

The Director's Report Y2004

David R. Criswell

Purpose of the Houston Partnership for Space Exploration

IN 1991 THE LEGISLATURE OF THE State of Texas established the Houston Partnership for Space Exploration. The purpose of HPSE is to advance any aspect of aerospace research, engineering, and applications through graduate and post-doctoral level programs at the University of Houston and the University of Houston-Clear Lake in cooperation with NASA Johnson Space Center, other Texas universities and businesses, and other organizations.

The Institute for Space Systems Operations (ISSO) is the operating agency for HPSE. UH and UHCL are also members of the Texas Space Grant Consortium. ISSO works through TSGC on a statewide level. Dr. David R. Criswell directs ISSO and is responsible for both the UH and UHCL activities. HPSE is funded under a State of Texas Line Item that allocated in 2004, with one-time carry-over of funds from 2003, \$410,574 to operations at the University of Houston and \$81,050 to operations at the University of Houston-Clear Lake. The 2004 ISSO State of Texas funds, as reported by the faculty in the following research articles, were leveraged by a factor of 8.8 through external funding.

Since 1991, the ISSO projects have established solid professional links between NASA-JSC, the Houston aerospace community, and UH and UHCL. NASA is undergoing major changes as the Office of the President of the United States and Congress are focusing the nation on a return to the Moon and development of a sustainable program for the exploration and development of space. ISSO provides the flexibility and resources for UH and UHCL faculty to fully participate in this rapidly evolving national program. Since 1991, faculty supported by ISSO research funds have reported obtaining \$17,000,000 of external funding and thus leveraged the research funds by 4.4 to 1 over the life of the program. Reported external funding has exceeded state funding by approximately \$11,800,000.

In the following three sections, a summary of 2004 accomplishments by ISSO supported researchers is provided, a short synopsis of each research activity is presented within seven study areas, and the seed-grants and new fellowships selected in 2005 are listed.



PLANNING—Dr. David Criswell, ISSO Director, seeks applicants for Post-Doctoral Aerospace Fellowships to join with UH and UHCL faculty and scientists at the NASA-Johnson Space Center in planning for missions to the moon and Mars. Investigators encourage undergraduate and graduate students with research potential to work on space projects.

The primary activities of ISSO are the unique Post Doctoral Aerospace Fellowship (PDAF) program between UH/UHCL and the NASA-Johnson Space Center and providing seed-level funds to UH and UHCL faculty for pursuit of new aerospace research projects. Both the PDAF and seed-grant projects are proposed to ISSO by UH and UHCL faculty and selected through a peer review. The peer reviewers are selected from UH, UHCL, JSC, other local universities, and local aerospace companies.

The PDAF program started in 1995. It operates through a Memorandum of Understanding between JSC and the two universities and is now funding the third set of post-doctoral fellows. Each fellow is selected and directed by a team consisting of at least one UH or UHCL faculty member and a research member of the Johnson Space Center. A fellowship appointment is for two years with a possibility of a third and final year.

In 2004 ISSO provided \$263,734 in research funds to UH and UHCL faculty to support 19 new seed-grant projects and



TV PRODUCTION—David Criswell (l.) discusses lunar/solar power with Magnus Sjostrom, producer, (c.) and Daniel Stein, cameraman, of the Swedish Educational Broadcasting Company. They were on campus to develop a documentary on scientific advances in space research at the University of Houston.

the start-up of four of nine new PDAF projects. ISSO requires investigators to report results on projects for five years after completion of funding of a given project. In 2004, prior funded and currently funded UH and UHCL faculty reported submitting 46 proposals applying for \$19,950,000 of external funding. They report obtaining \$4,310,000 for these proposals and proposals submitted the prior year. The 2004 ISSO State of Texas funds were leveraged by a factor of 8.8. Of course, the leveraging of the 2004 funds will continue to increase as more proposals are submitted based on follow-up results of the 2004 projects.

