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Involving Students in Engineering the Infrastructure of a Space-Based Economy

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Abstract

Many students enter aerospace engineering with visions of participating in the human exploration and development of Space. While we wait for national leadership towards grander objectives, we are using a spinoff from a NASA-sponsored competition to develop thinking and problem-solving related to the infrastructure needed for a sustainable human presence beyond Earth. Student teams have developed a conceptual framework for a Space-Based Economy which justifies usage of extra-terrestrial resources. A test case of a large project is used to illustrate the process of breaking immense problems into bite-sized chunks for engineering solution. The problem of building the radiation shield of a one-km-radius, two-km long cylinder is revisited in the light of recent studies on bootstrapped lunar solar-electric power plants, mass drivers, and autonomous spacecraft. The paper describes the process of getting first-year and senior-level students interested, prepared and active in solving these problems.

I. Introduction

The central issue in this paper is how to get students involved in large interdisciplinary projects at an early stage. In the past three years, enrollment in aerospace engineering at the author's institution has risen sharply. This rise appears to be related to the expectation that there will be a wealth of Space-related opportunities, resulting from the Mars Exploration plan [1] and the "Gold Rush to Low Earth Orbit"[2] seen in the late 1990s. The rigorous courses on fundamental mathematics and science in the first two years of college afford little occasion to remember why one wanted to enter engineering in the first place. In the 1990s, we tried to address this demoralizing aspect by setting up a Design-based Introduction to Aerospace Engineering course[3], enabling students to experience the conceptual design of aircraft in their first weeks in college. While this has inspired the students who see themselves as airplane designers, it has left unmet the needs of the 40% of our first-year students who see themselves as Space enthusiasts[4]. There is not time in a course at this level to teach more than the rudimentary aspects of "rocket science", and even this must be done at the end of the course. We needed better ideas to get students involved in Space-related endeavors at the freshman level.

Developments on a related frontier offer an opportunity. Aerospace enthusiasts have long realized that the commercial potential of Space resources is the best argument for a large Space program. Since 1997, annual commercial expenditures in Space-related activity exceed government expenditures related to Space [5,6]. However, there is widespread disillusionment among Space enthusiasts[7] regarding the pace and ambition level of current plans. For example, the Mars Exploration plan developed by NASA has rapidly been de-scoped to the point where the human exploration aspect appears to have been completely shelved. Today only a very few government employees and billionaires can reasonably hope to experience Space flight. A groundswell of opinion appears to be slowly building to argue for a major push for tourism in Space, as a viable commercial activity which would then provide the critical size needed for all-round growth [7]. This is still a small fraction of what could become a Space-based economy.

II. The Space-Based Economy Concept

Currently, the development of Space as an economic frontier is hindered by the very high cost of launching from Earth, and hence of maintaining and protecting equipment or humans launched from Earth. This cost hinders the development of infrastructure in Space – infrastructure which could dramatically reduce the costs and hence open the frontier. The author is one of many aerospace enthusiasts who hope that this vicious circle of obstacles is only temporary – and that the Space program can indeed lead a massive development of human technology and economic success. Thus it is worthwhile to educate students about the real issues and the vast range of opportunities to solve interconnected problems related to the Space program – and get their imaginations working along scientifically relevant paths.

The idea for this project was developed through a NASA-sponsored competition [8] which aimed to develop public support for Mars exploration. This program enabled some thinking and problem-solving related to the infrastructure needed for a sustainable human presence beyond Earth. Under NASA's Reduced Gravity Flight Opportunities program, and later under the "NASA Means Business" program, teams of Georgia Tech students have developed a concept called the Space-Based Economy [8-10]. The concept is that a synergistic economic framework which justifies usage of extra-terrestrial resources is essential and sufficient to free us from the fundamental barrier of Earth-based launch cost. Such a framework requires a massive effort to educate the public about the benefits to all segments of society, accruing from a Space-based economy.

Today there are numerous commercial interests in Space – but only a few of these can gather and risk the huge resources needed to go into Space-based business. Each such enterprise must separately overcome the launch cost barrier, and the near-impossibility of on-site repair, which require extreme redundancy and expense in the design and development of every component. We started with the notion that synergy between all such enterprises would in fact generate a breakthrough path. To illustrate this, we investigated, in turn,

a. The costs and the "net present value" of a technology-based startup company which would seek to start a Space-based construction industry [8].
b. the impact of Space-based construction on the cost and viability of long-duration human missions such as a Mars mission [9].
c. the feasibility of building the most difficult part of a large human settlement in orbit, using today's technology and economic considerations [10].

