NASA Space Commercialization

Space Product Development

The sky is no longer the limit...

2001


SPACE PRODUCT DEVELOPMENT
SPD
Space For Business to Grow

A New Era For Commercial Research

With the advent of operations on the International Space Station (ISS), a new era in commercial research and development has begun. No longer is long-term research limited to what can be done on the ground, constrained by gravity, or limited to a single environment. Instead, gravity is now a variable, environments can be changed from open room to vacuum as needed, and a host of other possibilities can be realized. Most importantly, this incredible resource is available to businesses of all sizes and types in an affordable manner.

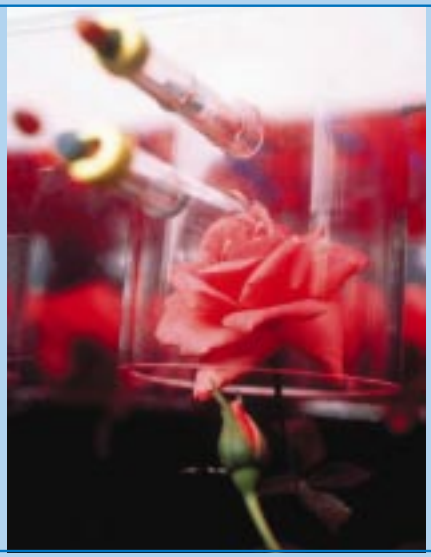
A number of Industry Partners, working through Commercial Space Centers or Space Act agreements, have begun taking advantage of this opportunity. From plant growth to structure-based drug design, research has been conducted for months at a time on the ISS before being returned to Earth. More commercial research has begun, and in the coming months and years, a variety of new commercial research facilities will be coming online on orbit. Additionally, this year we are pleased to welcome the inclusion of four additional Commercial Space centers that became a part of our program.

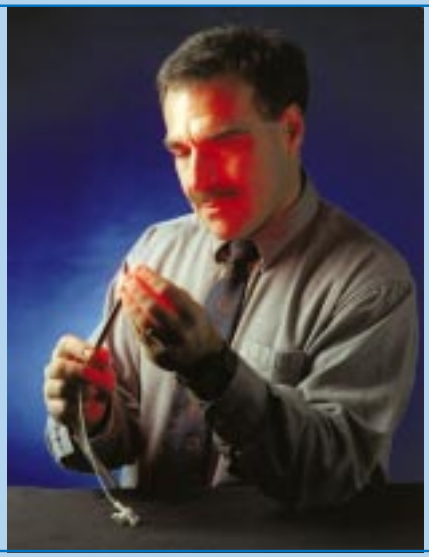
There is already a list of companies wanting to make use of this opportunity, and steady and reliable access to space remains a challenge. Yet, that challenge is bringing out innovation both within NASA and without. From helping stimulate private launch initiatives to encouraging changes within NASA, solutions and new ideas are being found. As a result, this out-of-this-world research opportunity is already providing down-to-Earth results for business.

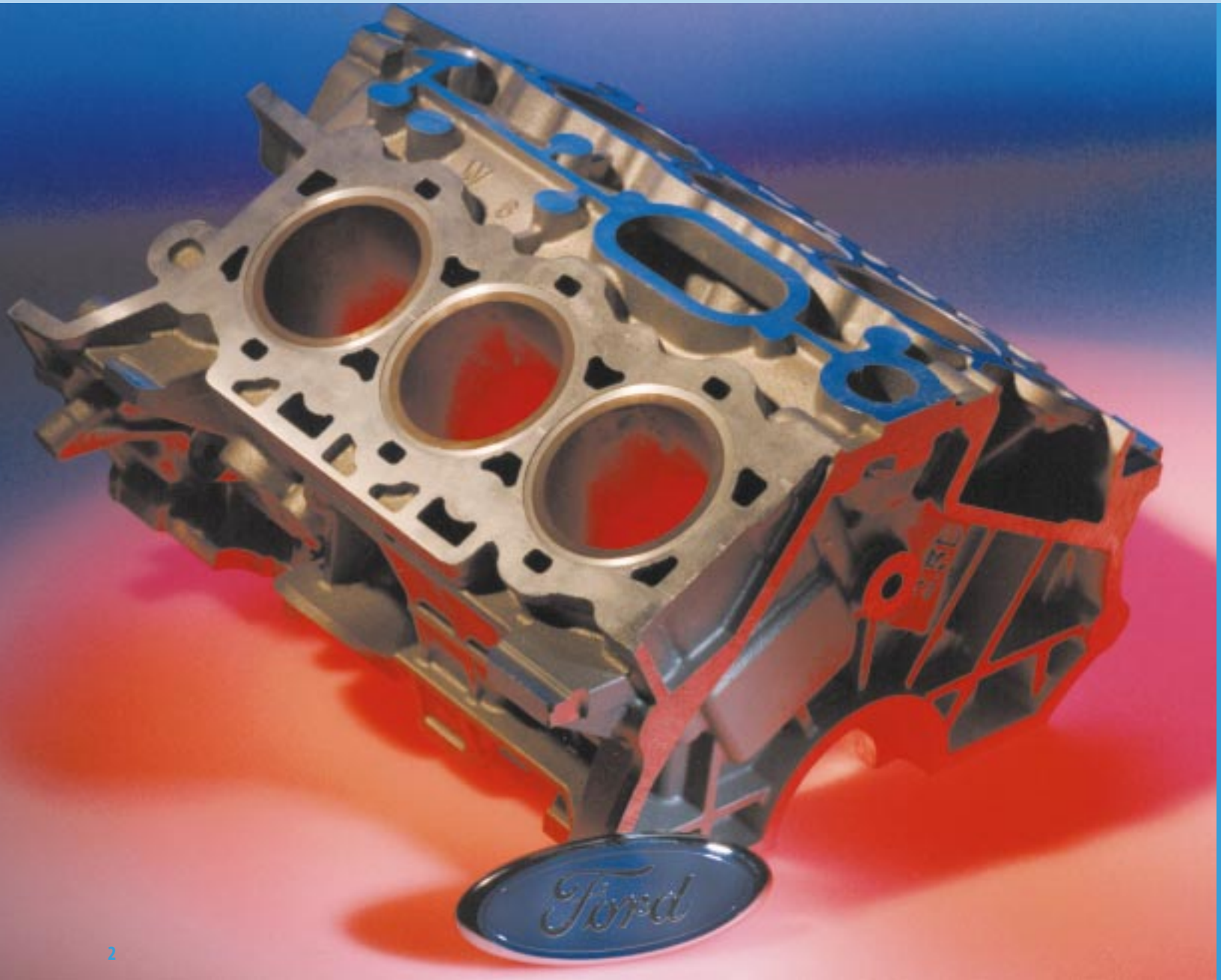
One important advantage of most commercial payloads is that they have been designed to be operated from the ground. This was an important lesson learned by the Commercial Space Centers during operations on Spacelab, and current commercial research is benefiting from this and other lessons learned. As a result, full-scale commercial research is able to proceed during construction and the attendant limitations on crew time.

In the following pages, you will see the successes obtained by companies of all sizes and types who have made use of the space and microgravity environments for their research, the triumphs and innovations of the Commercial Space Centers, and how this work is continuing to provide a solid foundation of success for NASA's space commercialization efforts.

Mark Nall
Manager
Space Product Development Program
Marshall Space Flight Center






Ford

Bringing Benefits Down To Earth

Taking Business To The Stars

Your competitors are starting to explore the potential and reap the rewards of space—Why aren't you?

The commercial development of the space frontier is one of the greatest opportunities facing America. It is the growth of business into space that will bring the benefits of space down to Earth and enrich the everyday lives of all Americans.

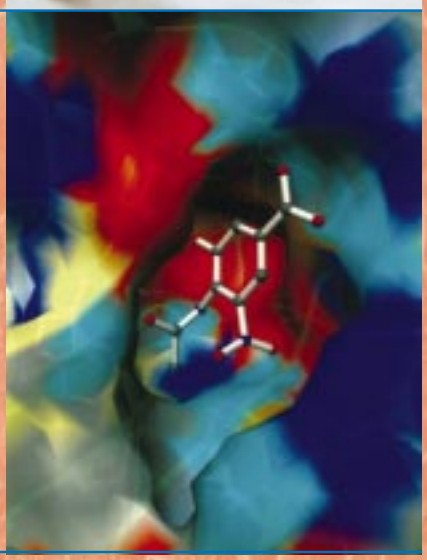
NASA is encouraging businesses to seize this opportunity through the Space Product Development (SPD) Program and its Commercial Space Centers, to help ensure the continued economic growth of the U.S. and to bring the opportunities for new advances, technological understanding, products, and jobs to the public.

Space commercialization efforts spearheaded through the program have already resulted in products that are commercially available, and have laid the groundwork for future industries such as private space platforms and launch services. Commercial space and microgravity research has been involved in everything from helping improve cast automotive parts for Ford, to facilitating the discovery of a new "space rose" scent now being used in Zen perfume from Shiseido. Light Emitting Diodes (LEDs), originally developed by Quantum Devices, Inc. for commercial plant growth research, are now used in medical applications from treating cancer to aiding the healing of wounds. Water purification products from WTC/PentaPure, Inc. have benefited from research on the Space Shuttle, and for sport water bottle use, that technology is now being provided on an exclusive basis to Katadyne for use in it's Exstream (U.S.) and Katadyne (world-wide) sport water bottles.

Advanced electronics research is providing advances ranging from high-temperature superconducting wire that will be used in power transformers to a special optical detector that may offer the hope of sight to many people with retinal eye problems. Other commercial research is helping produce new bone replacement materials that will be stronger and longer lasting than current replacements. Advanced research in this area could even lead to a replacement that will dissolve as natural bone grows back. Pharmaceutical companies are making use of commercial space and microgravity research to design new, more effective drugs that have fewer side effects, while exploring ways to improve drug production and reduce costs on Earth.

As a result of these and other successful efforts, commercial space and microgravity research reaches across every facet of today's marketplace. From research and development of new and improved materials to the rich fields of agribusiness, this research is helping American businesses get ahead. In the pages that follow, you will see some of the results and opportunities that await U.S. industry and learn how space can make your business truly out of this world.


CAUTION



Successes

A consortium focusing on biomaterials—implants and other materials designed to be used with living tissue—has been established by the Center for the Commercial Applications of Combustion in Space (CCACS) and BioServe Space Technologies. This consortium builds on the advanced biomedical materials development work at CCACS and the advanced biotechnology research at BioServe. Industry Partners are anchored by Hewlett-Packard and Sulzer Medica, and more partners are being recruited for this effort, which has the potential to revolutionize the production of biomedical implants.

Two potential anti-cancer compounds from BioServe Space Technologies were optioned for licensing by AnorMed, Inc. of Vancouver, Canada. These compounds, developed at BioServe's Kansas State University location, have been found to exhibit inhibitory properties against cancer. AnorMed hopes to further develop the compounds into anti-cancer therapeutics for future clinical studies.

The Center for Biophysical Sciences and Engineering (CBSE) has been chosen as one of National Institutes of Health's (NIH) seven National Centers for High-Throughput Structural Proteomics. The purpose of NIH's commitment is to support the development of new technologies in molecular biology and high-throughput protein expression methods, crystallization, and structure determination to enable researchers to perform high-throughput crystallography. These capabilities, combined with the completion of the sequence of the human genome as well as the genomes for dozens of bacteria, viruses, and other species make it possible for the CBSE to consider the determination of the 3-dimensional protein structures of entire genomes. This information will provide a powerful capability for understanding functions for these biological molecules and provide key information for the development of new pharmaceuticals for chronic and infectious diseases.

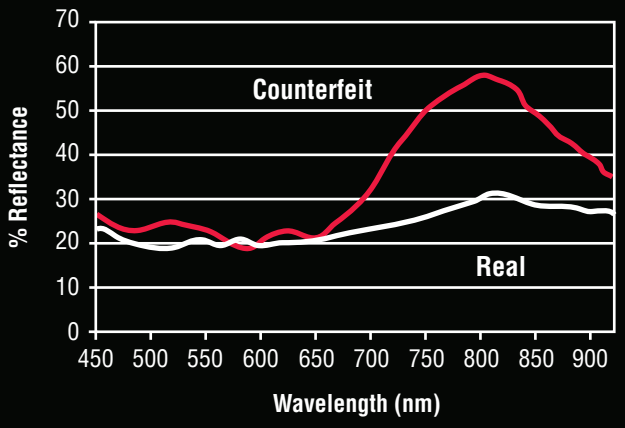
ProVision Technology's food quality and safety program with Sanderson Farms and the United States Department of Agriculture has developed algorithms that can detect contaminated chickens on the processing line with the birds moving at the operational plant speed of 70 birds per minute. If incorporated into future chicken processing equipment, this could help increase food safety by allowing contaminated chickens to be easily identified and dealt with.

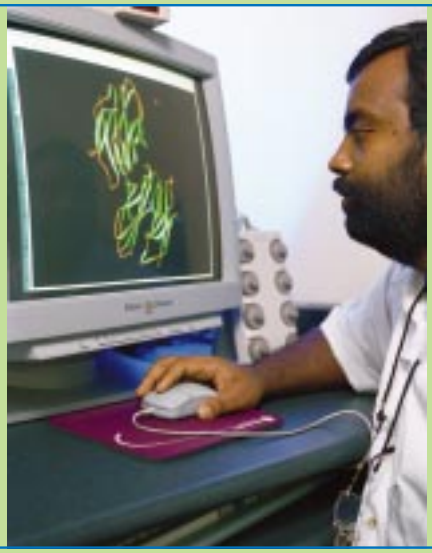
Collaboration between the Center for Space Power and Advanced Electronics (CSPAE) and the Center for Microfibrous Materials Manufacturing at Auburn University has led to the production of nickel-carbon supercapacitor electrodes, which were made using a semi-automated papermaking facility. These composite electrodes are the first in the marketplace, and have been used by Industry Partner Eagle Picher LLC of Joplin, Missouri, in 30V, 5 Farad space-rated supercapacitors. Supercapacitors are being examined by a number of companies, and by NASA, for use in applications with high peak power requirements, such as high-reliability electromechanical actuator systems and hybrid electric vehicle drive systems.

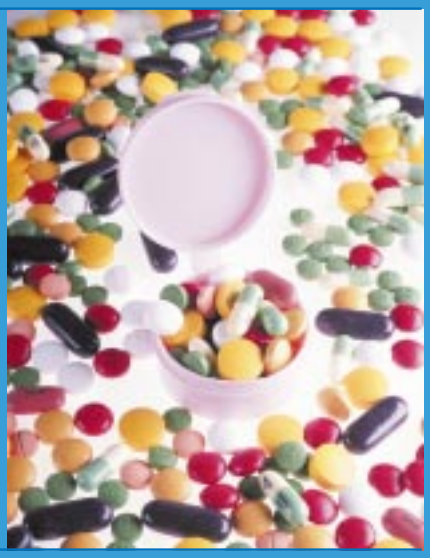
The Federal Bureau of Investigation (FBI) and ProVision Technologies conducted a pilot study to determine the utility of hyperspectral imaging for differentiating ink types. Encouraging results indicate the potential of using this technology in detecting altered documents, counterfeit money, and forged passports. An expanded program will occur in 2002 with funds and technical support obtained from the FBI. ProVision Technologies will place an employee and a hyperspectral sensor at the FBI Academy in Quantico, Virginia to conduct this work.

Counterfeit

Real





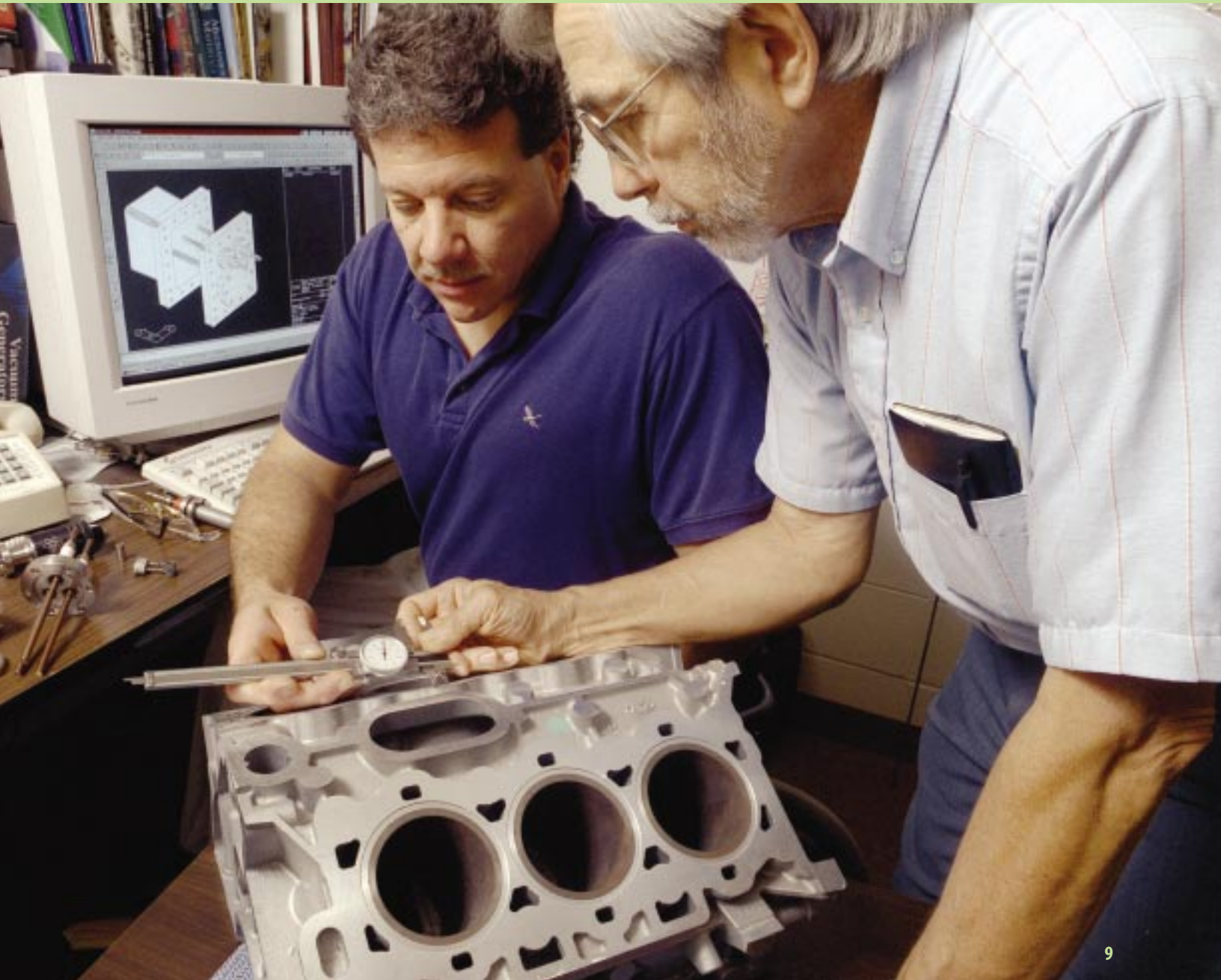


Researchers affiliated with the Consortium for Materials Development in Space (CMDS) have determined the crystal structure for human tyrosine phosphatease sigma (PTPs) protein. This protein is found in a variety of human tissues, including bone, brain, and lung, and in osteosarcoma, a bone cell cancer. Mapping the structure of PTPs provides an important target for new drug design, since inhibiting this protein may help fight bone diseases ranging from osteoporosis to bone cancer.

