ANNUAL ACCOUNTABILITY REPORT
July 1, 2005 – June 30, 2006

Center for Structures in Extreme Environments

Prepared by
Professor Haym Benaroya, 29 July 2006
Executive Summary

This is a report of the activities of the Center for Structures in eXtreme Environments, a center within the Department of Mechanical and Aerospace Engineering, in the School of Engineering. This has been our second year of operations, but, we believe, that much has been accomplished, organizationally, with regard to infrastructure, and for research and instruction. In addition, plans have been laid out for collaborative efforts in the disciplines of self-repairing systems and structures, and the modeling of the dynamics and control of nano and mesoscale structures, a continuation of studies of space settlement and lunar structures, in addition to core disciplinary research. Research and teaching continues in the disciplines of offshore structural dynamics, and aircraft response modeling to high-rate loading.

Mission Statement

The focus of the Center for Structures in eXtreme Environments is the study of structures that are exemplary of the human spirit for exploration and advancement - whether it be the exploration of space, the settlement of the Moon and Mars, or pushing the frontiers of understanding and development of the ocean. Long-term goals are to contribute to the nation’s efforts to return to the Moon and Mars and create permanent settlements. Short-term goals address current needs in structures for commercial activities and security and national defense.

We are glad to be a part of a very exciting aspect of the human adventure.

Introduction to the Center and its People

Professor and Director  
Haym Benaroya

Administrative Assistant  
Patricia Mazzucco

Post-Doctoral Associate  
Yuriy Gulak

Current Graduate Students
Elan Borenstein
Jason Florek
Paola Jaramillo
Subramanian Ramakrishnan

Current Undergraduate Students
Nir Pony
Jackelynne Sylva

Board of Advisors

We are in an ongoing effort to recruit a Board of Advisors for the Center. We believe that these distinguished people can be a valuable resource to the Center as it expands its base of activities. Our website holds more information on each Board Member, including links to their professional websites. To date, the list below comprises the names and affiliations of those who have agreed to our invitation. Our Board will meet once per year.
Professor Larry Bell  
Director, SICSA  
University of Houston  
122 College of Architecture Bldg  
Houston, Texas 77204-4000

Professor Earl H. Dowell  
William Holland Hall Professor  
Department of Mechanical Engineering and Materials Science  
School of Engineering  
185 Hudson Hall  
Duke University  
Durham, NC 27708

Dr. Bradley C. Edwards  
President/Partner  
Carbon Designs, Inc.

Howard J. Fleisher  
Manager,  
Protection Systems RDT&E Branch  
U.S. Department of Homeland Security  
William J. Hughes Technical Center  
Transportation Security Laboratory, Building 315  
Atlantic City International Airport, NJ 08405

Terry J. Hart  
Hart & Associates, LLC  
PO Box V  
Hellertown, PA 18055

Dr. Roger D. Launius  
Division of Space History  
National Air and Space Museum  
Smithsonian Institution  
P.O. Box 37012  
NASM Room 3550, MRC 311  
Washington, DC 20013-7012

Dr. Wendell W. Mendell  
Manager  
Human Exploration Science  
NASA Johnson Space Center  
Mail Code KX  
Houston, Texas 77058
**Robert M Sexton**  
Starmark Offshore Inc.  
302 Greenway Lane  
Richmond, Virginia 23226-1632

**Dr. Ronald J Statton**  
Director of Computer Operations  
Clark Public School District  
365 Westfield Avenue  
Clark, NJ 07066

**Professor Marian Wiercigroch**  
Centre for Applied Dynamics Research  
School of Engineering and Physical Sciences  
University of Aberdeen  
King's College  
Aberdeen AB24 3UE, Scotland, UK

**Professor Aspasia Zerva**  
Professor of Civil, Architectural and Environmental Engineering  
Affiliated Professor of Electrical and Computer Engineering  
Drexel University  
3141 Chestnut Street  
Philadelphia, PA 19104

**Descriptions of Research Activities**

**Haym Benaroya (director)**  
Research has been in collaboration with all the student members of the center, as described below. In addition, individual research has continued on the engineering and related aspects of space exploration, and structural concepts and design for the lunar surface.

