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NASA'S GREATEST INVENTIONS AND CONTRIBUTIONS OF DUAL-USE TECHNOLOGIES IN THE 1990'S

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ABSTRACT

The Inventions and Contributions Board was chartered by the National Aeronautics and Space Act of 1958 to recommend to the NASA Administrator awards of up to $100,000 to contributors of scientific and technical innovations that are significant to NASA's mission and that have been sponsored, supported, promoted, or used by NASA. Over the last 37 years, NASA has granted over 60,000 so-called "Space Act Awards" to worthy recipients worth over $19,000,000 (1994 dollars). During the last four years, there have been a number of awards that have involved success stories for NASA-derived technology wherein not only has the innovation been useful for space applications, but also to the private sector for terrestrial uses. The most significant of these include applications in water treatment, manufacture of electronics, new materials, telecommunications, microburst detection, medical technology, and environmental technologies. We estimate that these recent contributions may have an impact on U.S. GNP of over $10 billion. This paper identifies seven specific Space Act Award cases within these fields that save lives, generate new jobs, reduce the cost of goods, raise the quality of life, and improve the productivity of American industry.

Background

In the arena of technology transfer, NASA stands out among federal agencies as a paragon of success over the last 37 years. This success derives from three contributing factors:

1. superior technology developed to enable space exploration and further aeronautics,
2. a chartered mandate to transfer technology to industry, and
3. an enlightened management approach designed to reward technology transfer success.

The Space Act of 1958 not only created NASA, but laid the framework for NASA to spin off space-based technology to the private sector. Legislators realized that many new scientific and technical ideas would emerge from NASA-sponsored work, and they made special accommodation for these inventions and contributions. The Space Act created the Inventions and Contributions Board (ICB) at NASA to review new ideas in science and technology for determination of who would receive the intellectual property rights (NASA or the contractor),

and also to make a determination of whether a special Space Act Award would be granted to the contributor(s); i.e., an amount of money given directly to these innovators. By law, the amount is limited to no more than $100,000 without congressional approval. This amount was very large in 1958, about the same value as the Nobel Prize in that year. Since that time, the ICB has granted over 60,000 Space Act Awards worth over $19,000,000 (1995 dollars). The law makes it clear that these applications for award be judged fairly, equitably, and consistently.

The seven cases discussed herein are unique in several respects. Each represents a story of early successes and failures, of trial and tribulation, and ultimate conquest. Each has either already had a strong impact on the Space Program or on the private sector, or will do so in the near future. Some have grave implications for our survival as a species, some enable that survival. Each derives its essence from at least one innovator who thought of a new way to accomplish a task, and found that good commercial value in terrestrial uses was possible. Each case also received "Exceptional Award" status from the ICB, an honor given to only about 10 cases each year.

Case 1: CARES/Life -- Ceramic Analysis & Reliability Evaluation of Structures Life

The co-winner of the 1994 competition for the NASA Software of the Year Award was NASA/CARES Life. It is a program that acts as a post- and pre-processor for the reliability analysis of ceramic parts designs and is used by engineers as part of structural design and materials selection. About 250 corporate, academic, and government sites use CARES/LIFE. It has been available since 1985, restricted to use in the U.S. in its latest version. We estimate that its impact on U.S. industry to date easily exceeds $100 million. Uses include ceramic machine parts, semiconductors, engines, high-temperature process parts, and all applications involving glass. One company, Intel, used CARES to fix a flaw in the production line for the i486 chip in 1991 before it could go into high production. Another, Philips, uses it to design TV picture tubes. First time design analysis for monolithic ceramics reliability (failure modes) has been achieved, including cyclic fatigue failures, for any defined geometry. It uses MSC NASTRAN, PATRAN, ANSYS, COSMOS/M, AND ABAQUS to adapt to a host of structural analysis tools. Each of the four authors of CARES/Life (J.P. Gyekenyesi; L.A. Janosik; N.N. Nemeth of Lewis Research Center; L.M. Powers of Cleveland State University) received $10,000 as an initial award under the Space Act. A viewgraph description of the case is given in Figure 1.