Work by the Solidification Design Center (SDC) with GM Powertrain will result in shorter development time for complex metal castings. Using software called ARENA™, developed by Industry Partner Flow Simulation Services, the SDC was able to accurately simulate the complex process of producing the cores and molds needed for such parts. This will eliminate the traditional "trial-and-error" process for making cores and molds, allowing a reduction in development time and improvements to product quality.

Industry Partner Space Explorers, Inc. and the Wisconsin Center for Space Automation and Robotics have demonstrated the ability to grow plants in microgravity without crew intervention. Using the Advanced ASTROCULTURE™ (ADVASC™) unit, they successfully grew *Arabidopsis thaliana*, more commonly known as mustard weed, on the International Space Station. This proves that plants can be grown over a complete life cycle without the need for the crew to be involved with the process, and opens the door for both more research and for the ability to grow crops and plants in space.

Successes



"We are pleased to announce our partnership with NASA Food Technology Commercial Space Center," comments Kurt F. Heiar, Chief Executive Officer, Advanced Analytical Technologies, Inc. (AATI). "We believe the applications for our new rapid bacterial detection technology are exciting, not only in the food industry, but also in the pharmaceutical, beverage, and environmental testing sectors."

"The Solidification Design Center at Auburn University provides the entire metal casting industry with access to space and space-derived technologies. A growing number of industry engineers are becoming interested in the value of these technologies to better understand and control their manufacturing processes," says Dr. Joe Santner, Director of Research for the American Foundry Society. "The Space Station era promises unimaginable benefits for unique materials data, advanced manufacturing processes, and improved quality"

"For our NASA contract to investigate two-phase flow behavior in microgravity, the CSP provided a two-phase flow facility and technical support for research flights aboard the NASA KC–135 aircraft. The CSP team configured the hardware in the test section to meet our specifications, provided a robust test facility with high-speed data acquisition, worked with the NASA JSC Reduced Gravity Office to schedule the flights, completed the safety review requirements, delivered the hardware to the test site, and provided key personnel aboard the aircraft. The reliability of the facility and the expertise of the operators resulted in two flight campaigns that were both highly successful. Obtaining microgravity data at over 100 test conditions during two flight campaigns of 160 parabolas each exceeded our expectations." Chris Crowley, Principal Engineer, Creare, Inc.

Mike Hunter, chairman of the Iowa Soybean Promotion Board's Market Development Committee, says, "Working with NASA Food Technology Commercial Space Center and Iowa State University, we are developing food products and processes that will allow soybeans to provide a sustainable food system in space. NASA needs a very simple means of processing soybeans into edible oil and meal that can be used for a multitude of products."

"Our current research collaboration with Dr. George Marchin at BioServe Space Technologies at K-State, have helped aid in the discoverery of certain nanocrystalline materials that are very effective biocides in air or in water. They function by strongly adsorbing the bacteria or toxin such that chemical bands are broken, and are thus termed 'destructive adsorbents.' These adsorptive properties coupled with other chemical properties make these nanocrystals very promising reagents for air and water disinfection." Kenneth J. Klabunde, Chief Scientist, Nanoscale Materials, Inc.

Mr. Michael Stevns, Director of Innovation at Arla Foods amba, says, "We strive to improve the well-being of the modern consumer in space. The crew has a tough life up there, with a tremendous amount of restrictions. If Arla Foods can contribute to a little more joy through inspiring dairy foods, I would be proud! As a spinoff of this program, we also hope to build fruitful research and development relationships with other leading-edge companies and universities, thereby developing exciting and nutritious milk-based products for our terrestrial consumers."

"Microgravity protein crystal growth experiments have yielded very positive results in terms of crystal size and crystal size uniformity. The space-grown crystals provided enabling

Quotes From Industry

information for use of crystals in drug delivery and formulation applications. We look forward to having the research platform-microgravity laboratory of the International Space Station to manipulate purity, size and quality of crystals and crystalline suspensions." Mr. Paul Reichert, Schering-Plough Research Institute, Inc.

"We at GM Powertrain have been very impressed with the progress of this work. The code will be of great use in helping to improve productivity and reduce lead times within the metal casting industry." Dr. David Stephenson, Manager of Manufacturing Process Analysis for GM Powertrain

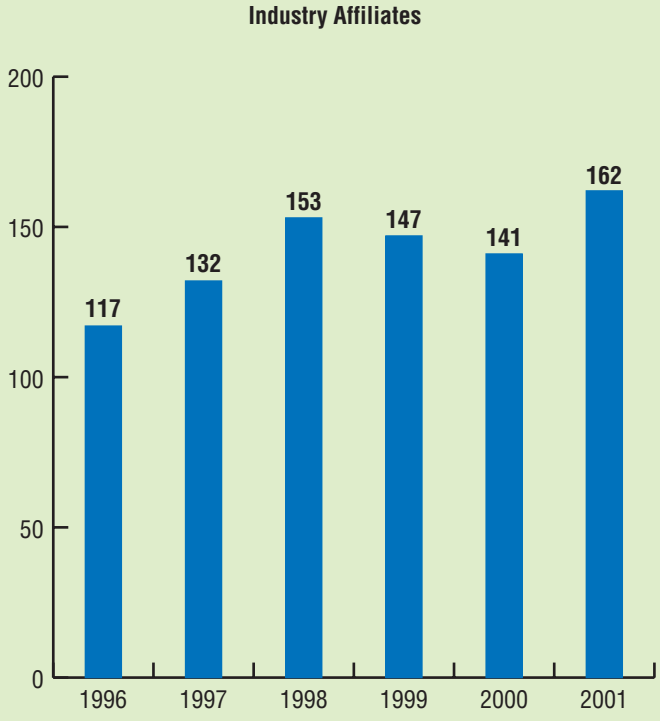
"The research work of and collaboration with the Center for Satellite and Hybrid Communication Networks (CSHCN) were strategically important and instrumental in our efforts for validating the business model and for establishing Hughes Network Systems as the premier provider of Internet via satellite services. DirecPC, which was the commercial product resulting, in part, from this collaboration, currently forms the basis of the multiple broadband platforms that Hughes Network Systems (HNS) envisages fulfilling the needs of both enterprises and consumers alike as the demand for high-speed delivery becomes even greater. Dramatic growth is envisaged for DirecPC as HNS anticipates more than 1 million subscribers by 2003. HNS has entered into an agreement with AOL that will allow AOL subscribers the ability to receive broadband multimedia content through a small rooftop dish if they use DirecPC as the delivery mechanism. The new service is to be called AOL-Plus. Our productive collaboration with the CSHCN continues vigorously through our current joint work on two-way Internet over satellite and further extensions into the new generation of Ka-band broadband satellites that Hughes is to be launching within the next three years." John Kenyon, Senior Vice President, Hughes Network Systems

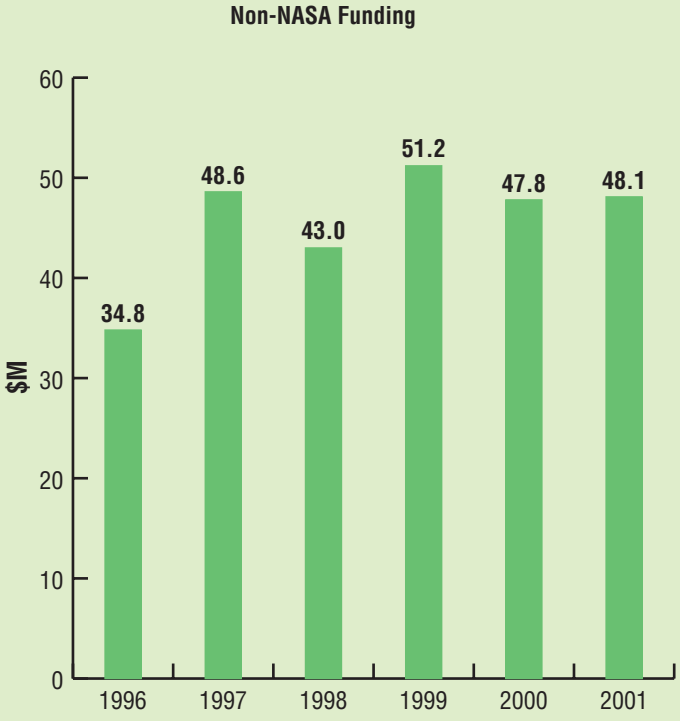
"I feel that your work in modeling, analyzing and attempting to understand the significance of this phenomenon shed much light on its importance, and underscored the fact that we need to continue to pursue a greater understanding of its impact." Jerry Fausz, Program Manager, Integrated Control Systems, AFRL/VSSV

Industry Partners are the cornerstone of NASA space commercialization activities. When many different types of businesses, both small and large, become involved in using space for their purposes, a broad industrial base develops that understands the benefits of using space and microgravity. This broad base forms the foundation for future commercial activities in space, from research and production on private space platforms to the private launch services needed to reach those opportunities. In this way, NASA space commercialization works with industry today to help them develop the technology, products, and services they need for their future.

Growing this industrial base is one goal and function of the SPD program and its Commercial Space Centers. While NASA provides the Centers with their base funding for operations, the remainder of their funds must be sought from other sources, primarily through partnerships with industry on commercially-driven research projects.

Because industry funds the majority of the research, jointly performs the research, pays for a portion of the launch costs, and brings the resulting products or services to market, commercial intellectual property and proprietary data, techniques, and systems are protected.



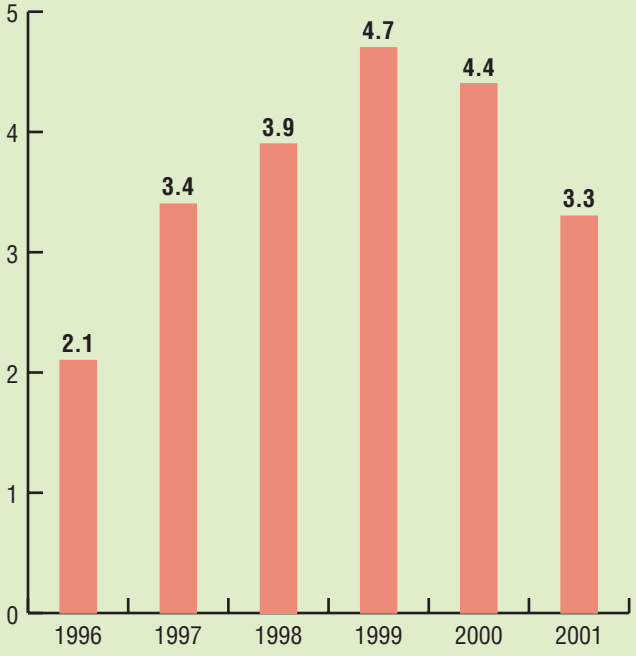


While ground-based research is an important part of any research program, it is the access to space and microgravity that allows NASA's Industry Partners to advance their research. By making use of these unique environments, investigators can distinguish events and phenomena that normally are masked by gravity, gather data quickly and precisely without the interference of gravity, and do processing not practical or possible on the Earth's surface.

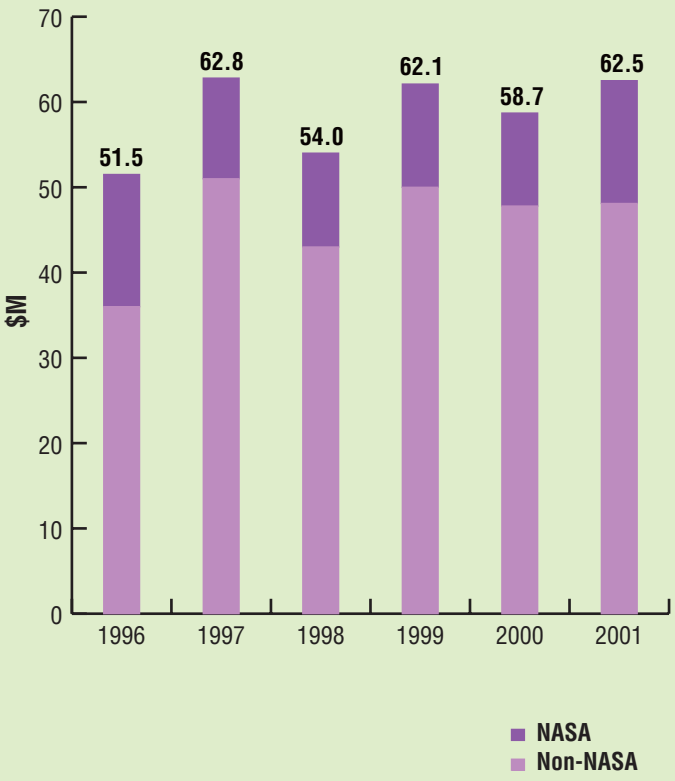
The SPD program works to provide the Industry Partners with access to space and/or microgravity through a variety of means. Drop tubes and towers can provide 1–5 seconds of microgravity, KC–135 aircraft can provide 20–30 seconds of microgravity at the top of a parabolic arc, the Shuttle can provide up to two weeks of microgravity and/or space, and the International Space Station will provide months of opportunity for investigators. All available flight opportunities are being utilized. SPD is prepared to take advantage of any additional flight opportunities that arise.

SPD Metrics

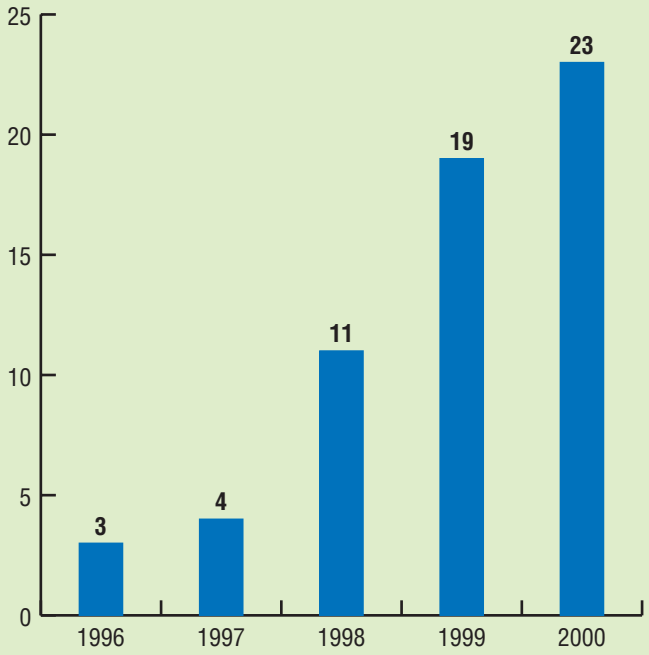
Ratio of Non-NASA Funding to NASA Funding



