

**AC 2007-330: ENABLING THE U.S. ENGINEERING WORKFORCE FOR  
TECHNOLOGICAL INNOVATION: THE VALUE OF ENGINEERING TO THE  
NATION'S GROWTH AND SECURITY**

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# **Enabling the U.S. Engineering Workforce for Technological Innovation: The Value of Engineering to the Nation's Growth and Security**

## **I. Introduction**

This is the fourth of four invited papers prepared for a special panel session of the National Collaborative Task Force on Engineering Graduate Education Reform that is focusing its efforts on the deliberate advancement of professional engineering graduate education to enable a strong U.S. engineering workforce for competitiveness and national security purposes. This final panel paper is focusing specifically on the worth of the engineering workforce to the nation.

Providing a thorough assessment of the value of engineering to our nation is a complex undertaking involving objective and subjective elements. A simple, factual approach would be to equate that value with the sum of the salaries of all individuals performing jobs classified as engineering. By 2006, that value reached approximately \$150 billion.<sup>1, 2</sup> While not an insignificant sum, an argument can be made that the actual value is much higher.

Subjectively, the value could be equated to the public perception of engineering. Public perception about most topics including engineering fluctuates. During the U.S. quest to put a man on the moon in the 1960s, engineering was recognized as a highly respected profession. Late in the 20<sup>th</sup> century, though, the desirability of engineering as a career or even as a significantly positive contributor to society was questioned as job demand waxed and waned. In addition, the growth of technology was viewed by many as complicating their lives, and engineering was perceived as part of the problem rather than a solution. We might call this the "Dilbert effect."

The authors' view is that an evaluation built on simplicity or public perception underestimates the value of engineering to our nation. In our opinion, the engineering workforce is at the center of national wealth creation and the economic and physical securities we enjoy. We believe engineering will ultimately provide the solutions for a great many of the problematic issues in today's complex society.

The purpose of this paper is to recognize the many benefits provided by the engineering workforce that contribute to the freedoms and securities we enjoy today and to make a case for growing both our nation's engineering capability and capacity through a structured program that encourages the induction of new engineers and places priority on specific life-long learning opportunities.

Ascendancy of the U.S. within the global economy over the past hundred years can be related to a number of factors from entrepreneurial spirit to an abundance of natural resources. A major factor is that the U.S. has been at the forefront of systems engineering, even to the point of defining and developing products and technologies whose manufacture and ultimate refinement are associated with other countries.

Beginning with automobiles and airplanes in the early 1900s, even the short list of such notable system developments is impressive:

- Radio
- Television
- Optics
- Video cassette recorders (VCRs)
- Microchips
- Computers
- Global positioning systems (GPS)

The U.S. continues at the head of much of the high technology product and system food chain today by maintaining a preeminent capability in the engineering of complex systems. This capability is underpinned through: 1) a competence in program and technical program management, 2) an effective technology development process enabled by the U.S. government and academic research establishment, 3) high levels of research and development (R&D) investment that create demand that produces a highly skilled engineering workforce, 4) robust, lean processes and state-of-the-art analytical / empirical methods, and 5) an environment that encourages workforce creativity and passion for success.

Discussion of program management other than in relation to processes for delivery of technological solutions and the role of environment in fostering workforce creativity and passion are beyond the scope of this paper. The roles of engineering development, a highly skilled technical workforce, and technical processes are, however, within the intended scope.

## **II. Technology Creation Is Essential and Requires New Educational Approaches**

Much technology advancement, particularly since the middle of the last century, has centered on technology development addressing critical U.S. Government sponsored initiatives. Engineering developments and the technologies created in response to defense product, space exploration, and national security needs have found applications across the broadest spectrum of both military and commercial products. As technologies have become available off the shelf, they have spawned a technology push enabling innovative products that have provided the U.S. a unique competitive advantage. Continued high levels of Government activity in this arena are essential to maintaining a competitive edge.

System focused technology planning processes are now being established to better facilitate the delivery of systems and solutions providing breakthroughs in functionality. These processes identify needed technical capabilities that would enable systems to offer these new levels of functionality. Increasingly, delivery of identified technologies is being accomplished by cross-functional teaming within both the research and product engineering communities. Hence, academia and industry are moving from a reactive push system toward a more balanced system that also employs technology pull. Supporting processes are in place to provide better program management of the delivery of needed technologies. The totality of these technology planning and delivery processes will be key enablers of the U.S. maintaining leading systems engineering capabilities.