**Refereed Journal Papers**  


Presentations of all kinds
By H. Benaroya:
- Lectured students in Rutgers Governor’s School, Summer 2005, Lunar Bases & Space Elevators
- Lectured potential students at Engineering Discovery Day, 12 July 2005, on Lunar Bases & Space Elevators
- Lectured potential students 28 September 2005, on Space Elevators and Lunar Bases Center for the Nontraditional Career Resource Center, Center for Women and Work, School of Management and Labor Relations
- Lectured students in Rutgers Junior Science Symposium, 7 February 2006, on Lunar Bases and Space Elevators
- Lectured students in Rutgers Governor’s School, Summer 2006, Lunar Bases & Space Elevators
- Lectured potential students at Engineering Discovery Day, 7 July 2006, on Lunar Bases & Space Elevators


H. Benaroya, Structures for Lunar Habitation, 10th Biennial ASCE Aerospace Division International Conference on Engineering, Construction and Operations in Challenging Environments (Earth & Space 2006) League City/Houston, TX; March 05-08, 2006

H. Benaroya, Performance-Based Engineering for Lunar Structures, 10th Biennial ASCE Aerospace Division International Conference on Engineering, Construction and Operations in Challenging Environments (Earth & Space 2006) League City/Houston, TX; March 05-08, 2006

L. Bernold,* H. Benaroya, ISRUs on Moon and Mars Create Synergistic Interdependencies, 10th Biennial ASCE Aerospace Division International Conference on Engineering, Construction and Operations in Challenging Environments (Earth & Space 2006) League City/Houston, TX; March 05-08, 2006

* Presenter
\" Presenter
J. R. Florek,* H. Benaroya, A Large Deflection Model for Thin, Rectangular Plates Subjected to Blast Loading, 47th AIAA SDM Conference, 1-4 May 2006, Newport RI


Other writings

Yuriy Gulak (post-doctoral associate)
Reduced modeling of fluid-structure interactions. Analysis of nonlinear dynamical systems on nonassociative algebras with applications in fluid dynamics, cellular automata, iterations of maps. Combinatorial search for identities in groupoids and other nonassociative structures using computer algebra systems and automated theorem provers.

Refereed Journal Papers

Yuriy Gulak, On elementary and algebraic cellular automata, submitted to InterJournal May 2006

Presentations and Participation in Professional Meetings:
Yuriy Gulak, Algebraic Properties of Elementary Cellular Automata, NKS2006 (June) Wolfram Science Conference, Washington, DC,

Yuriy Gulak “Algebraic properties of elementary cellular automata” at the Wolfram Conference Blog:

Yuriy explores the idea to replace conventional CA rule with algebraic operation by grouping pairs of cells (Pedersen 1992, Moore 1997). Then, the ECA evolution can be computed by groupoid multiplications of neighboring elements. Generally, the complexity of computation of evolution is N². Can one do better? Yes, under certain conditions. Namely, there are certain “shortcut” identities. One can empirically search for these identities, but can they be derived? A “basis” is a set of identities from which all other identities follow (these are like axioms). “Finitely based” groupoids have finite basis. 4-element groupoids are not necessarily finitely based: some “true” identities cannot be derived from other lower-degree identities. There is a recursive algorithm that would determine if a groupoid is finitely based (is there?) Here, Yuriy is making a hint on a connection between incompressibility and non-finitely-based groupoids. In particular, the fact that 6 is the least order of
semi-group without a finite basis for identities vs. NKS book, page 887. Traditional math is based on a finite number of axioms, and to develop complexity, one needs non-finitely-based systems. The fewer identities there are, the more interesting is the structure. Pretty cool, I would say. It would be interesting to see how those identities appear in the numerous CA evolution pictures. Something like longer-term rules?

