Indian Society for
Non-Destructive Testing
Hyderabad Chapter

Proc. National Seminar on
Non-Destructive Evaluation
Dec. 7 - 9, 2006, Hyderabad

Foundations, Accomplishments and Challenges
"First A.K. Rao Distinguished Memorial Lecture"

W.D. Rummel
D &W Enterprises, LTD., Littleton, Colorado, USA

Abstract

It is my honor and pleasure to present the "FIRST A.K. RAO DISTINGUISHED MEMORIAL LECTURE" to celebrate the life and contributions of Professor Rao. NDE has progressed from a general art that was applied by craftsmen in self-assessment of the quality of their work, to a specialized engineering technology that is integral to the quality of our daily lives and to the world economy.

The unique contributions of Professor Rao are evident in a review of technology development and the foundations of new developments to meet daily challenges. The aerospace industry has richly contributed to NDE progression in the form of unique and demanding needs. The vision and creativity to produce solutions to these needs have distinguished the aerospace industry and has set a baseline of expectations.

Changing needs and expectations continue to drive NDE progression. Increase in NDE knowledge has expanded significantly and is the timely subject of NDE2006. Metrics for assessing NDE capabilities and uses provide challenges for all applications.

Timely challenges and research and guidance in increasing NDE reliability, extending the life of aging systems and infrastructure, and new industry applications are summarized to excite the imagination in the tradition of work by Professor Rao.

1. Introduction

I was overwhelmed, honored and humbled by your invitation to deliver the **"FIRST A.K. RAO DISTINGUISHED MEMORIAL LECTURE"** as a legacy to celebrate the life and contributions of Professor Rao. It is both an honor to be professionally recognized to deliver this prestigious lecture and a special honor to be selected as an international representative.

During his life, Professor Rao was recognized and received many honors for excellence in his professional work and his tireless work for India. To paraphrase George Washington, the first President of the United States of America, **"the willingness of young people to contribute shall be directly proportional to how they perceive and view those who have contributed are treated by their nation"**. This Memorial Lecture is a legacy to recognize and honor a great scientist and a great contributor to India and to the world. I am most honored to initiate this tribute Akella Kameswara Rao was born, 17 September 1929, in Madras, India and passed from this life on 10 December 2005. As I contemplated those bookends of an extraordinary life, I tried to identify special characteristics that he might consider to be hallmarks of his life. I settled on a few:

Akella Kameswara Rao
(1929-2005)

- ABILITY – The gift of brilliance
- INITIATIVE – The drive and persistence to develop and use that brilliance
- WISDOM – Dreams and recognition of next steps toward realization
- FAMILY / FRIENDS (EXTENDED FAMILY) – Human generosity and personal joys to his life
- BUILDER – "Can do" principles
- EDUCATOR / MENTOR – Sharing his life and knowledge
- LEADER – Visionary for advancements in both technology and many Indian Institutions
- CITIZEN – Of India, the technical community and the world
- LEGACY – Family, memories and accomplishments that have enriched and added to knowledge in our world

I was born in the same time frame and can relate to many of the challenges and accomplishments in the era. In tribute, I will share some viewpoints that have been addressed in that era.

We are born with the gift of intelligence. A.K. Rao was particularly gifted and used his gift to finish **FIRST** in his various educational pursuits. The thirst for knowledge to use the gift of intelligence comes from within. In America, one of the thought provoking slogans used to raise educational funds is – **"A mind is a terrible thing to waste."** That thought was elegantly captured by Dr. APJ Abdul Kalam, President of India in his book "**Ignited Minds**". A copy of that book was presented to me as a gift during a past visit to India. I was so inspired that I bought 10 copies of it to carry home (in my overweight luggage) and gave those copies to close friends. Knowledge is both a tool and a building block for personal contributions. The thirst for knowledge is tempered by opportunity. Great personal sacrifice is often required to continue the knowledge thrust and to initiate the process of contributing to the knowledge base. We have seen progress in opportunities for knowledge acquisition and application in India and in the world. We need more.

We seek and benefit from the work, experience and knowledge contributions provided by the legacy of those who have gone before us as the foundations for making our own contributions. It has been estimated that the total knowledge of the world doubled between 1940 and 1950 and has doubled each decade since. Increases in the knowledge base have necessitated combining expertise and collaborating for maximum benefit. A wise mentor of mine used to say, **"All of us are smarter than any of us".** I have found that to be a universal truth. The theme of this meeting is "NDE in a Knowledge Society" – we have great knowledge in our society, but we must collaborate and work together to apply the collective knowledge for beneficial use. I propose that we currently have an Information Society and are challenged to progress to a Knowledge Society.