The National Aeronautics and Space Administration (NASA) has developed a very useful technology delivery program methodology built around the technology readiness level (TRL) concept. Initial TRLs of 1 to 3 generally correlate to university, scientific and research lab activities typically associated with graduate degree awards. Mid TRLs of 4 to 6 and upper TRLs of 7 to 9 correspond to typical engineering development programs and are usually delivered by the larger engineering workforce. The creation of useful technology is a full partnership requiring the best efforts of the research community and the engineering workforce. But, delivery of innovation in useable form occurs when actually embedded in a product or system. This is consistent with issuance of patents upon a concept being reduced to practice.

The breadth and depth of the U.S. university-based academic research program has been a critical enabler of the technologies delivered in our system solutions. A number of significant factors are converging that create a need for U.S. academic institutions to now play a greater role in enabling our engineering workforce to embed these technologies and in future systems level innovation.

The pending retirement of the baby boom generation will result in loss of unique engineering experience relative to technology maturation and integration into complex systems. Concurrently, the exponential growth rate of scientific knowledge and the ever increasing multidisciplinary nature of today's complex systems have increased the need for continuous education for the practicing engineering workforce.

At the same time, industry is increasingly committed to the adoption of new, lean processes. These factors will challenge industry's ability to provide the necessary new learning. A compelling case can be made for the U.S. university system to offer a purpose-built professional curriculum for life-long engineering education.

The National Collaborative for Graduate Education Reform is a partnership of leaders from U.S. Universities and Industries committed to delivery of such a life-learning system. The collaboration recognizes that the U.S. has an innovation driven economy and that the engineering workforce creates our useable technology and innovation ensuring our national competitiveness. Lifelong development of the graduate engineering workforce is its priority.

Accordingly the collaborative endorses systematic development of engineers through a skill development structure from entry level to chief engineer level that will ensure the necessary capacity of appropriately skilled engineers is available. It further endorses integrating advanced university graduate studies with experience and the practice of engineering to better facilitate future technology development. This would involve nonresearch based advanced degree programs that include such topics as strategic thinking, leadership of multidisciplinary teams, system thinking, innovation in engineering, as well as specific technical subject matter expertise.

Creation of a national network of universities delivering such a life-long learning curriculum is essential if our country is to produce the highly innovative workforce needed for delivery of the unique technologies needed to enable our next generation of products and systems.

### **III. Research and Development (R&D) Spending – Depends on and Enables a Highly Skilled Engineering Workforce**

The U.S. leads the world in levels of R&D expenditure. In 2006, U.S. R&D efforts totaled \$320 billion.<sup>3</sup> This equates to almost a third of global R&D spend, is roughly equal to the amount of R&D spend in all of Asia, and is approximately one-and-a-half times Europe's equivalent R&D expenditure during that year. Within the global R&D spend, the more complex R&D addressing systems development tends to be accomplished in developed countries.

Hence, in addition to total spend, the vast scope of activities provides engineers in the U.S. and the other highly developed countries with the opportunity to integrate the most recent technologies into systems providing new functionality. The nature of R&D in the developing world is related to business opportunities where those countries have a competitive advantage, and by necessity these tend to focus on endeavors where labor rates and capital costs for land, facilities, and other materials are lower. The implication is that the quality of R&D either from a value-added standpoint or from the opportunity to develop advanced engineering skills corresponds to the complexity of the work being performed.

The U.S., as the preeminent practitioner of R&D activities, derives significant competitive advantage from its leading position. Consequently, it has the world's largest core of highly skilled, highly experienced engineers who are afforded more complex opportunities than in any other country. Maintenance of this competitive advantage is tied to sustaining high levels of R&D but even more importantly to applying these expenditures to the most complex problems that require a deep understanding of the latest technologies and the ability to integrate them to the fullest advantage in novel systems solutions. Workers' skills are perfected by performing challenging tasks and by iteratively employing the lessons learned from mistakes and opportunities resulting from those tasks.

