Session 1454

Acoustic Shaping, Inc.: Business Plan for Space-Based Manufacturing

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Abstract

A Business Plan to help NASA's Mars Mission is used as a vehicle for developing entrepreneurial skills and experience among engineering students. A team of students at all levels is guided through the process of conceptualizing and developing a proposal and a Business Plan, and articulating these to NASA and other audiences. A technology developed through a NASA-sponsored Student Flight experiment is used as the nucleus of a Space-based construction industry over the next 20 years. The team structure, and its evolution over the first year of the project, are presented. The GT team's endeavor has served to focus attention on the central role of Space-based infrastructure to enable development of a Space-based economy.

I. Introduction

The NASA Means Business (NMB) program was started in 1998 by the Mars Exploration Office of the NASA's Human Exploration and Development of Space (HEDS) division[1]. The opportunity was publicized in Fall 1998. Six student teams would be selected, based on their proposals to help develop NASA's Business Plan for a human mission to Mars. A NASA Reference Mission was provided, and the plans were to be selected based on approaches to six aspects:

1. Vision
2. Strategic Plan
3. Product Development
4. Market Analysis
5. Outreach
6. International component

Selected teams would work closely with NASA experts in the development of NASA's Business Plan for the human exploration of Mars. Proposals were due in mid-December 1998. This paper describes the efforts of the team from Georgia Institute of Technology, (GT) which has won a place in this program in both years of the competition to-date. In the first program year (1999), the GT team's strategic plan helped to focus attention on the critical role of space-based infrastructure in improving the prospects for establishing business in space. In 2000, the competition focus is on Customer Engagement. The GT team has enlisted the participation of Business students at Emory University and Georgia State University to expand the entrepreneurship aspects. This last aspect is discussed in the context of integrating entrepreneurship and engineering curricula.

II. Process

a. Identifying the approach

The Experimental Aerodynamics Group at Georgia Tech's School of Aerospace Engineering has been helping undergraduate student teams to participate in the NASA Undergraduate Student Flight Opportunities program[1] since 1996. We had developed the technology of Acoustic Shaping, where walls of specified shape could be built from pulverized material in microgravity using a specified sound field. The NMB solicitation was discussed extensively among the student team and the advisor, and it was determined that our Business Plan would be one centered on the development and exploitation of this technology. The perceived advantage was the strong experience that we had acquired in this technology, including 2 years of flight experiments[2-5] on NASA's KC-135 Microgravity Flight Laboratory (a.k.a. "The Vomit Comet"). Sam Wanis, the Acoustic Shaping Team Leader, submitted a Letter of Intent (LOI). In mid-November, a NASA communication acknowledged the LOI, and gave us the list of those who had submitted an LOI.

b. Analyzing the Opportunity

The solicitation itself was "wide open", as NASA contact personnel described it. The e-mail list of those who had submitted LOIs was seen to include names from several top US universities, but predominantly from business schools rather than engineering schools. Our niche was seen as being a team, which focused on their own technology development. The timetable for the proposal was discussed. The deadline right after Final Exams in December 1998 was realized to be a common problem for all schools, and as such an advantage to a compact and well-organized team which was used to meeting project deadlines.

c. Team formation

The other respondent from Georgia Tech was found to be lone first-quarter freshman, who was welcomed into the team with NASA's approval. Announcements were sent out to faculty colleagues in the Dupree School of Management, and the School of Bioengineering seeking interest and support, while the students canvassed other interested students. Team expansion was limited to those who would contribute. Catherine Matos, expert at putting together major off-site experiment programs, and Richard Ames, MBA from the Dupree College, were recruited as team members. Thus, the core proposal team included the two Ph.D. candidates, the flight team leader who was a senior, and two freshmen.

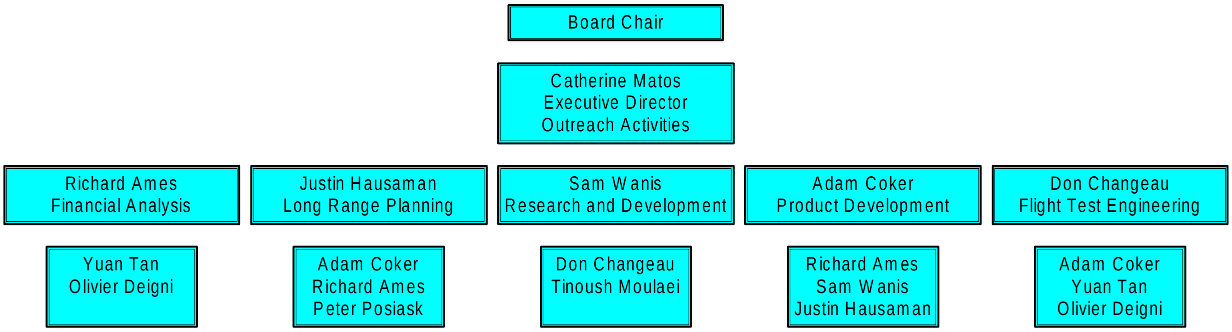


Figure 1: The team structure of ASI, for its first phase, as a university-based technical team.