In 2004 the ISSO investigators report submitting 76 professional papers, delivering 119 professional presentations and interviews, and submitting one patent application. Five undergraduates participated in the research activities. Forty master's-level students and 13 students pursuing the doctor of philosophy participated in ISSO research projects along with seven post-doctoral fellows.

Forty-seven UH, UHCL, and UH-Downtown faculty participated in the ISSO research along with 10 professors from other universities, 25 NASA researchers, and three from industry. In addition to JSC, 17 other organizations participated. They are:

- British Antarctic Survey
- CERN
- Institute for Biomedical Engineering (Zurich)
- Integrated Micro Sensors, Inc. (Houston)
- INFN Milan
- Jet Propulsion Laboratory (NASA contractor)
- NASA-Langley Research Center
- Computational Structures & Materials Branch
- University of Pavia

- Physical Science Inc. (Andover, MA)
- Rice University
- Bioengineering
- Mechanical Engineering
- Physics and Space Science
- Robert Wood Johnson Medical Center
- Department of Medicine
- Texas Space Grant Consortium
- Tietronix, Inc.
- University of Quebec at Montreal
- University Space Research Association
- University of Texas Medical Branch - Galveston

ISSO worked at the University of Houston with Dean John Bear (Natural Science & Mathematics), Dean Raymond W. Flumerfelt (Engineering), Dean William E. Fitzgibbon (Technology), Dean Robert K. Wimpelberg (Education), and Dr. Alex Ignatiev (TCSAM). ISSO thanks them for their support in the research projects. At UHCL, ISSO worked primarily with the School of Science and Computer Engineering. Thanks are sincerely extended to Dean Charles W. McKay.

Summary of 2004 and 2000-2003 Progress Reports

Aerospace Engineering, Systems and Instrumentation

Control of vibration of mechanical devices and systems is a major on-going task for many engineers. **Professors Heidar Malki** (UH: Technology) and **Karolos Grigoriadis** (UH:

Mechanical Engineering) and graduate student **José Canelon** have applied neural networks to the control of vibrations of a Black Hawk Helicopter. This ISSO seed-grant project (2004) has shown that after a short transient the vibration can be progressively reduced to almost zero [90-95].

Professor Wajiha Shireen (UH: Electrical/Electronics Technology) worked with graduate student **V. S. Babu** on the development of a power distribution system for spacecraft. Under this 2004 seed-grant they demonstrated the linkage of a AC-DC-AC Converter with small DC-link capacitor to reduce the overall mass of a power converter [96-99].

Virtually all spacecraft and planetary rovers use batteries to store electric energy from the primary power source and release that energy later to supplement or replace the primary power source. **Professor Albert M. K. Cheng** (UH: Computer Science), under a 2004 ISSO seed-grant, has developed new software based to control the storage and release of energy from batteries in anticipation of future power needs. The control method considers the constraints of time, energy, and quality-of-service while meeting operational constraints such as conservation of battery energy [54-58]. In 2001 Dr. Cheng conducted a seed-grant project to verify the real-time software for control of the NASA X-38 Crew Return Vehicle. The control system was modeled using a commercial product, Real-Time Logic, and Presburger Arithmetic representations. The timing analysis methodology can be applied to other space vehicles [58-59].

Management of thermal energy (heat) is critical to the performance and operational life of spacecraft. **Dr. Abdelhak Bensaoula, Dr. Chris Boney, and Dr. David Starikov** (UH: TCSAM) and **Dr. Brian Mayeaux** (NASA-JSC) are initiating research on the use of passive thin metal films to transfer thermal power from inside a spacecraft to space. They focus on refining the performance of micro column arrays recently developed by a Houston company—Micro Sensors, Inc. The work was supported in 2004 by ISSO seed-grant and the work will be expanded under an ISSO Post-Doctoral Aerospace Fellowship grant [102-103].