Posted by Konstantin Kouptsov on Tuesday, June 20, 2006 at 07:59 AM

Yuriy Gulak* and Haym Benaroya, *Nonassociative algebraic structures and complex dynamical systems*, International Conference on Complex Systems (ICCS2006), June, Boston

**Elan Borenstein (post-qualifying PhD student)**
Research involves analyzing blast load parameters of simplified loading models to better understand the loading behavior of blasts and the sensitivity of the various parameters of the different loading models. Modeling blast loadings on plates is being accomplished numerically using ANSYS. Detailed study continues of blast loading models, and computational methods for solving probabilistic and deterministic models. One such method is chaos polynomial theory.

**Presentations and Participation in Professional Meetings:**

**Conferences attended:**

Modified and updated the Center's website. Created the logo and website for the Lunar Base Symposium. Recorded seminars and talks to be put onto the Center's website.

**Jason Florek (post-qualifying PhD student)**
Research involves the study of the effects of blast loading on thin-walled structures, most notably plates and shells. Both deterministic and random, as well as uniform and non-uniform, pulse-pressure loadings are used as input to these simplified structural models. The gross large deflection, elastic-plastic material behavior and the result of varying pulse shape parameters are analyzed. Furthermore, the accuracy of using different assumed elastic and plastic mode shapes is assessed. These results are verified through comparison with both experimental results found in the literature and finite element results obtained by the software package ANSYS. The ultimate goal is to give the designer a number of simple models to accurately assess damage caused by an explosion aboard an aircraft.

* Presenter
Refereed Journal Papers:

Presentations and Participation in Professional Meetings:


R. David Gabbai (defended PhD)
David successfully defended his PhD last December and is now a post-doctoral fellow at the National Institutes of Standards and Technologies in Bethesda, MD. He is working under the direction on renowned researcher Dr. Emil Simiu.

Paola Jaramillo (post-qualifying PhD student)
Research continues with the modeling of carbon nano-tubes for the MS degree. Paola will be jointly advised by Professor Manish Chhowalla of the Materials Science Department. Her work will focus on the modeling of Boron-based materials for shielding applications. In particular:
1. Understanding the importance of single-walled carbon nanotubes for the reinforcement of composites. It has been found that adding approximately 1% of carbon nanotubes improves the mechanical properties of composites up to approximately 40%.
2. Modeling single-walled carbon nanotubes as space-frame structures to analyze its mechanical properties using finite element modeling. The modeling also considered a continuum model for comparison with the space-frame structure. The continuum model examined the single-walled carbon nanotube as a beam as well as a thin shell.
3. Working on a review paper that briefly describes the physical, mechanical properties, and the importance of single-walled carbon nanotubes.
4. Developing alternative configurations to model single-walled carbon nanotube bundles to understand the changes occurring in these structures and the effects of these configurations when compared to properly align single-walled carbon nanotubes.

Subramanian Ramakrishnan (post-qualifying PhD student)
Research focuses on classical and quantum aspects of control of nano-mechanical systems. The theme of analytical models for nonlinear dynamics and control of nano electromechanical systems (NEMS) has been taken forward this year. In particular, progress has been made in extending two recent models developed for the interaction of a single electron transistor with a nanomechanical resonator (Armour et al, Phys. Rev. B

* Presenter
to the nonlinear regime. A focus of this work is an attempt to develop a theoretical model that can account for recent experimental results (Naik et al, in press) that are unaccounted for, by the current models. The implications of the preliminary results from this research for nonlinear control of NEMS are currently under investigation.

The above effort was presented and defended as a dissertation proposal as part of the requirements of the doctoral program of the department of mechanical and aerospace engineering, Rutgers University.

Presentations and Participation in Professional Meetings:
Invited talk titled Nonlinear Dynamics and Control of Nanomechanical Resonators at the Nano-Dynamical Systems Day, Dept of Physics, Dartmouth College, June 2006.

Selected as an official participant for summer school on The Principles and Applications of Control in Quantum Systems, Division of Engineering and Applied Sciences, Harvard University, August 2006.