As shown in Figure 1, ASI is organized as a team where everyone is involved, and knowledgeable, about all aspects, but each person has primary responsibility for one aspect. This is to give each participant the experience both of leading and being a team player. The faculty advisor is the Board Chair. The Executive Director is also the central person to ensure that all communications get disseminated to the right people, and that messages are conveyed to student team members on priorities. This eliminated the faculty advisor as the usual communication decision bottleneck. The Chair and the Executive Director handle outreach. Each "division leader" is responsible for the progress of that division, and is expected to enlist the help of anyone needed. A public-access web page was constructed[6], and the proposal was posted there[7].

d. Incorporating business concepts

The students' use of the Internet in developing such an endeavor is of interest. The student team commenced an extensive search of NASA and other space resources, and the results were systematically collected and disseminated. While the advisor provided the team with books on Business Plans, Entrepreneurship, etc., freshman Don Changeau, by typing the words "business plan" into his Internet search engine, collected a list of links, and found an excellent template for a business plan from the U. North Carolina College of Business. The faculty advisor provided guidance on proposal writing, and the students, with input from parents etc., developed the business plan. The Plan summary is given in the Appendix. The project logo in Fig. 2 shows the niche of the "company" in developing complex shapes from mathematical specifications. Early in January 1999, the project team started weekly 8am meetings.

Figure 2: ASI's Logo

III. Business Plan Development

a. Corporate vision
ASI will lead the space-based manufacturing industry of the 21st century, continually reducing the costs associated with space exploration, habitation, and development.

b. Strategic Plan
A strategic plan suitable for the company's grand objectives, as well as its path of getting there from the present, was developed. Briefly, this plan is in 4 phases:

- *Phase 1: University-based research/exploration/planning team:*
  - Conduct technology development, planning and design for the next 3 years, while the team members were still in school.
  - Mature to the level of sounding-rocket flights, and preparation of a flight package for the International Space Station by the Year 2002.

Phase 2: NASA/University R&D Project Team:

- Evolve into a technical project team working with NASA to take the technology to the Technology Readiness Levels (4-9) needed for space flight.
- Use a partnership with NASA to get into space without borrowing money for the launch costs, by getting NASA to fund launch costs in exchange for a substantial interest in the company.

Phase 3: Startup Company with NASA Partnership:

- Use customers on the ISS and beyond to provide revenue and advance technical capabilities to the level of manufacturing large-scale components in space using space-derived resources.

Phase 4: Space-Based Construction Technology Company:

- Use venture capital to develop large-scale production facilities in orbit and on the lunar surface. This will support the construction of the next-generation Space Station at the Lagrangian point L-5 (a region where the gravitational forces of the Earth and its Moon cancel). It will also help build the paraphernalia for ventures to Earth and lunar orbit, Mars and beyond.

Phase 5: Technology Provider:

- Evolve into a leading-edge technology provider in the long run, fostering development of the construction industry in space.

IV. Project Presentations

a. Teleconference, Midterm Videoconference Presentation, and Visit by NASA Mentor

There was a telephone conference for each team with the NASA personnel, with each team member asking some questions. All teams in the presentation first saw each other through a Midterm Videoconference. Each team had 15 minutes to present their work. Considering the on-site presentation, the faculty advisor overruled the traditional opinion of the team, and asked them to prepare a presentation with 6 presenters. The team prepared, with several levels of backup to survive technical surprises: the videoconference experience was new to all of us. While the freshman presenters were visibly nervous, the graduate students calmed them. The GT presentation (fortunately the last one) appears to have been seen and heard by all the other teams and the NASA personnel quite clearly[8]. The multi-presenter strategy appears to have been a large morale-booster, judging from the following performance. Later in the Spring, Ms. Joyce Carpenter, NASA's Mentor for the Georgia Tech team visited GT, discussed the project with the team, and presented NASA program plans to a faculty/student audience.

b. Final Presentation and Report

The Strategic Plan presentation of the team involved thorough preparation. The Dean and Associate Dean of the College of Engineering at Georgia Tech came observe a draft version of the presentation and gave excellent pointers to the team, which were used to prepare the final presentation. For the Final Customer Interaction Conference, the team traveled to Houston's Lunar and Planetary Institute (LPI). They presented their work in 20 minutes and participated in Working Groups the next day. The GT team's particular leadership group was on Product Development; the report was presented by one of the freshman team members, the Chief of the team's Product Development division. The Final Presentation[9] , the Final Report and the GT Team's input to the Composite Report of the NMB program[9], are available on the Internet at http://www.ae.gatech.edu/research/windtunnel/nmb/nmbhome.html

V. Outreach

The advisor developed a presentation to the undergraduate students in the school, presented in February. In April, team Executive Director Ms. Matos, and the faculty advisor visited a local elementary school, and gave a half-hour presentation to the 5th grade class, received with an eye-opening level of enthusiasm and awareness of space exploration issues. An important lesson learned, was to resist any temptation to distribute "goodies", however trivial, (pieces of the model Space Shuttle taken there for demonstration, for example) to the audience, however attentive and superbly-behaved they might seem. Their teachers' assistance was required to re-establish order when this was attempted. University faculty do not normally have experience of operating in such environments, as delightful as the students are. Other outreach programs are being developed through the NASA Georgia Space Grant Consortium.