From 2000 to 2003, **Professor Abdelhak Bensaoula** directed two ISSO seed-grants and an ISSO Post-Doctoral Aerospace Fellowship focused on the development of miniature optical sensors for the detection of water and air contamination. Dr. David Starikov and graduate student Clement Joseph participated in portions of this research [105-106]. Very small sensors often output weak signals that are buried in noise. The team has implemented well-proven communication coding schemes in an effort to increase the signal to noise ratio through excitation source coding.

Carbon nanotubes hold the promise of extremely high strength fibers, ropes, and panels that are also rugged, especially in the space environment. **Dr. Viktor G. Hadjiev** (UH: TCSAM) and **Dr. Leonard Yowell, Dr. Bradley S. Files, and Dr. Sivram Arepalli** (NASA-JSC) are applying Raman Spectroscopy to the examination of the interfaces between single wall nanotube (SWAT) composites. **Mr. Keesu Jeon** (UH: Graduate Assistant) participated in the research that was done in cooperation with **Professors D C. Lagoudas**

(TAMU), **James M. Tour** (Rice University), and **Dr. Ramanan Krishnamoorti** (UH: Chemical Engineering). They have examined the relative change of composites under mechanical loads, SWAT buckling, and strain as a function of temperature [107-109, 110-113].

Dr. Milko N. Iliev (UH: TCSAM) provides a short report on the third year after completion of four years of Post Doctoral Aerospace Fellowship support for studies to characterize nanotubes using Raman and infrared spectroscopy [119].

Professors James B. Dabney and Dr. Thomas L. Harman (UHCL: Science and Computer Engineering) report on the 2004 ISSO seed-grant research. The third year of this work focused on demonstration of real-time control of piezoelectric motors. With **Dr. M. Randolph-Gips**, they are focusing on the detection of torque load in the motor and the use of that load to control motor at very low speed. Very low mass piezoelectric motors hold promise for actuating and controlling the motions of a space-based robot [129-131]. The project obtained \$100,000 of support from NASA beginning in 2003.

Friction between surfaces is a major problem both in mechanical joints and in programming actuators to overcome, if possible, the friction. The dry vacuum of space and the need to maintain a clean environment about a spacecraft restricts the choice of lubricants. **Professor LieJune Shiau** (UHCL: Mathematics) received an ISSO seed-grant in 2004 to develop new computational methods to model non-smooth friction between surfaces, such as in the joints of the remote manipulators of the Space Shuttle and the International Space Station [142-143].

Within spacecraft that envelope humans, as well as our own industrial environments on Earth, it is necessary to monitor air for dangerous contaminants. **Professor Thomas L. Harman** (UHCL: Computer Engineering) and **Professor Frank K. Tittel** (Rice U: Electrical and Computer Engineering), **Dr. John C. Graf** and **Dr. Peter Bethke** (NASA-JSC), and **ISSO-JSC Post- Doctoral Aerospace Fellow Dr. Yury Bakhirkin** (UHCL and Rice U) are developing very compact and low power devices that can remotely monitor for chemical contaminants. They continue a program to develop and demonstrate continuous wave and pulsed cascade lasers and detectors [134-140].

Computer Science and Engineering

Very large data sets, such as for patients and their ailments or the operating characteristics of large aerospace systems, stored within computers can be sources of useful knowledge. However, the challenges of extracting useful knowledge can exceed human capabilities or even that of traditional software programs compiled by people. Genetic Programming (GP) is a technique for writing software units, conceived to be similar to genes and chromosomes of DNA, that can explore an extremely large data set, look for new relations within the data set, and that can evolve new software units on the basis of newly discovered relations. **Professor Gary D. Boetticher** (UHCL: Computer Science) and graduate student **Ms. Kim Kaminsky**, supported by a 2004 ISSO seed-grant, focus on

Earth's magnetic field contains energetic streams of protons and electrons. **Professor William R. Sheldon** (UH: Physics) and **Dr. V. Anderson** (UH: Physics) employed 2004 ISSO seed-funding to develop a proposal to NASA to identify how a significant portion of the electrons are lost in the upper atmosphere of Earth above Halley Bay in Antarctica. They worked with colleagues in the British Antarctic Survey [84-88].