Jackelynne Silva (undergraduate research associate)
Research has focused on understanding and quantifying the risks associated with lunar base structures. We address points that will verify that a certain construction is dependable and offers trust. A design philosophy is proposed within the scheme of reliability concepts, which demand higher factors of safety compared to those taken on Earth [1]. This design establishes relationships between, and shows the importance of, having a good understanding of constructability, redundancy, parallelism, and logistics.

The primary contribution of this work is to consider the reliability of a structure proposed by Ruess et al. [2]. Related to this is the examination of how various classes of structures are amenable to a reliability analysis, and whether one has an overall advantage. Monte Carlo simulations [3,4] were utilized to analyze a simple thin-walled arch, very similar to a three-arch shell structure proposed in Ruess et al. The data was used to perform a reliability analysis. Two conclusions were found: first, the arch can have a uniform cross-section; and second, in order to get an efficient cross-section for the tie it has to be adjusted to the distribution of internal forces. Although there might be other variants that make the structure fail, the stresses found via the Monte Carlo calculations do not lead to yielding. This would mean that we are in a safe zone and can certainly design this lunar structure.

Presentations and Participation in Professional Meetings:

Jackelynne Silva, *Reliability of Lunar Structures*, Aresty Research Symposium, Rutgers University, New Jersey, April 21, 2006

**Proposals for Funding and Research Initiatives**
A major portion of our efforts has gone to the extension and development of ideas that we believe to be of importance to the community and have potential for funding by major agencies of the Federal Government. In addition to continuing with past research efforts, activity including team-building proceeded at a significant pace. We have offered a number of SOE Faculty the opportunity of affiliating with the Center for purposes of research and teaching. These currently include:

Professor Alberto Cuitiño
Professor Zoran Gajic
Professor Masanori Hara
Professor Andrew Norris
Professor Jerry Scheinbeim.

**Spaceport New Jersey**
Initial steps have been taken to investigate the possibilities for creating a spaceport in New Jersey. Dean Don Brown and Haym Benaroya have visited the FAA in Washington DC to learn more about the certification process for spaceports and to meet with two senior administrators: Herb Bachner, Manager FAA Space Systems Development Division and Dr. George Nield, Deputy Associate Administrator Commercial Space Transportation. We are working on building a base of support within interested partners within Rutgers, and then will work outside.

The following proposals and white papers have been submitted:
We continue to lay the groundwork for proposals for external funding. We have prepared two proposals for NSF. One was submitted directly but was not funded. The other (an IGERT) was not supported internally for submission.

Dr. Yuriy Gulak submitted a proposal to the McDonnell Foundation based on work on cellular automata, but this was not funded. Other opportunities for funding this work are being developed. Initial interest by DARPA is being cultivated and a proposal is being prepared for submission.

We are gearing up during this summer to continue our efforts on a proposal on self-healing materials, as well as to look for opportunities for other sources of funding in areas that define our research. We believe DARPA is a potential funding source.

* Presenter
Our Center Administrative Assistant, Patricia Mazzucco, coordinated the proposal writing, which sometimes included several dozen faculty members, and prepared the budgets for FASTLANE.

**Lunar Base Symposium Planning**
Organizational efforts are beginning for a Symposium **Rutgers Symposium on Lunar Settlement** June 2007. We are organizing for a Symposium that will bring together the leaders in the disciplines that are supporting the Return to the Moon, to stay, as part of the vision of the President of the United States, George W. Bush.

Our interest is to invite pioneering minds in Engineering and Science, Business and Finance, Policy and the Social Sciences, to present current thinking on the Return to the Moon. As important, gaps in capabilities will be discussed and addressed.

This weeklong Symposium will result in new teaming efforts in support of the Return to the Moon. Our goal is to have the Symposium in New Brunswick, New Jersey, at the main campus of Rutgers University, during the early part of June in 2007.

We are moving forward with planning for the Symposium planned for June 2007 at Busch Campus. An organizing committee is being formed and local arrangements are being planned. Invitations for presentations will be sent out this summer.