VI. Learning from the other Teams

One of the greatest benefits of this project was the opportunity to observe and interact with the other teams participating in this program. This gave the young team and their advisor a perspective on others' views and approaches, given the same opportunities and constraints that we faced. While justice can certainly not be done to all these teams in the space of this paper, these teams' Final presentations can be accessed at:
http://www.ae.gatech.edu/research/windtunnel/aclev/asi/preslinks.html

Very briefly, MIT's ThinkMars team proposed and conducted an extensive publicity campaign to promote public awareness of the imperative for Mars exploration. They proposed a privately-funded venture to perform the human mission to Mars, in return for full rights to commercial exploitation of the technology of the mission and its products. The U. Illinois team proposed ways of developing Mars missions through a series of "small victories", involving SBIR (Small Business Innovative Research) programs and other such projects. U.Colorado's team emphasized the education of the K-12 population regarding space exploration in order to build a well-informed popular support base for the future. U. Maryland's team proposed a scheme to develop lunar resources in order to produce fuel on a commercial basis. U. Texas proposed a system-view of the space program, in order to enhance the efficiency of the process. Each team had its own outreach activities.

VII. Project Impact

At the Customer Interaction Conference, feedback from NASA and from students on the other teams indicated that the GT team's role was perceived as follows: we had taken the concept of a small company startup, a long way through the process, and helped clarify the issues which would be encountered by most companies attempting a similar endeavor. Extracts relevant to the GT team from the final NASA press release for the program[10] are given below, and provide an excellent capsule on how our project's message was received:

"*NASA means business…*

"Georgia Tech students proposed a new microgravity manufacturing process to turn sound waves into construction machines. "By reducing the cost of manufactured components to a fraction of the cost of earth-built or machined components", their plan says, "[it] will provide an enabling resource for human exploration of the solar system."

….. It was spun off another student competition geared more towards science, with a microgravity flight in a KC-135A aircraft as the prize.

But though the stated reward for this business competition is $1,000 and a trip to a conference with NASA…the real prize is having your idea in NASA's official business plan for Mars exploration."

The project provided a business perspective to use along with the technical development, and this flavor was presented to the USRA in Huntsville by the present author. The business and technical aspects of the project were presented at the First Space Resource Utilization Roundtable in Golden Colorado in October [12,13]. In November 1999, one of the team members was selected to give a 20-minute presentation to a gathering of United Technologies Pratt and Whitney Co. executives, and a group of Georgia Tech faculty and students. Four of the other team members traveled to Pasadena to present their work as a poster paper at the American Astronautical Congress meeting. This in turn appears to have been well received, judging from the questions and contacts that we have received.

VIII. The Imperative for Infrastructure Development

The central conclusion of the Georgia Tech team's work on this project was a finding relevant to every effort to establish a space-based economy. This is the critical role that can and should be played by the government and organized private effort, to establish a basic infrastructure in orbit and on the lunar surface. Two essentials are suggested:

1. A large increase in the pressurized volume available for establishing a human presence in Space. This can be achieved by taking the External Tanks of the Space Shuttle into orbit and using them to construct an orbital station. At present, the tanks are discarded when they have achieved practically 99% of the energy required to get into orbit, and fall down to burn up over the Indian Ocean. Alternatively, the "TransHab" inflatable module concept may also provide viable solutions. Even a single external tank would provide habitable volume comparable to that of the International Space Station. Such a facility would benefit a variety of businesses that need more than the "glove-box" dimensions of present experimental facilities on the Space Station.
2. An electromagnetic launcher system on the Moon. The lunar day provides intense sunlight, enabling capacitors to be charged up to power an electromagnetic rail system. The velocity required to launch from the lunar surface to lunar orbit is only of the order of 2200 m/s, far lower than on Earth, and there is no atmosphere to cause drag on the Moon. While being beyond the resources of individual companies, such a "transit system", perhaps fully automated or remote-controlled from Earth or orbit, will vastly reduce the costs of getting materials off the lunar surface, and be of use to a multitude of businesses.