The solar system formed approximately 4.5 billion years ago from a solar nebula. Materials that compose some comets are thought to be unaltered from the time they condensed in the outer portions of the nebular cloud. The NASA Stardust spacecraft is thought to have successfully captured, on January 2, 2004, grains expelled from comet Wild II. The Stardust spacecraft is also capturing tiny grains of dust orbiting the sun. The grains are decelerated from 6.2 km/sec and their material captured in blocks of very low-density aerogel. The spacecraft will return them to Earth. **Dr. Viktor G. Hadjiev** (UH: TCSAM), **Dr. Michael Zolensky** (NASA-JSC), and **Mr. Andrew Coleman** (UHCL: Lecturer) are demonstrating the application of Raman Spectroscopy to the analysis of cometary materials captured in aerogel [107-109].

2005 Seed-grants and Post-Doctoral Aerospace Fellowship Projects

University of Houston-Clear Lake

ISSO received eight seed-grant and two Post-Doctoral Aerospace Fellowship proposals in November 2004 from UHCL faculty. They requested \$90,430 in seed-grant funding and \$40,000 in fellowship funding. The peer review group (UHCL, UH, JSC, and Rice University) met in December 2004 and approved five seed-grant projects for a total of \$54,000 for 2005 and one new PDAF. The panel considered that seven of the eight seed-grant proposals were worthy of funding. However, this would have required \$76,000. Note that the ISSO request for proposals is widely circulated to faculty in all colleges and departments.

Seed-grant projects from the UHCL School of Science and Computer Engineering, serve a variety of research needs:

Al-Mubaid, Hisham, Computer Science: *Natural Language Interface Models for Fast Responsiveness Applications*

Al-Mubaid, Hisham, Computer Science: *A Text-Mining Technique for Literature Profiling and Automatic Extraction of Information from Biomedical Literature*

Dabney, James B., Electrical Engineering: *Real-Time Active Loading of Piezoelectric Ultrasonic Motors for Simulating Space Robotics Applications*

Lu, Jack Y., Chemical Engineering: *Contaminants Removal from Fuel Cell for Aerospace Applications*

Shih, L.-J., Computer Science: *Parallel Monte Carlo Performance Analysis of Space Radiation Simulation*

The new Post Doctoral Aerospace Fellowship project is: Dickerson, E. T. (UHCL: Electrical Engineering) and Arndt, D. (JSC): *Ultra-Wideband Communications and Passive Tracking System Design for Applications on Space Station, Space Shuttle and Lunar/Mars Exploration*

UHCL has three fellowship projects approved for the third round of the ISSO-JSC program. One Post-Doctoral Fellow is onboard. The others are expected to be active by August 2005.

University of Houston—Central Campus

ISSO received 21 proposals in February from University of Houston faculty requesting a total of \$303,293 of seed-grant funding for the spring and summer of 2005. In March the peer review group (UH, UHCL, JSC, Rice University members) noted that 20 of the 21 proposals were appropriate for funding. However, this number of awards would have required \$289,593 in funding and only \$129,000 was available. Under this funding limitation, the following nine new 2005 seed-grant projects were selected.

Bensaoula, Abdelhak, Natural Science & Mathematics, Physics: *Investigation of III-Nitride Materials for Space-Based Solar Cells*

Cheng, Albert M. K., Natural Science & Mathematics, Computer Science: *Building and Verifying Fault-Tolerant Autonomous Real-Time Systems for Space Applications*

Clarke, Mark S. F., Education, Health & Human Performance: *Validation of a Novel Micro-Capillary Array Fluid Collection Technology for Determination of Biomarkers of Bone Metabolism in Human Sweat*

Fox, George E., Natural Science & Mathematics, Biology and Biochemistry: *Earth Origins of Genetic Systems*

Hollingsworth, Donald K., Engineering Mechanical: *The Effect of Martian Dust on Radiator Performance*

Malki, Heidar A., Technology, Engineering Technology: *PWM Control of Formation Flying Space Vehicle*

