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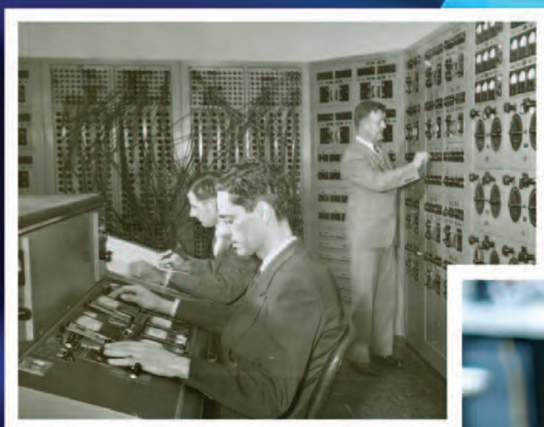

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Cultivating the Test & Evaluation Workforce

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The ITEA Journal
December 2012
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TECHNICAL ARTICLES

DEPARTMENTS

ON THE COVER: The opportunity and challenge of "Cultivating the Test and Evaluation Workforce" is not one simple task but rather a series of interrelated, continuing activities that should be synchronized to achieve the best desired outcome. The relevant activities include retaining the current workforce, attracting new employees from government and industry, and ensuring there is an adequate supply of new post secondary graduates in the right academic majors for future test and evaluation needs. The cover photos depict the test and evaluation workforce in all age groups and from on the job training to hands on training, mentoring, and professional education.
Cover designed by Ms. Amber Rice, Georgia Tech, Atlanta, Georgia. Photos courtesy of © Georgia Institute of Technology.

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■ For over thirty years the International Test and Evaluation Association (ITEA), a not for profit education organization, has been advancing the exchange of technical, programmatic, and acquisition information among the test and evaluation community. ITEA members come together to learn and share with others from industry, government, and academia, who are involved with the development and application of the policies and techniques used to assess effectiveness, reliability, interoperability, and safety of existing, legacy, and future technology based weapon and non weapon systems and products throughout their lifecycle. ITEA members embody a broad and diverse set of knowledge, skills, and abilities that span the full spectrum of the test and evaluation profession. All of which is shared with others through the ITEA Journal the industry's premier technical publication for the professional tester and at ITEA's Annual Symposium, regional workshops, education courses, and local Chapter events. Join the thousands of ITEA members your peers in the industry in contributing to the ITEA Journal and participating at ITEA events so that you also can benefit from the opportunities to learn from others, share your knowledge, and help advance the T&E industry.

■ *The ITEA Journal* (ISSN 1054 0229) is published quarterly by the International Test and Evaluation Association at 4400 Lakes Court, Suite 104, Fairfax, Virginia 22033 3899. Single issue cover price for *The ITEA Journal* is $25. ITEA offers annual membership for individuals, full time students, and any organization interested in advancing the test and evaluation profession. Annual membership dues are $60 for individuals ($80 if located outside of the U.S.) and $25 for full time students. Annual Corporate Membership dues are $500 for small organizations (less than 50 employees), and $1,000 for large organizations (50 or more employees). Corporate Memberships include three (3) Individual Memberships for small organizations and five (5) Individual Memberships for large organizations. Annual dues include a one year subscription to *The ITEA Journal*. The annual subscription rate for libraries and other organizations providing timely reference material to groups is $75. All overseas mail (air mail or AOA) requires an additional $20. *The ITEA Journal* serves its readers as a forum for the presentation and discussion of issues related to test and evaluation. All articles reflect the individual views of the authors and not official points of view adopted by ITEA or the organizations with which the authors are affiliated.

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2013 *ITEA Journal* Themes

The ITEA Publications Committee has established themes for the 2013 issues of *The ITEA Journal* and invites articles in the following areas:

T&E Challenges and Issues (March issue). Challenges are the rule not the exception in test and evaluation (T&E) and innovation is a necessity not a choice. Budget and schedule constraints are a fixture but the daunting task facing us is addressing the technological hurdles. New system complexity increases as technology allows designers to do more in a smaller volume. Test technology must evolve faster than those systems to be tested, and must produce more sensitive instruments than the systems to be measured. The number of ranges available and facilities on those ranges continues to diminish and encroachment on land and spectrum accelerates. Autonomous and cognitive systems present all new test requirements, and cyberspace testing pushes us beyond thinking outside the box – there is no box. T&E challenges range from characterizing the required test environment, providing production representative articles for operational testing, and producing adequate threat systems through assimilating emerging technology, distributed testing, and shortage of critical skills, to loss of test facilities, hypersonics and integrating new with legacy systems.
(Manuscript deadline: December 1, 2012)