The impact of these investments can be seen in Figure 3, below, where the Net Present Value of an investment in ASI is computed, for 3 different options. The first option is where ASI invests the funds needed for all costs. Here the typical "billion-dollar dip" that characterizes every space enterprise is clearly seen. If this is filled in using capital investment, the long wait to Return on Investment, and the high risk, make the possibility of making a profit very uncertain. A positive NPV is predicted, but has a large uncertainty. The second option is where NASA participates as a partner in the small company's enterprise, providing research support on the ground and on the Space Station, and supporting the initial launch costs in return for a substantial stake in the company. Here the venture is shown to be feasible. The third option is where the venture uses an already-in-place infrastructure, as well as NASA partnering. Here, the economics of human commercial development in space become entirely viable. It should be noted that such analyses, however rudimentary are new to all except those team members who had taken business curricula

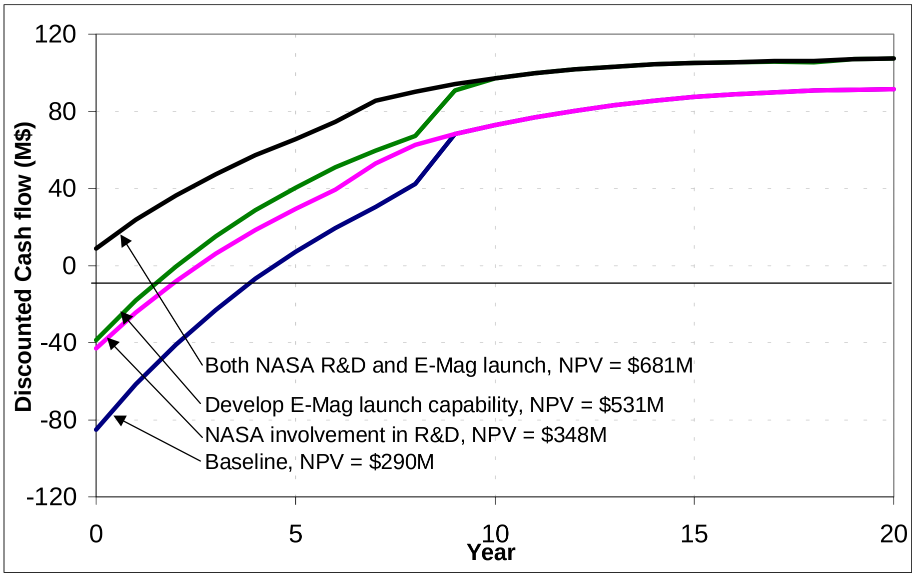


Figure 3: The "launch-cost dip", and the effects of NASA support and infrastructure on the Net Present Value of a Space Business Venture.

IX. Curricular Issues

Formal curricular credit for such an experience remains a difficult issue, though it is clear that the students on the project team go through an intense introduction to the issues in entrepreneurship. In Fall 1999, the School of Aerospace Engineering instituted AE2xxx/3xxx/4xxx "Project" course credit to recognize students who participated in such programs and competitions. Students who have the room in their programs for such credit are encouraged to take them: the fact remains that some students find their course schedules too full to permit getting this credit, yet participate on the project out of enthusiasm. Efforts to start joint programs with the Dupree School of Business as still in progress.

In February 2000, we were informed that the GT team had won a place in the 2000 NMB program. With this recognition, we sent requests to faculty at Emory University's Goizeuta School of Business, and Georgia State University's School of Business. A team from Emory has been formed, and is in the process of identifying slots in student competitions at both the MBA and BBA levels where Space-Based Construction would be a topic. Potential student team leaders participated, along with Asst. Professor Reshma Shah, and Assistant Dean Andrea Herstatter in a meeting with the ASI Chair and Executive Director in March 2000 to start this process. With the help of Dr. Ben Oviat of Georgia State University's Entrepreneurship Center, we have also started collaboration with GSU faculty, with presentations by the ASI team scheduled for Case Study discussions in two graduate classes on Strategic Marketing conducted by Prof. Pam Barr in mid-March 2000. The experience gained from these efforts, beyond the immediate value to team participants, is aimed to develop larger programs where engineering and business students collaborate on identifying, brainstorming and developing business concepts.

X. Faculty Advisor's Role

The faculty advisor is as much a learner as the students are, in this project. Unlike a formal course on entrepreneurship, the learning had to be done on-the-job; however, this project provides excellent opportunities for using the strategy of "Iterative Leaning"[14, where people have several opportunities to revisit concepts and hone their skills. Below we consider how each of several aspects of entrepreneurship, as listed in Ref. [15], were touched upon, during the project.

