Automatic Construction of a Radiation Shield

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A. Abstract

NASA’s HEDS Grand Challenge aims to develop a self-sustaining human presence beyond Earth. A fundamental obstacle to building human settlements in Space is the construction of the massive outer shell which acts as a radiation shield. Our experiments have shown that by tailoring potential fields, large numbers of objects can be moved into desired positions and desired shapes can be constructed. This idea holds promise for several types of force fields suitable for automated construction at levels ranging from nanometer-scale discs and fibers, to kilometer-scale human habitats. Results from microgravity experiments at the $10^{-1}$ m level are used to illustrate the concept. Next, the sample problem of building the radiation shield of a 1km-radius cylinder is taken through system/architecture considerations, to show basic feasibility. This constitutes a particular solution to a general problem. Finally, general solutions based on waveguide technology are considered, for automated construction on a massive scale. The proposal starts with well-agreed ideas of what a human habitat requires, and flight proof of the TFF idea, shows the feasibility of a subset of TFF in constructing this well-established system (within 15 years), then takes off into the regime of how huge habitats or spaceships may be built from near-earth asteroids. The project will focus on the issue of building the infrastructure of a space-based economy using electromagnetic and acoustic fields. In Phase 1, a force-field tailoring simulation tool will be developed. The sample problem of the 1km-radius cylinder will be taken to detailed feasibility examination. The test case of reconstituting a spaceship from pulverized asteroid material at the Earth-Sun L-5 point will be taken through architecture definition. These two test cases will be refined further and missions designed in Phase 2.

B. Concept Description

B.1 Need for Tailored Force Fields

A multitude of objects can be made to simultaneously arrange themselves along specified surfaces in a suitably-tailored potential field. We have demonstrated this concept in small-scale microgravity experiments relevant to low-cost manufacturing and construction in Space. We now show that the concept can be extended over a wide range of sizes and force fields, to solve some problems for which no solution existed before. Specifically, this concept enables a new approach to the primary goal of the NASA HEDS Grand challenge: the development of “safe, fully self-sustaining integrated human and robotic presence in space and on other planets, independent from Earth and for indefinite periods of time”.

Figure 1: Island One, a Space settlement in orbit, with people living along the equator of a rotating sphere [1,2].

Figure 1 shows "Island One", a 1-km-radius orbiting community, contained within a rotating “Bernal sphere” [2]. Two fundamental obstacles to building such communities are: (a) the need for human or human-like robotic labor, and (b) the transportation, delivery and cost of the immense mass of the radiation shield needed to protect humans during and after the construction. In Ref. [2], the construction of the radiation shield was recognized as the dominant cost item. Calculations [3] show that a shield made of sand or soil would be 2 meters thick. The material was assumed to be launched by a nuclear- or gas-powered electromagnetic mass driver from the lunar surface.
Construction was assumed to proceed using human labor, which had to be sustained from Earth and protected until the shield was complete, the sphere pressurized and sealed. Even at projected STS launch costs of $110/lb to LEO [2], versus today’s $12000/lb, this was considered prohibitively expensive and dangerous. Some automatic means of constructing the radiation shield is essential.

Ideally, material brought from the Moon or asteroids would be moved into position and fastened to the outer framework of the “city” under automatic control, using forces which are generated by converting sunlight or other energy. This would enable the radiation shield to be constructed over a period of years, at little additional cost beyond the capital needed to establish the lunar or asteroid mass-driver. If part of the interior structure can also be built automatically, human habitation can wait until safe and hospitable conditions are established. For construction at L-2 human operators on Earth can do the controlling if needed, using near-real-time video feedback. 

The massive scale of the needed construction forces and machinery is the problem. In this proposal we will show the system and architecture by which this construction can be accomplished, and then argue that this is a particular solution, a special case of a general approach to build a much wider size-range of items using tailored force fields (TFF). Our proposal starts with relatively well-agreed ideas of what a human habitat requires, and flight proof of the TFF idea, shows the feasibility of a subset of TFF in constructing this well-established system (within 15 years), then takes off into the “far-out” regime of what might be done many years from now to build huge habitats or spaceships from near-earth asteroids.