In the process we looked at how to estimate costs, risks and payoffs of each type of activity. It became increasingly clear that a Space-based economy would become more and more viable as one increased the number and variety of enterprises which would accept a synergistic plan. Table 1 summarizes the differences between today's space-related businesses, and the vision of a Space-Based Economy

Table 1: Differences Between Today's Space Enterprise and a Space-Based Economy[10]

Current models of Space Enterprise	Space-Based Economy
• Earth as the only possible market. • "Faster-better-cheaper" to compete in today's global business environment. • Three-to-five year return on investment (ROI) expectation by investors. • Terrestrial launch cost reduction as key enabler. • Lack of infrastructure for repair or resupply sharply heightens risk for all investors. • Support constituency: NASA Centers, Space launch companies, space science community. • Competition for decreasing government funds forces adversarial competition between segments of the Space-enthusiast community. • Limited and decreasing interest and funding.	• Most raw materials and products originate outside Earth. • Large Space-based infrastructure • Extra-terrestrial raw materials. extraction and processing, • Large scale manufacturing capabilities in space. • Exchange of products and services between space-based enterprises. • Support constituency: diverse businesses and professions – broad cross-section of taxpaying public. • Required critical mass of funding and long-term investment rules out private funding.

A critical need in this endeavor is to develop the knowledge resources needed to gather public support for a Space-based economy – an economy which offers payoffs for all segments of society, not just the aerospace community [8,10]. Such resources must bridge the gap between the sources which are technically accurate and the intended recipients who need material presented in simplified form. The technical resources are spread over various aerospace-related institutions, and are difficult for the person outside aerospace engineering to find or use without some guidance. This is where engineering students can help – they can find the material, and present it in a form comprehensible to people outside engineering.

Interactions with various segments of the technical and business community prior to Fall of 2001 showed that there is a strong need for studies of the technology and the economics of the various aspects of a Space based economy. There is a need for such studies at various levels as well – tailored towards the needs of different segments of society. This is where undergraduate engineering students can be of great help, even as the experience contributes to their motivation and education.

III. Test Case of a Large Project: 1km-radius Radiation Shield at L-2

A test case of a large project was used to illustrate the process of breaking immense problems into bite-sized chunks for engineering solution. A fundamental obstacle to building human settlements in Space is the construction of the massive outer radiation shield needed to protect humans. The paper by Ganesh et al [10] was used to illustrate the relevance of a comprehensive plan in developing a Space-based economy (SBE). The problem of building the shield was revisited in the light of recent studies on bootstrapped lunar solar-electric power plants, mass drivers, and autonomous spacecraft. This test case violates the usual assumptions about Space exploration in that it deals with constructing a massive, spacious structure with relatively simple technology to demonstrate a viable path to the infrastructure of an SBE. The example shows that both the technical feasibility and the affordability of such a human settlement rise substantially when viewed in the context of a comprehensive program for a SBE.

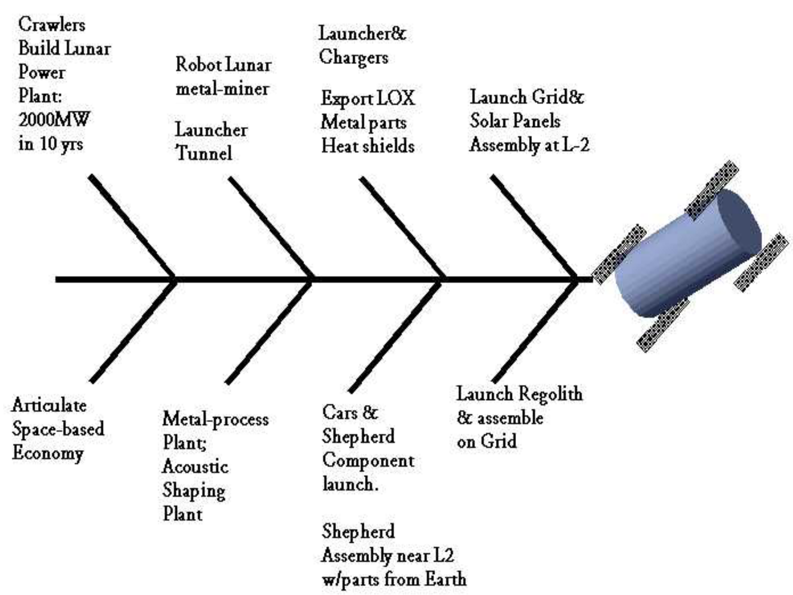

Figure 1: Architecture of a plan to build the radiation shield for a human settlement in orbit[10].

Figure 1 illustrates the architecture of the project. We modified the concept from that of the Bernal Sphere developed in the 1970s [11]. We developed a scheme for building the radiation shield using electromagnetic forces in a wire grid to position metal containers filled with lunar regolith. The containers would be filled with regolith and launched by an electromagnetic accelerator. The power to drive the accelerator would come from solar-electric plants distributed around the lunar equator – each such plant would use a field of solar cells built into the lunar surface in situ using a set of robotic rovers[16] which focus sunlight to melt the surface, and add some pure substances to create the cells and other circuits .