Entrepreneur's features	How learned
Meaning of "Entrepreneur"	Not learned: risks postponed till graduation
Belief in the Idea and in Oneself	Proposal-writing, presentations to national audiences (first-time presentations for the freshman team members).
Simplicity / Big-Picture Orientation	Presenting entire effort in very few slides.
Creativity	Solving problems under pressure
Flexible Planning	Preparing proposal and presentations under uncertainty about customer expectations.
Optimism	Entering a national business competition with well-established teams from the nation's best business schools, while still a freshman.
Realism	1. Relation to the NASA Planning. 2. Interactions with the other teams, and with NASA personnel, in actual technical settings. Discussions with business experts.
Communication	1. Weekly group meetings. 2. E-mail interaction. 3. Daily discussions 4. Team telecon 5. Team midterm videoconference. 6. Final presentation 7. Watching other teams 8. Breakout Group discussion 9. Product development presentation 10. Final Report.
Risk-Taking	Deciding on approach and presentation formats; deciding on numbers to use for cost estimation / projection in an area where no one has ventured before.
Persistence	Getting flight test equipment ready
Action-Orientation	Performing under tight deadlines

Some of the "keys to innovation" listed in Ref. 16 are related to this project in the following ways:

Table 2: Keys to Innovation

Concept	Relevance to ASI
Invest in Applications-Oriented Small Starts	ASI is a small startup, with a route plan laid out to resolve major uncertainties while still small.
Pursue Team Product/Service Development	ASI is organized at present as a team, with sub-teams dealing with product development and technology development
Encourage Pilots of Everything	KC-135 flight test experiments
Practice Creative Swiping	Extensive review of Internet resources.
Make Word-of-Mouth Marketing Systematic	No plans yet for this.
Support Committed Champions	Irrelevant in a student team environment.
"Model" Innovation / Practice Purposeful Impatience	Numerical modeling of acoustic shaping technology; bold flight test experiments to drive rather than validate predictions.
Support Fast Failures	Research lab environment does this.
Set Quantitative Innovation Goals	Planned flight test goals each year; fast-paced plan with weekly targets during NMB project
Create a Corporate Capacity for Innovation	ASI operates in a research lab environment

Table 3: Keys to "Thriving on Chaos" from Ref. 17, and how they apply to the ASI project environment

Achieving Flexibility By Empowering People	Team structure empowers everyone. Minimal dependence on faculty advisor for communication.
Involve Everyone in Everything	Team structure does this.
Use Self-Managing Teams	Team structure with individual responsibilities known, self-motivated student team members.
Listen/Celebrate / Recognize	Faculty advisor deals with this issue
Spend Time Lavishly on Recruiting	Faculty Advisor makes time to talk to interested students and follow up.
Train and Retrain	Research lab environment does this.
Provide Incentive Pay for Everyone	Irrelevant at present
Provide an Employment Guarantee	Students know that they are respected team members from Day One.
Simplify / Reduce Structure	Every team member is authorized to communicate at any level and make purchases, provided they report and document their work.
Reconceive the Middle Manager's Role	Faculty advisor and Exec. Director in

	helping / motivating roles; no "permission" needed except for safety-related issues.
Eliminate Bureaucratic Rules and Humiliating Conditions.	Research lab environment constantly strives to achieve this.

XI. Concluding Remarks

The exercise of developing a Business Plan for a start-up company is used to explore the business aspects of a technology developed by a student team. This project provided the students with a real-life experience in competing as well as collaborating with top business students across the nation, and working with NASA engineers. The startup company concept, called ASI, plans to develop into the leader in the space-based construction industry. The planning process revealed the critical role of infrastructure development to the economic feasibility of most space-based ventures. The results were communicated to NASA and the external community through presentations and discussions, and appear to have been received well. The project is proceeding in its second year.

XII. Acknowledgements

The opportunities and financial assistance provided by NASA and the Texas and Georgia Space Grant Consortia, are gratefully acknowledged. Mr. Humboldt Mandell and Ms. Joyce Carpenter of NASA, Mr. Burke Fort of TSGC, and Professor Erian Armanios and Ms. Wanda Pierson-Jeter of the GSGC, have provided tremendous personal support throughout this program.

XIII. Bibliography

1. NASA Reduced Gravity Flight Opportunities for Undergraduates, URL: http://www.tsgc.utexas.edu/floatn/
2. Wanis, S., Komerath, N.M., Armanios, E.A., "Acoustic Shaping in Microgravity: 3 Years of Flight Tests. " Proceedings of the ASEE2000 National Conference, Session 2225 Space Grant.
3. Wanis et al [1998]: Wanis, S., Akovenko, J., Cofer, T., Ames, R.G., Komerath, N.M., "Acoustic Shaping in Microgravity". AIAA Paper 98-1065, 36th Aerospace Sciences Meeting, Reno, NV, January 1998.
4. Wanis et al [1999]: Wanis, S., Sercovich, A., Komerath, N.M., "Acoustic Shaping in Microgravity: Higher Order Modes". AIAA Paper 99-0954, 37th Aerospace Sciences Meeting, Reno, Nevada, January 1999. URL: http://www.ae.gatech.edu/research/windtunnel/aclev/final990954.pdf
5. Wanis, S., Matos, C.A, Komerath, N.M., "Acoustic Shaping in Microgravity: Technology for Space-Based Construction. AIAA Paper 00-1020, Reno, Nevada, January 2000.
6. Web Page of the "NASA Means Business Program"http://www.tsgc.utexas.edu/nmb/
7. Web Page of the GT Team in the NASA Means Business Project. URL: http://www.ae.gatech.edu/research/windtunnel/nmb/nmbhome.html
8. Proposal of the Georgia Tech Team in the 1999 NMB competition. URL: http://www.ae.gatech.edu/research/windtunnel/aclev/asi/NMBprop.html
9. Midterm Videoconference Presentation of the Georgia Tech team in the 1999 NMB program. URL http://www.ae.gatech.edu/research/windtunnel/asi/sld001.htm
10. Final Presentation of the Georgia Tech Team to the 1999 NMB Customer Interaction Conference, Houston, TX, May 1999. URL http://www.ae.gatech.edu/research/windtunnel/nmb/finalpres/index.htm
11. Sorid, Daniel D. "NASA Takes a Business Lesson From Students". Web Page of Space.com, July 20, 1999. URL http://www.space.com/business/people/nasa_comp.html
12. Komerath, N.M., Matos, C.A., Coker, A., Wanis, S., Hausaman, J., Ames, R.G., Tan, X.Y., "Acoustic Shaping: Enabling Technology for a Space-based Economy". Proceedings of the Space Resources Utilization Roundtable, Colorado School of Mines, Golden, Colorado, October 27-29. LPI Contribution No. 988. Pages 11-12. See also, http://www.ae.gatech.edu/research/windtunnel/presentations/srurt99/index.htm

