SUB-ORBITAL SPACE TOURISM:
Predictions of the Future Marketplace Using Agent-Based Modeling

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Mr. A.C. Charania
Senior Futurist
SpaceWorks Engineering, Inc. (SEI)
ac@sei.aero

Dr. John R. Olds
CEO
SpaceWorks Engineering, Inc. (SEI)
john.olds@sei.aero

Mr. Dominic DePasquale
Systems Engineer
SpaceWorks Engineering, Inc. (SEI)
dominic.depasquale@sei.aero
Firm Overview
Overview of Agent-Based Modeling
NESC Model Overview
Sample NESC Model Simulations

Contents
Firm Overview
Overview:
- Engineering services firm based in Atlanta (small business concern)
- Founded in 2000 as a spin-off from the Georgia Institute of Technology
- Averaged 130% growth in revenue each year since 2001
- 85% of SEI staff members hold degrees in engineering or science

Core Competencies:
- Advanced Concept Synthesis for launch and in-space transportation systems
- Financial engineering analysis for next-generation aerospace applications and markets
- Technology impact analysis and quantitative technology portfolio optimization

Introduction to SpaceWorks Engineering, Inc. (SEI)
Practice Areas

**Space Systems Analysis** | What is the System?
- Conceptual Level Engineering Analysis
- Conceptual Level Engineering Design
- Life Cycle Assessment
- Cost Engineering
- Advanced / Robust Design Processes

**Technology Prioritization** | What are the Implications?
- Technology Anticipation
- Technology Benefit Assessments
- Technology Prioritization

**Financial Engineering** | Is the Project Viable?
- Business Design
- Future Venture Due Diligence
- Real Options Analysis

**Future Market Assessment** | What is Next?
- Scenario Planning
- Market Forecasting
- Market Analysis

**Policy and Media Consultation** | How to Express the Vision?
- Government Initiatives
- Policy Consultation
- Television, Film, Radio, Internet Presence
From Vision to Concept

Including:
- Engineering design and analysis
- New concept design
- Independent concept assessment
- Full, life cycle analysis
- Programmatic and technical analysis

Including:
- Storyboards
- Technical concept illustrations (marker and pastel in B&W and color)
- 2-D line engineering drawings with technical layouts and dimensions
- 3-D engineering CAD models of concept designs
- High-resolution computer graphics imaging (renders)
- Concept / architecture summary datasheets and single page handouts / flyers
Including:
- 2nd, 3rd, and 4th generation single-stage and two-stage Reusable Launch Vehicle (RLV) designs (rocket, airbreather, combined-cycle)
- Human Exploration and Development of Space (HEDS) infrastructures including Space Solar Power (SSP)
- Launch assist systems
- In-space transfer vehicles and upper stages and orbital maneuvering vehicles
- Lunar and Mars transfer vehicles and landers for human exploration missions
- In-space transportation nodes and propellant depots
- Interstellar missions
- In-space and surface human habitats
Recent Exploration Experience

Including:
- NASA Exploration Systems Mission Directorate (ESMD) Concept Exploration and Refinement (CE&R) Study Subcontractor
- NASA Exploration Systems Mission Directorate (ESMD) Economic Development of Space (EDS) Project
- NASA MSFC exploration architecture trade studies (launch vehicles, in-space stages, lunar landers)
- NASA MSFC Prometheus follow-on study: Nuclear Electric Propulsion (NEP) mission to Pluto/Kuiper Belt
- NASA LaRC Lunar Lander Preparatory Study Phases 1 and 2 Concept Design for NASA JSC
- Rocketdyne propulsion technology assessment on lunar exploration architectures
- Mission Scenario Analysis Tool (MSAT) architecture optimization tool development
- Moonraker in-space stage and habitat sizing tool development
- In-space trajectory tool development
- Lunar exploration economic and life cycle cost analysis
Sample Economic Analyses

Human Exploration Cost Estimates

Scenarios of Reusable Launch Vehicle (RLV) Price Sensitivity

Space Tourism Economic Modeling

International Space Station (ISS) Support Market

See: http://www.sei.aero/library/technical.html for more information and technical papers on above analyses
Sample Economic Analysis Tools:
- **NESC** (Nodal Economic Space Commerce Model, agent-based space market simulation financial tool)
- **CABAM** (Cost and Business Analysis Model, general space transportation)
- **LMNoP** (Launch Markets for Normal People, tourism model)

Recent Projects:
- Economic Development of Space (**EDS**) sponsored by NASA Langley Research Center
- Simulating Emerging Space (**SES**) Industries with Agent-Based Modeling sponsored by NASA Marshall Space Flight Center

Recent Papers (**www.sei.aero**):

Sample Clients and Partners:

SEI's Background Related to Economics of Emerging Commercial Space Transportation
Overview of Agent-Based Modeling
The world is complex

Complex group interactions

Simple individual/agent behaviors

Conditions change -> agent behaviors change

**Microsoft Excel – strains to model complexity**


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**Trying to Model the World (or even a small piece of it)**

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SpaceWorks Engineering, Inc. (SEI)
www.sei.aero
The Nodal Economic Space Commerce (NESC) model is a dynamic, agent-based space market simulation and financial engineering tool.