We all have dreams. We seek the wisdom and energy to realize those dreams. Wisdom includes the vision, knowledge, initiative, practical assessment, planning and organization that are necessary to progress toward our goals. Professor Rao excelled in making dreams come true. His work extended beyond NDE and his contributions to science, general engineering and initiation of institutional collaborations have supported the foundations and progress of NDE technology.

We depend on the knowledge base of past contributors, on opportunity and on the combined work and support of our family, friends and institutions. No dream or accomplishment would be satisfying without the support and recognition by our family and extended family. Professor Rao was supported and enriched by his wife of 52 years, three sons and one daughter, 3 grand children, 25 PhD students, 50 Masters students and a host of colleagues, friends and enlightened students in his extended family. In crafting this MEMORIAL LECTURE, I have chosen to divide my address into three areas:

- **FOUNDATIONS** for the knowledge gifts that we have been given
- **ACCOMPLISHMENTS** in increasing knowledge and resultant benefits (making our contributions)
- **VISION** in current and future challenges

2. Foundations of Knowledge

The foundations of knowledge in engineering and specifically NDE have been driven by vision, exploration, opportunity and failures when we pushed beyond nature's limits and our knowledge base. Although we have introduced much science (with exact solutions) into the engineering knowledge base, the state of much of engineering and much of NDE engineering requires deterministic solutions based on past practices and specific tests. Variance in materials behavior demands knowledge based analyses supported by tests of operational materials, components, structures and systems. As we explore new frontiers, we encounter new and old problems that have not been solved and conditions that have not been addressed. The challenge to the engineering community is to "**turn ideas into reality**". "**By doing what we have always done, we will (hopefully) get what we have always gotten. To get something different, one has to do something different**."

Engineering problems and advances must be viewed as challenges to the best and brightest to do something different; to add knowledge; and to benefit in the process. We are not always successful. An engineering failure is a challenge and a goal not achieved, but we may learn much from failures. We strive to make most failures the result of a planned test. In the conference room of one of our railroad engineering institutions is a sign that reads, **"One test is worth a thousand expert opinions."** The results of a test should add to our knowledge base and thus reduce the need to repeat the same tests. Results should be incorporated as supporting data to utilize prior materials knowledge in a new materials lots and new materials applications.

The foundation of NDE is the need to prevent failures and reduce risk. NDE was initially developed as an extension of the five human senses and has been integrated into modern engineering technologies and practices. As its use and needs grew, it has evolved as a special engineering discipline that encompasses broad knowledge of engineering technologies and specialized knowledge of methods and applications. These challenges are rarely met by NDE engineering alone, but require integrated materials, structures, NDE and other functional engineering solutions. Although NDE was and is used as an important tool in quality control / quality assurance of engineering materials and processes, how much is enough was difficult to quantify. The trend in America is management as an "Information Society" rather than as a "Knowledge Society". Information is time based and often has an expiration date; knowledge is the management tool required to integrate and use information. Knowledge is more durable and is applicable to both current and future applications. I am often reminded of the story of the Bishop of the cathedral at Pisa, Italy, who acted on the information provided by his accountant that 50,000 lire could be saved by not performing a soil test. The result is a living monument to "managing information rather than knowledge managment." **"If we fail to learn from our mistakes, we are bound to repeat the same mistakes in the future."** Quantification of NDE capabilities is one method of determining "how much is enough" and is a key element in projecting risk analysis in engineering systems. The hard won lessons learned that moved NDE to an engineering technology were integral to the development of fatigue and fracture mechanics technology.