The Changing Face of Developmental Test & Evaluation (June issue). Within the Department of Defense big changes are taking place in developmental test and evaluation. The Office of the Deputy Assistant Secretary of Defense (DASD), Developmental Test and Evaluation (DT&E), was established effective June 23, 2009, "*to serve as the principal advisor to the Office of the Secretary of Defense and the Under Secretary of Defense for Acquisition, Technology and Logistics in matters relating to DT&E in defense acquisition programs*." The Air Force has restructured its developmental test centers into the Air Force Test Center. The Army Test and Evaluation Command sought efficiencies by reorganizing and incorporating the functions of its Developmental Test Command into higher headquarters. The US Marine Corps has established a developmental testing organization. After three years of change this issue takes a look at subsequent developments; the impact of the changes on the services, their contractors, and industry; integrated testing, system of systems testing, joint and developmental evaluation, new organizational conflict of interest policy, and related ideas.
(Manuscript deadline March 1, 2013)

Truth in Data (September issue). The test and evaluation community is moving to a more rigorous and scientific basis. Vocal support has come from the Office of the Director of Operational Test and Evaluation in the Department of Defense, championing rigor and objectivity in T&E, and the Air Force Flight Test Center has an initiative in statistically defensible T&E. Many organizations have embraced design of experiments for test planning and evaluation; however, there are two caveats: statistics is more than just design of experiments; and statistics can be used to prove anything, even the truth. A scientifically based T&E process is naturally rooted in systems engineering and takes an end-to-end view to testing. Modeling and simulation and distributed testing are common tools, which introduce the requirements for verification, validation, accreditation and certification. Looking beyond T&E, there are commonalities with the operations research/systems analysis community, which uses many of the same fundamental approaches to evaluate mission performance against desired operational outcomes, but during real-world operations. Truth in Data seeks insights into, lessons learned and success stories from scientific rigor in T&E and the quest for more efficient and effective testing. It also investigates common ground with the operations research/systems analysis community.
(Manuscript deadline: June 1, 2013)

T&E in the Global Marketplace (December issue). The economy is global with a degree of connectedness which has never existed. Ownership of companies is fluid, moving overseas only to return, resulting in sister organizations distributed around the world. Product development is often spread among many partners to distribute cost and risk, share revenue, and to cultivate markets. Software companies have development partners around the world allowing work to progress 24 hours a day. The interrelationships also present problems, not least of which are multiple time zones, culture, language, units of measure, security and protecting intellectual property. T&E in the Global Marketplace looks outside the confines of the Department of Defense to testing in other government agencies, in industry and universities, and recognizes the "I" in ITEA.
(Manuscript deadline: September 1, 2013)

Articles and Submission: T&E articles of general interest to ITEA members and *ITEA Journal* readers are always welcome. Each issue includes specialty features, each 2-3 pages long: **"Featured Capability"** describes unique, innovative capabilities and demonstrates how they support T&E; **"Historical Perspectives"** recall how T&E was performed in the past or a significant test or achievement, often based on personal participation in the "old days" of T&E; **"Tech Notes"** discusses innovative technology that has potential payoff in T&E applications or could have an impact on how T&E is conducted in the future. **Interested authors:** Submit contributions to the ITEA Publications Committee Chairman (itea@itea.org, attention: James Gaidry). Detailed manuscript guidelines can be found at **www.itea.org** under the ITEA Publications tab.

ITEA Journal 2012; 33: 273

It is hard to believe that 2012 is coming to an end. Because of publication deadlines, I am actually writing this article before we know the results of the 2012 elections, the reality of sequestration, and the myriad of implications these two events may have on the Test and Evaluation (T&E) community. Many folks have asked me what I thought would happen. I tell them a simple, truthful answer, whatever the results, things will be different. That much we know will be true “business as usual” will never be the same regardless the outcome of the elections or sequestration. So what does that mean to the T&E profession and to ITEA?


Mark Brown, Ph.D.

This issue of *The Journal* is focused on the T&E workforce. This is very appropriate; because at the end of the day, any change will affect the workforce. At the same time, the T&E community has an obligation to ensure the products we test, whether a military system or commercial product, will operate in an acceptable fashion and meet the users' requirements. While improvements in testing technology will be enablers to this new “business as usual” test environment, it is the T&E workforce that must be equipped to deal with the new norm. Central to this is training. The workforce must be trained to use new tools. As our more seasoned and experienced team members retire, the next generation must be mentored to become subject matter experts on T&E. Use of more efficient test methodologies, such as Design of Experiments, must be embraced. All of this must be accomplished with tighter budgets and leaner workforces, on both the government and commercial sides.

Equipping our workforce is an area where ITEA can help. At the National and International level, ITEA offers a variety of exceptional training opportunities at our excellent workshops and conferences, as well as outstanding stand-alone courses that can be delivered at any location. Many of these courses count towards Continuing Education Units (CEUs) required to maintain professional and government certifications. The ITEA professional development committee has also investigated a number of unique ways to deliver training courses, from live courses taught at the ITEA Headquarters, Chapter locations, and workplaces to distributed, web-based courses that can be taken at your home or office. At the Chapter level, many meet quarterly (or more frequently) and offer unique opportunities to learn more about advancements in T&E capabilities and interact with other T&E professionals to both increase individual knowledge, but also foster a greater community of interest for the T&E workforce. Many of our chapters also offer their own educational opportunities through vendor workshops and tutorials. As I have said before, I believe the local chapter is where you can learn and interact with people working on similar challenges. There is no better way to solve a challenge than by working with your chapter and community of interest.