In the SBE concept, the massive construction project required to build the radiation shield, is itself used to give a start to several other enterprises –

1. A solar-electric power plant system, with sites located around the lunar equator.
2. A metal extraction and metal-working plant
3. An electromagnetic launcher system with sites distributed around the lunar equator.

4. A manufacturing facility which builds cable and flat plates for use in the launcher.
5. A shuttle system of small "Shepherd" spacecraft which are used to guide payloads launched from the Moon to the construction site at the Earth-Moon Lagrangian Point L-2.

There is conceptual and detailed technical work on each of the above five items [11-20]. The issue then is to make students aware of these, in a context where each concept has economic relevance and is vital to the overall Space-based economy.

IV. Assignments in Required Core Undergraduate Courses

The AE1350 Introduction to Aerospace Engineering course introduces Newton's laws of motion and gravitation as the basis for much of aerospace engineering. Two initial assignments explored the acceleration and trajectory of a rocket from launch until the burnout of the first stage. Instead of attempting analytical integration (which most students had not studied yet) they were asked to perform calculations in small time steps using a spreadsheet program. In the process, a simple expression for air drag was also included in the calculation. In doing this assignment, students explored the NASA websites and obtained information on the eace shuttle, and thus started having a reason to explore the space-related sites. Rocket propulsion concepts were covered under the propulsion section of the course, in the third quarter of the course. The last chapter in the course dealt with orbital mechanics. Students worked in teams of two over the last six weeks of the semester to develop a conceptual design of an aircraft. This project required an extensive amount of literature search and iterative calculation procedures. The SBE-related project was added on to this as another team effort.

In this initial iteration of the Space-related assignment experiment, students were asked to select one of the items below, and write an essay, working in teams of two. A list of web links was given, guiding students to papers and reports related to each of the topics. Due to lack of time at the end of the semester, plans to require design calculations from the students were abandoned for this initial experiment.

Table 2: Essay topics for first-year aerospace engineering students, Fall 2001.

#	Essay Topic
1.	Vehicle to shuttle between lunar surface and L-2 Lagrangian Point. Only hydrogen fuel can be shipped regularly from Earth - use lunar-derived materials for all other items
2.	Lunar-based solar-electric power plant
3.	Lunar-based Mass Driver Launch System
4.	Hydrogen Fuel-Cell-based Mars Cycler which keeps orbiting between Mars and Earth

In Winter/Spring 2002, Space Economy- related projects are being developed as part of the senior-level propulsion course. Here, students are being asked to develop validated conceptual designs and calculations for the propulsion aspects of the SBE – the electromagnetic launcher, the Shepherd spacecraft for orbit transfers, and a Mars Cycler Transit System. These students are asked to consider the literature on cost estimation and other economic aspects related to such projects. Results are posted on web pages, samples are taken with student permission for use in articulating and further developing the SBE concept.

V. Participants Engaged, and Their Response

To-date, we have made efforts to engage different segments of the population for different aspects of such an endeavor, since 1999. The efforts are tabulated below.

Table 3: Engagement of Various Community Sections with the Concept of the Space-Based Economy

Participants	**Focus**	**Reaction # (see below table)**
Middle Schoolers: Career Day presentation	Space engineering as a technical career	1
Business School Graduate Class	Strategic aspects of business development in Space	2
Aerospace Industry Engineers	Concept and methods	3
Space Resources Utilization Roundtable, 1999,2000	1. Concepts for Space-based manufacturing 2. Cost-reduction using Space-based construction of large spacecraft.	4
College undergraduates (engg., advertising & business) : NMB national competition participants	Various concepts for customer engagement related to the Mars program; Space-based economy.	5
Elementary Schoolers: Class presentation and assignment	"What business would you like to run in Space?"	6
NASA engineers, scientists and managers @ 38^{th} Space Congress, KSC 2001	Relevance of Space-based economy in planning for the next 50 years	7
Space Studies Institute Conference	Engineering feasibility and relevance of a synergistic plan for developing a Space-based economy	8
Engineering undergraduates	Conceptual design of major elements in an SBE	9
Engineering faculty	This paper: opportunities to use the SBE as a focal point for engineering school assignments	10

Reaction #1: Middle-schoolers (5^{th} graders) visited on their Career Day in a local Atlanta School remained very attentive for an hour to a presentation on Space issues. Some were very much aware of internet sites – for example, at least 3 instantly recognized a digital image from Space of Baja California, downloaded from a NASA website. Students at this level were mostly interested in the hardware aspects, but were willing when asked to think about the issues related to living and working in a different environment such as Mars.