13. Wanis, S., Komerath, N.M., "Acoustic Shaping in Microgravity: Technology Issues" Proceedings of the Space Resources Utilization Roundtable, Colorado School of Mines, Golden, Colorado, October 27-29. LPI Contribution No. 988. Pages 41-42.
14. Komerath, N.M., "Progress Towards Iterative Learning". ASEE Annual Conference Proceedings, Session 3536, paper 2, June '95.
15. Maul, L., Mayfield, D., "The Entrepreneur's Road Map to Business Success". Saxtons River Publications, P.O. Box 1609, Alexandria, VA 22313
16. Peters, T., "Thriving on Chaos". Handbook for a Management Revolution. Harper & Row, Publishers, 1987.

XIII. Biographical sketch

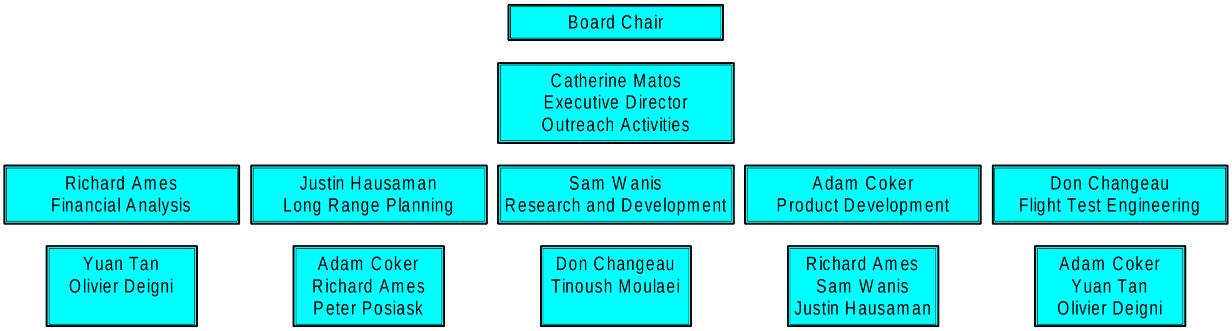
Dr. Narayanan Komerath, Professor in AE and director of the John J. Harper wind tunnel, leads the Georgia Tech Experimental Aerodynamics Group (EAG). He has taught over 1600 AEs in 19 courses in the past 15 years. He is a principal researcher in the Rotorcraft Center of Excellence at Georgia Tech since its inception in 1982. He is an Associate Fellow of AIAA. EAG research projects have enjoyed the participation of nearly 100 undergraduates over the past 14 years. EAG is a leader in multidisciplinary team-oriented projects, including the Aerospace Digital Library Project at Georgia Tech: http://www.adl.gatech.edu

Appendix A

II. BUSINESS PLAN

II.1 Executive Summary

Acoustic Shaping Inc.



EarthBase R&D Center, 225 North Avenue
School of Aerospace Engineering,
Georgia Institute of Technology
Atlanta GA30332-0150
404-894-9622

Operational Locations:
Solar System Manufacturing Facility: CanalView Business Park, Mars Orbit
Earth Regional Manufacturing: ISS Freedom, Low Earth Orbit
Payload Exchange Operations: Lunar Orbit Station