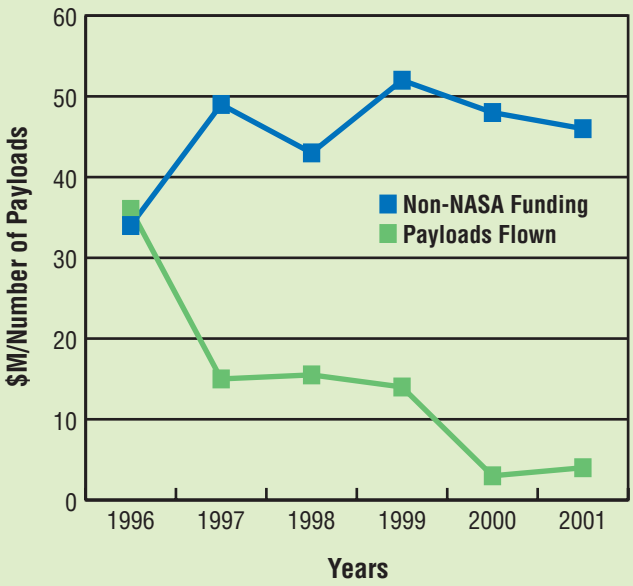
CSC Leveraging



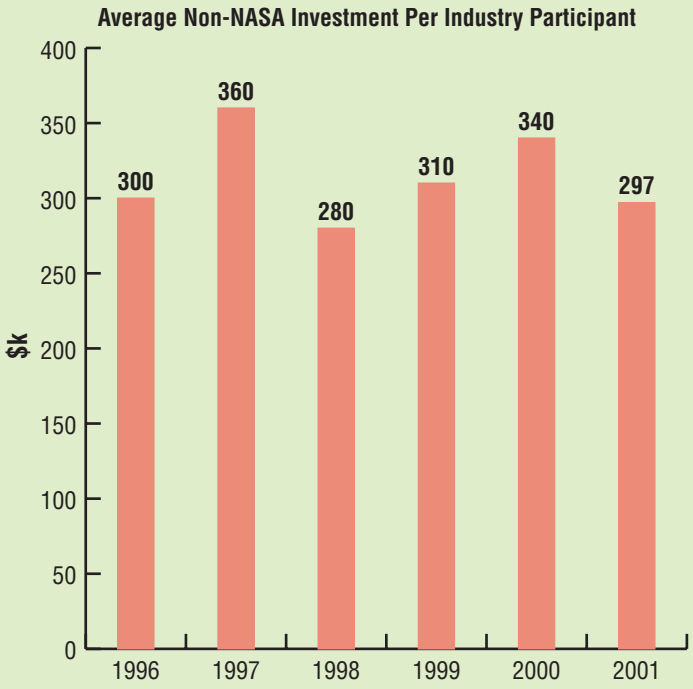
Licensing/Equity Agreements



Correlation Between Flight Opportunities and Co-Funding



Data offset one year. Current data available at
http://cscsourcebook.nasa.gov/


Average Non-NASA Investment Per Industry Participant
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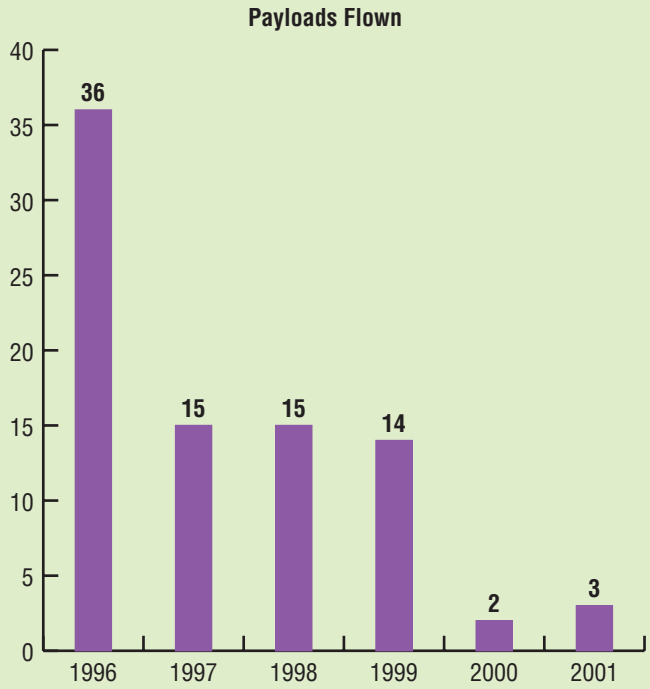
Payloads Flown
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BioServe Space Technologies specializes in life sciences research and space flight hardware design in the areas of biomedicine, biotechnology, and agriculture. BioServe, in collaboration with its Industry Partners, conducts both ground-based and space-based research designed to result in Earth-based commercially viable products. Current research ranges from anti-cancer agents to antibiotic fermentation to bone loss studies to lignin biosynthesis. In conjunction with their commercially-based research projects, BioServe continues to educate and support students in the areas of life science research, aerospace engineering, space flight hardware development, and mission operations and integration. BioServe is jointly located within Aerospace Engineering Sciences at the University of Colorado at Boulder (UCB) and the Division of Biology at Kansas State University (KSU).

FY 2001 was a challenging year for BioServe as it prepared for its first long-duration mission (ISS–6A) aboard the International Space Station (ISS). This research was conducted in collaboration with BioServe's partner, Bristol-Myers Squibb. BioServe's engineering team designed and built a fed batch culture insert for its Commercial Generic Bioprocessing Apparatus (CGBA) payload, called the Multiple Orbital Bioreactor with Instrumentation and Automated Sampling (MOBIAS). The implementation of MOBIAS was a critical step in the progression of this research. Determining whether the increased production previously observed in space is maintained under these more optimal conditions within MOBIAS will provide valuable insight into identifying the underlying cause. The overall goal of the project is to use this knowledge to improve the efficiency of antibiotic fermentation processes here on Earth. This project will continue aboard ISS–8A in March 2002.

BioServe also continued to prepare for the flight of its commercial research with Amgen, which examines the effectiveness of an Amgen discovered protein, Osteoprotegerin (OPG), against microgravity-induced bone loss. For this research, BioServe successfully completed an odor test for the flight hardware in order to receive approval to fly mice for up to 17 days aboard the Space Shuttle. This is an extremely important milestone and paves the way for other biotech research that utilizes small murines. OPG has the potential to revolutionize treatment for osteoporosis, a major health threat for over 28 million Americans with associated healthcare costs estimated at $13.8 billion annually. These expenditures are expected to increase significantly with the aging of the American population. This research flew aboard STS–108 in December 2001.

BioServe continued preparation of the Plant Generic Bioprocessing Apparatus (PGBA) and conducted ground-based research for a project that investigates microgravity effects on lignin biosynthesis in the Arabidopsis plant and trees of commercial value. BioServe has formed a consortium with Industry and the USDA Forest Products Laboratory for this research and is currently recruiting various forest product companies to join. BioServe's goal is to develop a transgenic tree that will benefit the forest product industry, the environment and the U.S. economy. This project is scheduled to fly aboard ISS–9A in August 2002.

In FY 2001, BioServe developed a research collaboration with a new commercial partner, Nanoscale Materials, Inc., of Manhattan, Kansas. Founded in 1995, Nanoscale is an advanced materials company that develops and commercializes reactive nanoparticles and other related technologies. The extraordinary physical and chemical properties of nanoparticles hold great promise in meeting the needs of various markets such as water and air purification, decontamination, and protection from highly toxic substances, including chemical and biological warfare agents; control of odor; and drug delivery. A key strategy in Nanoscale's business model is to develop strategic alliances with partners through which they can develop new manufacturing processes and ultimately reduce time to market. The scientific partnership with BioServe researcher Dr. George Marchin will further investigate a novel application of their materials in combating new contaminants or Microcystins, the byproducts of growth of blue-green algae, in surface water supplies. Microcystins are typically heptapeptides with hepatic toxicity and tumor-promotion activity and a growing problem on Earth. Research plans are underway to examine the stereospecificity of nanoparticles and the potential product development

benefits that research studies in the microgravity environment could offer.

BioServe also continued its dedication to the K–12 student population by agreeing to continue its partnership with SPACEHAB Inc. on the STARS™ program. During the past year, BioServe finalized the design and development of six different habitats for its CGBA payload that will contain the student-developed experiments for STS–107 scheduled to launch in June 2002. The experiments will investigate how microgravity affects the behavior and responses of five different insects and one fish species.

The Aerospace Engineering Sciences Department at UCB conducted a formal search for a faculty position for the newly developed Bioastronautics program developed in direct support of BioServe activities. This curriculum will emphasize space life sciences, habitat and advanced life support system technologies, and small payload design, and is built upon a number of existing and newly developed courses currently being taught by BioServe research faculty.

In continued academic achievement, two BioServe students received Ph.D.s this past year. One accepted a research position at the University of London and the other was employed by industry with the engineering firm Airsys ATM. In addition, nine BioServe student researchers obtained their Masters and Bachelors degrees. Currently, BioServe is supporting a combined total of 49 graduate and undergraduate student researchers at UCB and KSU.

Case Study

Challenge An interdisciplinary research focus of BioServe involves drug discovery programs that utilize both natural products and synthetic compounds. Several BioServe laboratories are working on new compounds that show promise with human health issues. These medical issues that are confronted by older citizens in our nation include diseases such as cancer, heart/circulatory, and Alzheimer's.

Importance Circulatory disease is the number one killer in the United States. It is now projected that one out of three U.S. citizens will contract a clinical case of cancer during their lifetime. Additionally, it is well known that the number of Alzheimer's cases is rising as the age of our population increases.

Solution Carry out an aggressive and successful series of studies to develop and characterize new compounds that have a promise in alleviating the tragic consequences for citizens who have contracted these serious diseases. Already associated with this goal are four unique natural and synthetic compounds that have been successfully patented or have had disclosures filed as the first step in the patent process.

Benefit To allow all of humanity to live longer and more productive lives.

The mission of the Center for Advanced Microgravity Materials Processing (CAMMP) is to develop strategic partnerships between industry, government, and universities to utilize space and microgravity for peaceful economic development. CAMMP is a state-of-the-art research laboratory, and has available, if required, the most sophisticated laboratory in the history of human kind: the International Space Station (ISS). The ISS can be used to more rapidly bring products and process improvements to the market place. The initial target products for CAMMP will be in the field of advanced/smart materials. Research is presently on going on zeolites, zeo-type materials, carbon nanotubes, and fuel cells.

CAMMP objectives are:

1. To develop an infrastructure that is "friendly" to commercial development to help industry establish how to best use CAMMP and the ISS as a national resource.

2. To develop high-commodity and special products that can benefit from the microgravity environment, and, where appropriate, produce the actual product or a subset of that product, or to use the knowledge gained from ground and space research to develop or improve processing of that product on Earth.

3. To develop a body of knowledge that will reduce the high-risk nature of "leap-frog" technologies. This will require world class research facilities and top researchers.

4. To develop income streams for CAMMP based on individually structured intellectual property agreements with CAMMP's Industry Partners.

5. To educate students in the latest technical, business and entrepreneurial approaches to process and product development, and thus create the next generation of entrepreneurial "risk takers."

6. To develop an educational component of CAMMP. This will stimulate interest in science and technology in K–12 education and establish curriculum through hands-on exposure of K–12 teachers to "real-life" product-based applied and basic research. To have teachers practice and understand how science is used to develop new technology so they can pass this on to future scientists and engineers.

Case Study

Challenge Developing an efficient storage medium for hydrogen fuel.

Importance Hydrogen is a pollution free source of energy, and because hydrogen is the most abundant element in the Universe, the fuel reserves would be virtually infinite. In addition, burning hydrogen eliminates hydrocarbon pollutants, producing only water.

Solution Zeolites and zeo-type materials, high surface area carbon, and carbon nano-tubes are being developed and tested as a possible storage medium for hydrogen fuel. These materials are being tested as ambient condition, high-volume hydrogen storage matrixes.

Benefit The market for this product would be enormous. Present market targeted is gasoline burning engines in commercial and non-commercial vehicles. Hydrogen could replace petroleum, coal, natural gas, and other polluting fuel sources.

The Industry Partnerships developed by CAMMP are primarily domestic, but can include international partners, reflecting the worldwide market place. This will build a strong base for technology development. Graduate students and postgraduates, as well as undergraduates, will be educated in the latest technological developments from a product-oriented prospective. These products (and/or process improvements) will often be so-called "leap-frog" technologies; that is, products or innovative processes that will replace existing products or processes and, in so doing, capture market share. All research performed is based on products identified for specific markets. Industry, through CAMMP's Board of Directors, directs the research and development activities based on potential product/process discovery and development.

FY 2001 has been a good year at CAMMP. With respect to each of our objectives CAMMP has met or exceeded all of our objectives for FY 2001.

Objective 1: CAMMP has helped in the development of control system and scenarios with Intek Inc. (a CAMMP partner) for use on ISS (IZECS/ZCG-FU) for zeolite crystal growth, which has expanded and enhanced Intek's competitive edge in flow controllers and space hardware development. In addition, the production of nano-crystals (jointly patented with Dupont and the University of Connecticut) for detergent use is potentially a major benefit to the commercial detergent market (the patent at present is being applied for).

Objective 2: CAMMP has eight full-time Industry Partners. Every member who has joined CAMMP has maintained its relationship with CAMMP. Our product portfolio consists of nano-carbon tubes and zeo-type materials for ambient condition hydrogen, self-assembly zeo-type films for sensors, new catalytic materials, and meso-porous materials for film stabilizing. This is a good indication of the esteem with which CAMMP researchers and students are held. At present, CAMMP is negotiating (intellectual property) with both Boise Corp. and A. D. Little to join CAMMP's research team to develop innovations in fuel cell technologies.

Objective 3: At present, all CAMMP partners demonstrate their commitment with cash and in-kind funding support of operations at CAMMP. CAMMP researchers are presently developing two additional (in addition to the recently applied-for Dupont patent) patent applications.

Objective 4: CAMMP researchers have published, or had accepted for publication, eight papers in archival journals, seven refereed conference proceeding papers, and ten formal technical presentations at national and international meetings, including two distinguished lectureships (the Eyestone lectureship at Kansas State and an International Astronautical Federation Invited lecture in Rio de Janeiro, Brazil). These covered areas ranging from nano-crystal technology to software. In addition, CAMMP has filed its first patent with Dupont and the University of Connecticut on the production of zeolites A nano-crystals for use in detergent.

Objective 5: CAMMP has funded 21 graduate students (graduating eight with Masters degrees) and funded two co-op students (undergraduates) and two honors students (undergraduates). In addition, CAMMP researchers have trained three post doctorial fellows during FY 2001 and had a faculty member from Worchester Polytechnic Institute do a one-year sabbatical at CAMMP. In addition, researchers from several of our Industry Partners regularly do research work in partnership with the CAMMP staff, and are trained by CAMMP in many new techniques of crystal growth.

Objective 6: CAMMP put on a four week "real laboratory experience" for eight elementary and high school teachers in order to excite them about bringing Space Research into their classroom. The STARS (Stimulating Teachers in Academic Research through Space) was funded through NSF, NASA, and MIT and produced eight modules to bring crystal growth into the classroom. The educational levels were second grade through high school honors programs. In addition, the work done by the teachers was incorporated into one submitted journal article and formed the bases for some decisions on ISS pre-flight operations.

In FY 2001, CAMMP has built and qualified two computer controlled and tele-science furnace systems for crystal growth. Associated with this development, CAMMP has trained one shuttle crew and three ISS crews to help with science duties on orbit. To meet orbit crew time restraints, CAMMP developed new crystal growth strategies and developed and automated "mixing" techniques to meet our Industry Partner's needs.

CAMMP's projects cover the use of advanced technologies and materials to change the way cars will be powered in the next decade, on how chemicals are produced, films are processed, and on how to accurately monitor and control materials at the part per billion and trillion levels. These projects are presently at various stages of development, some being patented (on spin off technologies) and some at the early stages of development (ambient condition hydrogen storage).

The Center for Biophysical Sciences and Engineering (CBSE) partners with pharmaceutical/biotechnology industries, enhancing their drug development capabilities by using the Center's ground- and space-based technology platforms. The CBSE has three overall goals: 1) to partner with industry using structure-based drug development methodology and when needed, microgravity crystallization to develop new pharmaceuticals for chronic and infectious diseases, 2) to explore structure/function relationships of biological macromolecules, and 3) to foster collaborative interactions between faculty and students. The CBSE consists of 152 scientists, engineers, and support staff with backgrounds as outlined below:

Science

Cloning and Expression
Protein Purification
Crystal Growth
Structure Determination
Structure-Based Drug Design
Structural Energetics
Medicinal Chemistry
Structure-Directed Combinatorial Chemistry
High-Throughput Screening
Assay Development
Preclinical Trials (in-vitro and in-vivo)

Engineering

Design
Mechanical
Stress Analysis
Software
Electrical
NASA Documentation/Certification and Testing
Precision Machine Shop

The Center's Industry Partners in FY 2001 included: 3-D Pharmaceuticals, Atlantic BioPharmaceuticals, ANALIZA, Inc., ArQule, Inc., Athersys, Inc., Bede Scientific Instruments, Inc., BioCryst Pharmaceuticals, BrazSat, Bristol-Myers Squibb, Bruker, Diversified Scientific, Inc., Eli Lilly and Company, GlaxoSmithKline, Ibbex, Johnson & Johnson, Oceaneering Space Systems, Oculus Pharmaceuticals, Inc., Pfizer, Schering-Plough Research Institute, SPACEHAB, Inc., The Upjohn Company, Vertex Pharmaceutical, and Virtual Drug Discovery, Inc. The Center's faculty currently are involved in 30 grants from the National Institutes of Health (NIH), NASA, foundations, and industry, all of which involve structural biology and/or drug development research. FY 2001 yielded 22 research papers published in peer-reviewed journals, 21 presentations at national and international meetings, and four new commercial affiliates of the Center. The CBSE currently has 15 students working on Ph.D. degrees in graduate programs with structural biology as the main emphasis of their research.

In October 2000, the CBSE was chosen as one of NIH's seven National Centers for High-Throughput Structural Proteomics, providing $2.0 million a year for five years. The purpose of NIH's commitment is to support the development of new technologies in molecular biology and high-throughput protein expression methods, crystallization, and structure determination to enable researchers to perform high-throughput crystallography. These capabilities, combined with the completion of the sequence of the human genome as well as the genomes for dozens of bacteria, viruses, and other species make it possible for the CBSE to consider the determination of the 3-dimensional protein structures of entire genomes. This information will provide a powerful capability for understanding functions for these biological molecules. Furthermore, it will provide key information for the development of new pharmaceuticals for chronic and infectious diseases. Microgravity has aided the CBSE by providing higher quality crystals from which the atomic arrangement of key proteins can be mapped.

The CBSE has fostered the formation of four biotechnology/pharmaceutical companies. CBSE's first spinoff, BioCryst Pharmaceuticals, Inc., is a publicly traded pharmaceutical company focused on therapeutics in cancer, cardiovascular afflictions, and infectious disease. BioCryst currently has new pharmaceuticals in phase I, II, and III human clinical trials.

During FY 2001, the engineering division of the CBSE completed the first flight of the High Density Protein Crystal Growth (HDPCG) hardware, as well as the modifications of the Commercial Refrigerator Incubator Module (CRIM) fleet to qualify them for flight on the International Space Station (ISS).

Case Study

Challenge It is extremely difficult to produce protein in sufficient supply for the thousands of crystallization screenings necessary to produce diffraction-quality crystals.