B.2 Acoustic Shaping: TFF demonstration on the $10^1$ m scale:

A demonstration of the basic concept follows. Figure 2 shows a curved wall, roughly 0.1m high, forming from loose solid particles in a microgravity flight test on board the NASA KC-135. The TFF in this case is a resonant acoustic field in an air-filled container. The particles, dispersed at random in the container, form walls along the nodal planes of the resonant sound field. Wall shape and position are determined by the frequency and phase of the sound. The walls are single-particle thick. Videos show the particles adjusting position to fill gaps in the walls.

Figure 2: Styrofoam particles form into walls along the nodal surfaces of the 110 mode of a rectangular chamber, under a resonant acoustic field. Georgia Tech experiment on the NASA KC-135 Reduced Gravity Flight Test Laboratory, April 1997.

Extension from 1m to $10^6$ m: Liquid / Powder Sheets: The nodal surfaces are also regions of low static pressure, so that liquids sprinkled with micron-scale powder rise into thin walls even in a 1-g environment. We have demonstrated cooling and phase change in the acoustic field to harden walls. With these results, the manufacture of small components in orbit or on low-gravity planet / asteroid surfaces already appears to be feasible, using low-intensity audible-frequency sound sources. The resonant field amplitude is determined by the balance between energy input and losses; thus the actual field intensity inside the chamber can be several orders of magnitude higher than source intensity. The practical implication is that panels, heat shields, radiation shields and pressure vessels, essential to space habitation, can be built in extraterrestrial environments at low cost using automated processes, low-weight facilities and low-grade raw materials. The technique is compatible with solar energy sources in space.

Figure 3: Thin curved wall of water with suspended calcium carbonate (chalk) powder formed in a resonant sound field in 1-g. GT ground test, June 1999.
Lessons from Acoustic Shaping:

These are powerful demonstrations, because the acoustic field is essentially a potential field. The “radiation force” which drives the particles towards the stable planes requires interaction between the field and the particles. Air drag does play a role in convecting particles rapidly to the nodal planes, but this is not an important consideration in long-duration microgravity. Further, analysis [4] shows, and flight tests confirm, that high sound amplitude is not essential, and in fact may be counter-productive. While acoustic force fields require a medium such as a gas, other force fields which do not need a medium would be appropriate for large-scale construction in orbit. The broad question raised by this demonstration is: “What other force fields may be tailored to produce similar effects?” This issue is explored further below.

B.3 Electromagnetic Field Tailoring: TFF at $10^6 - 10^9$ m in the construction of the Radiation Shield of a 1km-radius rotating cylinder in Space

B.3.1 Basic Premise
The equations describing electromagnetic fields are similar to those describing acoustic fields, and so are their solutions for mode shapes. Electromagnetic TFF can open up automated construction on a huge scale. We will draw upon past work on traveling magnetic wave propulsion [Ref.11], space-tethers, [Ref. 12] and tether-based electromagnetic propulsion, and tie these to work in the areas of waveguides and mass-drivers.

The driving force on particles in such fields would come from induced or artificially-generated magnetic fields in the particles: the means for this would depend on the specifics of the material and the construction project. We focus on constructing a 1km-radius settlement at the L-2 Lagrangian Point of the Earth-Moon system to demonstrate that a particular solution is feasible with current technological capabilities, at a cost which is justifiable by economics. We emphasize that this demonstration of basic feasibility is to prove that a particular solution exists to the general TFF model: therefore the search for more general solutions and understanding of this concept is very important.

B.3.2 Previous Studies of Human Settlements in Orbit
Various visionaries have studied the dream of “Outposts” in space: great space cities which will act as stepping-stones to economic utilization of extra-terrestrial resources, and to systematic exploration of Space. O’Neill [2] considered in detail the issues in developing large settlements in Space. He recognized the fundamental obstacle of earth-based launch costs. He identified economic opportunities as the correct motivator for development. He identified the Lagrangian Point L5 as the logical location for the settlement. O’Neill described a spherical “city” named the “Bernal sphere”, with toroidal agriculture stations attached on either side. The Bernal sphere would spin co-axially with the toroids to generate artificial gravity close to one Earth ‘g’ near its equator. O’Neill envisaged the sphere shell being made of aluminum and glass (to admit sunlight ), with a support structure made of aluminum ribs and/or steel cables. Radiation shielding dominated the mass of the settlement; the structural mass was a small fraction of the total. Even at projected earth-LEO launch costs of $110/lb, O’Neill saw that the material would have to come from the Moon. He postulated a lunar-based mass driver to send much of the required mass into Space.