There are several notable engineering failures (**LESSONS LEARNED**) that are hallmarks in the path of development of general engineering knowledge of fatigue and fracture. The De Havilland "Comet" was the first commercial jet aircraft to be introduced into the world market. It incorporated several engineering innovations including jet propulsion and a pressurized cabin for high altitude operation. Unfortunately, the structures qualification tests did not reveal a shortfall in design engineering knowledge. As a result, operational aircraft suffered premature failures. Since these aircraft operated over water, failure analysis was difficult and the cause of failure was not initially recognized. After several failures, the cause was traced to fatigue crack initiation and growth from the corner radius of passenger window ports. The square window pattern, in conjunction with a pressurized cabin, resulted in stress concentration and early fatigue crack initiation and rapid growth to failure. These failures prompted focus on materials fatigue, crack initiation and slow crack growth properties assessment and research. Simultaneously, increased research and improvements in stress analysis methods were developed. The failure of the "Comet" is one of the few cases where engineering "lessons learned" have been dramatized in a "Hollywood" film ("No Highway in the Sky"). The aircraft and failure mechanism depicted are fictional, but the actual events and recognition of the need for additional engineering knowledge are portrayed. Recognition of fatigue and slow crack growth as material properties was a major milestone in prevention of structural failure and resultant increased operational safety.

Although NDE had been previously applied to crack detection in critical structures, NDE requirements were increasingly focused on areas of high stress and areas where stress analysis was difficult and less rigorous. The NDE community was challenged with a "**no cracks allowed**" acceptance criteria, and structural integrity and safety were addressed by conservatism (margins) in stress analysis and materials properties knowledge. The traditional capability and integrity of the NDE procedures are applied through "best engineering practices / past practices". The majority of engineering systems in operation today are dependent on such practices. "When in doubt, add a large margin (perceived safety factor) in the design." Many of the modern engineering structures such as aircraft and space systems demand more efficiency in design and implementation to meet operational systems challenges. Better engineering tools were needed. The observation of an optimist may be that "the glass is half full". The pessimist's observation is that "the glass is half empty". The engineer's observation is that the glass is grossly over-designed. The operational function of the engineering structure must be a major consideration in the design, the life expectancy requirements and the interim maintenance requirements.

The second notable engineering failure (**LESSONS LEARNED**) that I wish to cite is that of unexpected fracture of American "Liberty Ships" during World War II. Welded steel ships, that had been designed and fabricated using the best prior art and information available, unexpectedly fractured in early service. Fracture analysis was difficult due to the engineering knowledge base at that time. Work to find the cause eventually led to an understanding that the failures were due to a change in materials properties (fracture resistance) at cold temperatures.

These, and other engineering failures, prompted the development and use of "fracture mechanics" as a design and life cycle analysis technology. The ability of a material to tolerate a crack of a given size while under a given load was identified as a material property that is now known as "fracture toughness". Material analyses were further refined to include temperature and environmental effects and are now used as integral design tools. Indeed structural testing may benefit by lowering the temperature for some materials to screen for small flaws. The cold proof test concept was used to screen small flaws in titanium pressure vessels used in various space systems and to screen small flaws in (D6AC) steel in areas of the F-111 aircraft that are not accessible by conventional NDE.

Work to characterize crack growth and materials behavior, revealed that a stress wave is generated by the incremental (but sub critical) growth of a crack. This characteristic was termed "acoustic emission (AE)." If we imagine a sphere of uniform thickness, fabricated from a uniform material and then load it above its designed operating stress, critical flaws should result in fracture of the structure and NDE would not be required to provide assurance of structural integrity. Further, if we monitor the structure during proof loading, sub-critical crack growth should result in acoustic emission and, if detected, the loads might be reduced and the structure repaired. While the theory is sound, the maturity and practicality of acoustic emission monitoring of many structures does not eliminate the need for classical NDE. Acoustic emission was incorporated as an NDE method and has been useful in many specific applications.

Professor Rao (and his students) made significant contributions to the maturity and application of acoustic emission and to its' acceptance as an NDE tool. He founded the "Acoustic Emission Working Group" (AEWG) in India and was honored with a "GOLD MEDAL" for his contributions to that technology.

Acceptance and application of fracture mechanics and life cycle management generated a formidable challenge to the NDE community to identify and quantify the flaw size that can be reliably detected by an applied NDE procedure. It was recognized that NDE application does not assure that a structure is "flaw free" (the degree must be defined). The proverbial question of "**what is the smallest flaw that you can find?"** was changed to "**what is the largest flaw that you might miss**?" These issues were addressed in India by work at the "National Aeronautical Laboratories"; in the USA by the "National Aeronautics and Space Administration (NASA)" for application to the SPACE

SHUTTLE; and by the United States Air Force Materials Laboratories (AFML) for application to advanced aircraft.