A significant longer term threat to maintaining a highly innovative engineering workforce is the lack of interest and related low performance of our primary and secondary school students in science, technology, engineering and math (STEM). Regional, state and local efforts supporting recruitment of young students into STEM areas include the FIRST Robotics Competition and the Project Lead the Way® pre-engineering curriculum within Middle Schools and High Schools. These and other similar projects deserve our fullest support.

A move to restore the perception of engineering as a rewarding and value adding career is also needed, thus our Government and our educational institutions need to also embrace this initiative to market engineering. The goal of such an activity should be to convince parents of the economic and societal value added by engineers and encourage them to influence their children accordingly. Another needed step is to strengthen primary and secondary school teaching staffs in the areas of math and science. Having knowledgeable and enthusiastic teachers is a necessary step to enlisting students into a technical career path.

The lack of interest in STEM areas in the U.S. contributes significantly to the fact that the developing countries are graduating multiples of the numbers of U.S. engineering graduates.

However, most of these engineers from developing countries will be employed in the more routine engineering/R&D tasks when compared to those associated with highly complex systems realization. While not an absolute barrier relative to having U.S. engineering capabilities surpassed, this factor will provide a significant buffering effect.

Offshore placement of white collar work including engineering has also made national headlines as a threat to our national economic well being. Engineering offshoring is made possible by creation of significantly lower cost engineering capabilities associated with the increased engineering graduation rates in developing countries. From an engineering perspective, outsourcing of lower value-added tasks can actually enhance design process efficiency and free up highly experienced engineers to address more critical systems integration tasks. The experience of many U.S. companies to date has resulted in the use of offshore capability to perform lower value-added engineering tasks as they approach mechanical repetition and lend themselves to computer automation. The generation of detailed computer drawings and performance of noncomplex stress analysis are examples of engineering work that has lent itself to being placed offshore.

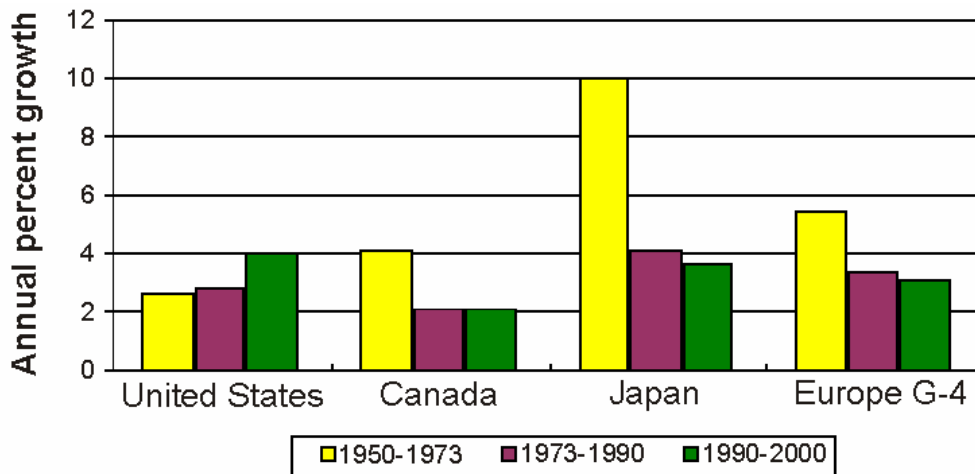
While information technology (IT) based virtual working enablers will eliminate some of the barriers to offshore placement of higher level systems engineering tasks, other barriers are likely to remain. Complex systems development requires a concurrent design approach with full involvement of engineers from the entire value chain. This implies that developing countries must create advanced manufacturing and manufacturing-related supplier infrastructures in addition to engineering capabilities if they are to add value at higher levels. Development of infrastructure can be a lengthy process.

While engineering graduation ratios and offshore job placement will continue to cause debate, they need not pose a threat if our government/industry complex continues to launch high rates of new, domestic programs that require integration of rapidly changing, highest complexity technologies. Such programs will ensure continued generation of the necessary highly skilled, highly experienced U.S. engineering workforce to maintain competitive advantage.

#### **IV. Engineering's Contribution to Productivity Improvements Enhances GDP**

As Figure 1 shows, over the past decade the U.S. has led developed countries of the world in terms of productivity improvement.<sup>4</sup> This measure of productivity is related to the level of labor necessary to deliver a unit of product. Worker training and capital expenditures for improved equipment are widely acknowledged factors in overall productivity growth. However improved productivity has also been enabled by lean six-sigma methods and enhancements in manufacturing that are provided by design-for-manufacturing-and-assembly and by manufacturing method advances.