Ref. [3] resulted from a 10-week expert study of technologies for settlements. From various configurations, a toroidal shape was selected to provide the highest artificial gravity at the lowest rotation rate, with the lowest overall mass and cost of construction for a small human settlement. The toroid could also be used to generate magnetic fields to help deflect charged particles.
B.3.3 Summary Architecture for Building the Radiation Shield

There are seven important differences between the assumed models of 1975, and today, shown in Table 1. These differences are significant enough to justify a new look at the process of building a “city” in space.

<table>
<thead>
<tr>
<th>#</th>
<th>1975 models</th>
<th>Present model using Tailored Force Fields (TFF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$110/ lb Earth- LEO</td>
<td>$1,300 to $14,000 per lb to LEO</td>
</tr>
<tr>
<td>2</td>
<td>Human labor for all construction and facility operation.</td>
<td>Robotic manufacturing, miniaturized digital electronics and fuzzy-logic control. Most work automated. Human operators for verification, trouble-shooting &amp; redirection, directly from Earth. Pathfinder, Voyager, Autonomous craft prove feasibility</td>
</tr>
<tr>
<td>3</td>
<td>Construction at L-5</td>
<td>Shell construction at L-2 followed by slow move to L-5</td>
</tr>
<tr>
<td>4</td>
<td>Lunar mass driver gas-powered; required H2 from Earth.</td>
<td>Robotic, large-scale manufacture of solar power fields on lunar surface is feasible [4]. 20 launchers distributed around the lunar equator to enable round-the clock launches; no fuel cost.</td>
</tr>
<tr>
<td>5</td>
<td>Baseball-sized payloads. High Isp. Debris threat. 30g; 10km run</td>
<td>Launchers sized to railcar-sized payloads. 8-g acceleration to reduce structure weight, longer track. Longer cars minimize alignment problem. Simpler capture of payloads.</td>
</tr>
<tr>
<td>6</td>
<td>Entire interior pressurized for “shirt-sleeves” comfort.</td>
<td>Only 10 to 30 meters at rim pressurized, using membrane with 30-meter bubbles to provide micro-climates as needed.</td>
</tr>
<tr>
<td>7</td>
<td>Machinery required to make panels etc.</td>
<td>Non-contact Acoustic Shaping with solar-heated powder sintering &amp; furnaces. Robotic assembly of payloads.</td>
</tr>
</tbody>
</table>

The purpose of the following discussion is to present a credible method of automatically and efficiently building the massive radiation shield and outer shell of a hollow cylinder, 1 km in radius, and 2 km long. This “particular solution” shows the basic feasibility of TFF construction on the scale of $10^7$ m and beyond. Whether the ends should be capped, and with what material, is a minor issue in our model; these can be addressed in the Phase 1 study. Unlike a sphere, the cylinder can be a segment of a much longer “space tunnel” [2]. Other aspects:

- The 1km radius permits 1-g with 0.95 rpm: this is within the comfort parameters of the vast majority of humanity [2]. It thus removes one of the prime obstacles to the popular appeal of the space program: the idea that one has to be a super-fit youngster trained to military levels to participate in Space.
- The net output rate of the lunar mass drivers controls the time needed to build the city shell.
- The basic unit used in building the outer shell is a rectangular container similar to an open-top railroad box car: the 2-meter depth of regolith provides adequate radiation shielding [3]. The car bottom and sides are manufactured by acoustic shaping or other non-contact processes on the lunar surface from metal extracted there; industrial-type robots assemble the cars, load them with compacted lunar regolith and place them on the carriage of a launcher. Following acceleration at 8g to 2.4km/s, (40km of track) each car is launched into lunar orbit, with sufficient energy to reach L-2. The alternative technology of Space Tethers and “staircases” could be used for the launch instead of electromagnetic mass drivers.
- Orbiting “shepherd” propulsion units will each be equipped with gas thrusters (assumed to be solar-heated H2 or He) and a trio of fuel-cell powered electromagnets (for guidance through the force-field). Two of these units will be attached to each pair of box-cars in lunar orbit, and will guide them to the entrance to the 1km-dia cylinder. O2 for the fuel-cells will come from the Moon; H2 may have to be imported from Earth. Helium for the orbit-transfer may be available from the Moon; else H2 will be used.
- Structural strength comes from a grid of cables. Rings of 12.5mm cable segments, 1km in radius, spaced 4 meters apart, will be connected by longitudinal cables 45 degrees apart. The grid is powered by solar panels, with hydrogen or helium thrusters to provide orbit corrections. Every node of the grid will be an electrical switching unit, so that a strong electric current can be passed through any segment of the grid independently. Rotation about the axis, initiated using small thrusters, holds the grid in tension during the construction of the shell.
• A radial arm which can be moved along the axis and around the azimuth holds an inner grid segment. *These current-carrying wire segments help guide the cars during construction.*

• Each “train” is assumed to enter the grid along a longitudinal trajectory with respect to the grid, at a relative speed of 1km/h. This requires some intricate orbital mechanics, but can be achieved using the orbit of the grid about L-2, and the mass-driver launcher. *The electromagnets on the shepherds are activated to decelerate and attach the boxcars to the grid.* The shepherds are then released and accelerated by the inner grid for their *journey back to catch new box cars and form the next train:* a thruster burn may be needed. Radial force due to rotation keeps the boxcars in position until connectors are automatically activated and they are fixed permanently to the grid.

• The boxcar floors form the outer skin of the cylinder. Regolith 2m thick forms the radiation shield.

• With adaptive control as the construction proceeds, the ΔV needed for the orbit-transfer and positioning operations can be continuously minimized; just how close to zero it can come remains to be seen.

The words in italics above constitute the “particular solution” of TFF in action on a 1km-scale: By controlling current amplitudes, directions and segments, as well as the force interaction due to the electromagnets on the propulsion units, mass is maneuvered accurately and safely into desired positions, piece by piece. The wire grid is an extremely simplified representation of a TFF waveguide, and the operation appears to work with DC or very low-frequency current. It can be easily seen that with two controllable wire grids (inner and outer), and individually-controllable electromagnets arranged as a triangle on the propulsion units, any arbitrary force direction can be obtained. Calculations show that the currents required are on the order of 35 amps, intermittently. This is feasible.

Figure 5. Schematic of a 16 m portion of the 2000m total grid system. The inner grid is shown as a complete cylinder for simplicity.

The figure above shows the layout of the wires and the city would lie between the two concentric grids. Construction parameters are listed in Table 2. They look feasible!!

**Table 2: Construction Parameters:**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>City Radius</td>
<td>1km</td>
</tr>
<tr>
<td>Length</td>
<td>2km</td>
</tr>
<tr>
<td>Shield Depth</td>
<td>2m</td>
</tr>
<tr>
<td>Rotates at 0.945 rpm for g</td>
<td></td>
</tr>
<tr>
<td>Current through large coil</td>
<td>35 amps</td>
</tr>
<tr>
<td>500 loops of cable: Wire dia =12.5mm</td>
<td></td>
</tr>
<tr>
<td>Solar Panel area required to power grid</td>
<td>350 m²</td>
</tr>
<tr>
<td>Boxcar dimensions</td>
<td>2mx2mx20m</td>
</tr>
<tr>
<td>Shield Mass</td>
<td>160,000 kg</td>
</tr>
<tr>
<td>(regolith sp.gr.=2)</td>
<td></td>
</tr>
<tr>
<td>10 launchers operational at any time (20 total around lunar equator)</td>
<td></td>
</tr>
<tr>
<td>Propulsion unit current required</td>
<td>5 amps</td>
</tr>
<tr>
<td>Total time to build</td>
<td>4 years of automated construction/assembly work</td>
</tr>
</tbody>
</table>
As was known before, the cost of building the City is dominated by that of the radiation shield and outer shell. With our proposed technique, the cost of actually building the shell is made negligible in comparison with that of delivering the huge amount of material detailed in Ref. [38SpaceCongressPaper]. Again, the cost for this delivery is negligible (little recurring fuel to that of amortizing the electromagnetic launcher. So the the City-Building project really depends on the will to mass drivers or other launch systems which use solar congruence of various needs for such launchers on the construction of the radiation shield for a 1km-radius, 2km becomes quite feasible!! In fact this project can be lower end of the NIAC “20-40 years” scale, given NASA the needs and potential payoffs of a massive Space-Based Economy [GTemoryNMB2001].