Importance If a sufficient supply of all proteins in the human genome were available, it would revolutionize structural biology and accelerate drug design for most chronic and infectious diseases.

Solution Diversified Scientific, Inc. (DSI) works with CBSE scientists and engineers to commercialize new crystallography technology originally developed in the CBSE. In the past year, DSI has commercialized the following CBSE technology:

- DC-PCG—a dynamically-controlled protein crystallization system.
- CrystalScore™—an image acquisition and data analysis system.
- NanoScreen™—a fully automated high-throughput crystallization system that prepares 800-protein crystallization experiments per hour with experiment volumes as low as 15 nanoliters.

These three technologies were exclusively licensed to a new CBSE spinoff, Oculus Pharmaceuticals, Inc. With exclusive use of the NanoScreen™ system, Oculus is the only company in the world that can crystallize and determine structures of proteins using less than 300 micrograms of protein material. NanoScreen™ represents a significant technology breakthrough that is of tremendous value in the field of structural biology and structure-based drug design. The combined technologies licensed into Oculus, plus the capabilities of the CBSE, attracted a premiere genomics company, Athersys, Inc., to form an exclusive partnership with Oculus and the CBSE. Athersys is the only company in the world that can provide microgram quantities of any human protein. Oculus is currently raising its first round of private funding (it is expected that they will raise $10M with an additional $5M contributed by Athersys). Oculus will pay for the CBSE's ISS microgravity services for improved crystallization for several hundred different protein crystals. The CBSE is positioned to accommodate Oculus' needs with its latest commercial microgravity crystallization system, Commercial Protein Crystal Growth (designed, fabricated, and qualified by CBSE engineers). The system can accommodate 1,008 crystallization experiments in one EXPRESS Rack locker.

Benefit The CBSE's technology and scientific expertise in structure-based drug development has led to the formation of an exciting new pharmaceutical company, Oculus Pharmaceuticals, Inc., as well as an exclusive partnership with a premiere genomics company, Athersys, Inc. This partnership will have an additional strategic advantage in that Oculus will be able to improve their success rates by growing crystals on the ISS using the CBSE's high-throughput crystallization system, CPCG.

The mission of the Center for Commercial Applications of Combustion in Space (CCACS) is to work with industry to bring the benefits of space research down to Earth in the design of new and improved combustion-related products and processes. It accomplishes this through research and education in all scientific areas related to combustion, with a special focus on those areas where the results can be applied to the development of commercial products and processes and where the research can benefit from the unique properties of space. CCACS product focus areas include new combustors for improved efficiency and emissions characteristics in gas turbines, industrial process heating, and home heating and cooking; inorganic ceramic membranes for pre-combustion gas separation and purification; fine water mist fire suppression technology for replacement of Halon aboard ships, aircraft, and spacecraft; combustion synthesis of advanced porous materials for application in high-temperature filters, insulation, catalyst supports, and bone replacement; flame synthesis of oxide and non-oxide ceramic powders for making high-value ceramic components for the automobile and electronic industries; and sensors for diagnosing, monitoring, and controlling combustion processes.

FY 2001 marks the fifth anniversary of the founding of CCACS. It has been a year of solid building and growth, which included a doubling of non-NASA cash revenues. This represents the largest one-year increase ever in non-NASA revenues for the center. In addition, there were new developments at the Colorado School of Mines (CSM) that strongly support the center's long-range plans.

A comprehensive long-range plan for CCACS was completed during FY 2001. The overall plans are to continue building CCACS with funding growth to above $5 million over the next few years and to establish it as the top combustion center in the United States. Program trends during this period will stress further consortium building, increased flight activities, and added focus on biotechnology companies, particularly those engaged in orthopedic implant research in Colorado. The most recent development is a bioengineering consortium formed in partnership with BioServe Space Technologies at the University of Colorado at Boulder. This new consortium will consist of companies manufacturing bone implants and associated devices and materials. CCACS will concentrate on the biomaterials development while BioServe will work on the biomedical aspects. Hewlett-Packard and Sulzer Medica are the first companies to join the consortium. Other companies targeted for the consortium include Chiron, Wright Medical Technologies, Biomet, Inc., Zimmer, Inc. (a subsidiary of Bristol-Meyers Squibb), Johnson & Johnson, and Smith & Nephew Orthopedics, Inc.

Flight hardware for both Shuttle and International Space Station (ISS) continues to come together, as well as the new Payload Development and Operations Facility (PDOC) in the CCACS headquarters. The first CCACS Space Shuttle flight is scheduled for June 2002 and the first flight to the International Space Station to install SpaceDRUMS™, a major CCACS ISS facility, is scheduled for January 2003. All of the CCACS milestones for FY 2001 were achieved as the Center moved closer to flight phase in two of its projects and toward commercialization in all of its projects. The Shuttle hardware is currently on-dock at Kennedy Space Center (KSC). The Water Mist Experimental Mounting System (WMEMS) will be inserted into the Combustion Module CM–2 for flight on STS–107. SpaceDRUMS™, the containerless processing system to be used for combustion synthesis of glass-ceramics and porous ceramics, is on schedule for launch on ULF–1 in January 2003.

The new developments at CSM include the introduction of a biomaterials option within the Materials Science M.S. and Ph.D. programs and the beginnings of a Bio-Engineering and Life Sciences (BELS) thrust throughout the school. These developments were prompted in part by the CCACS activity in biomedical applications of materials produced by combustion synthesis, but they also build on work going on in other departments on campus and they present exciting opportunities for growth of the CCACS research into new areas. This development has also moved the institution into a strong position vis-a-vis the state's other major institutions of higher education; namely, Colorado State University, the University of Colorado at Boulder, and the Colorado University Health Sciences Center, by complementing their strengths in biomedical areas.

In order to accommodate the increased activity and personnel, CCACS will move into a new CSM general research building in August 2002. CCACS will occupy half of one of the three floors in the building, approximately doubling the space currently available for payload development and operations, offices, and central CCACS laboratories. The new quarters have been designed to provide high-quality space for research related to flight hardware development, in addition to facilities for final assembly of the hardware. There will be special areas for combustion, materials synthesis, and biomaterials research, complete with fume hoods, hazardous chemical storage, and clean rooms. The mission control and student work areas will be expanded and office space will be provided for research faculty and postdoctoral associates. The CCACS spaces will be just off the main public entrance to the building to enhance visibility. A large conference room, adjacent to the CCACS headquarters, will provide space sufficient for all the Center's meetings and workshops. These new spaces represent an approximate $1.5 million in-kind contribution to CCACS by CSM.

Case Study

Challenge Today's bone implants, primarily stainless steel and titanium alloys coated with various biomaterials designed to promote attachment of the natural bone, are unsatisfactory in many cases. They often wear out, loosen, and need to be replaced. Bone loss around the implant is also a significant problem. New implant materials are needed.

Importance It is estimated that 40 million people who are alive in the U.S. today will need some degree of bone repair or replacement over the next 20 years. The market for hip implants alone is in excess of $7 billion annually and is growing at a rate of 8% a year.

Solution Develop bone implant materials that are strong, biocompatible, and bioactive; i.e., that actively promote bone in-growth. Porous ceramics produced by combustion synthesis show strong promise of fulfilling this need.

Benefit Porous ceramics synthesized on Earth sag under the weight of gravity while they are still in a molten state, creating flattened and elongated pores. While these pores are similar to Haversian canals in normal cortical bone, the ceramic's structure is not mechanically capable of providing initial bony fixation and encouraging continued bone in-growth. The same materials synthesized in microgravity show more spherically shaped pores of sizes giving materials greater overall strength. Research in microgravity may yield the capacity to combine these pore morphologies to create a new class of non-uniformly porous implants with the associated bioactivity and structural mechanical properties that better mimic the physiologic functions of the bone they replace. By studying how these materials form in microgravity, CCACS researchers and their Industry Partners, including Guigné International, Ltd., Hewlett-Packard, and Sulzer Orthopedics Biologics, hope to gain new knowledge that will be invaluable in producing these materials commercially here on Earth.

The Center for Satellite and Hybrid Communication Networks (CSHCN), a NASA Commercial Space Center, experienced a very productive year in 2001 in its collaborative research and commercialization projects with industry and government. The CSHCN research emphasized Internet-like networks over wireless media including satellites and in particular new results for broadband networks. In addition, during 2001, increasingly greater emphasis has been placed in the distribution of multimedia information over hybrid communication networks. This has led to many challenging design problems involving the joint design of the communication network and the information distribution scheme. In addition, the CSHCN increased its efforts in characterizing and modeling multimedia traffic on the Internet over satellite services. The CSHCN has been asked, and accepted, by the Satellite Division of the Telecommunication Industry Association, to lead a technical working group to define standards for Internet traffic metrology and modeling, security, reliable multicasting, on the Internet over satellite systems.

The CSHCN faculty and staff held some 40 meetings with industry partners to brainstorm on research addressing industry problems, review progress on projects, demonstrate implementations and prototypes and develop further commercialization plans. Some 30 meetings were also held with researchers from government laboratories to review progress on military communication networks, the development of Internet-like networking for NASA and NASA missions, and the use of commercial satellite and hybrid telecommunication networks for both needs. Some 20 graduate students from the CSHCN held internships during the summer of 2001, at industry partners' facilities, continuing their research, implementation and commercialization efforts there. The Industry Advisory Board (IAB) of the CSHCN met twice to review progress and define direction and research priorities. The Industrial Affiliates Program (IAP) of the CSHCN included the following companies: Verizon, Boeing (BM), Ericsson, Hughes Network Systems (BM), IBM, Lockheed Martin Corporation, Lockheed Martin Global Telecommunications (BM), Motorola, Orbital Sciences Corporation (BM), Philips, British Aerospace Engineering, Space Systems Loral, Tektron, Telcordia (BM), Telesystems, TRW, and U.S. Sprint. The designation BM denotes companies with members in the IAB.

The CSHCN continued its long record in graduating outstanding students to fulfill the manpower needs of US telecommunication industry in the challenging area of networking. Some eight students completed their Ph.D. theses, and some sixteen students completed their M.S. theses, and went on to careers in industry and academia. Four of our new Ph.D. graduates went on to faculty positions at major US research universities, while four others went on to key positions with leading industry R&D laboratories.

In commercialization work and transfer with Hughes Network Systems, the product focus is on Fast Internet over Satellite and, more specifically, with the transition from the DirecPC™ product line to the much faster Spaceway™ Internet product line. DirecPC™ is HNS's satellite Internet service that provides up to 400 Kbps Internet access. Hughes' Spaceway™ will provide high-speed bandwidth-on-demand satellite communications in 2003 for multimedia at rates between 16 Kbps to 6 Mbps.

In commercialization work and transfer with Lockheed Martin Global Telecommunications (LMGT), the product focus is again fast Internet over satellite and, more specifically, the Astrolink satellite constellation. The Astrolink system is a global satellite communication system being designed to provide broadband data and multimedia services directly to the user terminals with transmission speeds up to 20 Mbps and download speeds up to 220 Mbps. Deployment of the Astrolink system and services is scheduled for 2003. The work and commercialization efforts of the CSHCN focused on two critical problems for these satellite networks and services: traffic modeling for voice, audio, video, streaming, Internet for network dimensioning, and secure and efficient multicast over satellite. In the first area, the CSHCN developed various traffic models for LMGT as well as methods for fitting these models to traffic traces. In the second area, the CSHCN is modeling and evaluating various multicast schemes as well as transferring some of its inventions on multicast security and key management to LMGT for commercial deployment in Astrolink and other networks.

Lockheed Martin (the parent company of LMGT and Astrolink), a founding partner of the CSHCN, has invested to date over $1.3 billion in the Astrolink system. The market for this system includes both consumer and corporate segments and its size is estimated at 1–2 million users initially, while rapid growth is anticipated subsequently. Industry contact for these advances and contributions by the CSHCN is Roger Mancuso, Chief Technical Officer, Lockheed Martin Global Telecommunications, (301) 897–6379.

These technical and commercialization efforts are in direct relation to the commercialization of the ISS. More specifically, the CSHCN continued to lead in joint efforts with NASA and industry for the design and development of alternatives for the use of commercial GEO and LEO/MEO satellite constellations for the communication needs of various NASA missions and the ISS. Current implementation includes two paths: Place a Ka band payload on the ISS for commercial high data rate (HDR) service to and from the ISS and also use it for interoperability experiments between satellite and terrestrial broadband networks for the SatCom industry. In this context the CSHCN has collaborated closely with NASA Glenn and NASA Goddard field centers. The CSHCN is also seeking commercial partners with interest in investing in these ventures and has initiated and promoted the development of a European commercial-government consortium towards the same goal. In addition, the CSHCN has organized a panel discussion on this topic to promote these ideas and activities in the ISS Commercialization Conference, October 15–19, 2001, in Florida.

The CSHCN worked closely with HNS engineers on two other projects addressing critical subsystems of next generation Ka band satellites. The first was the development of an intelligent system for monitoring Ka band satellites. The technology was transferred to HNS for inclusion in the Spaceway™ system. The CSHCN developed adaptive systems for retrieving, storing, assessing, processing and monitoring statistics. More specifically the CSHCN developed and implemented a JAVA-based integrated scheme, and a native code-based efficient API. Industry contact for these advances and contributions by the CSHCN is Mike Skeith, Vice President, Hughes Network Systems, (301) 428–5549. These technical advances are also applicable to NASA spacecraft monitoring and this is pursued in discussions with NASA Goddard engineers.

The second project focused on the development and design of schemes for dynamic power and burst scheduling in Ka band satellites. Rain attenuation and schemes to provide robust performance under all weather conditions are critical for the commercial success of Ka band constellations. The CSHCN conceived, developed and designed a fast (12 ms), fair (no service missed) and efficient (100% antenna, 99.8% power utilization) scheme for dynamically and adaptively (to rain fall and traffic demand) scheduling the power allocated to the various beams and the packet bursts, for rain areas from 2% to 18%. Industry contact for these advances and contributions by the CSHCN is Mike Skeith, Vice President, Hughes Network Systems, (301) 428–5549. These technical advances are also applicable to NASA HDR missions, satellites and spacecraft.

The commercialization value of the CSHCN contributions is reflected in an example statement from Mike Skeith, Vice President with the CSHCN partner HNS. “The size of the satellite networks we are developing requires highly intelligent network management systems. The use and complexity of today’s satellite networks makes this essential. In collaboration with the Center for Satellite and Hybrid Communication Networks (CSHCN) we are developing highly adaptive monitoring systems targeted for our next generation satellite networks. There is a high degree of alignment between the research of the CSHCN and the commercial objectives of HNS in this area. The results will be included in the management systems or in our products in the near future. The participation and work by the CSHCN researchers has been indispensable towards this goal.”

Case Study

Challenge Given the difference in capacities between fiber optic and satellite networks, how can the advantages in adaptive connectivity and bandwidth reuse of satellites be exploited to provide competitive broadband communications via next generation Ka band satellites to mobile users including astronauts on orbit? More specifically how can scalability to millions of users be achieved and how can Internet operations become “satellite friendly”?

Importance The need for broadband access for multimedia communications is increasing and demand for Internet over satellite services increased by 500% worldwide. Applications where satellites excel include “push” information services, telemedicine, emergency and disaster relief, streaming video and audio distribution worldwide, broad connectivity of mobile users, environmental data collection and monitoring, and broadband communications to the ISS and NASA missions. Establishing satellites as viable interoperable nodes in the Internet can provide efficient and less expensive solutions for many users worldwide. Such systems can also be used to effectively combat the so called “digital divide.” HNS, a founding partner of the CSHCN, has invested to date (or projected) over $1.5 billion for DirecPC™ and over $2 billion for Spaceway™. The market size for DirecPC™, is over 100,000 users, growing by nearly 1,000 users per week, expected to reach 1 million users with the new (launched in 2001) HNS/AOL two-way satellite system. The market size for Spaceway™ is much larger, projected at 1–2 million users initially.

Solution Working with Hughes Network Systems, the CSHCN focused on two critical problems. The first is the design, analysis, development and prototype of advanced Multiple Access Protocols for the return satellite path that combines fixed and dynamic bandwidth allocation so as to provide all-satellite (two way) systems scalable to millions of users. The second is the design, development, prototype and testing of “satellite-friendly” Internet applications such as HTTP, TCP, etc. Both tasks address principal needs for the next generation of Ka band commercial satellite constellations. In addition the CSHCN developed an improved reliable multicast scheme using “air cache” (an CSHCN invention) that resulted in 4-fold improvement in performance and further improved an adaptive hybrid (broadcast-unicast) data delivery scheme which increased scalability by 2 to 3 orders of magnitude.

Benefit These technical developments were critical in products that established HNS as a world leader and pioneer in Internet over satellite business systems. These technical and commercialization efforts are in direct relation to the commercialization of the ISS. More specifically the CSHCN continued to lead in joint efforts with NASA and industry for the design and development of alternatives for the use of commercial GEO and LEO/MEO satellite constellations for the communication needs of various NASA missions and the ISS.

Case Study

Challenge How does one control the high-speed rotor of a flywheel energy storage system?

Importance Energy storage has long been the Achilles Heel of spacecraft power systems. Batteries, the only current option for long term energy storage in space, have many features that limit life and performance. A flywheel system operating at greater than 60,000 RPM would match a battery in energy storage density, without the life limiting electrochemical mechanisms. In addition, flywheels provide the basis for an integrated satellite energy storage and attitude control system, which would save considerable mass and volume on a satellite. The main roadblock to achieving this performance in a flywheel system is the inability to monitor and control the position and behavior of the flywheel rotor.

Solution Develop a monitoring and control system, based on non-contacting sensors and controls, that will allow the flywheel rotor to operate in a safe and efficient manner. Use magnetic field measurements and innovative feedback loop algorithms to monitor and adjust the position and behavior of the rotor.

Benefit A flywheel energy storage system would help long-duration space missions, and may also provide an innovative solution to the electric car problem.