**csXe Instruction**
We have been presenting in-house lectures on topics of mutual scientific interest. Such lectures are being presented by all members of the Center. For the graduate students, this represents an opportunity to practice and enhance communication skills that are a crucial component of a successful engineering/scientific career.

These are being placed on the Center website for future and general accessibility.

**Summer Interns & Outreach**
As part of our outreach efforts, we have brought in a number of summer interns, paying them a modest stipend, who have expressed a serious interest in some of the research activities of the Center. All of us have worked with them, mentored them, asked them to write research reports and make a concluding technical presentation at the end of the summer of their work and achievements. These are also to be placed online.

This summer (2006) all our interns (except Nir Pony) are focusing on readings and research on the concept of the Space Elevator. In addition to analysis and computation, an experimental project is in progress.

Our Center students and staff, especially Dr. Gulak and Elan Borenstein, have created a series of short courses for the interns: Intro and Advanced (vectorization) MATLAB, Intro to MAXIMA and MAPLE, problem-solving with MAXIMA, Introduction to R (a statistics program), Introduction to LATEX, Introduction to LINUX, Installation of
LINUX/UBUNTU operating systems and introduction to system administration for home users, Computer hardware assembly.

Summer Internships 2006

Dan Burton  
Rutgers University Mechanical and Aerospace Engineering

Gabriel Cummings  
Union Hill High School, Union City, New Jersey

Josh Denholtz  
Rutgers University Mechanical and Aerospace Engineering

Sergey Galkin  
Rutgers University Mechanical and Aerospace Engineering

Adaleena Mookerjee  
Bridgewater-Raritan High School, Bridgewater, New Jersey

Nir Pony  
Rutgers University Mechanical and Aerospace Engineering

Nir has just started interning at the Center in the study of forces on aircraft structures. This work will lead to a Slade Scholar program for the Fall and Spring and may lead to the basis for his MS research.

Prof. Richard Pelz Memorial
Dr. Gulak has spent considerable efforts setting up this memorial to our friend and colleague, Rich Pelz, Professor of Mechanical and Aerospace Engineering, who passed away almost three years ago, at a young age. The memorial consists of a bookcase of his books, reprints of his papers, and a place in our website. This has been accomplished with the assistance of his wife, Maggie.

Work on this memorial has been completed.

Center Infrastructure Improvements
During our second year of operation, the physical and scientific infrastructure has been brought up to a high level. Patricia Mazzucco can be credited for bringing the physical infrastructure to its current attractive state. These included activities centered around interior design, conference room organization, performing fiscal activities, and beginning to create a database for Center activities.

Dr. Yuriy Gulak and graduate student Elan Borenstein can be credited for bringing the computational infrastructure to its current advanced state. These efforts included the specification of hardware and software purchases, system administration, software installation, and assisting graduate students with integration into the system.

Elan Borenstein created the Center website and maintains it professionally. Not only is the site user-friendly, but it provides an archive of our activities, and the facility for interested parties to be placed on an e-mail list.

Degrees Earned

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<tr>
<th>Date</th>
<th>Name</th>
<th>Thesis Title and Committee Members</th>
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MALAPERT LUNAR BASE SIMULATION
Manny Pimenta
President and Founder of Lunar Explorer, LLC

A comprehensive design for a permanent, large-scale lunar colony is presented. The constraints for the lunar base design are predicated on establishing an economically viable lunar settlement, accessible to all sectors of the population and to achieve this within one generation.

These objectives can all be accomplished if the lunar colony design is restricted to using only current or near term technologies, takes maximum advantage of in-situ resources, and is planned as a hub of varied economic activities with lunar tourism as a primary profit center.

Lunar base design studies have been done ad infinitum in the past half-century or so. Most have concentrated on initial permanent research bases, which are normally limited in capacity and capability.

The Malapert project is a large-scale facility, designed to provide a living and working environment for 300 or more people engaged in wide range of activities that are commercially viable in their totality.