It is seen that with TFF construction, the actual construction cost can be brought to a tiny fraction of the cost of obtaining the material, and the construction can be done over a reasonably short period, with minimal risk to humans, and minimal human labor in Space. This has very large implications for the HEDS Grand Challenge. The next issue is how to generalize this result, and develop, from first principles, versatile techniques for building on a very large scale. Such things are obviously on the 40-year time scale and beyond; hence we will dare to dream of Helium-3 fusion power sources, conductor grids on the 10-100km size scale, and a Vehicle Manufacturing Facility parked in or near the Asteroid Belt to capture large masses of desired characteristics. We will how the science-fiction dream of human settlements and interstellar travel in hollowed-out asteroids, can be realized: how to build those craft. As the reader ventures into the next section, we stipulate that the detailed understanding of the 1km-
scale cylinder construction detailed above is the real key to understanding the construction of these massive structures.

B.4 Electromagnetic Waveguides: TFF beyond 10^3 m scale.

The preceding discussion showed using very simple considerations of electromagnetics and energy that large, massive shapes could be constructed with a high degree of automation by tailoring electromagnetic force fields. We now relate this to developments in the field of waveguides for electromagnetic waves, and extrapolate the architecture to build very large structures automatically. This section is certainly speculative, and we are not in a position to give engineering estimates: at the end of the 6-month Phase I, we should be much further advanced in this respect.

Consider a cylindrical wave-guide several kilometers across, near the Asteroid belt. The waveguide surface is made of plates assembled from acoustic shaping, perhaps by the city-shell-making architecture described in B.3. Energy from controlled Helium-3 fusion, or from sunlight focused by large mirrors, drives the resonator. Focused energy is used to pulverize asteroids, turning them into molten slag. Magnetic fields generated inside the cylinder separate different kinds of materials. Electromagnetic fields are used to move the desired materials near the nodal planes of the resonator, which depend on the driving frequency. The material forms into walls along and parallel to the nodal planes. Energy at other frequencies is beamed onto these surfaces to melt the material near the surface and fuse the walls; cooling hardens them into rigid, pre-fab structures. With this, we can imagine huge hollow spaceships being formed for long-duration missions, or giant space stations.

Technical uncertainties which inhibit engineering analyses on this scale are:
a) the nature, power level and cost of the energy sources.
b) material composition of asteroids
c) technology for pulverizing asteroids without leaving harmful radioactive particles
d) material / technology to make efficient waveguide shells (i.e., do they really need to be continuous metallic surfaces? What frequencies are appropriate for consideration?)

B.5 Present state of knowledge on the Assumed Architecture

<table>
<thead>
<tr>
<th>#</th>
<th>Major Component</th>
<th>Status</th>
<th>Timeframe</th>
<th>Cost</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>1</th>
<th>LunarSolar-Electric Farm</th>
<th>Concept for space-based power [Ref. 7] well advanced: close to flight. Solar-cell production on lunar surface, and robotic development of solar fields: [6] under testing at JSC.</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Lunar metal extraction / regolith processing</td>
<td>Data on lunar materials is abundant, and the feasibility of making building materials from these is good [Refs. 15-16].</td>
</tr>
<tr>
<td></td>
<td>Acoustic Shaping:</td>
<td>Preliminary cost estimates show that manufacturing of panels and pressure vessels using acoustic shaping would cut costs of space missions substantially.</td>
</tr>
<tr>
<td></td>
<td>Orbit-Transfer Vehicles</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cable Manufacture</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Robotic cable loading</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Grid deployment</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Massive Waveguides</td>
<td></td>
</tr>
</tbody>
</table>

![Diagram](image-url)
C. Advanced Concept Development Work Plan

Two primary items are proposed for progress during the Phase 1 period of 6 months. These are stated in C.1 and C.2. In addition, progress will be made as possible on items C.3 and C.4, which are items where continuing work will be required for many years.