The Center for Space Power (CSP) conducts research and educates students in scientific areas related to energy generation, storage, and distribution, as well as thermal management. While our 2001 program focused on NASA technology needs, we are in the process of shifting to focus on the development of commercial products. Even in the NASA technology needs mode, the CSP works with industry to bring the benefits of space power technology development to commercial applications.

FY 2001 has been a year of steady progress for the CSP, in which our ongoing projects met milestones on or ahead of schedule. Many of the longer term projects underway are beginning to show positive, signifcant results, which should be ready for transition to industrial products in the near future. The CSP funded 24 graduate and 9 undergraduate students, together with 6 postdoctoral and research staff. Center staff and students published 47 papers, 32 of them in refereed journals.

CSP industrial partners in FY 2001 included Boeing, TRW, Advanced Modular Power Systems, Thermacore, US Flywheels, and Lockheed-Martin. Each of these companies has an interest in commercializing products based on CSP projects. We also worked closely with Glenn Research Center, the Jet Propulsion Lab, and Johnson Space Center (JSC) on specific technologies of interest to their mission needs.

Phase separator activity continued on several fronts, including work with Boeing on helium separation associated with zero gravity propellant transfer. Work also continued with JSC on applications of Texas A&M's phase separator to life support recycling needs.

The ilmenite project made a significant discovery in finding that it may be possible to make the material emit blue light. They are working to confirm the blue light emission, and determine whether it is strong enough to warrant commercial development as a blue Light Emitting Diode (LED). This would be beneficial to a variety of applications, especially data storage. Replacing red LEDs with shorter wavelength blue LEDs would allow the amount of data stored on a CD to be quadrupled.

Alkali Metal Thermal to Electric Converter (AMTEC) technology continued to meet critical milestones for the Advanced Radioisotope Power System program. Refractory metal cells continued to meet or exceed performance targets. Advanced electrode work moved ahead, with improvements in fabrication and testing methods. Commercial activity increased significantly, with CSP supporting Advanced Modular Power Systems in a design and test effort to evaluate the commercial viability of a specific AMTEC application.

Magnetic bearings continued to improve the performance and reliability of its control and sensor technologies, which enabled a prototype flywheel to achieve 60,000 rpm rotor speeds in a

configuration useful to ISS for the first time. Commercial efforts moved forward as well, with progress being made in adapting the magnetic suspension technology for use in military vehicles and locomotives.

Multi-quantum well photovoltaics development continued to run slightly ahead of schedule, demonstrating the ability to fabricate Si-barrier-Si and Si-barrier-Si-barrier-Si devices. Considerable progress was also made in measuring the electrical properties of the devices, as well as modeling the behavior of the quantum wells in a solar cell configuration.

Multichip module cooling work pressed on towards the target of a demonstration of actual heat removal from a chip, as opposed to the temperature leveling seen in current chip thermal management approaches.

Lithium battery work expanded into the low temperature regime, in support of Mars exploration, with experiments to measure the performance of lithium battery electrodes and electrolytes at –40 ^{o}C. Research continued to focus on the solid electrolyte interface, particularly with the anode.

DC-DC converter development continued to focus on the development of modular DC-DC converters with zero voltage switching and bi-directional power flow capability. This work will feed into the Power Electronics Building Block work underway for the International Space Station, offering smaller volume, lower mass transformers with improved reliability and lifetime.

Two new projects were initiated this year, a Stirling alternator project to support the Advanced Radioisotope Power System program, and a microencapsulation project to commercialize JSC's work on microencapsulation for drug delivery.

Case Study

Challenge Develop a new oxide-type layer that would lead to development of a practical SiC (silicon carbide) MOSFET (Metal Oxide Semiconductor Field Effect Transistor) switch.

Importance SiC has many desirable attributes and creation of an easily controlled switch would open a huge market replacing silicon-based MOSFET devices.

Solution An easily deposited mixed oxide was developed in collaboration with Vanderbilt University that reduced harmful defects by an order of magnitude and improved switching performance.

Benefit Faster switches able to carry more power and reduce energy consumption of power appliances.

The Center for Space Power and Advanced Electronics conducts research and technology development in the broad area of Hyper-Electric Vehicles. In doing so, they exploit and develop the latest advances in high-performance electronic devices such as SiC (silicon carbide) and SiGe (silicon germanium), leading electronics packaging technologies, reliable, modular power supplies and a range of energy storage technologies. The Center works collaboratively with Industry Partners and government agencies to develop products that may reach commercial success.

FY 2001 has seen a major focus on developing technologies that may benefit NASA missions in extreme environments. SiC is an emerging material that has the promise of stable operation at temperatures above 350 °C. Its main strength lies not only in this high temperature capability but also in its ability to effectively switch high voltages and currents. However, this switching capability had not been achieved in MOSFET-type (Metal Oxide Semiconductor Field Effect Transistor) devices until advances made in this program. First, a new process for depositing a mixed-oxide layer has reduced harmful defects in the layer hence enabling rapid switching.

Secondly, manufacturing process innovations that create graded junctions have increased the yield of devices as well as simplifying processing. Both aspects have attracted commercial interests. Additionally, the radiation stability of these devices has exceeded comparable silicon-based technology by several orders of magnitude in dose.

Manufacturing process development and test vehicle fabrication has been completed for United Technologies. The process included a number of area array packages including ceramic ball grid arrays, ceramic column grid arrays, plastic ball grid arrays, mBGAs, CSPs, and flip chip. The process that was developed included the use of reworkable underfill for improved reliability.

A procedure has been developed to fabricate 100 micron thick underfill encapsulant uniaxial tension test specimens that are dispensed and cured using the same conditions and equipment that is used in flip chip on laminate assembly. With the cast and cured samples, uniaxial stress-strain, creep and stress relaxation curves for underfills at several temperature levels have been measured. Such data are needed to ensure accuracy of finite element reliability simulations by NASA and its contractors and our Industry Partners.

Thermal cycle and thermal shock testing of chip resistors and transformers on printed wiring boards indicated serious reliability issues with the transformer solder joints.

The first study of proton irradiation on SiGe Heterojunction Base Transistor (HBT) circuits with monolithic passive elements has been completed. Three circuits that were chosen include a band gap reference circuit (precision analog), a voltage controlled oscillator [key Radio Frequency (RF) building block], and an LC (inductor/capacitor) bandpass filter (key RF building block). These three circuits have all proven to be robust up to very high proton fluences (5E13), thus paving the way for larger level system applications in space.

In another first, high temperature measurements (275 °C) were made on SiGe HBTs. Despite the fact that these narrow band gap devices are generally thought to be unusable at these high temperatures, these SiGe HBTs worked very well and their off-state leakage remained low and acceptable.

Center for Space Power and Advanced Electronics

Working with the Goddard Space Flight Center, quasi-3D models were developed for SiGe HBTs operating in digital circuits in order to aid understanding of Single Event Upsets (SEUs). This model explains unusual observations and is being used to aid in the design of SEU-tolerant circuits—a problem that affects most space vehicles.

Collaboration with the Center for Microfibrous Materials Manufacturing located at Auburn University has led to two important advances. The first is the production of nickel-carbon (Ni/C) supercapacitor electrodes that were included in the first space-rated package 30V, 5 Farad supercapacitors developed by Eagle Picher Technologies. LLC, in Joplin, Missouri, which can lead to space qualified supercapacitors. The electrodes were made using a semi-automated papermaking facility on campus. These Ni/C composite electrode supercapacitors are the first in the marketplace and are being examined by NASA and several companies for inclusion in applications that have high peak power requirements. Applications include high reliability electromechanical actuator systems that can replace hydraulic systems and hybrid electric vehicle drive systems.

The second collaboration with the Center for Microfibrous Materials Manufacturing was the production of a sample heat pipe wick made from microfibrous metallic fibers. These wicks were produced like sheets of paper, fired to form the metal matrix, then simply punched out to the proper dimensions and sintered together. The demonstration of near-net shape fabrication suggests cost reductions of five- to ten-fold over the cost of wicks produced by powder metallurgy. Interestingly, these new materials can be produced in a way that independently varies pore size and porosity. This enables many new applications for this tailorable material. In addition, catalyst or sorbent particles can be entrained within the stable matrix leading to improved electrodes for batteries or fuel cells, filters for harmful gases, and many other applications.

In collaboration with a potential partner, a lightweight compact ultracapacitor made from ruthenium oxide (RuO_2)as been demonstrated. This ultracapacitor was made using low-cost screen-printing technology. This printing approach can be tailored to many different shapes and sizes, as the application requires. The demonstration capacitor weighed 545 g, had dimensions of 4x4x2 inches and operated at 300 V with 0.05 Farad.

Such lightweight, high voltage capacitors open the door to higher power applications. This unique RuO_2 material was also supplied to a commercial capacitor supplier for inclusion in an advanced product for a large potential marketplace. The RuO_2 material provided superior performance and commercial viability of the product is under study.

Multidirectional composite flywheels offer the promise of higher speeds, Reliability, and energy density compared to alternative materials. Working with NASA Goddard Space Flight Center, a novel design concept was developed for composite flywheels using multi-direction reinforcement. This design increases the flywheel tip speed and enhances the energy density. Equipment to manufacture Multi-Direction Composite (MDC) flywheels has been placed in operation. This machine has a multi-axial motion control system and fiber tension system and will be used to fabricate flywheel rims with hoop and radial layers. MDC rims made on this machine will be tested to destruction to confirm the models. Flywheels are being developed as potential replacements for batteries in many satellite applications.

Case Study

Challenge	Help a small company bring to market a new space technology product with application to nearly all future commercial and government satellites.
Importance	Essentially every commercial or government satellite requires a subsystem to measure and control the satellite's attitude. A new star tracker technology that provides a low-cost, light-weight, highly accurate, and reliable attitude determination can satisfy the needs of nearly every satellite builder and therefore fill a significant market niche.
Solution	Leverage private investment from industry, the creativity of the Texas A&M Aerospace Department, and a flight opportunity from NASA's New Millenium Program to design, build, and fly a prototype of this high performance star tracker. A CSCE-led team is accomplishing this mission with an Industry Partner committed to manufacturing an advanced new commercial star tracker after the technology is demonstrated on an upcoming NASA New Millenium satellite.
Benefit	A U.S. company will manufacture a widely used space technology item that leapfrogs the competition, enhances the U.S.'s national economic position, and provides a low-cost solution for NASA, Department Of Defense, and commercial satellite builders.

Located at Texas A&M University, the Commercial Space Center for Engineering (CSCE) promotes commercial engineering research and technology development on the International Space Station (ISS). Our goal is to help industry use the ISS for their commercial purposes. Working with Industry Partners, the CSCE designs and builds commercial payloads that use external attach sites on the ISS as a space-based engineering testbed and as a platform for revenue-generating projects. The primary external sites available for industry on the ISS are the Express Pallets, specialized platforms mounted on the ISS truss. The Express Pallets provide a combined environment of microgravity, thermal cycling, and vacuum, which cannot be replicated in ground-based test facilities. In addition, the unique vantage point of the Express Pallets allows validation of communication and remote sensing technology before it is installed on costly constellations of orbiting satellites. These engineering research payloads, funded by commercial businesses, can also generate revenue for their sponsor while operating on the ISS.

The CSCE's strategy aims initially to help its Industry Partners decide whether the ISS opportunity fits their commercial need. During FY 2001, the CSCE and its Industry Partners conducted a number of joint concept definition studies to evaluate potential payloads. These studies include an assessment of the business rationale for performing a specific ISS-based test, a conceptual-level design of the payload, and a cost estimate—information that allows the commercial partner to decide on further investment in actual flight hardware. Key concept definition studies accomplished over the past year include:

- Commercial Imager (PetroSat, Inc.), an advanced hyperspectral imager for environmental assessments.
- Broadband Antenna Experiment (Harris Corporation), very high data rate communications downlink from ISS.
- Thermal Management Testbed (Boeing, formerly Hughes Space and Communications Company), an engineering demonstration of advance thermal management components and subsystems for future commercial satellites.

The CSCE formally managed each of these joint Industry/CSCE design efforts. During the study Industry Partners defined the technology they sought to test/demonstrate on the ISS. The Industry Partners also led development of the business case for the flight experiment. To generate a conceptual design, cost estimate, and performance summary for the payload, the CSCE provided all the space-related technical analyses and ISS-unique information. This CSCE input included derivation of the overall experiment requirements; systems engineering and solid modeling; thermal, structural, and orbital analyses; knowledge of the ISS safety and interface requirements; space envir-onment effects; and safety and operational requirements. The output of the completed concept definition study provides the technical and market information needed

Commercial Space Center for Engineering

for a formal business proposal, to upper management or a venture capitalist, to justify financial investment in the flight experiment.

During FY 2001, the CSCE significantly increased its ability to assist industry with design, fabrication, and testing of payloads for the ISS. We added two new work stations to our integrated design center and expanded our inventory of state-of-the art analytic design tools to perform structural, thermal, and orbital calculations that meet the highest aerospace industry standards. In addition, we began outfitting a 10,000 square foot university-provided facility with the equipment needed for testing and flight qualifying ISS payloads. This new Space Systems Integration Lab (SSIL) includes large and small vacuum chambers, cleanroom, environmental chambers, coordinate measuring machine, altitude chamber, EMI cage, and other space hardware test equipment. The SSIL will give our Industry Partners the ability to readily fabricate and test proof-of-concept hardware, engineering models, prototypes, and flight qualified payloads. Hardware fabrication and testing are essential steps in the cost-effective development of new spacecraft technology.

In addition to commercial payloads for the ISS, the Center also develops commercially sponsored technology and engineering payloads for the Space Shuttle. For example STS–107, a Shuttle flight scheduled to launch in spring 2002, will carry a commercial star-tracker prototype that was designed, fabricated, and flight qualified by the CSCE. In addition, the CSCE, an Industry Partner, and the Aerospace Engineering Department at Texas A&M have teamed up to develop a novel and highly capable star tracker to provide pointing information for a future NASA Earth observing satellite. Our Industry Partner, who is working closely with the CSCE, will use the information gained from this project and the shuttle experiment to complete the design of a unique new star tracker for the commercial market.

The CSCE understands and knows how to address the issues associated with palletized payloads, whether targeted for the ISS or for other space vehicles. Although the launch of the Express Pallet to the ISS has been delayed until 2005, early planning for Express Pallet payloads is invaluable, and a number of Industry Partners are currently in various stages of concept definition work with the CSCE. In addition, near term access to palletized space exposure is also available via Shuttle and other launch vehicles. The CSCE has the capability in place to work with industry to assess and prepare for a broad range of engineering and commercial activities in space.

The Consortium for Materials Development in Space (CMDS) at the University of Alabama in Huntsville (UAH) supports research in the areas of electro-optical and photonic materials, biotechnology, and the life sciences. Its commercial efforts are industry-driven and product-focused, and are oriented towards the use of the microgravity environment as an adjunct to ground-based research and development. In order to meet industry wants and needs, CMDS has expanded its scientific capabilities through the formation of strategic alliances with research centers at UAH, with universities other than UAH, and with NASA Science Centers. These partnerships have led to the successful recruitment of new Industry Partners, as well as progress in the development of a broad range of products. These include Organic Light Emitting Diodes (OLEDs) for flat panel displays, optical fibers made of heavy metal fluoride glasses for infrared transmission, DNA microarrays for the study of differential gene expression in bone diseases (e.g., osteoporosis), a novel drug delivery vehicle for bone targeting, potential new drug targets for treatment of breast cancer and osteoporosis, and isolation of proteins/factors that promote adult hematopoietic stem cell renewal and expansion.

In 1999, the CMDS underwent a complete restructuring and refocus, and is now beginning to reap the benefits of its investments in product development over the last two and a half years. The increase in industrial and other non-NASA support to CMDS-funded projects has resulted in an upward trend in the ratio of non-NASA to NASA funding, rising from less than 1:1 in FY 1999 to 2.5:1 in FY 2001. CMDS now supports 17 students, 21 research faculty and staff members, and four regular tenured faculty members, the largest personnel complement in the Center's history. CMDS-affiliated faculty and students published 21 papers in refereed journals, and made 34 presentations at various scientific conferences, meetings, and symposia.

CMDS Industry Partners supporting Center materials development projects in FY 2001 included Parvus Corporation, Durel Corporation (a joint venture of 3M and Rogers Corporation), Lucent Technologies/Bell Labs, Infrared Fiber Systems, Inc., Brimrose Corporation of America, Rice Systems, Inc. and Celeste Optics. Our Industry Partners for biotechnology-related efforts are Research Genetics (a division of Invitrogen), Shearwater Polymers (a subsidiary of Inhale Therapeutic Systems, Inc.), and Prototec, Inc. Preliminary discussions have also been initiated with a number of other biotechnology and pharmaceutical companies.

Significant milestones were achieved on all CMDS projects co-funded by industry, and steady progress has been made on proof-of-principle studies initiated during FY 2001. Biomineralization, the process responsible for bone growth and repair, is a major focus of research and development efforts. This project resulted in the development of our first commercial product, a DNA microarray for bone research. Produced and marketed by Research Genetics as the Biomineralization GeneFilters", this tissue-specific microarray provides bone researchers with an important tool for identifying the genes and, ultimately, the proteins responsible for bone growth, destruction, and repair. This information will be of paramount importance in the development of new therapeutics for treatment of bone diseases.

Another major accomplishment recorded in FY 2001 was the identification of two, and possibly more, protein targets for structure-based drug design. CMDS-affiliated researchers in the UAH Laboratory for Structural Biology (LSB) solved the crystal structure for the cell signaling protein, human tyrosine phosphatase sigma (PTPs). PTPs is expressed in a variety of human tissues, including bone, brain, and lung, and in the bone cell cancer, osteosarcoma. A class of drugs known as bisphosphonates used for treatment of bone diseases such as osteoporosis inhibit PTPs activity, suggesting that this protein is the putative target of bisphosphonate action. Solving the structure of PTPs provides an important candidate for new drug design. Additional proteins associated with the biomineralization process are now being isolated and will soon be crystallized for structural analysis.