The AFML application was accelerated by early failure (100 hours on a 4,000 hour life design) of an F-111 aircraft. An elegant treatment of the history involved in moving the United States Air Force (USAF) from a "Safe-Life" (static strength) to a "durability and damage tolerant" policy is described by Dr. John W. Lincoln in a paper entitled "DAMAGE TOLERANCE – USAF EXPERIENCE" [1]. In summary, the critical flaw / defect size that can be tolerated (material, location and stress level) and the size that may be detected by NDE are shown schematically in Figure 1. Figure 2 provides a life cycle management concept based on damage tolerance analyses and interim application of NDE. The NDE capability must be quantified and provide high confidence (reliability) for detection. The wisdom of this policy has been validated both by service life experience and by structures tear down analyses.

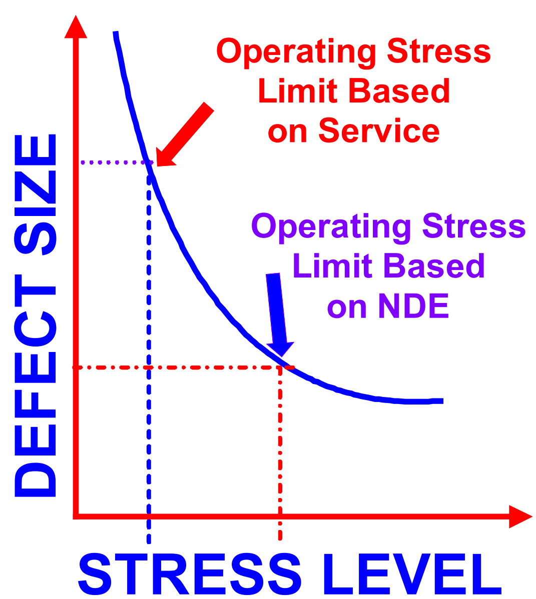

Fig. 1: Defect size versus

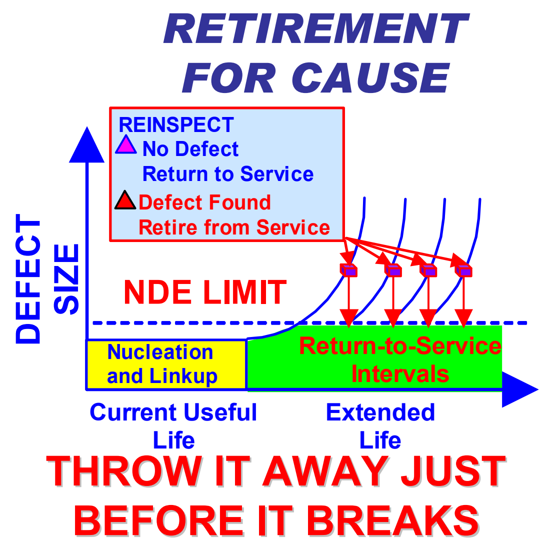

Fig. 2: Life-cycle management based stress level on damage tolerance

In approximately the same time frame, the National Aeronautics and Space Administration (NASA) incorporated damage tolerance design philosophies and principles in the original Space Shuttle design and in subsequent space structures programs. In most cases, the NASA safety design margins were lower and quantification of capabilities was critical. A new challenge to the NDE community was in quantification of NDE capabilities for the procedures that are typically used in production. Programs to quantify detection capabilities resulted in the establishment of the probability of detection (POD) metric and methodologies. Those methods and rationale have been adopted as the "standard "for detection capabilities demonstration and validation throughout the world. The historical basis and methodologies for demonstration are discussed in detail in prior presentations and references [2,3].

Two important points are evident from this work. First is that crack / defect detection is a probabilistic process due to response variations of cracks of the same size and to variations in the response of human operators to the NDE stimuli (outputs). The second point is that detection is bounded by practical aspects of application. A long / shallow crack or a short / deep crack differ from the classical thumbnail shaped crack (a/2C=0.5) that is usually assumed for purposes of fracture analysis. In addition, changes in the detection mode may occur when the size of the NDE probe field approaches the size of the crack.