Vision

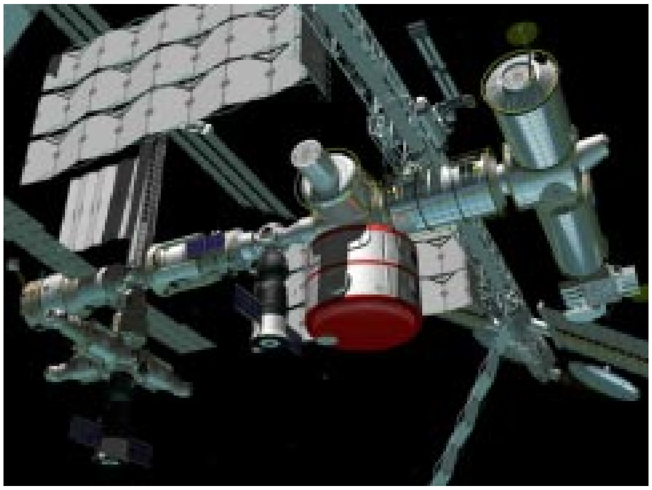
ASI will lead the space-based manufacturing industry of the 21st century, continually reducing the costs associated with space exploration, habitation, and development.

Objectives

ASI will provide:

- Custom-fabricated parts for the International Space Station.
- Standardized components for spacecraft.
- Standardized components for the construction industry in Space.

Business Description



At $5,000 per lb. to Low Earth Orbit, the cost of shipping components and machine tools from Earth is a large obstacle to the human venture into space. ASI provides a solution to this problem: manufacturing using adaptively controlled sound waves to form surface shapes in microgravity, from granular or liquid-state materials. ASI will offer non-contact, flexible manufacturing of sophisticated components to Mars explorers and to the construction business in the Solar System. Initial operations located on the

International Space Station (ISS) in low Earth Orbit will serve near-term *Orbiting Space Station.[MarsSociety,1998* customers on ISS, using material shipped from Earth. As revenue and markets develop, the primary manufacturing facility will be located in lunar orbit to help build the second ISS, and start lunar mining. As this market develops the main manufacturing facility will be built and located at the Mars orbital station. Material brought from lunar and asteroid mines will be turned into precision-formed components at ASI. Products will be delivered by aerodynamic decelerators to customer sites on the planetary surface, and carried on Cycler Shuttles to customer sites in GEO / LEO / lunar orbit. From these beginnings, ASI will lead the space-faring construction business in the Solar System.

Market

Space-related business accounts for over $121B/yr in 1998. Currently, all items are shipped from Earth, at costs-to-orbit of over $5K per lb. The International Space Station alone is expected to grow to an Earth-weight of over 1 million lbs. by 2004. Demand for Space-based construction is projected to be $20B/yr in 2005, rising to $500B/yr by 2020 as human space exploration progresses. ASI's role in this market is both as market enabler and as supplier. ASI's customer base consists of two types of industries:

1) NASA and Aerospace firms contracting to NASA and ESA for construction of :
   - International Space Station components
   - Spacecraft for Solar System & Deep Space exploration
   - Lunar and Mars surface base facilities

2) Customers for Earth-based products, such as composites, crystals and optics that require high purity, high precision products.

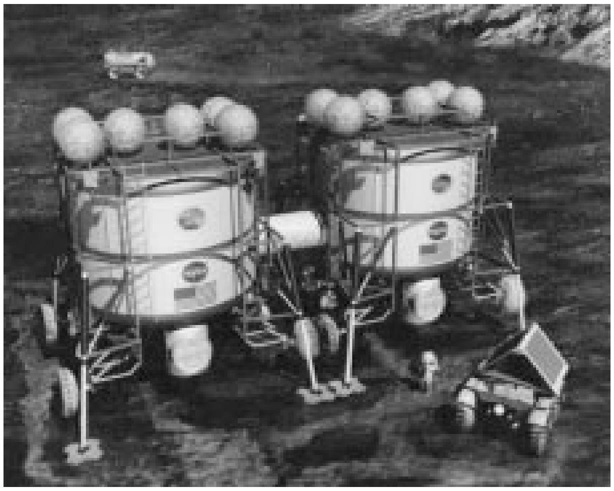
As Space Commercialization proceeds, these firms will transition to serve the developing commercial markets on Earth for the development and habitation of space, with attendant increases in size.

Examples of ASI-built products are:

- Space-Station outer and interior panels.
- Habitation modules for use on Mars, the Moon and other planets
- Local transportation for other planets
- Power plants
- Space-based Mining Equipment
- Nozzles
- Plumbing components
- Pre-fabricated, pressurized habitation modules.
- Pressure vessels

Competitive Edge

ASI's core technology is the Acoustic Shaping technology proven by our team in over 200 parabolas of microgravity flight on NASA's KC-135. Our core competence includes the depth and breadth of technical/ business/marketing capabilities from schools and research labs at Georgia Tech, one of the premier technological institutes of the world. Access to Georgia Tech translates into a complete capability across the life-cycle of this technology.



Artist's concept of a potential Mars mission, from NASA Web pages, showing connected pressure vessels to form habitation modules. From [Mars Society, 1998]

These Earth-based facilities offer complete concept-to-test capability, spanning such areas as System Design and Life-Cycle Analysis/Simulation/Optimization, Booster technology, Hypersonic Controls, Spacecraft Attitude Control, Re-entry Aerothermodynamics, Acoustics, Modeling & Simulation, and aerodynamic glide/ decelerator technologies.