Miller, John H., Natural Science & Mathematics, Physics: *Electromagnetic Probes of Biological Molecular Motors*

Pinsky, Lawrence S., Natural Science & Mathematics, Physics: *Initiating the Detector Deployment for a Currently Planned NASA Accelerator Measurement (Summer 2005)*

Wosik, Jaroslaw L., Engineering, Electrical and Computer Engineering: *Magnetic Microscopy Studies of Magneto-Tactic Fossils on Martian Meteorite ALH84001 and Related Earthbound Analog Systems*

Texas Space Grant Consortium

The United States Congress established the National Space Grant College and Fellowship Program in 1987. The general objective was to organize universities to accomplish for U.S. aerospace activities what the land grant colleges and universities did for the agricultural and applied arts (i.e., industry). The University of Houston became a charter member of the Texas Space Grant Consortium along with The University of Texas at Austin and Texas A&M University at College Station. Because of its national objectives, the UH charter membership was supported by the UH Office of the Provost. Starting in 2003, the funding to support University of Houston charter membership in the Texas Space Grant Consortium was shifted to shared funding by the Office of the Vice Provost for Research (\$20,000), the Institute for Space Systems Operations (\$15,000), and the Texas Center for Superconductivity and Advanced Materials (\$15,000).

The ISSO Director is an associate director of TSGC and on the Board of Directors. The UH campus representative in 2002–2004 was the TCSAM director. A faculty member of the University of Houston-Clear Lake represents that campus.

In 2004, TSGC made \$16,000 of awards to UH students and faculty in response to requests for fellowship and scholarship announcements and requests for research proposals.

2004-2005 TSGC Fellowships

James Camp, \$5,000; award declined

9 applications not accepted

Joy Chavez, \$1,000

3 applications not accepted

New Investigators Program

Dr. Ji Chen (PI)

Dr. A. Ignatiev (Agreement contact)

An efficient full-wave framework for future micro and nano electronic devices modeling/simulation

September 2004 to August 31, 2005, \$10,000

Invitation to Read the 2004 Report

State of Texas funding of the Houston Partnership for Space Exploration enables extensive research between UH, UHCL, and the NASA-Johnson Space Center. UH and UHCL faculty leveraged this state funding by a factor of 8.8 in 2004.

UH and UHCL faculty consistently submit two to three times more worthy proposals, as judged by peer reviews, than the Institute for Space Systems Operations can fund. In 2005, ISSO peer review panels awarded 17 new seed-grant projects. The results will be presented in the 2005 ISSO *Annual Report*. The panels also awarded two new ISSO-JSC Post Doctoral Aerospace Fellowship projects thus enabling 10 UH/UHCL-JSC projects for the 2005-2007 time frame. Five of the fellowships have been awarded. All the fellowships should be filled by the end of 2005.

This document contains reports on all of the 2004 projects and results of work ISSO has supported since 2000. This report is also available online at <<http://www.issu.uh.edu>>.

ISSO Research Reports

David R. Criswell, ISSO Director [UH-UHCL]

Dr. David Criswell directs the Institute for Space Systems Operations at the University of Houston and the University of Houston-Clear Lake. His primary research interests are in industrial development of the Moon and the economic benefits to Earth of a sustainable global electric economy. He is also an associate director of the Texas Space Grant Consortium. He regularly attends the fall and spring monthly meetings of the Houston Chapter of the International Association of Energy Economists, the annual national Lunar and Planetary Science Conference, and the meeting of the Board of Directors of the Texas Space Grant Consortium.

Dr. Criswell works extensively with Dr. Helen Lane (Director of University Programs at the Johnson Space Center) and Dr. Donn Sickorez (University Affairs Officer) to coordinate the ISSO research program with primary program goals at JSC.

Over the past year, he has expanded his interests to consider the role of Earth's oxygen atmosphere in obtaining net energy from the combustion of fossil fuels and the geophysical implications of utilizing fossil fuels as the primary source of commercial power. He has provided scientific articles and interviews to members of the general and aerospace press.