C.1 Development of an inverse design simulation for Force Field Shaping:
A prime requirement to develop the system and architecture of Tailored Force Field construction is a simulation tool where the possible energy input locations, frequencies and phase relationships to produce given nodal surfaces is investigated. Such a module will be developed using MATLAB/SIMULINK and Fortran90 where needed. The simulation tool will be validated against flight test results using the Acoustic Shaping experiments.

C.2 Detailing of the City-Building Architecture, including the Orbit-Transfer vehicles and their fuel cell/ electromagnet systems for guidance inside the grid.
To-date, we have considered the City-building scheme in sufficient detail to understand the cost drivers, magnitudes of forces, distances and energy requirements, and initial stress calculations to verify that the selected materials and dimensions are reasonable. Several refinements suggest themselves, and should be done to exploit the promise of this idea better, and reduce the architecture to a detailed set of steps showing their interlinkage. Some of these are:

- The decision whether to build the city at the Earth-Moon libration point L5, or build at L2 and tow to L5 (our present choice). During the construction phase, due to mass changes and reactions to decelerating the incoming material, orbit-correction thrust will be necessary almost continuously. This negates some of the advantage of L5 being more stable than L2. Also, L2 can be reached (i.e., enough DV imparted to payloads) by the e-mag launcher on the lunar surface, thus reducing the fuel cost greatly. Since over 314,000 payloads have to be launched, (average of 15,700 per launcher), each launcher will have plenty of opportunity to “learn” and fine-tune the launch speed, angle and time to optimize arrival at the Grid. The optimization can be either for minimal orbit correction /deceleration of the payload, or for correct delivery of orbit-correction to the Grid itself due to the reaction of forces used in decelerating the payloads.

- Deploying the Grid still poses some awkward problems: Should the cables be taken up as large wire-wound spools and allowed to assume their final shape as radial force develops during rotation? Or should they be deployed using inflatables or thrusters?

- The “shepherd” propulsion units for driving the payloads to the Grid and maneuvering them into position, are a hybrid spacecraft, employing both conventional thermal, as well as electromagnetic propulsion. As presently envisaged, each will have a set of thrusters powered by solar-heated hydrogen, helium or oxygen. Three electromagnets arranged in a delta configuration appear to pose a convenient means of producing electromagnetic force in any desired direction when traveling through the field induced by the currents in the Grid wires. The design of these vehicles needs some more thought, taking into account their full mission lifecycle. Note, however, that our point in using this simple configuration was to prove that a simple orientation of magnets and electric currents would enable automated delivery of huge masses to the Grid. This point is already proven.

C.3 Refinement of cost and architecture models
Cost estimation for each step of the process will be commenced. To progress this far, we have used two different strategies. For short-term projects, such as the construction of the outer shell of a Mars Cycler vehicle at L-2, we used a “Delivered Cost Approach” to compute the cost savings due to building using Acoustic Shaping in Space, with lunar-delivered materials. We argued that we would have to pay what the market would bear, and also that the market would not be able to charge us more than the lowest launch cost from Earth because of competition. Thus the price per lb of delivered material was essentially the lowest projected launch cost from Earth $1000/lb. This approach is inadequate for the City-Shell project, where this procedure would have yielded a result of $23 trillion, which is quite unrealistic. Here [ ] we used the idea that the City project would pay for amortizing the cost of the entire lunar manufacturing and launch complexes, with a decent profit added. Thus, with an assumed upper bound of $1 trillion for the entire lunar complex, and a 4-year construction period for the City shell, we showed that the shell-building cost would be roughly 2 trillion dollars. This would get the entire Space-Based Economy going, because

the infrastructure on the Moon, oxygen supplies, transport/shipping companies, would all be allowed to come up to satisfy the demands. Now the driver is the cost of building facilities on the Moon: some study is needed to get a more realistic estimate of this, so that the City-building cost can be estimated with sufficient accuracy to include all the second-order items.