If you want to set yourself apart, ITEA is working on a new opportunity for you. We will be launching our T&E Professional Certification in the near future. For the past several months, panels of T&E experts, or “Grey Beards”, have been meeting to identify the knowledge base a certified T&E professional should possess. These working groups have been creating a cache of examination topics and questions in preparation for the first T&E professional examinations to be administered in 2013. To support this certification, the ITEA Board of Directors recently established an independent Board of Examiners to oversee the T&E Professional Certification process. As this certification becomes a reality, it will provide you, the T&E workforce, a way to distinguish yourself from the rest of the crowd. Look for more information on this exciting opportunity in the near future.

The T&E workforce is very diverse, from operators in the field who instrument systems and gather data, and analysts who distill data into knowledge, to senior decision makers who determine if the system meets the users' needs. We are part of a unique community that is critical to the world we live in. Whatever the future holds, we can be certain the need for equipping and maintaining our unique workforce will continue. As always, it is my honor to be part of this great community.

ITEA Journal 2012; 33: 274

Cultivating the T&E Workforce. Test and evaluation are professions not academic disciplines and as such we can't merely recruit more as needed. We recruit engineers, physicists, computer scientists, mathematicians, chemists and other degreed professionals and train them in test and evaluation. As technology changes and systems and instrumentation become more complex, test and evaluation (T&E) professionals need to continue formal education as well as improve T&E expertise. In addition, we need to consistently attract young people to the disciplines of science, technology, engineering, and mathematics. Cultivating the T&E workforce requires asking the question: what should the T&E professional's background consist of today and what should it be tomorrow? We need to prepare the future workforce for T&E, and prepare T&E for them. This issue features articles from students in high school and our service academies, from faculty, from T&E leaders, and from our T&E professional society on certifying the T&E workforce.

Dr. Robert McGrath, Director of the Georgia Tech Research Institute, describes workforce challenges from an academic perspective in his *Guest Editorial:* encourage the current outstanding T&E force to stay as long as possible, recruit adequately prepared new hires from other parts of the government and industry, and hire new STEM graduates in the right academic mix to support T&E of today and the future. Dr. Catherine Warner, Science Advisor to the Director, Operational Test and Evaluation, uses *Inside the Beltway* to encourage early and continuous engagement between the testing and requirements community to better craft requirements that are mission oriented, realistic, and testable. In *Historical Perspectives,* Arnold Air Force Base Historian David Hiebert traces the 60 year history of what was originally the Air Engineering Development Center, one of the country's premiere developmental testing complexes.

The articles begin with a special student section arising from the ITEA Annual Symposium Academia Day paper competition, held in Huntington Beach, CA. First place winner, Bradley Matheus, senior at California Academy of Mathematics and Science in Carson, CA, outlines the benefits of numerically controlled machines and 3-D printing for rapid prototyping. Second place winner, Zaki Molvi, senior at Troy High School in Fullerton, California, provides a future professional's perspective on increasing the number of graduating scientists and engineers through a combination of STEM education, specialized courses and hands-on training during undergraduate years. Finally, third place winner Sara Pak, senior at Diamond Bar High School in Diamond Bar, CA, reinforces the necessity of test and evaluation for future product development, to ensure to consumers that new products are safe and suitable.

Robert Arnold, Chief Technologist of the 96th Test Wing, Eglin Air Force Base, Dr. Eileen Bjorkman, Chief Technologist of the 412th Test Wing, Edwards Air Force Base, and Dr. Edward Kraft, Chief Technologist of the Arnold Engineering Development Complex, Arnold Air Force Base, present the Air Force Test Center's new human capital strategy which emphasizes investment in technical competence on par with test infrastructure improvements and sustainment. James Gaidry, ITEA Executive Director, rolls out the new ITEA Test and Evaluation Certification Credential and reviews how it came about and its benefits. Dr. Michael Kendra of the Air Force Office of Scientific Research explains workforce development in two components, bringing new science and engineering personnel into T&E, and advancing the professional development of the existing T&E workforce through training, coursework, certification, and advanced degree awards.

Tony Stout *et al.,* speaking for the Joint Interoperability Test Command, encourage shifting focus from managing people and projects to measuring the gap between current skills and future needs and using this knowledge to drive training, hiring, work allocation, contracting and human resource management decisions. Thomas Simms, *et al.* describe the Deputy Assistant Secretary of Defense for Developmental Test and Evaluation roadmap for workforce development. Dr. Raymond Hill, Professor of Operations Research with the Air Force Institute of Technology, defends using specialty training, for example in statistics and design of experiments, as a supplement to formal undergraduate and graduate education, not a substitute for it.