The next step in development of the POD metric was the introduction of a model to describe the POD function [4]. A knowledge base for typical NDE capabilities has been documented in the "NDE Capabilities Data Book" that is available in the public domain [5] and has been presented in previous lectures in India [6]. Introduction of POD methodologies, concepts and design requirements for quantified NDE capabilities have been drivers in moving NDE from an art that is provided primarily by skilled craftsmen in the European "GUILD" tradition to an engineering technology with checks and balances that are integral to engineering principles, documentation, practices and responsibilities. The "guild / art" paradigm persists in many sectors of the world economy and is particularly notable in qualifications of NDE personnel skills. ISO 9000 is a particular dichotomy where production and operation of a product are deemed to be the responsibility of the producers, but personnel skill certification may be relegated to an outside entity. USA law places the responsibility for skill certification and NDE operator performance with the producer / employer. Training and examination may be contracted out but performance responsibility cannot be delegated.

During the time that the fracture mechanics, durability and damage tolerance principles, and probability of detection knowledge base were being advanced and solidified, Professor Rao was advancing acoustic emission NDE methods and was developing stress analysis methods for mechanically fastened joints. His foresight in selecting problems with a widespread need for solution was outstanding. For example, a typical fighter aircraft may contain approximately one-half million fasteners. The assembly process requires fit-up, drilling, reaming or other surface improvements, inspection / gauging of sample hole diameters, and the selection and installation of a fastener. Transport aircraft and airliners may contain approximately 2 million fasteners and a Boeing 747 contains over 3 million fasteners. Preparation and installation of fasteners was collectively the largest fabrication cost in the assembly of an airframe (exclusive of engines) and constituted the largest single cost in inspection and maintenance of an airframe. Critical degradation of joints at fasteners was the most probable cause for retirement of an airframe. Analytical methods for analyzing the variances in fastener joint assemblies and for the transfer of loads was a major need for all traditional aircraft production. Professor Rao's work engendered long term association with Lockheed, Boeing and other airframe producers and was a substantial contribution to the engineering knowledge base.

3. Recent Accomplishments and Advances in Technology

During the 40+ year era of our concurrent working careers, vast technical progress was made in the world. In India, great general economic progress has been aided by excellence in engineering and NDE engineering. Most notable are the autonomous development of nuclear power, space launch systems, an aircraft industry, petroleum / petrochemical industry, and advancements in many fields of education, engineering, sciences, industrialization and information technology. There is little doubt in my mind that the nuclear power industry in India is unique and one of the most advanced in the world. My heart is warmed and my hat is tipped to the significant advancements that are apparent each time I visit. My first visit to India was in 1987 to administer and proctor Level III examinations for the American Society for Nondestructive Testing (ASNT). My love for India was kindled by my experiences during this visit and I stayed at a new Juhu Beach hotel, near Bombay. In the lounge, a Bollywood film was being made and they needed a westerner for a scene. Somewhere a record of my visit is on Bollywood film. If you have seen this film, you should be kind and let me know – it would be kinder to say, "—and you haven't changed a bit" – but this is a professional meeting and we must honor truthfulness.

During the short period of my tenure, technology advances in the world have been astounding. My father was born in a sod house. The farm house where I was born did not have electricity and water was pumped by wind power. I lived at a very fortunate time period and was able to transition from a farm boy to a **ROCKET SCIENTIST**. I am continually amazed and grateful for the opportunities that were opened to me and for my involvement in some very exciting and useful programs during my career. Some of those include:

- The first jet powered seaplane
- Ballistic missiles
- The Gemini launch vehicle
- The Apollo launch vehicle (Saturn V) and the Apollo capsule
- The Lunar lander including the drill used in sampling
- The Space Shuttle program – Original and now
- The Titan heavy lift launch vehicles – Titan III and Titan IV
- The Viking – Mars lander in 1976
- The F-111, A-10, F-15, F-16 and F-22, C-5, DC-8,DC-10, L-1011, 747 and other aircraft programs
- Various advanced launch vehicle and satellite programs

In NDE, advancement programs:

- Penetrant and automated penetrant inspection
- Eddy current and automated eddy current inspections
- Ultrasonic - from tube (valve) type instruments to laser generated, phased array and automated / robotic scanning
- Magnetic particle and flux leakage
- X-radiography from film to computed tomography
- Visual from unaided to high resolution borescope
- Thermography from cryogen cooled to thermoelectric
- Acoustic emission from single to arrays and signal processing
- Leak test from bubble leak to helium
- Participant in the development of ASNT TC-1A and a member of the team that developed the ASNT Level III Examination program.