Collaborating scientists in the Department of Pathology's Bone Cell Core Facility at the University of Alabama at Birmingham have isolated and characterized novel proteins that bind to the estrogen receptor (ER) and regulate its activity. The ER belongs to the nuclear receptor (NR) superfamily whose members mediate the developmental, metabolic, and physiological effects of steroid, thyroid, retinoid, and vitamin D1 hormones. Proteins that interact with both an estrogen-occupied ER and with each other may be of importance in developing strategies to design safer, more effective selective estrogen receptor modulators (SERMs), a new class of drugs for the treatment of hormone-dependent medical disorders such as breast cancer and osteoporosis.

A third biotech project in FY 2001 was a collaboration with a CMDS spinoff company, Shearwater Polymers. Although recently acquired by Inhale Therapeutics, Inc., Shearwater will continue their partnership with CMDS to develop candidate therapeutic proteins for use with their patented polyethylene glycol (PEG) drug delivery system. Other collaborative projects include further development and refinement of a bone-specific targeted drug delivery vehicle, as well as expression, production, and purification of lead compounds identified by Shearwater.

In FY 2001, CMDS participated in two flight experiments aboard the Space Shuttle. Protein crystallization studies were conducted on STS–106 and STS–98 Shuttle flights via a guest investigator program with Dr. Alex McPherson of the University of California at Irvine. Results from the experiments indicated that, for some proteins, significant improvement in crystal quality was achieved in microgravity. The capabilities of CMDS in structural analysis of proteins have been substantially increased by a

private donation of $3.75 million to UAH for the establishment of a state-of-the-art Nuclear Magnetic Resonance (NMR) Facility. An addition to the Materials Science Building to house 800 MHz and 500 MHz spectrometers is under construction. Once completed, the NMR facility will give UAH capabilities matched in the southern U.S. only by Duke University and the University of Georgia. Another recent development related to the structural study of proteins is the design and construction of a prototype for an automated protein crystallization cassette.

CMDS's leading commercial electro-optical and photonics materials project deals with the development of new methods for preparing multi-layer thin films of electro-luminescent organic materials. The thin films will be used for construction of OLEDS, which in turn can be employed for fabrication of opto-electronic displays. Potential products incorporating OLEDs include pagers, cell phones, personal digital assistants and other hand-held electronic devices, automotive dashboard displays, and watches. In collaboration with the Optical Sciences Center at the University of Arizona and Durel Corporation, CMDS is using its physical vapor transport technology and hardware to prepare thin films for evaluation in devices.

In addition to its commercial product development efforts, CMDS is building hardware for the ISS. The Space Product Development Experiment Module (SPDEM) will be employed for growing inorganic crystals for acousto-optical devices and for processing ZBLAN, a heavy metal fluoride glass. Physical vapor transport (PVT) and polymer thin film growth (PTFG) "ovens" are being developed for deposition of organic thin films for use in electro-optical devices. While the PVT and PTFG hardware have previously flown on Shuttle, both are undergoing modifications to accommodate both ISS and industry requirements. The PVT oven is also being redesigned for multi-layer thin film deposition of electro-luminescent materials for OLEDs.

CMDS, through the Laboratory for Structural Biology (LSB) at UAH, has developed education and outreach programs. In FY 2001, more than 350 students and teachers attended nine protein crystallization workshops conducted by members of the LSB. The LSB also organized and taught a practical workshop of Macromolecular Crystallizations at the Medical School of the University of South Alabama. A public relations campaign to increase the visibility of commercial research in the CMDS was initiated. This campaign led to CMDS being featured in a number of newspapers and magazines, and on television and radio shows. Particularly noteworthy were newspaper articles in *The Huntsville Times* and *The Birmingham News* (Alabama) on the collaboration with Research Genetics that led to development of the Biomineralization GeneFilters" microarray.

FY 2001 has been an outstanding year for the CMDS. Our first commercial product was introduced to the biotechnology market. Progress has been made in identifying novel targets for drug discovery, new materials processing methods are being developed that will allow further advances in the opto-electronics industry, and hardware is being built for ISS that will pave the way for product development in space. The commitment of our academic and Industry Partners will ensure the continuing development of CMDS and commercial research.

Case Study

Challenge To develop more effective drugs for the treatment of diseases such as osteoporosis, breast cancer, and uterine cancer.

Importance Loss of estrogen in postmenopausal women leads to a marked decrease in bone mass, as well as increased risks of both bone fracture and cardiovascular disease. In the U.S., osteoporosis, the medical condition resulting from estrogen loss, affects one in two women over 50. Although estrogen replacement therapy is effective in preventing loss of bone mass and protecting against cardiovascular disease, synthetic estrogen also increases the risks of breast and uterine cancer in these women. These increased risks preclude the widespread use of estrogen for treating many systemic ailments in the over-50 female population. The design of new drugs that mimic estrogen may alleviate many of the serious side effects associated with estrogen replacement therapy.

Solution Proteins that interact with the estrogen/estrogen receptor complex are thought to regulate the various biological effects resulting from estrogen-induced gene activation. The isolation, and functional and structural characterization, of these proteins will lead to a better understanding of estrogen receptor pharmacology. The proteins may also serve as new targets for the development of safer, more effective selective estrogen receptor modulators, or SERMs, for the treatment of hormone-dependent medical disorders.

Benefit The successful design and development of second generation SERMs that act in a highly tissue-specific manner could significantly reduce the incidence of osteoporosis in women, as well as help in the prevention and treatment of breast and uterine cancer in this at-risk population.

Case Study

Challenge How does one deal with the solid wastes produced on a long-duration space mission?

Importance Solid wastes will make up a large and growing portion of the mass of any long-duration space mission, just as they make up the contents of landfills on Earth. Since landfills and space-dumping are not an option, and would waste the resources contained within the wastes, another option is required.

Solution Develop a composting system that will operate without access to the air and other environmental systems of the spacecraft, so that the wastes can be reprocessed to provide nutrients, water, compost for plant growth, energy, and other resources that can be used and reused.

Benefit Not only could such a system help long-term space missions deal with the problem of solid wastes, but it may also provide new and innovative solutions to Earth-based waste disposal as well.

The Environmental Systems Commercial Space Technology Center (ES CSTC) is NASA's newest Commercial Space Center, having been in existence for less than a year. The mission of the ES CSTC is to lead a national effort in developing environmental systems technologies that meet NASA's needs for safe long-duration human space flight, while serving as a catalyst for commercial, terrestrial application of the technologies developed. The center is already working with Industry, academia, and NASA to advance environmental systems' technologies.

The center is managed by an experienced team that includes: Dr. John Warwick, Director; Dr. David Chynoweth, Associate Director for Technical Projects; Mr. Bill Sheehan, Associate Director for Commercialization; and, Mrs. Nancy Garland, Office Manager. This team is augmented by an External Technical Advisory Committee and a Commercial Advisory Committee.

In January 2001, shortly after it was established, the center selected and funded two projects to begin its mission of addressing NASA's needs in environmental systems and recycling:

Project 1: "Effectiveness of Photocatalytic Reactor System for Water Recovery and Air Revitalization in Long-Duration Human Spaceflight"
Principal Investigator: Dr. Chang-Yu Wu
Co-investigators: Dr. Jean Andino, Dr. Matthew Booth, Dr. Paul Chadik, Dr. Sam Farrah, Dr. Yogi Goswami, Dr. Ben Koopman, Dr. Angela Lindner, Dr. Dave Mazyck
Technical Focus Area: Air/Water

Project 2: "Anaerobic Composting for Recovery of Energy, Nutrients, and Compost from Solid Wastes During Extended Space Missions"
Principal Investigator: Dr. David Chynoweth
Co-investigator: Dr. Tim Townsend
Technical Focus Area: Solid Waste

Environmental Systems Commercial Space Technology Center

The response to the request for pre-proposals for these efforts was gratifying, and allowed external and internal reviews to proceed. Responses are anticipated to be provided to the Principal Investigators by November 2001. Efforts to involve industry and explore terrestrial possibilities are underway.

In addition to this work, the center has also hosted numerous visitors and media contacts. An article on the center, and its recycling technologies and efforts, is in development by Air & Space/Smithsonian magazine.

The center is off to a good solid start, and shows promise for rapidly matching the commercial and technical successes of the longer-established Commercial Space Centers. This important area of research holds much promise for long-term space missions, and for terrestrial environmental systems and recycling.

The mission of the NASA Food Technology Commercial Space Center (FTCSC) is to lead a national effort to develop foods and food-processing technologies that enhance space missions and advance commercial food products through cooperative efforts with NASA scientists and technologists, commercial companies, and academic researchers.

To accomplish this mission, NASA FTCSC is developing partnerships with commercial companies to meet the challenges of developing food systems for short- and long-term space exploration and habitation. Our Industry Partners commit research staff, facilities, and materials to specific product development projects that address the unique requirements of space missions and have application on Earth as well. Industry Partners share the experience of working on a national/international project and maintain patent rights to potential developments.

Among the unique requirements of space food systems are 1) low weight, mass, and energy usage; 2) minimum food product shelf life of nine months for the Shuttle food system, one year for the International Space Station (ISS), and up to five years for planetary outposts; 3) a food supply that will be heavily dependent on regenerable crop production (cabbage, carrots, chard, dry beans, lettuce, onions, peanuts, potatoes, radishes, rice, soybeans, spinach, sweet potatoes, tomatoes, and wheat); and 4) food-processing systems that operate in microgravity (e.g., the International Space Station) and reduced gravity (e.g., planetary and moon outposts).

The NASA FTCSC Industry Partners—Advanced Analytical Technologies, Inc.; Arla Foods amba; Hy-Vee, Inc.; Iowa Soybean Promotion Board; Kemin Americas, Inc.; Kraft Foods, Inc.; Maytag Corporation; Pioneer Hi-Bred International (a DuPont Company); and Rocky Mountain Resource Labs, Inc.—are addressing some of these challenges. To date, NASA FTCSC Industry Partners have committed $2.25 million in cash and/or in-kind contributions toward these efforts. To learn more, visit the NASA FTCSC Internet site at http://www.ag.iastate.edu/centers/ftcsc.

NASA FTCSC affiliate faculty members are conducting research in the following areas of food processing, food safety, and product development.

- Soybean processing—Developing soybeans with improved flavor that will increase consumption by astronauts. Researchers have also been evaluating the influence of storage/shipping conditions on the functionality of soy flakes in an effort to improve the shelf life of soybean-based foods for use on planetary and moon outposts.

- Soybean-based food products—Developing cheese-like products and to improve the shelf life and sensory properties of soybean-based food products for use during space travel and on outposts.

- Fresh fruits and vegetables—Improving the shelf life and safety of fresh-cut fruits and vegetables for consumption in space.

- Food safety—Developing pathogen-free ready-to-eat meats with improved shelf life for space travel.

- Meat products—Producing a more shelf-stable, safer pork product for space travel.

- Enzymes—Developing glucoamylase, an enzyme with an extended shelf life used for starch liquefaction to produce sweeteners for space travel. They are also isolating microbial consortia that exhibit an array of different extremozymes that will benefit biomass bioconversion to simple sugars for use on outposts.

- Value-added food products—Identifying value-added cornstarches and oils to be used in producing improved shelf-stable food products for space travel and researching degradable polymers to be used in packaging foods and clothing for space flight.

Case Study

Challenge To develop simplified techniques for refining soybean and peanut oils obtained from mechanical oil extraction for use on planetary and moon outposts.

Importance Vegetable oil purification—the removal of gum (phospholipids), free fatty acids, and primary and secondary oxidation products—improves the shelf life and flavor of oil for food applications.

Solution Mechanically pressed (extruded-expelled) oil is easier to de-gum than is conventional solvent-extracted oil. A simple water de-gumming process will produce oil with acceptable phospholipids for physical refining. The undesirable free fatty acids and lipid oxidation products that are odor-causing compounds can effectively be removed by physical distillation.

Molecular stills may provide a robust and effective way to remove the free fatty acids and other volatiles from oils. The unique features of a molecular still include compact size and high efficiency, short heat exposure time (which produces less oil damage and structural change), purging volatiles without the use of steam (which is needed in conventional physical refining), and versatility for use in fractionation of other liquid- and heat-sensitive materials. These factors make the molecular still an excellent multifunctional machine for use on long-duration space missions and habitation.

Benefit Good quality and minimally refined vegetable oil can be produced from space-grown seed and space-pressed oil by employing this new oil-refining technology. Similar seed-processing and oil-refining techniques are being developed. This low-cost and natural method of refining oils will benefit small-scale soybean processors who are looking for value-added opportunities for their identity-preserved soybeans.

The Medical Informatics and Technology Applications Consortium (MITAC) has had another tremendously successful year in supporting the evaluation and validation of telemedicine systems and technologies. Much of MITAC's work has been focused on international test beds in Ecuador and Russia, distance education, home health care, and supporting NASA's telemedicine needs. MITAC's overall strategic vision, "To explore new technologies in medical informatics and health care delivery systems that will revolutionize health care in space and on Earth," remains solid.

MITAC's mission statement is to "Establish partnerships with academic, industrial, and governmental entities dedicated to 1) the improvement of health care through the use of space science and technology; 2) the maintenance of U.S. competitive lead in commercial applications of medical informatics and telemedicine; 3) the development and application of innovative technologies that can be embraced by human space flight; and 4) the integration of communications, information systems, and electromechanical interfaces between patient and health care team."

The goals that will enable the vision and mission are 1) to establish partnerships with academia, industry, and other government agencies to leverage technology and broaden the concepts of telemedicine and medical informatics as well as develop novel technologies in the sensors, transmitters, effectors, and process simulators; 2) evaluate technologies, process, algorithms, and protocols in international and domestic testbeds; and 3) shepherd these technologies into products, services, and processes in terrestrial and space medicine.

MITAC explores partnerships with academic centers; industry such as Tyco-US Surgical, Microsoft, Oracle and Aventis Pharmaceutical; and foundations to leverage resources, technological advances and unique environments. These partnerships are evolving and may mature in the coming year.

MITAC's relationship with NASA Johnson Space Center (JSC) and NASA Headquarters, as well as other NASA centers, is collegial, interactive, and is focused on meeting the Agency's needs with respect to telemedicine activities. This relationship was enhanced through MITAC's organization and the conduct of one of a series of symposia at JSC to support medical operations' needs. This symposium was focused on Wireless Sensors and Distributed Computing. It was well attended by national experts in these disciplines as well as key personnel from JSC and NASA Ames Research Center.

Telemedicine Testbeds

The integration of telecommunications and information systems is of tremendous value to the practice of medicine and medical education. MITAC, through its many activities, utilizes new tools and nascent technologies in its test beds that help overcome the barriers of distance and time to delivery of health care. Just like in space, bandwidth can be a significant issue with regard to reliable, real-time and continuous communications. Terrestrial test beds permit an opportunity to evaluate and validate telemedicine and distance learning technologies.

The benefits of these test beds and their results to the commercial market are tremendous. Industry can utilize the lessons learned to adapt concepts from these field works that validate innovative technologies. MITAC has collaborated in several international test beds to validate and evaluate technologies as well as further understand cultural diversity in the practice of medicine.

Ecuador

The remote reaches of Ecuador, whether jungle, alpine or waterway, provides a unique testbed for evaluating technology in remote medical management, education, and clinical consultation.

During the past year, the Ecuador telemedicine testbed has embraced the concept of distant consultation and management using high-frequency radio transmission of patient records from the remote area of Taisha to Macas and then to the MITAC labs. Data has been collected on a MITAC-developed electronic medical record of preoperative surgical requirements. Additionally, a database on indigenous medicine has been established between 'modern' medicine and Shaman medicine. A Shaman, akin to the medicine man, utilizes plants as remedies for illness or injury. This information has been collected and categorized and will be transmitted by CD-ROM or via the Web to support telemedicine needs as appropriate. Finally, the concepts of distant management and mobile medicine have been extrapolated to a floating health care facility. An ambulant health care worker equipped with an Iridium™ phone was tracked in real-time using the Global Positioning System during a trip up a tributary of the Amazon River near the border of Ecuador and Peru. Readings of river conditions were taken and transmitted to evaluate possibilities for remote telemedicine endeavors by boat. This concept will permit mobile health facilities to be fully integrated with a health care schema, providing patients in extremely remote areas access to a wider spectrum of health care.

Collaboration continues with Cinterandes Foundation, Dr. Edgar Rodas, Dr. Juan Leon of the Clinic Luxemburg, Hospital San Jose of Taisha, and two medical students. All of which have participated in training in telemedicine through a MITAC-developed course in telemedicine.

Home Health Care "Going Home"

The Going Home project relates to the remote monitoring of diabetic patients within their home and requires the development or adaptation of numerous non-invasive sensors that are worn by the patient. These sensors allow the clinician to monitor a spectrum

of physiological variables that portray a trend in the patient's chronic ailment. To date, the following milestones have been achieved by MITAC.

MITAC has developed the VitalPoll™ (Provisional Patent), which functions as a data capturing port and is capable of relaying that dataset to a remote PC workstation with Bluetooth™ wireless technology. The workstation is capable of forwarding this data stream to the existing backend server at MITAC. Formal collaborative agreements are being setup with MiniMitter, iSTAT/ Abott Labs, ADT, and Roche Labs. The sensors provided by each of these vendors (glucometer, blood chemistry analysis package, heart rate, skin temperature, and activity monitors) have successfully provided datasets. The cumulative data packets are being converted by programmers into a uniform extensible markup language (XML) format for warehousing into each patient's folder within the backend server. Additionally, a prototype clammymeter has been developed and tested for the measurements of skin moisture and temperature. Currently, attempts are being made for miniaturization of unit and incorporation of wireless technology. A WebTV unit has been tested and is successful in linking up as a patient home outlet for connection to the web. This will serve as a portal for the patient. Collaborative efforts with the Virginia Commonwealth University (VCU) School of Engineering Center for Bioelectronics, Biosensors, and Biochips are continuing, with attempts to develop miniature biosensors for patient monitoring.