Second Lieutenant Luke Grant presents his senior engineering project from the United States Military Academy where he used computational fluid dynamics and high performance computing to study the physics associated with fluid flow over gas turbine engine blades. Dr. Mehdi Ghoreyshi *et al.* from the United States Air Force Academy compare reduced order modeling with full field equations modeling of fighter aerodynamics and verify its accuracy while improving computational speeds by several orders of magnitude. Daniel Carlson and Erich Brownlow of the 412th Electronics Warfare Group, Edwards Air Force Base, apply Bayesian techniques to combine simulation data with limited flight test data to get a better understanding of aircraft performance. The issue concludes with an article by Dr. Paul Fortier, *et al.* of the University of Massachusetts-Dartmouth, who offer microsystems for test and evaluation applications requiring reduced power, weight and space, and for new capabilities that could not exist otherwise.

Finally, the Publications Committee thanks one of its own, Dr. Steven "Flash" Gordon, who adopted this issue and took a leadership role in defining, shaping and populating it. Thank you, Flash, excellent job.

ITEA Journal 2012; 33: 277–282

Cultivating the Test-and-Evaluation Workforce

Robert T. McGrath, Ph.D.
Director, Georgia Tech Research Institute (GTRI), Vice President,
Georgia Institute of Technology (Georgia Tech), Atlanta, Georgia

Cultivating the test-and-evaluation (T&E) workforce workforce development is a problem of supply, demand, retention, and education. Unless we can improve the way we approach workforce development, especially in light of changes in the nature of T&E, our problems with supply and demand will likely continue. The bow wave of retiring T&E experience will increase the demand for replacements over the next decade. Without increases in science, technology, engineering, and math outputs from our institutions of higher learning, that supply source for the T&E workforce is constrained. Yet we have seen innovative ways of improving output in those fields, improving retention of the current T&E force, cross-training into government T&E positions, and educating and certifying the T&E force for upcoming T&E challenges. Inevitably, the future T&E force will be younger and more inclined to communicate, coordinate, and learn by using social-networking media. Younger workers will assume new roles in legacy T&E organizations, and our goal should be to prepare that new workforce for the T&E of today and of the future. However, we will also need to prepare T&E to leverage the qualifications that these new workforce members will bring. Education, mentoring, cross-training, and other retention measures will keep the future T&E force strong.

It is an honor and a great opportunity to be invited to provide a guest editorial for the *ITEA Journal*, especially for this volume focusing on the test-and-evaluation (T&E) workforce. A review of the issues related to the T&E workforce from many perspectives is important because I believe that T&E contributes to virtually every acquisition program. In the simplest sense, T&E seeks to make systems safer, more efficient, and more effective and to make processes deliver what is intended with less friction. For the Department of Defense, T&E activities produce the knowledge needed to verify system effectiveness, suitability, and survivability and to deliver findings about reliability, lethality, trainability, and other important operational factors. The product of T&E is rigorous data from which decision makers can draw conclusions about system performance. Therefore, I believe that T&E is critical to national defense and that an educated, well-trained, and professional supporting workforce is essential. However, among the numerous challenges that we face are an aging T&E workforce, a shrinking pool of qualified new hires, changes to T&E processes, the expansion of the operational envelope, and the need for increased collaboration among government, industry, and academia on professional education. I will touch on these issues, and highlight ways that organizations like Georgia Tech can work with government, industry, and other academic partners to provide both a larger stream of new candidate hires and the most appropriate professional education for the T&E workforce.

Robert T. McGrath

The state of the T&E workforce environment

The current Defense T&E workforce of 8,600 is small compared to the size of the Defense acquisition workforce, which has over 150,000 employees (McMichael 2012). Given these lower numbers, shortages in specialized T&E personnel may be particularly significant in some acquisition programs, and may also make redirecting staff to programs in need of specific skills more difficult.

The current T&E civilian workforce in Defense is 68 percent engineers; 29 percent workers in other fields of science, technology, engineering, and math (STEM); and 3 percent non-STEM workers. Hiring trends in the current Defense civilian T&E workforce indicate a focus on engineering, with less emphasis on science majors. Unfortunately, locating new T&E hires may continue to be difficult, especially if the hires are coming directly from institutions of higher learning. The difficulty in hiring from universities is often caused by a limited supply of graduates with specialized degrees in engineering, along with increased Defense and industry competition for that limited pool of individuals.

In response, T&E may experience several modifications in its personnel mix and division of duties. For instance, to the extent that quality assurance allows, T&E is becoming increasingly integrated with developmental, operational, and live-fire testing, thereby becoming shared and collaborative efforts. Because of such trends, the T&E teams of the future may require refined training in leadership, team building, collaboration, and project management. Increased emphasis is also being placed on design-of-experiments methods to establish standard procedures for computationally framing critical decisions on sample sizes, levels of test inputs and outputs, and evaluation of results. Of course, the T&E team will also require resident (or at least accessible) statistical expertise in order to reach cost-effective solutions consistent with real-world constraints, design-of-experiments guidelines, and quality-control objectives of T&E missions.

