workshop)

**Format**
Presentations, Group Discussion

**General Goal**
Examine future drivers for economic development of space

**Specific Tasks**
- EDS project overview and update
- Team member presentations
- Examine and discuss case studies of the future space marketplace
- Examine NESC model and associated issues
  - Overview of NESC model
  - Update on progress of NESC model demonstration
  - Discuss and examine market modeling
- Examine and discuss technologies and potential gaps

**Results**
Presentations were given by SpaceWorks Engineering, Inc. (SEI) and other EDS team members. NESC model was demonstrated. Results were documented for future use. A CD with presentations was given out to all participants. A short face-to-face all-hands meeting for the team occurred after the end of the workshop on Day 1. A final report will be available soon.

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**Overview of EDS Workshop 2**
The Flamingo
SPACE FRONTIER FOUNDATION (SFF)
Return to the Moon VI Conference (RTM VI)
21-23 July 2005

The hotel at Mandalay Bay
EDS WORKSHOP NO. 2
20 July 2005

McCarran International Airport
Las Vegas, NV
b. Small Cargo Electric Propulsion-based Delivery Company [2010]
c. Advanced Solar Concentrator Technology Company [2010]
d. Advanced Power Conversion Technology Company [2015]
e. Low-Cost, Orbital Space Tourism/ISS Crew Delivery [2015]
f. Suborbital Passenger Flight Company [2010]
g. In-Space, LEO Robotic Servicing Company [2015]
h. Lunar Oxygen (LOX) Production Company [2020]
i. Space Toys Company (needs of Space Tourists) [2015]
j. Space Parcel Service [2020]
k. Spacecraft Protective Shield Venture [2015]
l. Inflatable Space Modules Company for LEO and the Moon [2010-2020]
m. Advanced Lunar Base Radiation Shield Company [2020]
n. Advanced Bio-Spacesuits Manufacturer [2020]
o. Terrestrial/Ground Space Tourism Company [2015]

NOTE: Underlined studies are those examined by audience at EDS Workshop 2
NOTE: Based upon qualitative rankings of participants

Top 5 Technologies

Government Technology Investment for Space Access and Activities

- Lightweight, efficient, higher power density fuel cells (e.g. PEM)
- Long duration in-space cryogenic propellant storage
- Surface nuclear power sources (~100kW class)
- Reusable graphite/epoxy composites (application to propellant tanks)
- In-situ resource utilization (ISRU) technologies (application to lunar oxygen production)
Nodal Economic Space Commerce (NESC) Model
The world is complex

Complex group interactions

Simple individual/agent behaviors

Conditions change -> agent behaviors change

**Microsoft Excel – strains to model complexity**

Different philosophies of modeling
- Equation-Based
- **Simulation-Based**
  - **Agent-based**: allows heterogeneous agents with varied and dynamic behavior

Simulation can represent plants and animals in ecosystems, vehicles in traffic, people in crowds, or autonomous characters in animation and games.

These models typically consist of an environment or framework in which the interactions occur and some number of individuals defined in terms of their behaviors.
- A system is modeled as a collection of autonomous decision-making entities called agents
- The characteristics of each individual are tracked through time

“Global consequences of local interactions of members of a population”

Selected Agent-Based Modeling (ABM) Examples

- School voucher programs
- Decision making in closed regimes
- Modeling the size of wars
- Voting dynamics
- Self-organizing computer networks
- Multi-cellular tumors
- Simulation for the everglades/big cypress region of south Florida
- Growth of individual plants and interactions with individual insects
- Social behavior in rat pups modeled by simple rules of individual behavior
- Individual and collective actions of people in large temporary gatherings (crowds, mobs, etc.)
- Modeling of prehistoric settlement systems in southwestern North America
- Individual-based models of the music CD business
- Electricity markets of how customers respond to different price patterns for electrical power
- Movement of individuals across the transportation network (use of cars or buses by the second)
- Seating in a theater, how the appropriate number of people decide to show up for an event
- Micro-analytic model to simulate the U.S. economy (agents represent various decision-makers)

Source: http://www.red3d.com/cwr/ibm.html
NESC Overview
The Nodal Economic Space Commerce (NESC) model is a dynamic, agent-based space market simulation and financial engineering tool
- Between competitors, includes current and future competitors (expendable and reusable)
- Entrance of new competitors within existing and new markets, collusion of established entities against new entrants
- Different types of markets and sub-markets (duopoly, monopoly, etc.)
- Impact of the government actions (technology investment, anchor contracts, tax credits, etc.) upon commercial entities

REPRESENTATION OF EACH COMPANY AGENT
“REcursive Porous Agent Simulation Toolkit”
- Repast is an open-source software framework for creating agent-based simulations using the Java programming language
- Developed by Social Science Research Computing at University of Chicago 01/2000: http://repast.sourceforge.net
- Modeled on Swarm agent software but easier to use and better documented

First implementation of NESC (version 0.2)
- Based upon agent-based simulation framework of RePast
- Multi-agent environment
- Market: suborbital space tourism

Companies compete for customers with the goal of maximizing revenues
- Each company autonomously decides its pricing strategy given its unique capacity, costs, and vehicle characteristics
- Model outputs financial health of each company

Can explore various scenarios:
- Supply vs. demand effects
- Customer preferences
- Company Strategies
  - Product differentiation
  - Cost leadership

Sources:
http://www.duncanrobertson.com/research/simulation.htm
http://sourceforge.net/projects/repast/

NESC v0.2 FORMULATION ON PC DESKTOP
Company A

Has unique:
- Costs
- Vehicle Characteristics
- Discount rate

Desires to maximize:
- Profits = Sales - Cost

Company B

Same logic as Company A but with different variable values

Company C

Same logic as Company A but with different variable values

Customers purchase

Price offering per year

General NESC Dynamics
Nodal Economic Space Commerce (NESC) model v0.2 is a beta concept demonstrating:
- Potential for dynamically modeling the space marketplace
- Modeling in an agent-based software framework
- Autonomous decision making by agents
- Communication between agents
- Simple price setting strategy

Case studies and expert interviews provide inputs to define company behaviors

After space tourism market, next major case to be examined will be ISS cargo/crew re-supply
- NASA HQ decisions to implement innovative acquisition approaches for such services and multiple companies have interest in responding to such an RFP

Future Work
- Additional Markets
  - Orbital space tourism, space activities, space solar power, resources, etc.
- Additional Products
  - Besides Earth-to-Orbit crew and cargo launch services
- Financial Modeling
  - Method for determination of company initial price point
  - Allow companies to enter and exit the market
  - Higher fidelity financing tools available to companies
- Agent Strategy
  - Allow companies to estimate the actions of their opponents
  - Allow companies to make production decisions to increase fleet size
- New Agents
  - Express demand as individual customer agents or groups of customers with unique desires and behaviors
  - Vehicle production agents
  - Government agents including taxes
EDS Workshops 1 and 2 were successful in engaging both EDS team and external representatives of commercial space companies (integrated workshop report out soon)

Proper start on NESC modeling in RePast framework
- Multiple lessons learned from initial development
- EDS Workshop 2 provided opportunity to disclose first aspects of NESC model (even in beta form)
- Interest from space industry on outputs
- Interesting and relevant future results from NESC for ISS re-supply case studies (directly relevant for NASA Innovative Programs office)