Agent-Based Modeling (ABM): allows heterogeneous agents with varied and dynamic behavior
- Qualities: emergent phenomena, natural description of system, flexible
- Simulation can represent plants and animals in ecosystems, vehicles in traffic, people in crowds, or autonomous characters in animation and games

Modeling space capitalism in NESC
- Between competitors, includes current and future competitors (expendable and reusable)
- Entrance of new competitors within existing and new markets
- Explore variations in customer preferences
- Current markets: sub-orbital space tourism and ISS support
- Use available data (Futron, etc.) on demand and estimate supply

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
- Model differences in products/services

Based Upon “REcursive Porous Agent Simulation Toolkit”

Users of Agent-Based Modeling (ABM)

- **P&G** to understand the impact of alternative shipment and payment terms on retail in stock positions and company inventory
- **Macy’s** to generate new store layout options for maximizing customer satisfaction and spending
- **Hewlett Packard** to understand the effect on organizational performance by a change in hiring practices
- **NASDAQ** to understand what happen when the “tick size” changes from 1/8 of a dollar to 1/100 of a dollar
- **U.S. Department of Defense** to conduct war games predicting battlefield outcomes in a networked information environment
- **Pricewaterhouse Coopers** to predict CD sales in the Japanese pop (J-Pop) market using 75,000 agents (correlation coefficients of actual and predicted sales between 0.8 and 0.9)
- **Electronic Arts (EA)** and their “The SIMS” game

NESC Model Overview
Context: “Emerging” Space Products and Services
NESC Dynamics: Space Tourism

Use Aggregate Market Curve or Model Individual Customers

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 product

Limited information sharing:
- Price from prior year
- Vehicle characteristics

Company C

Same logic as Company A but with different product

Price offering per year

Customers purchase

Company adjusts pricing strategy:
- Stay at current
- Higher
- Lower
- Match competitor
Who is the Customer?

Does the customer want to buy?

Who does the customer want to buy from?

One at a Time: A Sub-Orbital Space Tourism Customer “Agent”
NESC Company/Customer/Market Agent Interaction
Since sub-orbital space tourism is a new industry, little data is available from actual sales and company revenues.

Data on customer characteristics and behaviors must be determined from market surveys, inferred from other industries, or deduced using intelligent assumptions.

One such source is the Space Tourism Market Study conducted by Futron Corporation in cooperation with Zogby International.

The market study involved telephone interviews of 450 people with household income of at least US$250,000 annually or net worth greater than US $1 million to examine the size, growth potential, and customer characteristics of the suborbital and orbital tourism markets.

The number of customers for the NESC sub-orbital model simulation is estimated to be around 53,000 for calendar year 2006. This is the number of customers who are interested in purchasing a sub-orbital experience and able to do so (financially and physically). It is derived by the following parameters:

- Number of Millionaires in World
- Take proportion who have requisite net worth (assume willing to spend 1.5% of net worth)
- Apply percent interested in participating (somewhat, very, and definitely likely) from Futron survey
- Reduce for fitness requirements (split between those over and under age of 65)

Source: Merrill Lynch and Capgemini, Source: http://www.us.capgemini.com/worldwealthreport06)

* 2004 numbers have been refined and minimally restated, as every year more accurate and recent data or sources of information are gathered.

Note: All chart numbers are rounded.

Source: Capgemini Lorenz curve analysis, 2006
Potential Customers at Various Prices (Source: Futron Space Tourism Market Study)

- The percentage of potential customers willing to pay for a suborbital tourism experience levels out at higher price points.
- The additional potential customers gained by decreasing price from $200 thousand to $150 thousand is small (a four percent increase) by comparison to the additional customers gained by decreasing price from $100 thousand to $50 thousand (a twelve percent increase).
- This suggests that the market for suborbital space tourism is relatively inelastic at high prices, but elastic at low prices.
NESC: Sub-Orbital Space Tourism
NESC: Sub-Orbital Space Tourism Model Visual Interface - Inputs
Sample NESC Model Simulations
Top Level Assumptions