Case 2: Long-Term Monitoring of Upper Atmospheric Aerosols and Ozone from Space

In 1986, Dr. M. Patrick (Pat) McCormick was named by Senator John Warner in a Senate speech and praised for his solution to a serious problem facing U.S. airlines. Aircraft windscreens were crazing over during flights in the stratosphere, rendering them unusable for safe takeoffs and landings. Dr. McCormick came up with the hypothesis that the acids in the upper atmosphere, deposited by recent volcanic activity, were the culprit. He suggested that the airlines merely wash down the windscreens with alkaline water after each flight. This simple solution worked, saving the airlines millions of dollars. However, Dr. McCormick is not only known for this contribution. His invention of the solar occultation technique was the enabling technology used to self-calibrate the sensors aboard earth observing satellites measuring ozone content in the atmosphere. These measurements have been taken continuously since 1978 (with a one-year hiatus in '84) and provide a definitive time-history log of ozone depletion over the last 15 years. NASA's data was

the irrefutable source which led to the international agreement (the Montreal Accords) banning chlorofluorocarbons (CFC's, or freon) worldwide. Dr. McCormick's theories and data led to a better understanding of CFC's interaction with particles in the stratosphere and ultimately with the ozone layer, explaining the ozone hole over the South Pole, and global ozone depletion. For their work, the team of Dr. McCormick and Dr. Edward Chu of Langley Research Center received a Space Act Award of $25,000 in 1993. A viewgraph description of the case is given in Figure 2.

Case 3: Regenerable Biocide Delivery Unit

This is the system used by NASA on all Shuttle missions since 1990 for water purification, and the selected baseline for all future manned spaceflight missions and bases. It uses molecular iodine (I_2) and an ion exchange resin bed that regenerates its iodine concentration during operation, recapturing the iodine used to disinfect the water. This system is an improvement over that for Apollo and Spacelab, when residual iodine levels were much higher. The system was fully tested for 114 days without mishap before its selection was made. It has many attributes, including high reliability, excellent disinfectant properties, including a broad spectrum of effectiveness against a wide range of infectants, low pH sensitivity, less iodinated organic byproducts, ease of monitoring, little or no offgassing, low power requirements, compactness, low weight, and full regenerability. There is literally no competition for space use, including chlorination, use of chloramines, ozonation, or radiation. The system is scalable up to municipal water treatment sizes, and could become a serious contender for terrestrial water purification with further development. EPA's new water treatment standards may restrict chlorination by 1996, which may dictate the use of some iodination. The patent is exclusively licensed by Umpqua Research, and is sublicensed to Vector Ventures which is commercializing the technology throughout the third world, e.g., VietNam, Pakistan, and India. This invention won the NASA Inventor of the Year Award in 1993, for Dick Sauer of the Johnson Space Center, and Gerry Columbo and Cliff Jolly of Umpqua Research. The team has received $22,500 in Space Act Awards. A viewgraph description of the case is given in Figure 3.

Case 4: Near-Azeotropic Mixture Substitute for Dichlorodifluoromethane (Freon 12) and Regenerative Adsorbent Heat Pump

As concern over the ozone layer depletion mounts, some solutions have come forth from the space program. Like Sauer, et. al. who found an iodine substitute for chlorine in water treatment, Jack Jones of JPL has found a drop-in substitute for Freon 12. The gas mixture, a near-azeotropic match for Freon 12, is superior to the R134a fluorocarbon (used in new automotive air conditioners) since it can be used directly in all existing automobile air conditioner systems as well as refrigerators, coolers, etc., and provides lubrication to bearings and moving parts, unlike R134a. Mr. Jones has also developed a new class of oil- or gas-fired heat pumps that utilize multiple regenerative beds for improved efficiency. These new units have coefficients of performance of nearly 1.3 for cooling (referred to the fuel energy) and up to 2.0 for heating -- twice the performance of conventional furnaces and gas-fired air conditioners. In this manner, new heating, ventilation, and air conditioning systems could be built to replace the Freon 22-based heat pumps and air conditioners with reduced costs to the consumer which would eliminate all freon use. For these two inventions, Mr. Jones received $7,000 in Space Act Awards. Viewgraph descriptions of these two cases are given in Figures 4 and 5.

Case 5: INS3D -- An Incompressible Navier-Stokes Solver in General 3D Coordinates

This case was co-winner of the 1994 NASA Software of the Year Award, and was developed by Drs. D. Kwak and S.E. Rogers of Ames Research Center; C. Kiris of the MCAT Institute, and J.L.C. Chang of Rocketdyne. This software enables the accurate and efficient solution to the Navier Stokes equations for incompressible fluid flow using any fluid and with any geometry, internal or external, for both steady and unsteady flow conditions with stationary or moving boundaries. To our knowledge, INS3D is the most versatile code in the world for solving incompressible flow problems. NASA developed this code to solve problems related to flow instabilities in the Space Shuttle Main Engine (SSME) advanced design. Many users have found other applications; e.g., Penn State University for the design of a prototype artificial heart and Baylor University for the design of a left ventricular assist device based upon a two-bladed twisted rotor. The code incorporates advanced, high-speed solution techniques along with exceptional flexibility in defining flow geometries and time/spatial variation. Its uses are just beginning to become well-known, and we expect its value to industry to increase substantially. This team received a Space Act Award of $40,000 for its contribution. A viewgraph description of the case is given in Figure 6.