Presentations, Interviews, Meetings

Criswell, D. R. Tele-lecture to the Planetary Science Class at the University of Hawaii, April 22, 2005, invited by Professor G. Taylor.

Dinkin, S. (interviewer) and D. R. Criswell. "Reaping Powerful Ideas from a Luminary," *The Space Review*, April 11, 2005 <<http://www.thespacereview.com/article/355/1>>.

Dinkin, S. "Rectifying the Case for Beaming Lunar Solar Power," *The Space Review*, April 11, 2005 <<http://www.thespacereview.com/article/354/1>>.

Criswell, D. R. "Statewide Assessment of Aerospace & Defense Clusters in Texas," Governor's Industry Cluster Initiative, San Jacinto College (Host) and Greater Bay Area Association, March 23, 2005.

Criswell, D. R. "Lunar Solar Power and the Nurtured Earth," Distinguished Lecturers Series, Farmingdale State University, Farmingdale, NY, Feb. 17, 2005.

Sjostrom, M. Interview with Dr. Criswell for Swedish Educational Broadcasting Company (Science Department), Feb. 15, 2005 (to be broadcast in Europe in Dec. 2005).

Criswell, D. R. and D. Livingston (interviewer). "Industrialization of the Moon and the Lunar Solar Power System," *The Space Show*, Dec. 7, 2004; available as web archive <<http://www.thespaceshow.com>>.

Criswell, D. R. "Industrial-Scale Lunar Sciences" (invited seminar 19 pp.) Lunar and Planetary Institute, Houston, TX, Oct. 29, 2004.

Criswell, D. R. Nomination for a World Technology Award in space, World Technology Network, Fairmont Hotel, San Francisco, CA, Oct. 7-9, 2004.

Criswell, D. R. NASA Workshop on Oxygen in the Terrestrial Planets, Lunar and Planetary Institute, Santa Fe, NM, July 19–24, 2004.

Criswell, D. R. Review with Professor J. Whiteside, the George Washington University program in Aero-flight Sciences, associated with NASA-Langley Research Center, June 22, 2004. (The GWU program was being replaced by a consortium of state universities in the region.)

Publications, Proposals, and Program Documents

Zolensky, M. (Proposer), D. R. Criswell (co-investigator), and others. “Use of Meteorites to Elucidate Formation and Characteristics of Pondered Deposits on Eros,” NASA Research Announcement ROSES-2005 (*submitted April 2005*).

Criswell, D. R. “Lunar Solar Power (LSP) System and Exploration of the Inner Solar System, Based on IAA-02-IAA 13.2.07,” International Astronautics Federation and World Space Congress, Houston, TX (*accepted 2005 with minor revisions*). 6pp.

Criswell, D. R. (Director), I. N. Rothman (Editor), and D. V. Bush (Associate Editor). Y2003 *Annual Report* of the Institute for Space Systems Operations of the University of Houston and the University of Houston-Clear Lake. Houston, TX, 2004-5006. 133pp.

Criswell D. R. (Director). Announcement of seven 2–3 year opportunities for UH/UHCL/JSC Post-Doctoral Aerospace Fellowships, April 2004 <<http://www.issso.uh.edu/>>.

Criswell D. R. (Director) and H. Lane (JSC). Peer Review of proposals (21) submitted by University of Houston faculty to ISSO for seed-grants by 21 faculty and research staff from UH, UHCL, Rice University, and NASA-Johnson Space Center, March 27, 2005.

Criswell D. R. (Director), H. Lane (JSC), and D. Sickorez (JSC). Peer Review of University of Houston-Clear Lake proposals submitted to ISSO for Post Doctoral Aerospace Fellowships (2) and seed-grants (8) by faculty and research staff from UH, UHCL, Rice University, and NASA-Johnson Space Center, Dec. 13, 2004.