Hence much of our productivity gains have been delivered through the design and manufacturing engineering communities working cross functionally. Because the public may not recognize the engineering workforce's role in designing highly producible products and improved manufacturing process development, a relatively weak appreciation of the engineering workforce's contribution to improved productivity exists.



**Figure 1. Historical productivity for G7 countries.**

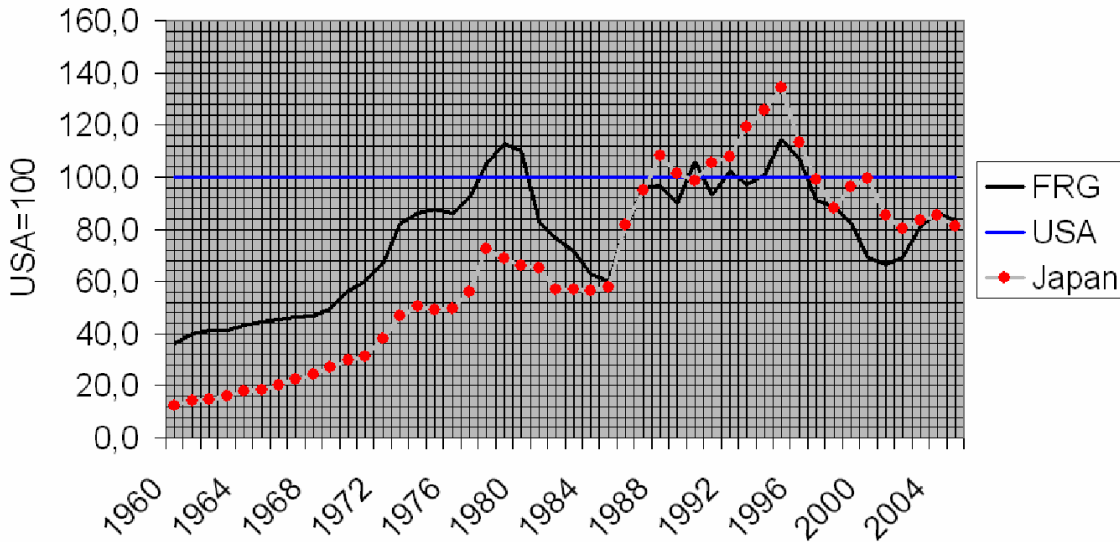
During product development, transactional process improvements combined with high fidelity, analytical methods and improved design processes have reduced product R&D engineering labor and expenditures. R&D expenditures are subsequently recouped as an overhead added to the cost of delivered product. Thus, design process enhancements and engineering methods manifest themselves as engineering productivity improvements.

While engineering productivity improvement is demonstrable at a qualitative level by comparing accomplishments of development programs with fewer resources and in less time, concise quantitative measurement has been more problematic. No two development programs are identical, so standard units for engineering tasks are not as quantifiable as standard times for repetitive manufacture of identical production parts.

It can be inferred that U.S. economic strength and competitiveness deliver the ability to provide for financial and physical security, and all are underpinned by the technical and engineering workforce extant in the U.S. Prior to the 1990s, the productivity of the rest of the developed world was increasing at a significantly higher rate than in the U.S. (Figure 1).

The higher levels of productivity improvements in the rest of the world in the earlier portion of the 20<sup>th</sup> century were arguably the result of emulation and refinement of U.S. production systems. This would include adoption of production lines and related mass production techniques. Globally initiated refinements include such approaches as lean and just-in-time manufacturing.

Figure 2 compares the per capita gross domestic product (GDP) of the U.S., Japan, and the Federal Republic of Germany.<sup>5</sup> The higher productivity rates demonstrated by the rest of the world from the 1950s into the 1990s (Figure 1) correlate to convergence of the per capita GDP gap through the mid 1990s (Figure 2). Higher U.S. productivity since the 1990s, however, has restored some of the GDP advantages the U.S. enjoyed through most of the 20<sup>th</sup> century relative to Japan and Germany.