The Malapert project serves a number of purposes: it brings together and crystallizes many related but disjointed concepts and ideas into a coherent engineering effort resulting in a compelling visual representation of an advanced off-Earth habitat; it provides an organizational structure for capturing new developments and discoveries as they come along; and it provides a conceptual “test bench” for studying what-if scenarios and “test fitting” original approaches to the problem of colonizing another planet.

The Malapert project is a living, evolving, cooperative design tool, which ideally will help to drive and facilitate real world efforts in establishing a permanent human presence on the Moon. As an evolving design tool, it is expected that it will adapt to changes in all real world parameters on a continuous basis and eventually converge with these real world efforts so that, ultimately, the model becomes the actual project.

While guided by real world events and parameters, the project will not waver from its core commitment to opening the space frontier for all people within our lifetime. Hence, two of its more important functions are disseminating information and educating the public at large about the many benefits that large-scale development of a space infrastructure will bring to society, and educate them about the technical and economic feasibility of establishing that infrastructure.

The one single assumption made is that the cost per kilogram to LEO will be brought down to some arbitrarily low number within 10 to 15 years.

Manny Pimenta is president and founder of Lunar Explorer, LLC, a company he formed to create a virtual reality simulation of the Moon that will soon be available to the public.
He has a background in Electrical Engineering and Computer Science, and received his Engineering degree from NJIT and his Masters in Computer Science from Stevens Institute of Technology. He has worked in radar systems, computer networks and utility information systems. He has also been very active in the Space Advocacy community for the last six years: He is currently an Advocate of the Space Frontier Foundation; he has served on the Board of Directors, has been the Return To The Moon Project Manager, and ran two Return To The Moon conferences. As a member of Pro-Space, he has also participated in every March Storm lobbying drive since 2001. He believes that every single person can contribute to the process of transforming the world into a space faring civilization. The role of all space advocacy organizations, as well as NASA and the government should be to create as many opportunities for individual participation as possible.

Monday 7 November, SERC 209 1:40.

Humans and Robots in Spaceflight: Assessing Accomplishments, Understanding the Future

Roger D. Launius, Ph.D
Chair, Division of Space History
National Air and Space Museum
Smithsonian Institution

This presentation is based on a forthcoming book that explores the history and possible futures for human/robotic spaceflight. While writing *Imagining Space: Achievements, Possibilities, Predictions, 1950-2050* (Chronicle Books, 2001), my co-author and I realized that the one area where all spaceflight visionaries failed to make meaningful predictions was in the rapidly advancing capabilities of robotics and electronics. For example, when Arthur C. Clarke envisioned geosynchronous telecommunications satellites in 1945 he believed that they would require humans working onboard to change the vacuum tubes. In such a situation, it is easy to conceive of the motivation that led people like Clarke and Wernher von Braun to imagine the necessity to station large human crews in space. Some of the most forward-thinking spaceflight advocates, in this instance, utterly failed to anticipate the electronics/digital revolution then just beginning. Humans, spaceflight visionaries always argued, were a critical element in the exploration of the Solar System and ultimately beyond. Human destiny required our movement beyond this planet, ultimately to the colonization of the galaxy as a means of assuring the survival of the species. With the rapid advance of electronics in the 1960s, however, some began to question the role of humans in space exploration. It is much less expensive and risky to send robot explorers than to go ourselves. This debate reached saliency early on and became an important part of the space policy debate by the latter twentieth century.
This presentation offers a history and analysis of how we came to the point that we have in human spaceflight, as well as a discussion of the relative merits of human versus robotic space exploration. In essence, I shall suggest that the old paradigm for human exploration—ultimately becoming an interstellar species—is outmoded and ready for replacement. I will specifically look to the future of humans and robots in space and suggest that the possibility exists that perhaps a post-human cyborg species may realize a dramatic future in an extraterrestrial environment.

Wednesday 16 November at 3:20 in B-120 School of Engineering Busch Campus

the
space
elevator
from science fiction
to science reality

ben shelef
the spaceward foundation

www.elevator2010.org

1:40 - 3:00pm
Thursday, April 13, 2006
CORE Building
Auditorium