- Company input information based upon available public data
  - Since incomplete information for these companies, results are to be taken as representative of industry as a whole and not specific to any one company

- Sub-orbital space tourism companies make decisions based upon impact on financial bottom line and not other “human” desires
  - Examined from the perspective of other capital investment projects and not as a hobby or altruistic venture

- Several case studies are presented here as examples of the capabilities of the NESC sub-orbital space tourism model:
  - Case A: One firm
  - Case B: Two firms (same start times)
  - Case C: Three firms (same start times)
### Overview of Firm Inputs

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<th>Item</th>
<th>Firm 1</th>
<th>Firm 2</th>
<th>Firm 3</th>
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<tr>
<td>Number of Vehicles in Fleet</td>
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<td>5</td>
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<td>Maximum Flights Per Vehicle Per Year</td>
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<td>Vehicle Production Cost ($M FY2006)</td>
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<td>Variable Operating Cost Per Flight ($M FY2006)</td>
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<td>$0.2 M / Flight</td>
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<td>Passenger Capacity</td>
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<td>0.9</td>
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<tr>
<td>Vehicle Freedom (Belt=1, No Belts=1.48)</td>
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<tr>
<td>Perceived Reliability (Qualitative 1-5)</td>
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<td>3</td>
<td>3</td>
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<tr>
<td>Perceived Vehicle Appeal (Qualitative 1-5)</td>
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<tr>
<td>Risk Premium</td>
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</table>

- **Customers**: 53,000 potential sub-orbital space flight consumers over a 15 year project period with 1) the financial means to pay, 2) physical condition to fly, and 3) the interest in suborbital flight have been categorized into over 20,000 “agent types” based on personal characteristics such as: pioneer vs. imitator, influence of perceived vehicle reliability, willingness to pay at various ticket prices, influence of cabin freedom (e.g. seat belt requirements), influence of perceived vehicle uniqueness/intrinsic appeal, etc.

- **Providers**: A user-defined number of sub-orbital passenger vehicle developer/operators can be included in any simulation: Each provider has a realistic business model including development and production costs, operating costs, vehicle capacity, perceived reliability, etc. Each 'CEO agent' can adjust its market price for a ticket from year to year in an effort to improve profitability. Firms select their initial prices based upon ROI.

- **Growth rate**: 6% per year
- **Price Ceiling**: $500k/passenger maximum amount that can be charged
Sample Simulation Results: Sub-Orbital Space Tourism Market

Case A  
One Firm

Case B  
Two firms (same start times)

Case C  
Three firms (same start times)
Sub-Orbital Space Tourism Market: Preliminary Observations

- Sub-orbital public space flight market can allow two companies to be profitable over time
  - A third competitor, competing with the top-tier operator, struggles to maintain viability
  - Can the first firms in the marketplace have enough capacity to capture total annual market?
  - Based upon results shown here and other sensitivity analyses previously performed
  - Caveat 1: Given current consumer and company modeling assumptions
  - Caveat 2: Need to re-examine in terms of higher fidelity NESC model (almost complete)

- Optimal pricing strategy must take advantage of “pioneer” and “imitator” effects
  - Initial prices should start higher (around $300k/ticket in simulations) than some initial “public” rates, companies could then decrease (to close to $150-200k/ticket) to maximize profit
  - “Virgin Galactic has, in the near term, been focusing on what it calls the ‘Founders’, its group of the first 100 customers who have paid their full $200,000 ticket price up front. With the Founders group now filled up, Virgin is now promoting two other groups of passengers: Pioneers and Voyagers. The Pioneers will be the next 400 passengers, paying a deposit of between $100,000 and $175,000, while the Voyagers will follow the Pioneers, putting down a deposit of 10 percent of the ticket price, or no more than about $20,000.” (Source: http://www.thespacereview.com/article/717/1, Monday, October 2, 2006)

- Future work will include enhancement and additional analysis
  - Include the effect of failure (cost and downtime) upon market demand and suppliers (Monte Carlo analysis)
  - Better pricing determination
  - Enhance financing model to include injection of venture capital and mezzanine financing, including stocks/warrants (beyond current debt-to-equity ratio formulation)

- NESC capability is ready to be applied by SEI for commercial ventures
SpaceWorks Engineering, Inc. (SEI)
www.sei.aero

Business Address:
SpaceWorks Engineering, Inc. (SEI)
1200 Ashwood Parkway
Suite 506
Atlanta, GA 30338  U.S.A.

Phone: 770-379-8000
Fax: 770-379-8001

Internet:
WWW: www.sei.aero
E-mail: info@sei.aero