Modeling and simulation will also continue to be used more and more to evaluate systems before they are built. They will be used to simulate performance of individual hardware components within the systems as well as to depict the overall performance and resilience of the systems in both normal and far-from-normal joint operational environments. T&E teams will need to define the best integrated simulation environments, the right architectures for test events, and the most efficient ways to accredit and certify the simulation assets.

Finally, both new technologies and new operational environments will change many aspects of the future T&E environment. While these new technology areas may be difficult to accurately predict, hints of the changes anticipated can be gleaned from the test-technology areas nominated to support future warfighter system-test needs by the Test Resource Management Center. These new areas include cyber, directed energy, electronic warfare, high-speed systems, net-centric systems, unmanned autonomous systems, advanced instrumentation systems, and spectrum-efficient technology. Insights gleaned from the list of test-technology areas suggest that the current blend in the Defense civilian T&E workforce of 68 percent engineers and 29 percent science majors may change to favor recruitment of more science talent with basic training in physics, statistics, and computational modeling.

Nurturing the current and future T&E workforce

The preceding section described the challenges for cultivating the T&E workforce. Now I would like to highlight approaches we can undertake to further nurture and grow this workforce asset that is critical to our collective national defense. I will briefly share some thoughts about Defense civilian T&E retention programs, cross-training into the Defense T&E force, new developments with potential to increase the throughput of STEM graduates, and some improvements in professional-education courses that can increase motivation and depth of technical expertise across the T&E workforce.

One of the most direct ways to maintain the current force is to retain the high-quality T&E professionals we already have. Current initiatives in rotational programs, professional certifications, short courses, and mentoring opportunities will help build retention and further improve the effectiveness of the current force while integrating new members of the team quickly. *Figure 1* illustrates a Professional Masters in Systems Engineering Session where case studies in systems engineering and T&E are being solved and briefed by teams. Rotational assignments have been used successfully for decades in industry, government, and academia. The Department of Defense could similarly sponsor rotations for T&E professionals, among government, academia, and industry in T&E-related fields.

Academic courses and certification programs can also offer ways to improve retention and the quality of

Figure 1. Professional Education Seminar.

the test force, providing a means for T&E professionals to maintain and increase skill levels. For example, over 5,000 professionals (20 percent of them uniformed military) complete courses in Georgia Tech's Defense Technology Professional Education series annually, and over 22,800 students complete Georgia Tech's short courses each year. In 2011, Georgia Tech delivered 6,110 credit hours via distance learning, awarded 118 master's degrees, and provided 49,438 continuing-education units in professional education at locations worldwide.

Sponsoring selected members of the test force for advanced graduate-level degrees in engineering and science can also improve career advancement, job satisfaction, preparation for future test challenges, and retention. To this end, it may be advantageous to initiate a discussion among government, academia, and industry on the need for T&E degrees or the need for T&E concentrations in undergraduate and graduate STEM programs at select academic institutions across the country.

We may also be able to grow the Defense T&E workforce by recruiting experienced candidates from other sectors of the federal government or industry defense complex. Incentives such as access to interesting and challenging work in science and engineering, career-broadening opportunities related to professional education, advanced degrees, and assignments to government and industry laboratories may help attract professionals in the federal/Defense acquisition force to Defense T&E positions. Defense T&E can also identify candidate employees from industry and academia and seek to streamline the hiring processes for new candidates coming from outside the federal government.

The vast majority of new Defense T&E civilian professionals will join the workforce directly from institutions of higher learning. The Defense T&E profession will need to discover ways to increase the number of engineering and science graduates attracted into the field. One means of accomplishing this is to reach students as early as possible. Middle-school and high-school students can be reached by popular television shows like *MythBusters* on the Discovery Channel, which illustrates that curiosity about how things work (or fail sometimes catastrophically) can provide deep insights into underlying processes. It would be great to leverage this type of illustration to show what T&E does to make products safer and more useful. Tester job descriptions often include requirements to legally and safely blow things up, or at least find out what it takes to break or destroy systems. Such outreach to youngsters can increase the number of students considering STEM in college or, even better, wanting to become T&E professionals.

Organizations like ITEA, the Armed Forces Communications and Electronics Association, and the International Council on Systems Engineering sponsor internships, academic outreach, and STEM scholarship awards. These activities help attract STEM majors into technical schools, colleges, and universities. Many large conferences also allow and encourage students to attend technical sessions and visit exhibit halls. All such efforts are beneficial and can be directly targeted at recruitment into the Defense T&E workforce.

Many universities are also working hard to keep STEM majors on track and minimize rates of dropout and transfer to other fields of study. Experienced STEM instructors know that building a strong background is essential. Presently, fewer than 40 percent of students that enter college with the desire and intent to major in a STEM field complete college with a degree in engineering or science. Dropout or transfer out of engineering typically occurs early in the undergraduate program and often reflects a lack of adequate preparation or effective remedial tutoring. Remedial courses and peer-group mentoring on campus have proven to be effective means of bridging the gaps that often exist within a young person's preparations preceding college. More effectively addressing the learning gaps in our nation's middle and high schools has been the target of national initiatives under current and prior administrations, with somewhat limited success.