Case 6: Origination and Innovative Applications of the Rice Algorithms for Lossless Digital Data Compression

Bob Rice of JPL has created a series of data compression algorithms, known as the Rice Algorithms, which provide the highest compression ratio possible for lossless data compression. Recent studies at the Goddard Space Flight Center verify this claim in tests versus LZH, PKWare, ARC, and other popular techniques. The Rice Algorithms were originally developed to support the Deep Space Network, and are used on all deep space missions for encoding, transmitting, and decoding data from the spacecraft in the most efficient manner possible. A variant of the Rice Algorithms can be utilized for lossy data compression retaining excellent visual quality in graphics images with data compression ratios greater than 30:1. Mr. Rice received a $15,000 Space Act Award for these contributions. A viewgraph description of the case is given in Figure 7.

Case 7: Airborne Windshear Hazard-Risk Factor (F-Factor)

Dr. Roland Bowles of the Langley Research Center recognized the value of a simplified algorithm conceived by a Japanese analyst, known as the F-Factor, for making real-time, in-flight measurements of microbursts. He then began a crash program at Langley to develop hardware that could take these measurements. Then, a program was conceived to actually make the measurements by using a commercial jet to chase after windshear conditions in Virginia's famous thunderstorms. Using LIDAR, the F-Factor measuring system was able to accurately detect the presence of microbursts, or dangerous wind shear conditions, in the path of the aircraft in flight. Further, the processor was able to give warning of the windshear to the pilot between 20 and 40 seconds in advance (depending on flightspeed and altitude, etc.), enabling the pilot to turn away safely without harm to the passengers and crew. The FAA played a vital role in the system's commercialization by working with NASA in the development and testing, as well as mandating the use of the system in all aircraft by 1995. Most airlines are complying with the mandate. However, some aircraft are using a system which merely warns the pilot that the aircraft is in a

microburst, not the NASA-developed system. Dr. Bowles received a $15,000 Space Act Award in 1993 for this work. A viewgraph description of the case is given in Figure 8.

Note: All figures in this document are the original viewgraphs used to present the cases to the NASA Administrator.

Conclusions

NASA has sponsored, supported, and developed a broad range of scientific and technological innovations during its history, many of which have made a significant impact on our daily lives. In this paper, seven such contributions, among the best of the 1990's, are summarized. Each was the recipient of an Exceptional Space Act Award granted by the NASA Administrator upon the recommendation of NASA's Inventions and Contributions Board.

References

Files of the NASA Inventions and Contributions Board:

1. NASA Case Number LEW-16,018-1, *CARES/Life -- Ceramic Analysis & Reliability Evaluation of Structures Life*, Washington, DC, 1994.
2. NASA Case Number LAR-00,090-4, *Long-Term Monitoring of Upper Atmospheric Aerosols and Ozone from Space*, Washington, DC, 1993.
3. NASA Case Number MSC-21,763-1, *Regenerable Biocide Delivery Unit*, Washington, DC, 1993.
4. NASA Case Number NPO-18,030-1, *Near-Azeotropic Mixture Substitute for Dichlorodifluoromethane (Freon 12)*, Washington, DC, 1992.
5. NASA Case Number NPO-18,211-1, *Regenerative Adsorbent Heat Pump*, Washington, DC, 1992.
6. NASA Case Number ARC-12,121-1, *INS3D -- An Incompressible Navier-Stokes Solver in General 3D Coordinates*, Washington, DC, 1994.
7. NASA Case Number NPO-00,093-1, *Origination and Innovative Applications of the Rice Algorithms for Lossless Digital Data Compression*, Washington, DC, 1993.
8. NASA Case Number LAR-00,090-11, *Airborne Windshear Hazard-Risk Factor (F-Factor)*, Washington, DC, 1993.

CARES/Life -- Ceramic Analysis & Reliability Evaluation of Structures Life

John P. Gyekenyesi, Lesley A. Janosik, Noel N. Nemeth, LeRC; Lynn M. Powers, Cleveland State Univ.