In India I have observed and participated (a little) in NDE advancements:

- Initiation of ASNT Level III examinations (1987 and 1989). Examinees were knowledgeable, well prepared and had a higher success rate than in the USA during the same period. We were aware that some of the instruments and instrumentation referred to in the examinations might not be familiar in India, but no allowances were made.

- Development and production of liquid penetrant materials in India
- Development of world class ultrasonic instruments and transducers
- Development of technology, instrumentation and skills to support the needs of a growing economy in both industrial and high technology areas, including special expertise in acoustic emission technology
- Consolidation of the Indian Society for Nondestructive Testing (ISNT). The membership is approximately equal to that of ASNT (where 1/3 of the membership is foreign)
- Host of the very successful, 14th World Conference on NDT, in New Delhi, India, 8-13 December 1996
- Active innovator and member of the "World Federation of NDE Centers (WFNDEC) with two very active Centers in India at the Indian Institute of Technology, Chennai, and the Indira Gandhi Centre for Atomic Research, Kalpakkam, Tamil Nadu
- I am grateful to be able to include my many friends in India as students, colleagues, peers and mentors.

On 1 February 2003, we lost 7 seven Astronauts and the Space Shuttle "COLUMBIA". The Space Shuttle Program stood down for two and one-half years to provide time for analysis, extensive system review and recovery actions. On 9 August 2005, flight (STS-114) was again resumed [7]. The Space Shuttle is a very complex and ambitious engineering system and is viewed by much of the world as a triumph for modern engineering. It is now an aged system and further analyses and maintenance work are necessary to support the ambitious, planned flight schedule. This remains as a near term challenge. I was a contributor to the original program design and am continuing in the support of planned missions. We owe much to space age technologies including the benefits and curses of cell phones, precision navigation systems – the list is long – and don't forget "Velcro".

4. Vision and Challenges

We look forward to continuing benefits and conveniences that will result from pushing the technology envelope by space systems and space exploration. For example, the Nobel Prize in physics was awarded in 2006 to Americans John C. Mather and George F. Smoot for the discovery of small temperature variations in the "cosmic microwave background" that fills space. This is expected to change both the theories on the origin of our universe and the direction of space exploration for the next decade.

4.1 Engineering Infrastructure

Significant challenges to both India and the USA are being generated by increases in engineering infrastructure, by maintenance of infrastructure and by life extension of the infrastructure. These include roads, bridges, railroads, aircraft, buildings and an array of special systems. In aircraft maintenance alone, the Federal Aviation Administration (USA) requires action for maintenance and life extension of aircraft / airline systems. More than 50% of those actions are NDE solutions and the list is growing. Some 90% of the railroad tank cars in the USA have exceeded their design life. NDE is and will be a major requirement in both maintenance and life extension.

4.2 Energy

Global energy needs and usage are increasing rapidly. By-products of energy production and use threaten balance in our environment. Increased usage of fossil fuel, wind power, solar power and nuclear power are apparent in India, USA and the world. Nuclear power development in India has been rapidly accelerating and is anticipated to accelerate with commensurate demands for new NDE capabilities and new improvements. A science / engineering break-through is needed to satisfy increasing design and safe life requirements.

4.3 Water

Water sources, transportation / distribution (pipelines and aqueducts), treatment, use, re-use and management are critical to both the population and industry. We have significant challenges in India and in the western USA.

4.4 Health Care

Affordable and available heath care needs increase as the population increases, the population ages and sophistication of health care solutions increase. During my watch, I was involved in development of one of the first ultrasonic brain scanners. The health care industry benefited from transfer of technology developed in the industrial world and industrial NDE is now benefiting, in return, by transfer of technology from the medical industry. It is clear that we have a discipline and value crisis when the costs and reliability of medical NDE tools are compared with industrial NDE tools.

4.5 Education

In the USA and in many western countries, we continue to have significant engineering shortfalls and difficulties in attracting young people to engineering education. We are retaining and employing older workers, but the gap between demand and response continue to widen. India is outpacing many other countries in engineering education. This is a result of maintaining / improving education standards and quality and the viewpoint of “how engineering is honored and rewarded in each culture” (reflection on the message from President George Washington).