Some U.S. universities are taking many steps to cultivate increased graduation rates in STEM disciplines and help build the future engineering and science workforce. Additionally, many universities across the country are partnering with middle and high schools to better prepare students for university majors in STEM. Since 2006, for example, learning communities in Ohio have been partnering with K 12 schools, higher education, and employers via the Ohio Stem Learning Network. The five-city consortium works with local businesses, Ohio State, Case Western Reserve University, and other leading state institutions in offering problem-based curricula in over 10 high schools. With very effective training in basic math, physics, biology, and chemistry, these highly successful high-school students are then offered the opportunity to take college classes before they graduate from high school. In one such high school, the 2012 senior class of nearly 100 students earned more than 3,000 college credits at Ohio State University, achieving an average GPA of 3.5, accelerating their postsecondary progress, and taking nearly a year off of future college costs. Similarly, the Direct to Discovery program a collaborative partnership between the Georgia Institute of Technology, industry, and several urban, suburban, and rural school systems in Georgia brings world-class researchers and their laboratories into K 12 classrooms across the state. The program enables teachers and researchers to collaborate in providing rich, up-to-date science content that inspires, motivates, and empowers experiential learning. Such programs help to identify student interests and needs early, before the students graduate from high school.

Once students have enrolled in a STEM-related field of study, many universities are offering research experiences for undergraduates that further motivate young minds by providing real-world applications of the engineering and science basics being taught in traditional classrooms. Research-faculty members, postdoctoral fellows, and graduate students are key contributors to such programs. In addition, undergraduate juniors and seniors are often recruited to assist with research-experience mentorship. This peer-to-peer mentoring has proven to be very effective, providing outstanding role models that demonstrate to young people that they too can be successful and have a great deal of fun in highly technical fields. Over the years, academic success in STEM (and other) majors has been enhanced through a variety of innovative teaching practices. Real-time classroom-survey technologies now enable instructors to query the entire class, with anonymous responses providing immediate feedback on student comprehension of the concepts being presented. Other social-media technologies adapted for use in college courses now enable current generations of students to have the type of 24/7 access to course instructors and assistants that they have come to expect from the highly connected world in which they have grown up. Professional education courses now leverage computer labs for hands-on problem solving, computer-based learning, and group problem solving as illustrated in *Figure 2*. Similarly, stored and real-time video transmissions over the Internet have enabled students to access high-quality course offerings from outstanding universities worldwide.

Figure 2. Professional-education course.

Standards for the T&E workforce

Government acquisition professionals have superb professional-education opportunities provided to them through such outstanding institutions as the Federal Acquisition Institute, the Defense Acquisition University (DAU), and the recently inaugurated Center of Excellence for T&E, located at the Air Force Institute of Technology. Since October 2008, the Federal Acquisition Institute has provided over 13,000 certification-training courses and over 100,000 Web-based continuous-learning courses. Similarly, DAU offers over 250 training modules and has nearly 400,000 course completions annually for students at home stations or deployed anywhere in the world. Defense T&E professionals also have certification standards and Core-Plus Development Guides for test and evaluation levels 1 3, where one can easily find assignment levels, standards, and training courses available at DAU.

To the extent allowed by law, some T&E support to acquisition programs is also provided by contractor personnel working as prime or support contractor employees on important government programs. Contractor-provided T&E staff (unless they have served in prior government-assigned T&E or acquisition positions) most likely do not have the benefit of the government-standardized course offerings or certifications mentioned earlier. Consequently, Defense T&E practices overall could benefit from the adoption of certification standards for government, academic, and industry training programs for T&E professionals, much in the way that Accreditation Board for Engineering and Technology (ABET) standards serve to assure quality control across university engineering-degree programs nationwide.

Consistency in short course professional education content and certification standards across government, academia, and industry would help build a better combined T&E workforce. If industry and academia were to adhere to similar or identical standards for course content as those used by DAU, all members of the combined test force could have consistent T&E knowledge and interoperable expertise. This standardization would assist the government in realizing a pool of trained contractor support staff and candidate new hires that meet government certification standards. Compatibility between government and industry/academia professional education courses could also support more productive internships and rotational assignments. If a collaborative forum were established where government, academic and industry professional educators could exchange ideas on core courses, electives, course content, and academic standards, not only would the combined test force be better prepared and stronger, but the forum would promote an exchange of best practices and new topics for educating future T&E professionals.