- Program designed to perform detailed reliability analysis on ceramics, glasses, and semiconductors
- Acts as pre- and post-processor for structural analysis and display programs
  - NASTRAN, PATRAN, ANSYS, COSMOS, ABAQUS, etc.
- Over 250 U.S. corporate/government sites use CARES/Life
  - Used by INTEL to fix i486 production line flaw in '91
  - Used by Philips to design picture tubes
  - Used by USAF for ARGUS zinc selenide window
- Co-winner of '94 NASA Software of the Year Award

LEW-16,018-1 ***$40,000***

Figure 1

Long-Term Monitoring of Upper Atmospheric Aerosols and Ozone from Space

Dr. M. Patrick McCormick and Dr. William P. Chu, LaRC

- Contributions Impacting All Mankind
- SAGE I and SAGE II Satellite Experiments Measured Atmospheric Ozone Concentrations Since 1979
  - Using Self-Calibrating Solar Occultation Technique and Providing Vertical Profiles of Aerosol Concentrations Every 45 Minutes, Over 11,600 Annually
- Warning to Airlines After Mt. St. Helens Volcanic Eruption to Wash Aircraft Windshields to Reduce Crazing -- Led to U.S. Senate Resolution Praising NASA in 1986
- Data Analysis Led to U.N. Resolution Regarding Ban on CFC's in All Nations
- Measurements and Data Analysis Confirm Global Warming Theories, Ozone Depletion, and Formation of Polar Clouds

LAR-00,090-4 ***$25,000***

Figure 2

Regenerable Biocide Delivery Unit

Richard L. Sauer, JSC; Gerald V. Columbo and Clifford D. Jolly, Umpqua Research Co.

- A molecular iodine based water treatment system with a regenerable iodinator resin bed for use on manned missions
- Used on Shuttle for all missions since 1990
- Baselined for all future NASA manned missions, including SSF, lunar and Mars
- Possible scale-up to terrestrial water treatment – solves many problems relating to chlorination avoidance
- Systems sold abroad in Third World (VietNam and elsewhere) by Vector Ventures

MSC-21,763-1 ***$22,500***

Figure 3

Near-Azeotropic Mixture Substitute for Dichlorodifluoromethane (Freon 12)

Jack A. Jones, JPL/CalTech

- Drop-in substitute for Freon 12 (auto A/C type)
- Experimental study and computerized optimization that selected six refrigerant mixtures which closely approximate properties of Freon 12
- Low toxicity, stable, compatible with compressor lubricants and costs $0.70 to $1.00 per pound
- Testbed built and utilized to evaluate mixtures
- Funded by NASA for only $53,000
- Patent application now in process allowing all substantive claims

NPO-18,030-1 ***$5,000***

Figure 4

Regenerative Adsorbent Heat Pump

Jack A. Jones, JPL/CalTech

- Heating & cooling system for homes and commercial applications using R134a freon substitute or ammonia with activated-carbon, multi-bed configuration
- Can reduce gas/oil consumption for heating and cooling by over 50% at a 40% cost savings to users
- Small test model built and tested successfully
- System fully simulated on computer
- Funded through Phase I by Southern California Gas
- Requires design-to-cost development: joint funding possible with NASA and other entities
- Commercial applications worth billions of dollars

NPO-18,211-1 ***$2,000***

Figure 5

INS3D -- An Incompressible Navier-Stokes Solver in General 3D Coordinates

Dochan Kwak, Stuart E. Rogers, ARC; Cetin Kiris, MCAT Inst.; James L.C. Chang, Rocketdyne

- Simulates 3D viscous fluid flow over arbitrary surfaces, including unsteady flow and moving boundaries
  - handles both external and internal flow fields
  - applications in fluid mechanics throughout industry
- Works seamlessly with Plot3D and FAST for flow visualization; world's most advanced incompressible flow solver
- Used in SSME Phase II+ design, Baylor left ventricular assist device design, Penn State artificial heart
- Co-winner of '94 NASA Software of the Year Award

ARC-12,121-1 ***$40,000***

Figure 6

Origination and Innovative Applications of the Rice Algorithms for Lossless Digital Data Compression

Robert F. Rice, JPL

- Inventor of the Rice Algorithms for lossless data compression
  - now under development at GSFC for archived spacecraft data compression with an average of 3:1 compression ratio
  - used on Voyager Uranus and Neptune encounters
- Conceived the Advanced Imaging Communications System (AICS)
  - Saved $3 Million on Voyager and would have saved $5 Million on Galileo (until antenna failed to open)
  - Saved $22.4 Million on ground antennas for Voyager
- Responsible for several CCSDS telemetry standards
- Developed globally adaptive vector quantization algorithm in 1973, known as cluster compression or fractal compression, achieving lossy data compression at up to 300:1

NPO-00,093-1 ***$15,000***

Figure 7

Airborne Windshear Hazard-Risk Factor (F-Factor)

Dr. Roland L. Bowles, LaRC

- Theoretically-based, dimensionless parameter which characterizes windshear
- Empirically verified with extensive flight tests
- Gives pilots up to 40 seconds warning of severe and hazardous windshear conditions
- FAA has mandated use of instruments using the F-Factor criterion in all commercial air transports (about 8,000 aircraft) by 1995

LAR-00,090-11 ***$15,000***

Figure 8