4.6 World Economy

As the world economy becomes more homogenized, our engineering communities must address the issues of engineering standards, engineering instructions, data packages, and practices. An engineering system that is produced at one location for use in multiple locations in the world must be inspected, maintained and repaired at each user’s location. India is well aware of the difficulties of managing engineering systems that are produced elsewhere. An initiative is underway to “harmonize” some of the NDE procedures for common use throughout the world. We are in need of someone with the skills and energy of Professor Rao to drive this initiative to fruition.

4.7 Other Challenges

We must direct attention and energy to support challenges brought forth by new engineering projects and initiatives. Notable near term projects that are on the horizon include:

- Breeder reactors in India
- Expanded nuclear power in the world
- New aircraft
- New space launch vehicles
- New space exploration – back to the moon
- New satellites and space missions
- Ram jet propulsion – we have proof of principle in the NASA X-43

- High speed trains / ground vehicles and improved NDE for railroad systems

Specifically in NDE:

- Safe life extension of existing infrastructure and systems
- Composite materials, structures and systems challenges
- Multiple point NDE system calibration
- Data links to the NDE capabilities data base
- Ground transportation systems / railroads and alternate transport movers
- NDE training simulators
- New NDE methods / procedures
  - Shearography
  - Air coupled ultrasonics
  - Laser generated ultrasonics
  - Embedded sensors / health monitoring
  - Direct imaging
  - Electromagnetic imaging (NMR)
  - Microwave methods / imaging
  - X-ray backscatter / forward scatter methods
  - Supplemental methods to penetrant inspections
  - Remote sensing
- Materials properties measurements by NDE procedures
- Residual stress measurements
- Coating chemistry, integrity and thickness
- Inspections through coatings
- Second / multi-layer inspections
- Harmonization of NDE practices and personnel qualification
- NDE and NDE engineering education
- Automated scanning / remote scanning
- NDE data processing and data fusion
- Image processing
- NDE joint criteria processing acceptance
- And in general, NDE of all types of joining (gluing, bonding, etc)

5. Summary

In summary, I once again thank you for the honor of presenting this lecture.

In crafting this **"FIRST A.K. RAO DISTINGUISHED MEMORIAL LECTURE"** lecture, I chose to divide my address into three areas:

- **FOUNDATIONS** for the knowledge gifts that we have been given
- **ACCOMPLISHMENTS** in increasing knowledge and resultant benefits.
- **VISION** in current and future challenges

My goal was to honor the life and deeds of Professor A.K. Rao – husband, father and grandfather; scientist, engineer, educator, mentor; innovator, citizen, organizer, statesman; and great contributor to NDE engineering technology. Hopefully I have educated, informed and stimulated your minds and imagination in his tradition and legacy, and have supported the conference theme “NDE in a Knowledge Society”.

Thank you for your hospitality and attention.

6. References:

1. Lincoln, John W., “Durability and Damage Tolerance in Aircraft Design “, Proceedings of the 12th Symposium on the International Committee on Aeronautical Fatigue (ICAF), Pisa, Italy, 22-24 May, 1985.
2. Rummel, Ward D., Paul H. Todd, Jr., Sandor A. Freska, and Richard A. Rathke "The Detection of Fatigue Cracks by Non-Destructive Testing Methods” NASA, (NTIS N74-17285), February 1974.
3. Rummel, Ward D., “OVERVIEW of Non Destructive Evaluation (NDE) Capabilities Assessments and Probability of Detection (POD)”, Paper presented to the 14th World Conference on Nondestructive Testing, New Delhi, India, 8-13 December 1996, Published in the transactions.
4. Berens, A.P. and Hovey, P.W. (1984), “Flaw Detection Reliability Criteria, Volume I – Methods and Results,” AFWAL-TR-84-4022, Air Force Wright Aeronautical Laboratories, Wright-Patterson Air Force Base, Ohio, April, 1984.
5. Rummel, Ward D. and George Matzkanin, NDE Capabilities Data Book, Third edition, Available from the National Testing Information Analysis Center (NTIAC), DB-97-01, September 1997, (Book and CD), Austin, Texas, 78736-4725, TEL: (512-263-2106)
6. Rummel, Ward D., Pre-conference tutorial on “Quantification and Validation of the Performance Capabililty (POD) for Non Destructive Inspection Procedures”, 2003 Conference, Indian Society for Non Destructive Testing, Trivendrum, India, 11-13 December 2003.
7. STS 114 - Ref: http://www.nasa.gov /mission_pages/shuttle/shuttlemissions/ archives/sts-114.html (2006).