**NASA's Future
Missions—the
President's Vision
for Space
Exploration**

SPACE TRAVEL—Excerpts from the
Prepared Statement of NASA Administrator Nominee Michael Griffin to the
Senate Commerce Committee Confirmation Hearing
Russell Senate Office Building Room 253
Washington, D.C., Tuesday, 12 April 2005



IF CONFIRMED AS ADMINISTRATOR, MY PRIORITIES IN EXECUTING the duties of that office, consistent with the President's Vision for Space Exploration, will be:

- Flying the Shuttle as safely as possible until its retirement, not later than 2010.
- Bringing a new Crew Exploration Vehicle into service as soon as possible after Shuttle retirement.
- Developing a balanced overall program of science, exploration, and aeronautics at NASA, consistent with the redirection of the human space flight program to focus on exploration.
- Completing the International Space Station in a manner consistent with our International partner commitments and the needs of human exploration.
- Encouraging the pursuit of appropriate partnerships with the emerging commercial space sector.
- Establishing a lunar return program having the maximum possible utility for later missions to Mars and other destinations.

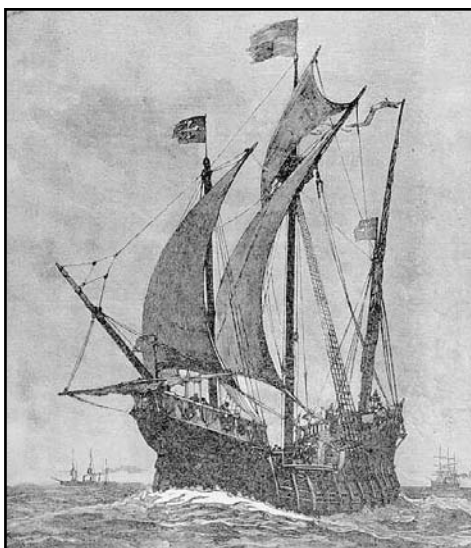
The aftermath of the tragic loss of the Space Shuttle Columbia on February 1, 2003 brought us to a watershed moment in the American civil space program. Choices had to be made. The President has put forth a choice, a strategic vision for the space program. That vision has been enunciated with exceptional clarity, and has been subjected to considerable public debate for over a year.

I think it may be said that, while differences of opinion exist, the President's proposal has attained broad strategic acceptance. It is now understood that the International Space Station, supported by the Space Shuttle, cannot be the centerpiece of the nation's human space flight program. The strategic vision for the U.S. manned space program is of exploration beyond low Earth orbit.

It is a daring move at any time for a national leader to call for the bold exploration of unknown worlds, a major effort at the very limit of the technical state of the art. And it was the same way back in 1492, when Queen Isabella overrode King Ferdinand's reluctance and backed Columbus's voyage to "the New World," the first step in the creation of Spain's colonial empire.

But few recall that 1492 was a key year in the history of Western civilization, entirely apart from the European "discovery" of the New World. The big news that year was the reconquest of Granada after a ten-year siege by Spanish forces, an event which essentially marked the conclusion of an eighth-century struggle against the Moorish occupation of Spain.

England, France, and Italy had arisen as European powers while Spain had struggled against the Moors, and Spain's tiny neighbor, Portugal, had prospered through the growth of her maritime prowess under Prince Henry the Navigator.



Columbus's flagship, the Santa Maria



The Lunar Landing Research Vehicle for astronauts

The “discovery” of the New World had happened before and would have happened again, whether or not Columbus had ever sailed from Palos. One way or another, European settlement of the New World was inevitable; however, it was Isabella’s bold action that secured Spain’s role in that future. If Columbus failed, she would be discredited, but if he succeeded, Spain would succeed, and would become preeminent among the nations of her time—and that was the way it happened.

And that is the way it is today. In the twenty-first century and beyond, for America to continue to be preeminent among nations, it is necessary for us also to be the preeminent spacefaring nation. Or are we willing to accept the world of a generation or two hence where other nations will be engaged in the development of the Solar System, and we are not?