Commercial Development

MITAC has submitted 11 invention disclosures to VCU during the past year. These have all been licensed to OrbitalMed, a new start up company housed in the Virginia Biotechnology Research Park (VBRP). MITAC initiated the creation of the Virginia Biosciences Development Center (VBDC), a service oriented, non-profit company that could facilitate MITAC and other academic centers of excellence in creating commercial entities to spin out validated technologies from the laboratory. During the past year, the VBRP established the VBDC to serve as an incubator. The concept of this center was created by MITAC's goal of transitioning technology to the commercial marketplace.

Continuing Medical Education (CME); WWW-based

Currency of knowledge is vitally important to maintaining skills. The integration of communications into the education process provides unique opportunities for faculty and students from around the world to participate in educational courses in a variety of disciplines. Lectures and grand rounds are formatted using exciting new technologies on the Internet. These technologies include video streaming, WWW-based training, and CD ROMs. Educational material can be viewed throughout the world and enhances our ability to transition our knowledge to students of all ages. These technologies have been evaluated and validated. Practicing physicians seeking CME can visit the MITAC WWW site, register for the lecture, observe the material, pay for the hour(s) of CME through a graphical user interface, download the CME certificate (awarded through VCU), and post questions to the professor.

MITAC continues to train students in the principles and concepts of telemedicine. Mr. Charles Doarn, MITAC Executive Director, taught an honors course in telemedicine during the Spring Semester 2001 at VCU. Additional interaction includes medical students from Ecuador, Armenia, Georgia (former Soviet Republic), and physicians and computer specialists who are participating in the NASA-sponsored East-West Space Science Center. Dr. Ronald Merrell, Mr. Doarn, and other MITAC staff have traveled to many different conferences and countries to give guest lectures. These include Russia, Saudi Arabia, Ecuador, England, Moldova, and Egypt.

Case Study

Challenge Develop and validate the capability to view the surgical field (site) from some distance removed from an operating room using low bandwidth telemedicine.

Importance Traditionally, the operating room has been a closed environment. Physicians—perhaps in space—could be mentored with such a tool.

Solution MITAC partnered with Computer Motion, Inc. to evaluate the use of the Alpha port of the AESOP, a surgical robot linked between two sites with a low bandwidth connection. (MITAC was the first to demonstrate this).

Benefit Surgeons in the local operating room, and in the MITAC laboratory several thousand miles away, could interact in a bilaterally beneficial mode from a teaching perspective.

Case Study

Challenge Determine if, and at what point, hyperspectral imaging can detect the presence of healing human tissue.

Importance The wound care industry is a $2.57 billion industry that currently has no tool to objectively assess the status of a wound. Currently, physicians rely on their subjective assessment of the wound to determine whether a wound is healing or not.

Solution Use hyperspectral imagery to assess the efficacy of a prescribed treatment modality based on the presence or lack of healing tissue in and/or around the wound bed. If healing tissue consistently possesses unique spectral signatures, then hyperspectral imaging may prove to be a viable means for future wound assessment.

Benefit Accurate and objective wound assessment can result in faster patient healing and reduced costs. This would be especially true if hyperspectral imaging is able to identify healing tissue before the physician can see it, thus telling the physician whether he or she is using the correct treatment.

In FY 2001, ProVision Technologies continued to expand its base of Industry Partners and to explore potential commercial opportunities for using hyperspectral imaging in the biomedical, food safety, and forensic industries. Throughout the year, new intellectual property was generated and protected to provide a foundation for commercialization. A commercial opportunity for using the hyperspectral sensor on the International Space Station (ISS) was also initiated this year.

The food quality and safety program with Sanderson Farms and the U.S. Department of Agriculture developed algorithms that can detect contaminated chickens on the processing line with the birds moving at the operational plant speed of 70 birds per minute. Two patents were written and submitted that discuss the sensor and automated analysis for detecting unwholesome chickens. Stork Gamco, Inc., one the world's largest suppliers of poultry processing equipment, is very interested in this application as a possible new product line. Commercial discussions held with this company will be continued in FY 2002 along with additional technical developments.

A joint relationship with Memorial Hospital at Gulfport, Mississippi, accelerated the wound care program this year. ProVision Technologies positioned two employees and a hyperspectral system on a full-time basis in the hospital to capture and process spectral data acquired from wound care patients. Hyperspectral and medical data were acquired for each wound on a regular basis so that spectral information could be correlated with the wound healing process. The goal is to prove that hyperspectral data can be used to characterize and monitor the wound at various stages of healing using spectral properties obtained from the wound. This could support humans on long duration spaceflights and also on Earth to determine the efficacy of the prescribed wound treatment.

The Federal Bureau of Investigation (FBI) and ProVision Technologies conducted a pilot study to determine the utility of hyperspectral imaging for differentiating ink types. Encouraging results indicate the potential of using this technology in detecting altered documents, counterfeit money, and forged passports. An expanded program will occur in 2002 with funds and technical support obtained from the FBI. ProVision Technologies will place an employee and a hyperspectral sensor at the FBI Academy in Quantico, Virginia to conduct this work.

ProVision Technologies

ProVision Technologies commercialization roadmap includes the development of a suite of four hyperspectral sensors capturing electromagnetic energy from ultraviolet to thermal. All applied research conducted in FY 2001 was with our patented visible/near infrared sensor (450–900 nanometers). This year the short wave infrared hyperspectral sensor (1,000–1,700 nanometers) was designed and built. In FY 2002, this new sensor will be tested and applied in some of the market sectors discussed in this roadmap. Also in FY 2001, the ultraviolet hyperspectral sensor (200–400 nanometers) was designed and some hardware components were purchased.

ProVision's WWW site www.pvtech.org was upgraded during the year to reflect current programs. It also included a brief survey to gather additional data on the market for hyperspectral sensors.

An exciting commercial opportunity to use the International Space Station was initiated in the latter part of the year. The visible/near infrared hyperspectral sensor can be used in the Window Observational Research Facility (WORF) for Earth observations to support activities such as petroleum exploration, agribusiness, and mineral exploration. The manifesting process was started and ProVision Technologies initiated discussions with private sector companies who could potentially use the instrument in the WORF to support their businesses.

Case Study

Challenge Sand cores and molds are aggregates of sand and binder mixtures used to define the shape of many complex metal castings. The manufacturing processes used to produce cores and molds possess many variables and have stubbornly resisted engineers' attempts at quantitative understanding. GM Powertrain, a division of General Motors Corporation, came to the SDC with just such a challenge for a critical engine part.

Importance Foundries frequently have to develop core-making and molding processes by trial-and-error. This often leads to long development times, low manufacturing yields and reduced quality in the manufacturing process.

Solution Flow Simulation Services of Albuquerque, New Mexico, a Solidification Design Center Industry Partner, developed state-of-the-art software called ARENA™ that accurately simulates the complex two-phase flow of sand mixed with binder being blown into a steel die. The software is undergoing final testing including beta testing of pre-commercial releases of the software.

Benefit GM Powertrain is now using the software and estimates that eight weeks of development time can be eliminated for manufacturing development of complex metal castings. In addition, application of the software tool to the production of lost foam patterns also looks promising.

The Solidification Design Center (SDC) has just completed an exciting year of metal casting research with the $25-billion-a-year foundry industry. A number of industry-sponsored projects are underway expanding our knowledge base of thermophysical and metallurgical data essential for enhanced competitiveness in this industry. Hardware design and development activities for materials research on the International Space Station (ISS) continue in anticipation of robust utilization of the orbital facility.

The majority of metal casting plants are small with 80% having less than 100 employees. Thus an innovative partnership has been adopted with the American Foundry Society (AFS) to enable industry-reviewed and cost-shared projects that benefit the entire metal casting industry. Teams of industry volunteers assist in the monitoring of projects and in transferring the technological benefits to the private sector. "The Solidification Design Center at Auburn University provides the entire metal casting industry with access to space and space-derived technologies. A growing number of industry engineers are becoming interested in the value of these technologies to better understand and control their manufacturing processes," says Dr. Joe Santner, Director of Research for AFS. "The Space Station era promises unimaginable benefits for unique materials data, advanced manufacturing processes, and improved quality."

The Center's aggressive research agenda is primarily focused on the following key research areas:

- acquisition of thermophysical property data of commercial alloys
- measurement of metallurgical data of commercial alloys
- development of advanced metal castings and casting techniques for commercial applications
- development of software for simulating flow of molding material aggregates and their binders

A comprehensive thermophysical properties database for commercial alloys is required for the development of reliable computational models of production casting processes. A number of commercial alloys have already been characterized and the data delivered to industry. Computational models can be critical for foundries to reduce times to market, enhance quality levels, and minimize manufacturing costs.

In addition, the next generation of casting simulations will require diverse metallurgical data for prediction of metallurgical microstructures and mechanical properties of cast components. Basic metallurgical data for a number of advanced alloys and processes are being pursued by SDC research teams. K+P Agile Inc. (Naperville, Illinois) and Northwestern University (Evanston, Illinois) are investigating convection effects on metallurgical grain structures in organic analog materials. Microstructural development in a variety of ferrous alloys is being investigated by PMS Inc. of Buchanan, Michigan. The role of convection on hot tearing behavior of high-strength aluminum alloys is being evaluated by Queens University (Kingston, Ontario) and CANMET (Ottawa, Ontario) for Allied Signal Aerospace of Phoenix, Artizona. Flow Simulation Services (Albuquerque, New Mexico) and General Motors (Warren, Michigan) are developing software to enhance the design of aggregate mold making processes. The fundamental heat transfer mechanisms (convective and conductive) when solidification is enhanced by immersing a mold filled with liquid metal into a cooling medium is being pursued by the University of Alabama

(Tuscaloosa, Alabama) and Brush-Wellman Inc. (Elmore, Ohio). Auburn University (Auburn, Alabama), Ford Motor Company (Deaborn, Michigan), and Stahl Specialty Co. (Kingston, Missouri) are developing a low-cost sensor to measure dissolved hydrogen levels in molten aluminum. Convection effects during the feeding of steel castings are under study by CANMET (Ottawa, Ontario) with Maynard Steel Casting Co. of Milwaukee, Wisconsin and Frogswitch Manufacturing Co. of Carlisle, Pennsylvania.

Auburn University and Citation Corp. (Birmingham, Alabama) are advancing semi-solid rheocasting of non-ferrous materials for automotive applications. Harmony Castings (Harmony, Pennsylvania) is working with the SDC to expand the process capability of the 'V'-process. In this unique metal casting process, environmental emissions during casting are considerably reduced due to the absence of binders in the molding materials. Increased understanding of how gravity affects solidification phenomena has lead the Herman Williams Company (Birmingham, Alabama) to invest in centrifugal casting techniques to increase the effective 'g' during casting. A new SDC project is investigating how enhanced 'g' levels can be reliably exploited to enhance metallurgical structures of ferrous castings. In addition, Vermont American (Auburn, Alabama) is utilizing SDC technology to reverse engineer expensive fabricated assemblies into new lower-cost investment castings.

The development of metal casting research techniques for SDC use on the ISS also made important progress during FY 2001. "Vulcan" was the mythological metalworker in service to the Roman pantheon of gods. In the same spirit of service, the Solidification Design Center, Wyle Laboratories (Huntsville, Alabama) and Anter Corp. (Pittsburgh, Pennsylvania) are developing the VULCAN™ modular series of ISS flight hardware to enable a number of key research activities to acquire low-g data which serves the metal casting industry. The first of these, VULCAN-TP™ (Thermophysical Properties), has been developed through low-g testing on the NASA KC–135 low-g aircraft and is now being re-designed for ISS use. The hardware successfully passed the Critical Design Review and the Phase II Safety Review during FY 2001 and is now being fabricated for delivery to the Space Station. Prototype designs of future VULCAN™ modules, e.g., VULCAN-DS™ (Directional Solidification), are also being developed for future space experiments.

One Ph.D student, two M.S. students, and two B.S. students employed by SDC graduated during FY 2001. In addition, 18 B.S. students completed their senior design project for the Center and also graduated. Six refereed and five non-refereed papers were published during FY 2001 and 12 papers were presented at major conferences.

In summary, FY 2001 has been an outstanding year for the SDC. Industry investments continue to increase and industry-sponsored projects are establishing the knowledge base for future experiments on ISS beginning in FY 2003.

Case Study

Challenge Develop a telemedicine system that includes a high-definition video camera and a high-definition ultrasound scanner that are suitable for use in space. Commercial HDTV cameras do not survive the radiation levels encountered in space.

Importance Such a system not only provides diagnostic facilities in space—it also advances the capability of terrestrial telemedicine applications.

Solution SCTC has licensed the camera technology to a company for commercial development. The center is currently developing a space-hardened HDTV camera and a high-definition ultrasound scanner suitable for use in space.

Benefit NASA missions can have advanced medical diagnostic capability. Telemedicine systems on Earth can provide advanced diagnostic service to remote areas.

The Space Communications Technology Center (SCTC) was established in 1991 as a non-profit consortium of industry, academia, and government that conducts space-based, high technology research and development in communications. Its mission, under the direction of Dr. William E. Glenn, is to develop the commercial use of techniques for transmitting video, audio, and data by satellite. By far, the most information transmitted by satellite is video.

The world-wide medical community is currently planning a radical change from traditional methods for diagnosis, training, and patient record archiving to incorporate electronic imaging—telemedicine applications across the board. Electronic imaging via wireless methods and the Internet will be used in the majority of medical applications. This is not only used for remote diagnoses, it is also being used in conjunction with remote surgery using robotics. These areas still have a distance to go, especially in the high-resolution imaging area, before products are ready for the commercial market. The SCTC is concentrating its efforts on advanced high-resolution imaging technology directed to the following medical applications:

- Inexpensive, portable, wireless high-resolution ultrasound scanners (under SCTC development) linked to a computer with video screen could replace the physician's stethoscope.
- Remote diagnosis, patient monitoring, robotic surgery, and education can take place with inexpensive small high-resolution progressive-scan cameras (under SCTC development) strategically placed in the hospital operating rooms, emergency rooms, intensive care units, and clinic examining rooms as well as in remote locations where medical care is limited or not available.
- Wireless data and high-resolution imaging (under SCTC development) entry and retrieval via the physician's pocket computer with video links of patient's medical records including MRI records, X-rays, CATSCANs, EKGs, EEGs, etc. can replace the traditional patient hard-copy record information management systems.

The SCTC has reorganized its advisory board in 2001 to include leaders in the medical community, (including physicians and researchers), medical technology industry, and imaging electronics industry. NASA and commercial applications for this technology include:

- Remote medical image transmission services
- Remote video surveillance
- Video conferencing
- Digital high definition image transmission to the media
- Monitoring scientific experiments

Center video compression R&D led to the development of a high-definition camera with the capability of recording and transmitting compatibly within existing standards. During Grant Year (GY) 98, the SCTC developed and demonstrated this solid-state progressively scanned, high-definition color camera. It is the first camera in the world to produce the progressive SMPTE 274M format. A camera of this design was built for delivery to NASA on the 98–99 CSC program. The Center also simulated a method of recording, transmitting, and displaying the output of this camera with a format compatible with High-Definition Television (HDTV) recorders and with the transmission encoding now used by CBS, NBC, and PBS based on its R&D in digital compression.

Space Communications Technology Center

Digital video has become the largest segment of the satellite communications business. NASA will need to convert to HDTV transmission of video from ISS and other missions. Although commercial products for digital video will be available (partially as a result of developments by the SCTC); it is unlikely that space-qualified units will be available on the commercial market, an area in which the SCTC might play a key role. Camera Charge Coupled Device (CCD) designs used in commercial cameras are susceptible to radiation. The design used by the SCTC camera is much less susceptible.

2000–2001 program

During the current GY (2000–2001), the Center completed the camera, its interfaces to the fiber link, and the hardware required to provide image transmission at various bit rates. The Center's advisory board was revamped to consist primarily of experts in telemedicine and industry representatives in the healthcare field. An advisory board meeting was held in February 2001.

Bell South, an Industry Partner, donated a fiber optic link between the two SCTC laboratories that are 30 miles apart. This digital link is operating with a bit rate of 1.5 gigabits per second. The equipment for transmitting uncompressed HDTV images from the SCTC camera over this link is operational. In addition, compression encoders and decoders have been constructed to allow evaluation of the bit rate required for various telemedicine diagnostic procedures.

The SCTC R.F. propagation experiments using the ACTS satellite in the Ka band continues to provide important data that will lead to additional spectrum use, which is needed to increase the capacity of satellite communication links.

On a subgrant from the CSC at VCU we performed a feasibility test on the design of the 4 Cm PC-based ultrasound scanner. This demonstrated excellent resolution and variable focus. This design will be the basis for the wireless PC-based scanner.

The center occupies approximately 10,000 ft^2 in two sets of laboratories and administrative offices at the main Florida Atlantic University (FAU) Boca Raton campus and at the Ft. Lauderdale Tower campus. The SCTC has acquired a significant amount of HDTV equipment, test equipment, large screen projectors, and laser optics. Two laboratories are dedicated to digital processing and hardware and software design, another to optics and laser R&D, another to analog and digital test, and another to radio frequency propagation studies. The center is comprised of 16 full-time research engineers, faculty and research coordinators and up to 14 student employees or research assistants per GY. During FY 2001, the center has supported three Ph.D. candidates, three M.S. students and three B.S. students. The SCTC resides within the College of Engineering directly under the Dean of Engineering.

The Space Vacuum Epitaxy Center (SVEC) creates advanced thin film materials and devices for commercial application through vacuum growth technologies using terrestrial and space vacuum environments. The SVEC R&D program encompasses four general areas of activity: 1) Optoelectronics, 2) Nitride Materials, 3)Photovoltaics, and 4) Advanced Oxides, all of which have shown major progress in technology advancement and product development in the past year.