Conclusions

Hopefully, the ideas summarized here will stimulate additional thinking across the community on best practices for developing the future Defense T&E workforce that our country critically needs. While some of our most experienced T&E personnel will soon be retiring, we can cultivate learning environments in which new generations acquire the skill sets and expertise needed to sustain Defense T&E requirements. We can increase practices that support retention of the current workforce, and enhance recruitment and training of future T&E professionals. We can also work to recruit and retrain experienced professionals from other parts of government and industry. Most importantly, we will need to hire new STEM graduates with the appropriate training and academic mix to support Defense T&E today and in the future. The supply of these graduates is dependent not only on the number of incoming college students that want to major in STEM fields but also on how we maintain interest and cultivate the career progressions of these young people. The entering members of the workforce we attract over the next decades will need incentives, encouragement, and support to enter and become highly successful members of the T&E workforce. While challenges abound, I am confident that we can, with a consistent and well-planned effort, ensure that the T&E workforce needed for future Defense programs will be able and ready. ❑

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References

Business-Higher Education Forum. 2010. *Increasing the number of STEM graduates: Insights from the U.S. STEM Education & Modeling Project*. Washington, D.C.: Business-Higher Education Forum. http://www.bhef.com/solutions/documents/BHEF STEM Report.pdf (accessed July 27, 2012).

Federal Coordination in STEM Education Task Force, Committee on STEM Education, and National Science and Technology Council. 2012. *Coordinating federal science, technology, engineering, and mathematics (STEM) education investments: Progress report*. Washington, D.C.: National Science and Technology Foundation. http://www.whitehouse.gov/sites/default/files/microsites/ostp/nstc federal stem education coordination report.pdf (accessed August 3, 2012).

Gansler, Jacques S., William Lucyshyn, and Michael Arendt. 2010. *Defense acquisition workforce modernization*. College Park, MD: Center for Public Policy and Private Enterprise, School of Public Policy and Private Enterprise, University of Maryland. UMD-AM-10-163.

Center for Public Policy and Private Enterprise, University of Maryland, sponsored by The Naval Postgraduate School. http://www.dtic.mil/dtic/tr/fulltext/u2/a555626.pdf (accessed July 22, 2012).

Gates, Susan M., Edward G. Keating, Adria D. Jewell, Lindsay Daugherty, Bryan Tsysinger, Albert Robbert, and Ralph Masi. 2008. *The defense acquisition workforce: An analysis of personnel trends relevant to policy, 1993 2006*. Santa Monica, CA: RAND Corporation. http://www.rand.org/content/dam/rand/pubs/technical reports/2008/RAND TR572.pdf (accessed July 22, 2012).

McMichael, James S. 2012. *Educating the workforce for future T&E expertise needs.* Plenary briefing to the 2009 ITEA Annual Symposium, updated August 1, 2012, for the September 2012 ITEA Symposium. Accessed through the International Test and Evaluation Association (ITEA), www.itea.org, office of the Executive Director.

National Math and Science Initiative. 2011. *The STEM crisis*. Dallas, TX: National Math and Science Initiative. http://www.nationalmathandscience.org/solutions/challenges (accessed July 22, 2012).

Office of the Deputy Assistant Secretary of Defense (DASD) for Developmental Test & Evaluation/Director Test Resource Management Center. n.d. *Technology development: Test & evaluation/science & technology (T&E/S&T) program overview*. Washington, D.C.: Office of the DASD for Development Test and Evaluation. http://www.acq.osd.mil/dte-trmc/technology development.html (accessed July 22, 2012).

President's Council of Advisors on Science and Technology. 2012. *Engage to excel: Producing one million additional college graduates with degrees in science, technology, engineering, and mathematics*. Washington, D.C.: Executive Office of the President. http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-engage-to-excel-final feb.pdf (accessed August 3, 2012).

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The Role of Test and Evaluation in Defense-System Requirements

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OSD DOTE

Recent Director, Operational Test and Evaluation initiatives to increase the statistical rigor of testing have revealed opportunities for significant efficiencies in the testing process through setting operationally meaningful and measurable requirements. By partnering with the requirements community, we can produce operationally meaningful, testable requirements that not only address warfighters' needs but also reduce test costs and provide inferential capability based on the outcome of the testing. As the DOT&E science advisor, I have made it one of my initiatives over the next year to engage the requirements community to improve coordination and cooperation between our organizations. I invite the rest of the test community to join me.

There is an inherent and necessary link between the requirements community and the test community. The requirements community must transform warfighting needs into concrete, measurable requirements. The testing community must then assess those requirements in an operational context to determine system effectiveness and suitability. However, despite the inherent link between these two communities, several recent independent studies have identified problems resulting from poor collaboration between the requirements community and the test community.

Catherine Warner

Last year, the Defense Acquisition Executive chartered an independent team to assess expressed concerns that the Defense Department's developmental and operational test communities' approach to testing drives undue requirements, excessive cost, and added schedule into programs. The assessment team "found no significant evidence that the testing community typically drives unplanned requirements, cost or schedule into programs." However, they did note that there were four specific areas that needed attention:

> *"the need for closer coordination and cooperation among the requirements, acquisition, and testing communities; the need for well-defined testable requirements; the alignment of acquisition strategies and test plans; and the need to manage the tension between the communities (Carter and Gilmore 2011)."*

The tension between the test and the requirements communities is not new. In 1998, the National Research Council (National Research Council Committee on National Statistics 1998) identified the need for greater interaction between the test and the requirements community. The council pointed out in 1998 that operational test personnel should be included in the requirements process in order to assist in establishing "verifiable, quantifiable, and meaningful operational requirements."