C.4 Exploration of large-scale construction using Asteroids and Resonant Waveguides.
This is a long-term, high-risk issue. In Phase 1, we will continue to study the feasibility of using electromagnetic fields to position objects along specified surfaces in orbit. The tool developed in C.1 will be used to assist here. The resulting capability will be used to study the feasibility, and designs of grid shapes and control systems for the production of given shapes. Material characteristics suitable for such construction will be investigated. In this process, developments in dielectric materials, as well as the conducting properties of large distributed arrays rather than continuous metal sheets, will be explored by studying the relevant advances in applied electromagnetics.

An initial test case will be the exploitation of an asteroid in NEO, taken to be located in the vicinity of the L-5 region of the Earth-Sun system where there are postulated to be a few hundred asteroids. Here the material to build the waveguide may be taken to be available from the low-gravity environment of a nearby asteroid; fuel to be extracted in situ from a water-bearing asteroid, and panels to be formed using microgravity Acoustic or electromagnetic shaping. An orbiting plant capable of manufacturing various items must be assumed; and the raw material and much of the heavy items for this must also come from asteroids or the Moon.

C.5 Collaborations with NASA Centers

The proposed project draws on the interest areas of several NASA Centers.

a. **JSC**: HEDS/ Mars Mission. The PI is the faculty advisor at Georgia Tech for the GeorgiaTech / Emory student team which has won a place in the 2001 “NASA Means Business” final program. We are developing an architecture for the Space-Based Economy of the future, of which NASA missions to Mars will be a part. The student teams from our school, under the guidance of Prof. Komerath, have been interacting with NASA engineers for over 3 years, in planning and conducting reduced-gravity flight tests, as well as in the development of Strategic Plans related to the Mars mission under the NASA Means Business Program.

b. **JPL**: Microgravity acoustic processing; robotic manufacture. There are several activities out of JPL which are very relevant to the proposed project, and interactions will be pursued to obtain historical experience as well as to gain synergy with current activities. The student team has already initiated contacts with JPL through a poster session at the recent American Astronomical Society meeting in Pasadena.

c. **Marshall**: Electromagnetic positioning / tether technology; microgravity materials processing at USRA. USRA’s Dr. Richard Grugel has provided valuable guidance related to the acoustic shaping. The original suggestion to look at large-scale construction techniques for Island One came from a NASA scientist at the First Space Resource Utilization Roundtable.

E. References

E. Personnel

**Dr. Narayanan Komerath**, Professor in AE, has taught over 1600 AEs in 19 courses, and published over 140 papers on experiments and analysis of problems in propulsion & combustion, fluid dynamics, diagnostic techniques, and the aerodynamics of rotorcraft, combat aircraft and parafoils. He has been a principal researcher on the Rotorcraft Center of Excellence since its inception in 1982. He is an Associate Fellow of AIAA and has served on the technical committees of AIAA and AHS. He has won GT awards for Outstanding Graduate Student Development, Outstanding PhD thesis advisor, and Most Valuable Professor (GTAE Class of '91). His Experimental Aerodynamics Group (EAG) has worked on high angle of attack aerodynamics of wing-bodies (Langley), rotorcraft aerodynamics (Langley and Ames), and won NASA JSC commendation for their work on the aerodynamics of the X-38 Crew Return Vehicle and its parafoil landing system. EAG has enjoyed the participation of over 80 undergraduates over the past 14 years, and has guided undergraduate teams under the NASA Microgravity Student Flight Opportunities program in 1997, 98 and 99, resulting in three AIAA Papers on Microgravity Materials Processing. Prof. Komerath has guided winning teams in the NASA Means Business Program for the 3rd year now, the GT/Emory team is developing an Customer Engagement architecture for a Space-Based Economy. EAG has won 3 Patents since 1992, in image processing, dynamic testing, and aerodynamic control technologies. The students who staff EAG facilities have notched up a unique record of excellence: 6 of 8 PhD theses have won School nominations for Georgia Tech's Sigma Xi Outstanding PhD Thesis Award, putting them in the top 10% of GT theses, and three have won ('93, '94 and '98), putting them in the top 1%. EAG is a leader in multidisciplinary team-oriented projects, including the Aerospace Digital Library Project which opens guided access to students at all levels to aerospace science and technology.