ASI seeks partnerships with the entities leading Space Exploration: NASA, the large aerospace companies Lockheed-Martin and Boeing, as well as a leading technological university, Georgia Tech. The ASI team in particular, and these Georgia Tech schools in general, are models of the future engineering environment envisioned by NASA, our project teams integrating diverse technical disciplines as well as people from all parts of the world.

Glimpse of an ASI Manufacturing Facility

At the core of the space-based Phase-Controlled Acoustic Shaping Technology (PCAST) facility are 10 Acoustic Chamber modules of various sizes, with up to 25 individually programmable speaker systems each. The chambers are pressurized with a suitable gas such as nitrogen. Raw material is received at the orbiting station and converted to the desired particle size or liquid characteristics in a preprocessing plant. The temperature and pressure are brought to the needed levels, and a pre-selected sound field is imposed. The material is fed into the chamber along with the binder component, so that the mixture solidifies along the desired surfaces; some processes will use solar / microwave heating or rapid cooling. After curing for the appropriate time, the formed shape removed, finishing processes applied, and the part is loaded back into transporters.

Business Location

Manufacturing will be located in orbit to use jitter-free, long-duration microgravity essential for quality control. The first location will be at the ISS to serve customers in LEO and GEO. The next will be in lunar proximity, to participate in ISS-2 construction and help initiate lunar mining. With material coming from lunar mines, the Mars station will be built and moved to Mars Orbit, for access to the Martian surface market and to major transfer orbits for missions throughout the Solar System. Mars orbit offers convenient access to Earth, to Earth's Moon, and to the Asteroid Belt. Subsidiary locations in lunar orbit allow exchange between raw materials from the Moon, and finished products.

Implementation Plan Summary

Phase I: Concept Validation The ASI team is composed primarily of undergraduates, with several in their freshman year. Thus, for the next 3 years, it is expected that ASI will continue to be a university-based R&D team operation.

1. NASA-GT collaboration to demonstrate technology on the NASA KC-135 Microgravity Flight Laboratory, 1996 - 2000. Over 200 parabolas flown; successful validation with various parametric variations.
2. Development of the concept through NASA TRL (Technology Readiness Levels) 1 through 3, with NASA support, in joint project with NASA/ USRA.
3. Sounding rocket tests to enable testing of surface hardening in microgravity. 2000-2002

Phase II: Technology Development

4. NASA-GT experiment: Advance TRL level to the stage needed for STS flight with model-scale production plant, 2002-2003.

Phase III: Production on ISS; Capital Infusion (Pilot)

5. NASA/GT/ASI/Other Aerospace company partnership to send scale model production chamber to ISS-1 to gain operational experience with producing space station parts. 2002 - 2005
6. Dual-chamber production plant placed in orbit and docked to ISS; goes into production. 2003-2005.
7. Automation of dual-chamber plant with resupply using STS and other launchers. 2003-2005.

Phase IV: Production in lunar orbit / ISS-2 construction

8. Dual-chamber plant flown to lunar orbit / L-5 Lagrangian Point to begin construction of ISS-2. Year 2008.
9. First raw material from Moon surface, Year 2008
10. Construction of ISS-2: Years 2008-2010
11. Construction of commercial facilities (e.g. "Hilton L-5") in orbit using material from lunar surface. 2008-2012
12. Construction of lunar surface facilities for mining, exploration and tourism: 2005-2015
13. Construction of Mars Orbit Station pieces in lunar orbit, 2006-2010
14. Mars station shipping and assembly. 2010-2015

Phase V: Revenue Generation and large-scale production:

15. Phobos material mining & delivery system. 2013
16. Mars surface operations 2012-2013
17. Mars station expansion 2013-2019

Phase VI: Out to the Solar System

18. Asteroid Belt Transit System 2016
19. First Solar System Expedition module delivered from Mars orbit facility, 2020.

Summary Gantt Chart

Phase	1995-00	2000-05	2005-10	2010-15	2015-20
Phase I: Concept Validation	——▼				
Phase II: Technology Development	——	▼			
Phase III: Production on ISS; Commercial capital		——▼			
Phase IV: Production in lunar orbit / ISS-2 construction		——	▼		
Phase V: Revenue Generation & large-scale production (Mars)			——	——▼	
Phase VI: Out to the Solar System				——	——▼

Project Team

Name	Responsibilities/expertise
Catherine Matos	Executive Director; Outreach
Sam Wanis	Acoustic Shaping technology Research and Development
Tinoush Moulaei	Life Sciences Applications
Don Changeau	Flight Test Engineering
Adam Coker	Product Development
Xinyuan Tan	Product Pricing
Justin Hausaman	Space Operations
Richard Ames	Business Management & Finanace
Narayanan Komerath	Faculty Advisor

Advisory Board

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