**Figure 2. GDP at current prices and exchange rates per employee, comparison U.S., FRG, and Japan.**

Acceleration of U.S. productivity in the 1990s reflects many engineering and technology enhancements that go beyond improvements exclusive to the manufacturing process. Selected U.S. companies and industries had been pursuing technology-enabled productivity improvements in both the design and manufacturing disciplines before these became vogue and began to materially influence the national productivity statistics. In 1993, Kronemer and Henneberger<sup>6</sup> studied productivity dynamics in the aircraft industry. They highlighted trends that continue to this date and accurately forecasted that “with the entrance of some computer aided technology, the industry, should post strong productivity gains in the decade ahead.” Further it stated that the aircraft industry had “registered a 16.8% gain in productivity in 1991” and the paper also recognized the opportunity technology would add from “paperless design.”

Kronemer and Henneberger highlighted that in new Boeing products of that era “all but 3% of the computer-aided manufactured parts fit perfectly the first time, compared with the best ever 50% achieved using a paper-based design.” According to Kronemer and Henneberger, on the B-2 aircraft, there was a “6-to-1 reduction in engineering changes” which “were made five times faster and could be inputted into both manual and computerized numeric-control milling machines 40% more efficiently.” These improvements resulted in an estimated elimination of 60% of associated engineering changes.

History has shown that since 1993, significant engineering and technology driven improvements in aerospace productivity have exceeded expectations. These include computer-aided design (CAD); advanced computer-aided manufacturing (CAM) capabilities; design for manufacture and assembly methodologies and six sigma process controls; direct part marking; universal identification methodologies; radio frequency identification capabilities; replacement of empirical design with analytical; and significant material property development. Thus engineering and technology improvements have provided productivity benefits to both the front end design and development activities, as well as to the production arena.

In the experience of the authors, actual product design engineering productivity has improved up to 30% in the last two decades although design is a relatively small portion (about 15%) of the total design and development of complex products like aerospace gas turbine engines. However, IT is also providing benefits in technical program management, in product life cycle management (PLM) tools, and in replacing elements of empirical qualification with high fidelity analytical simulation. Reduction of engineering cost of nonquality, i.e., engineering changes after product introduction, occurs when designs are right the first time. Toward that end it should be noted that, in the authors' experience, developmental hardware designed and manufactured in the new, robust PLM / CAD-CAM environments is nearly 100% form and fit compliant.

This section has attempted to demonstrate both the role of engineering in enhancing productivity, and the importance of productivity in maintaining our global competitiveness. Engineering clearly has an essential role in enabling operational productivity and is directly responsible for improving both its own capabilities and productiveness.

## **V. Conclusions**

The competitive challenges facing the U.S. will require our government, universities and industries to embrace changes that will build on the present strength of our engineering infrastructure. Continued Government sponsorship of R&D to address the needs within its charters of national security and strategic research is essential. Increasingly we need to establish the abilities to utilize both technology pull and push to enhance our systems capability. A significant challenge exists to maintain the university research capabilities while simultaneously strengthening the role of universities in providing lifelong professional engineering learning to enhance innovation and creativity as promoted by the National Collaboration for Graduate Engineering Education Reform.

The high level of R&D spend in the U.S. has created a large highly skilled engineering workforce capable of delivering the highest complexity system solutions. A virtuous circle exists between the level of R&D investment and the engineering workforce. The threats to maintain our system developments capabilities are: reductions in R&D spend; reduced complexity of R&D task; and/or loss of engineering workforce capability. Our government and industry must address the R&D level and content and also work closely with our educators and engineers to ensure an adequate supply of high school graduates who are qualified and enthusiastic about pursuing engineering educations and careers. Effective marketing of engineering within our populace must be a national priority.

National productivity is key to maintaining our economic preeminence and engineering is central to improving productivity. Maintenance of a level of productivity growth comparable to or greater than that of the rest of the world is essential to providing the ability to maintain necessary levels of R&D and the associated engineering capabilities to continue developing world leading system solutions. A clear engineering focus on improving our productivity in addition to engineering capabilities and the productivity of our manufacturing system needs to be a top priority.

The tenets outlined herein are key to maintaining U.S. economic prowess and the ability to provide our future security. We must act now to address these tenets and ensure that the U.S. Engineering workforce continues to provide competitive advantage by virtue of both its capability and its capacity.

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