If not, then it is time to recognize that we have squandered a once-insurmountable lead in the arts and sciences of space flight. The best we can say for ourselves today is that our grounded Space Shuttle is much more sophisticated than the operational vehicles belonging to the two nations which have sent people into space since we have last done so.

None of this is to say that the United States should necessarily plan to “go it alone” in space exploration. Great nations must be prepared to do so when necessary, but it is equally true that great nations need allies and partners.

There is room for these relationships in the President’s Vision for Space Exploration, and certainly we have benefited from the Russian capability to support the International Space Station during the two years in which the Shuttle has been grounded. But in the future, the United States should avoid dependence upon other nations for critical spacefaring systems.

Many who share the President’s strategic vision for space exploration are nonetheless lukewarm in their support, believing it to be unaffordable or unsustainable. This concern is understandable.

The strategic vision for space must therefore be broadly inclusive, to enable a consistent and appropriate level of financial support without disruptive funding peaks and valleys. The decision to have a robust space program is like the decision to have a capable military force—it cannot be made in one year and unmade in the next.

The nation does not debate, each year, whether or not it will have such forces. A similarly sustained bipartisan commitment to American leadership in space is required.

And, at least since the aftermath of the Challenger accident, nineteen years ago, we have had exactly that commitment. In constant dollars, NASA has received approximately the same allocation of funding from the taxpayers in the last sixteen years—the Space Station Era—as it received in its first sixteen years—the Apollo Era.

If we are less attracted to the results of the Station Era than of the Apollo Era, then we need to reconsider our goals and our manner of pursuing them. But if funding levels continue in accordance with the President’s plans, resources are sufficient to

enable a U.S. return to the Moon, and, later, to go to Mars.

The country has already demonstrated the consistent support that NASA must have over an extended period of time to execute a program of human exploration. We simply have been doing other things with that money.

The arts and sciences of space flight are not restricted to human space flight. Robotic spacecraft such as those of Spirit and Opportunity have taken us, by proxy, to the surface of Mars. Galileo, Cassini and Voyager have taken us to Jupiter, Saturn, and the outer reaches of the Solar System.

New Horizons will shortly set sail for Pluto, the last remaining planet (so far as we know) not yet visited by any spacecraft from Earth. And, of course, the Great Observatories, including the Hubble Space Telescope, Chandra, Spitzer, and Compton, have allowed us to extend our gaze to the very edge of the Universe, and back in time almost to its beginning.

The images and the knowledge returned to us by these, our surrogates, have shaped our culture, our view of the Universe, and our place in it almost as powerfully as if human explorers had been present. As we undertake to redirect our human space flight program, it is crucial that we do it without damaging NASA’s outstanding science programs, which have been among the crown jewels of the nation’s achievements.

Those who claim that NASA cannot afford robust programs in both robotic science and manned space flight are mistaken. NASA in the Apollo Era was hardly the “single mission agency” in the simplified view that is often heard today. In addition to the manned space flight development programs of the time, NASA executed dozens of Explorer-class missions, a dozen Pioneer missions (including Pioneer 10 and 11 to Jupiter and Saturn), Ranger 1-9, Surveyor 1-7, Mariner 1-10, the Orbiting Solar Observatory, Orbiting Geophysical Observatory, and Orbiting Astronomical Observatory series, and paid for most of the Viking missions to Mars, which were launched in 1975.

Communications satellite development was initiated with Telstar and Early Bird, while the TIROS, NIMBUS, and ESSA series did the same for weather satellites. In addition to these robotic science and technology development missions, NASA also executed 199 X-15 flights (which still hold the speed record for piloted flight within the atmosphere), and accomplished an otherwise vigorous program of aeronautics development, including the liftingbody research which enabled the development of the Space Shuttle. This hardly seems the record of a “single mission agency.”

The nation is not going to abandon space exploration, human or robotic. Given this, the proper debate in a world of limited resources is over which goals to pursue. I believe that, if money is to be spent on space, there is little doubt that the huge majority of Americans would prefer to spend it on an exciting, outward-focused, destination-oriented program. And that is what the President’s Vision for Space Exploration is about.