Of note is the post-incubation maturation of one spinoff company, the incubation of a second spinoff company, and the origination of a third spinoff company. Applied Optoelectronics, Inc. (AOI), a spinoff formed in 1998, received major venture capital funding, built its own 80,000 square foot facility and moved out of SVEC facilities in FY 2001, and now has more than 40 employees with sales topping $8 million. AOI's business is focused on the development of thin-film infrared (IR) semiconductor lasers for the telecommunications environment—a technology that came out of the SVEC thin-film IR laser efforts.

Metal Oxide Technologies Inc. (MetOx), another spinoff focused on the development of thin-film superconducting wire, received investment funding and has initiated, within University of Houston facilities, the fabrication and assembly of components of a pilot production line for the manufacture of thin-film high-temperature superconducting wire. MetOx is supporting this advanced technology development through both funding of SVEC personnel and funding for the facilities fabrication. MetOx has licensed an advanced thin-film superconductor technology from SVEC and is expecting first product by FY 2003.

Integrated Micro Systems, Inc. (IMS), is a newly formed spinoff company focusing on the development of advanced thin-film high-energy, high-temperature capacitors. IMS has obtained Small Business Innovative Research (SBIR) program funds, and will initiate a collaboration with SVEC on the commercialization of the new design capacitors that have been a focus of SVEC research for some time.

SVEC has focused on maintaining competitiveness and the attainment of NASA's goal of technology development and transfer through care about developing and advancing intellectual property. As a result, SVEC has applied for five patents in FY 2001 and has been granted three of those five. Patents are most useful when they become the seed of a license agreement. This has been achieved with two license agreements for SVEC developed technologies being signed in FY 2001.

SVEC scientists have continued to work closely with industry, academia, and government labs in the unceasing development of thin-film technologies. A major thrust in the Center is the development of micro-sensors for a variety of applications including space. The development of compact multifuntional sensors, for example, can resolve space issues such as those of weight, volume, and power consumption for long-term missions, as well as for the new generation of micro-size satellites. Furthermore miniature multifunctional sensors will allow rapid and precise monitoring of critical environmental parameters of enclosed space structures. The micro-sensor technology, however, has other major applications including terrestrial environmental monitoring and medical sensing.

Gallium nitride (GaN)-based thin film optical multifunction sensors have been fabricated, assembled and tested for performance as blue and ultraviolet (UV) Light Emitting Diodes (LEDs) with a UV and a broadband blue detector. This design allows for simultaneous measurement of fluorescence, absorption, and light scattering from liquid analytes that are in contact with the device. To date, fluorescence signals from Fluorescein™ and chlorophyll solutions down to 0.029 ppm have been measured, and optical absorption by polyethylene glycol in the range of 1,000–35,000 ppm has been measured indicating good future applications of the detectors for environmental monitoring. The sensor system has also shown sensitivity to glucose levels in blood, thus opening the way for a reliable glucose monitor.

A thin film oxide-based sensor is being developed for IR imaging in partnership with industry. The advanced oxide thin film design of the IR sensor allows for operation without cooling and is being developed for consumer 'night vision' applications such as currently utilized in the heads-up display for night driving being delivered in Cadillac automobiles.

SVEC scientists, in collaboration with industry, have recently demonstrated the first differential absorption Lidar (DIAL) based on the mid-IR type-II quantum-well laser. Two type-II quantum well lasers at 3.1 and 3.8 microns were used to detect a small amount of C_2H_2 leaked into the atmosphere at a very slow rate of $<8\times10^{-5}$ L/sec. In addition, by taking advantage of the clear distinction of absorption characteristics between films of vegetable oil and motor oil they have also demonstrated that DIAL is a powerful way to distinguish a film on

water due to petrochemical products versus other natural sources such as fish oil. It is expected that, with the integrated thermoelectric-cooled mid-IR laser under joint development with Jet Propulsion Laboratory and the digital signal processor (DSP) chips developed for the commercial wireless communication products, the group will be able to reduce the size of the DIAL system to that of a flash light and to realize a truly portable chemical and biological sensor.

Of final note on sensors is the SVEC effort in collaboration with the University of Texas Medical School on the development of thin-film ceramic optical micro-detectors for use as an artificial thin film retina—a "Bionic Eye" for restoration of sight in retinally blind patients. The program, with materials development roots in the Wake Shield Facility experiments of 1995 and 1997, has fabricated unique ceramic thin-film micro-detectors, has implanted them into rabbits and shown bio-compatibility, and has identified a productive technique for the surgical implantation of arrays of the micro-detectors in a patients eye. Human trials are expected to be initiated in FY 2002. If successful, the Bionic Eye may offer the hope of sight to many people with retinal eye problems.

In response to the need for space solar cells with efficiencies greater than 30 percent, SVEC has continued its investigation of nanostructure (quantum well) based multijunction solar cells. The patent covering the basic concept of the device was issued in FY 2001, and utilization discussions with major U.S. and European space solar cell/satellite manufacturers are already underway. The research work included the optimization of the modeling tools and quantum-well materials as well as preliminary fabrication of devices. The study has enabled identification of a new design that could potentially provide a practical efficiency in excess of 30 percent AM0 with zero performance degradation after 10 years in orbit. As an example, if successful, a direct replacement of the existing 12.6 percent efficient Si solar panels on the International Space Station by the proposed technology will result in nearly 3-fold increase in the available power.

Finally, in a direct support of the human exploration and colonization of space initiative and under the support of the NASA Cross Enterprise Technology Development Program, SVEC scientists have undertaken the evaluation of new architectures for in-situ development of solar cells on the Moon using lunar resources. The study is undertaken in collaboration with industry, the Center for Commercial Applications of Combustion in Space, and the Lunar and Planetary Institute. This first phase of the research has focused on identifying various materials refining/film deposition processes. An existing Ultra-High Vaccum facility has been modified to allow for simulation of lunar vacuum deposition, and thin film processing of lunar ores (JSC 1) has been initiated for the development of a lunar substrate for the solar cells.

Case Study

Challenge No compact, low-cost sources available in the mid-infrared wavelength, in particular, at the 3–5 micron atmospheric transmission window.

Importance Most industry, pollution, and greenhouse gases have strong, fundamental vibrational transitions in the mid-infrared wavelength. Even though they also have overtones at shorter, near-IR wavelengths, the absorption there is much weaker.

Solution SVEC, Applied Optoelectronics Inc., Opto Power Corp., and University of Connecticut are jointly developing the type-II quantum-well and inter-band cascade lasers, which could be cooled by the thermoelectric micro-cooler under development at Jet Propulsion Laboratory, for implementation into the chemical and biological sensors under investigation jointly with Honeywell Technology Center and Physical Sciences Inc.

Benefit The availability of semiconductor diode laser at the 3–5 micron atmospheric transmission window would enable the realization of compact, low-cost and portable sensors which could revolutionize the chemical and biological sensor industry. They would also benefit the space program significantly in studying Earth's atmosphere, monitoring space station environment, investigate interstellar gases, etc.

Case Study

Challenge Complete plant life cycle (seed to seed growth) in the reduced gravity environment without crew intervention.

Importance To determine whether WCSAR-developed technologies are suitable for such application; to determine whether plant can complete its life cycle in an enclosed and reduced-microgravity environment; to support future commercial research using commercial interest species; and, to support permanent human presence in space by providing fresh vegetable crops.

Solution ADVASC™ is capable of providing desired environment conditions suitable for plant growth and development in microgravity; ADVASC™ is able to autonomously maintain chamber environmental conditions without crew intervention; and, *Arabidopsis thaliana*, a model organism for studies on molecular genetics of flowering plants, does not require presence of gravity for growth and development.

Benefit To understand how plants respond to microgravity and to provide valuable data for future similar research.

The Wisconsin Center for Space Automation and Robotics (WCSAR) at University of Wisconsin-Madison focus on the development of environmentally controlled technologies for space- and terrestrial-based plant research. WCSAR's core competencies lie in the following areas:

- Provide state-of-the-art plant growth chambers and facilities with precise control of the environmental conditions for companies and research institutes to systematically study the effects of environmental conditions on plant growth and crop development.
- Possess the experience and know-how on the acceleration of plant growth by manipulating the environmental conditions and nutrient compositions. This technology will significantly increase the breeding throughput, and therefore, be beneficial to the crop industry.
- Offer space-based plant research expertise such as cell transformation, enhanced biosynthesis of secondary metabolites, and production of antibodies in the plants for conducting unique and novel commercial-oriented research.
- Provide automated and computerized technologies to minimize human process errors and to maximize the process throughput.

These competencies have greatly supported WCSAR's Industry Partners in the development of commercial products and new technologies.
In recent years, WCSAR has been aggressively engaged in expanding the collaboration with industrial companies and governmental entities in the areas of technology development, product design, and intellectual property process and transfer. Industry collaboration/partnership has become the cornerstone of the WCSAR program. When many different types of businesses, both small and large, become involved in the WCSAR's program, a broad industrial base develops that understands the benefits of joint academic/industrial or fundamental/applied research. Growing this industrial base is a principal goal of WCSAR's Program.

FY 2001 has been a very busy but certianly a growth year for WCSAR in which a two-year long program reconstruction and redirection effort began to bear fruit with significant increases in space-based commercial research participation, broad industry/WCSAR joint market development, and cutting-edge projects with commercial protential. In this fiscal year, WCSAR has reached agreement with Space Explorers, Inc. (SEI) for conducting the second *Arabidopsis* life cycle experiment on UF–1; International Flavors and Fragrances (IFF) has offered a three-year collaboration package for the development of commercially valuable compounds in space; WCSAR has also signed a collaborative agreement with Producers' Natural Processing (PNP) for conducting a gene transfer experiment on STS–107. In addition, WCSAR and PNP have signed a letter of intent to pursue joint market development for the mutual benefit.

WCSAR and SEI have successfully conducted the first seed-to-seed growth of *Arabidopsis thaliana* on the International Space Station (ISS) during the 6A mission, using its Advanced Astroculture™ (ADVASC) plant growth unit. ADVASC™ provides a completely enclosed, environmentally controlled plant growth chamber which is able to support plant research for a maximum duration of six months in reduced gravity environment. Advanced control software provides precise control of each environmental parameter in the plant chamber and creates the environmental conditions suitable for growing a wide variety

of plant species. Auto-prime technologies eliminate the need for power during Shuttle ascent/descent, and therefore, optimize Shuttle resources and the ISS crew time. State-of-the-art fault tolerance and recovery algorithms significantly increase overall system robustness and efficiency. Tele-science features allow engineers and scientists to receive telemetry data, to send remote commands, and to monitor plant development status via the video images and other data. This experiment has successfully demonstrated that ADVASC™ is capable of providing desired environment conditions suitable for plant growth and development in microgravity. ADVASC™ is able to autonomously maintain chamber environmental conditions without crew intervention.

On the cutting-edge projects side, WCSAR has launched the following three high-profile projects with commercial potentials:

Production of human-interest proteins (HIPs) in plants

HIPs are proteins that can be antibodies, vaccines, and pharmaceuticals/nutraceuticals. Antibodies are currently developed in animals and produced either in animals or in animal cell culture. Drawbacks of this system are potential cross-transfer of mammalian diseases, low production capability, high cost, and the need for a number of animal subjects. Using our transformation technology coupled with gene cloning/shuffling and cell culture capabilities, we may be able to produce commercial interest antibodies and vaccines in plants, and therefore, offer an animal-free production facility. This new method allows us to produce high valued proteins in large quantities at economical prices.

Environmentally controlled bioreactor

As the biopharmaceutical/nutraceutical industry continues to grow, increased attention has lately been devoted to the production of health-promoting secondary compounds using plant cell culture techniques. The efforts to increase the productivity by various means have had limited success. This is at least in part due to the lack of suitable technologies for such commercial scale applications. WCSAR has developed a state-of-the-art bioreactor for enhanced biosynthesis of commercial interest bioactive compounds. This bioreactor offers complete control of chamber temperature, photo treatment, multiple motions, gas exchange, and low shear stress. By using an optimal combination of these parameters, it can provide a desired condition for cell culture growth, and therefore, can significantly increase the productivity.

Low-altitude hybrid piloted remote sensing platform

The U.S. crop industry now faces a marketplace that is increasingly price-sensitive to crop quality and crop cost. Remote sensing technologies have greatly helped farmers in controlling the quality and cost of the crops by providing high-quality images describing soil properties associated with nutrition and herbicide, stresses caused by undesirable weather conditions, and symptoms related to the insects invasion. However, access to the images provided by the satellite and airborne plane are costly and inconvenient. WCSAR has initiated the design of Global Positioning System and remotely piloted (hybrid) remote sensing platform, that carries an array of infrared hyper-spectrum sensors for monitoring soil properties and plant stresses. The vehicle is designed to be miniaturized and portable, and to fly at low altitude, making it more flexible in its applicaton.

In the future, WCSAR looks forward to expanding its industry collaboration scope by providing the state-of-the-art and novel technologies to the companies, by participating companies' product development, and by involving companies' marketing activities.

The following is a selected list of Industry Partners and other affiliates. Not every company that partners wants to let its competition know about their activities. For that reason not every partner is included. It may be worth considering that one's competition might be one of those not listed.

- 3-D Pharmaceuticals
- Aeroponics Intl.
- Airsys ATM
- Allison Gas Turbines
- American Ag-Tech
- American Foundry Society
- American Qualex
- Amgen
- AnorMED, Inc.
- Anter Corporation
- Applied Optoelectronics, Inc.
- Arizona Mist
- ArQule, Inc.
- Atlantic BioPharmaceuticals
- Aventis Pharamaceutical
- Bede Scientific Instruments, Inc.
- BioCryst Pharmaceuticals, Inc.
- Biolog, Inc.
- Bionetics
- Boeing
- Boeing Space Systems
- Bose Corporation
- BrazSat

- Brimrose Corporatin of America
- Bristol Mums
- Bristol-Myers Squibb
- Bruker
- Brush Wellman Inc.
- Busek Co. Inc
- Calbiochem
- Canton Bio
- CCACS/BiomaterialsConsortium
- CF Technologies, Inc
- Chevron Research
- ChK Group
- Citation Corporation
- Computer Motion
- Conviron Technologies
- CoorsTek (formerly Coors Ceramics)
- Cyrano Sciences
- Diversified Scientific, Inc.
- Dupont, Central Research and Development
- Durel Corporation
- Dynatherm Inc.
- Eli Lilly and Co.
- Engelhard Corporation
- Environmental Engineering Concepts, Inc.
- ENVIRONMENTAL RESEARCH INSTITUTE
- Environmental Research Institute of Michigan (ERIM)
- Exstream Water Technologies
- Extreme Devices
- EXXON

- FERRO Electronic Materials
- Flow Simulation Services
- Ford Motor Co.
- Frogswitch Mfg. Co.
- GE Education Foundation
- General Atomics
- Genyzyme Corporation
- Givaudan Roure Flavors
- GlaxoSmithKline
- GM Powertrain Group
- Grace Foundation
- Great Plains Diabetes Research, Inc.
- Grower Direct Farm, Inc.
- Guigne International, Ltd.
- Harmony Castings Co.
- Herman Williams Co.
- Herzog Hart
- Hewlett-Packard, Inc.
- Honeywell
- Honeywell Technology Center
- Ibbex Pharmaceuticals
- imMedidate Care, LLC
- In Space Propulsion, Ltd.
- Informed Diagnostics
- Infrared Fiber Systems, Inc.
- Innerlink Corp.
- Innovative Scientific Solutions, Inc.
- Integrated Microsystems
- Intek, Incorporated

- International Flavors and Fragrances, Inc.
- Invitrogen
- Ionwerks, Inc.
- ITN Energy Systems
- Jackson and Tull, Inc.
- Johnson & Johnson
- K+P Agile Inc.
- Kraft Foods
- Laempe+Reich Inc.
- Lexington Garden
- Lockheed-Martin
- Louisiana Veteran's Research Corporation
- Lucent/Bell Labs
- MACC
- Makel Engineering
- MaxTor Corporation
- Maynard Steel Casting Co.
- Memorial Hospital at Gulfport
- Merck
- Metal Oxide Technologies Inc.
- Microsoft Corporation
- Midwest Research Institute
- Molecular Simulations Incorporated
- MONSANTO
- Nanoscale Materials, Inc.
- Numotech Inc.
- Oceaneering Space Systems
- Oculus Pharmaceuticals, Inc.
- Operation Helping Hands

- Opto Power Corporation
- Opto-Knowledge System, Inc.
- Optron Systems, Inc.
- Ormet Corp.
- Owen's Research Corp.
- Parvus Corporation
- PCC Structurals Inc.
- Pennzoil/Quaker State
- PetroSat Inc.
- Physical Sciences, Inc.
- Physicians for Peace
- Pioneer Hi-Bred International, Inc.
- Polaroid Corporation
- Pratt & Whitney Co.
- Producers' Natural Processing Corp.
- Professional Metallurgical Services
- Prototek, Inc.
- Raytheon Corporation
- Research Genetics/Invitrogen
- Sanderson Farms
- Schering-Plough Research Institute
- Sharp Laboratories of America
- Shearwater Polymers/Inhale Therapeutics
- Space Explorers Inc.
- SpaceHab Inc.
- Stahl Specialty Co.
- Stelsys, LLC
- Sulzer Orthopedics Biologics
- Syngenta

- Taconic, Inc.
- TDA Research
- The Timber Company/Lignin Consortium Members
- The Upjohn Company
- TRPL Inc.
- TRW Space ad Technology Division
- Tyco U.S. Surgical
- Uniao Quimica
- United Advanced Technologies, Inc.
- United Technology Research Center
- Vermont American Inc.
- Vertex Pharmaceuticals
- Virtual Drug Discovery, Inc.
- Wn-Pinchbeck, Inc.
- WTC/PentaPure Corp.
- Wyle Laboratories
- X-Rite, Inc.

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