Reaction #2: The author and his student team visited Georgia State University and gave 2-hour lecture/discussions on different aspects of the Space-based economy, on four different occasions over the past 3 years. The audience each time was the graduate class on Strategic Marketing. This audience was very much interested in the issues related to setting up technology startup companies in Space. NASA endorsement of technical plans was seen to be a critical issue for such planning. The need for usable technical/ cost information to enable business planning was also cited as a high priority.

Reaction #3: Aerospace Engineers working in industry – generally, the enthusiasm level from this important segment of the community has been low, unless their particular corporate entity is involved, and the project has a short-term horizon.

Reaction #4: Space Resources Utilization Community. This community provides strong support for each of the component businesses discussed here, but is engaged in a debate on whether it is appropriate to focus on the Moon or on asteroids as the initial sources of extra-terrestrial resources.

Reaction #5: College students at the NMB competition came from universities all over the US, and in one case from France. These students were for the most part quite inspired by the idea of a Space-based economy. However, the aerospace engineering students among them were less optimistic about the prospects of any such economy coming about within their lifetimes. Two observations were derived from these students – first, that the lawmakers (Senators, Congresspeople) who expressed support for the current Space program were almost invariably those who had large NASA / Space contractor constituencies. Secondly, that surveys of public opinion showed a high priority placed on NASA completing current projects before assuming new ones.

Reaction #6: Students at the Centennial Elementary School in downtown Atlanta provided the best input so far on living in a Space-based economy. As a class assignment, each described a business that s(he) would run, living in Space. A large demand was seen for food service (delivery by microgravity tossing was seen as a very desirable job), hair dressing (students noted the fact that astronauts' hair stood out straight in microgravity), and sports arenas were seen as very interesting business ideas, accompanied by color sketches.

Reaction #7: NASA personnel at the Space Congress at KSC. Here the focus was on near-Earth operations using the Shuttle STS and other launchers, and even the 50-year plan session had papers dealing with off-the-shelf launcher technology to reduce costs.

Reaction #8: Space Studies Institute participants. These visionaries considered a Space habitation to be under-ambitious, and were willing to consider much larger projects such as the capture of asteroids and the redirection of asteroids as needed.

Reaction #9: Undergraduates in aerospace engineering classes. This is the first time that students in "core" required courses are being asked to dedicate thought to such long-horizon concepts. The initial reaction from the freshman class is that they took it just as they take any other engineering assignment, searched and found the best possible information, and took it seriously. The students explored sites and printed resources from several sources including USRA's NASA Insitute of Advanced Studies (NIAC)[21]. In a survey administered through e-mail after the course was over, students cited books in the library, as well as the web pages provided with the assignment, as the main sources of information. The essay-writing provoked little comment – it appeared to be an assignment well within their capabilities. Their assignment web pages showed that they had in fact found several resources very relevant to the projects. The experience of dealing with more in-depth assignment in the senior propulsion class is underway. Here much more critical questions are expected, as are much better ideas and in-depth work. Samples of essays by the freshman class are cited by permission [22-23] along with several references provided by them [24-26]. It is too early at this writing to gauge the reaction of the senior propulsion class to the assignments requiring conceptual design of SBE elements – these results are expected to be available by the time this paper is presented at the ASEE Conference.

Reaction #10: Engineering faculty. Comments from the reader of this paper would be most welcome – please direct them to the author at narayanan.komerath@ae.gatech.edu

VI. Conclusions

1. Many of today's aerospace engineering students dream of careers which involve Space travel. There is considerable disillusionment regarding the pace of the Space program.
2. The prospects of economic development provide the best reason to expand the space program. The concept of a Space-based economy (SBE) can inspire students, offering opportunities for them contribute towards the realization of their dreams.
3. The SBE provides a framework for long-term, large-scale thinking independent of present government space programs – where the immediate need is to perform conceptual design and innovative strategies for risk reduction, as well as provide knowledge, on a grand scale.
4. The SBE concept is an integrator of engineering with other aspects of society. Unlike the present model of Space being the domain of aerospace scientists and engineers alone, the SBE requires the participation and support of all segments of society, and offers potential benefits to all segments. Students play an important role in grasping and conveying the key ideas, relevant methods and data to the general public in a manner which is likely to be less intimidating than scientific papers and government documents.
5. Essays at the freshman stage appear to have ignited students' imagination, and support the hypothesis that people with a high school education and some guidance can indeed take an interest, appreciate the ideas, and contribute usefully to developing the SBE.
6. Senior students in an aerospace propulsion class are being asked to help in the conceptual design of some key project elements of the SBE.

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VIII. Biographical Sketches

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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 operates the Aerospace Digital Library Project at Georgia Tech: http://www.adl.gatech.edu