Clearly, it is beneficial to have collaboration between the requirements and test communities early and often in the acquisition cycle of a program. However, this is easier said than done. I have made it one of my current initiatives as DOT&E science advisor to actively engage the requirements communities across all of the Services and Components. As I work to engage all of the different requirements communities, I have noticed three primary areas where increased interaction between the test community and the requirements community could result in improved test outcomes.

Mission-oriented metrics

Operational test and evaluation means "the field test, under realistic combat conditions, of any item of (or key component of) weapons, equipment, or munitions for use in combat by typical military users; and the evaluation of the results of such test" (10 U.S. Code § 139). Weapons systems sit in the motor pool, at the pier, or on the runway. Individual systems do not have missions. It takes trained military operators to make weapons do something to make them "work." Operational testing is about assessing mission accomplishment of the unit equipped with the system under test. To evaluate operational effectiveness, we seek to answer the question: Can a unit equipped with the system under test accomplish the mission? We seek to evaluate both mission success and system performance to gauge the impact of the system on mission accomplishment. End-to-end testing with operational users across the intended operational envelope is essential to assessing the system's impact on mission accomplishment. Additionally, the system must be evaluated within the context of the system of systems they will operate within. Requirements documents do not usually address systems out of their program of record.

Often the goals of the operational evaluation are not captured by system requirements documents. I have noticed that many systems have requirements that are more technical in nature. Technical performance requirements are necessary; however, they are not sufficient for the evaluation of operational effectiveness, suitability, and survivability. Ideally, key performance parameters (KPPs) should provide a measure of mission accomplishment, lend themselves to good test design, and encapsulate the reasons for procuring the system. DOT&E has seen many recent examples of KPPs that are not informative towards the evaluation of mission accomplishment. For example, a ground-combat vehicle had KPPs that only required it seat nine passengers, be transportable by a C-130, and have a specific radio system. Another example was an amphibious ship with KPPs for the number of helicopter spots, the number of storage spaces, and the maximum speed of the ship. While all of these technical specifications are important, they do not capture the actual mission of the ground vehicle or ship. Testers encouraged the use of mission-oriented metrics such as meeting the commander's intent in force-on-force missions or meeting an aircraft-sortie generation rate and adding self-defense capabilities. If the test community and the requirements community engage early, these measures can be fleshed out to ensure that testable requirements are used more directly in the determination of operational effectiveness.

Some suggested rules for establishing KPPs:

- Metrics should be quantitative and mission oriented, providing a determination of mission accomplishment.
- Metrics should lend themselves well to efficient test design.
- Metrics should encapsulate the reasons for procuring the system.
- Metrics should be testable and not require unsafe or unexecutable test constructs or cost-prohibitive instrumentation.
- Metrics should accurately represent the desired performance of the system; that is, good scoresshould correspond to desired operational performance.

Leveraging test-and-evaluation (T&E) knowledge in setting requirements

The T&E community has knowledge of legacy-system performance and capabilities that can provide useful inputs into the requirement-setting process. The T&E community can help identify unrealistic, unaffordable, and untestable requirements. Additionally, the T&E community's knowledge of the current threat environment and test infrastructure can help the requirements community understand what resources will be needed to test a given requirement. Services-requirements officers have stated that they want demanding requirements to drive vendors to achieve the best possible system performance, but history has shown that unachievable high requirements can be particularly destructive to program success in the long term. For example, the Future Combat System ground-combat vehicles required survivability (tanklike) and transportability (via C-130) that were incongruent. Additionally, reliability requirements were much higher than those of our current systems by nearly 10 times which was both unrealistic and unaffordable.

Testers have experience with the difficulty and cost associated with testing to certain metrics. For example, consider a requirement for 99-percent reliability for completing a 6-hour mission. This is comparable to 600 hours between failures and would require at least 1,800 hours of testing. If the requirement were 95-percent reliability for completing the same 6-hour mission, the testing could be reduced significantly. Now the mean time between failures is only 120 hours, requiring at least 350 hours of testing. It is important for both our communities to discuss these considerations, trade-offs, and the operational impact of the decision early in the acquisition process. The requirements and rationale should be revisited as often as possible and should remain open for discovery during the lifetime of the program.

Similar test considerations apply for performance testing; the T&E community notes that probability metrics are expensive to test because they require lots of replications. However, if requirements can provide meaningful continuous metrics that relate to probability requirements, testers can significantly cut test resources. Consider the following three requirements:

- The operator must be able to detect 90 percent of surface ships of size X.
- The operator must be able to detect surface ships of size X at a range Y.

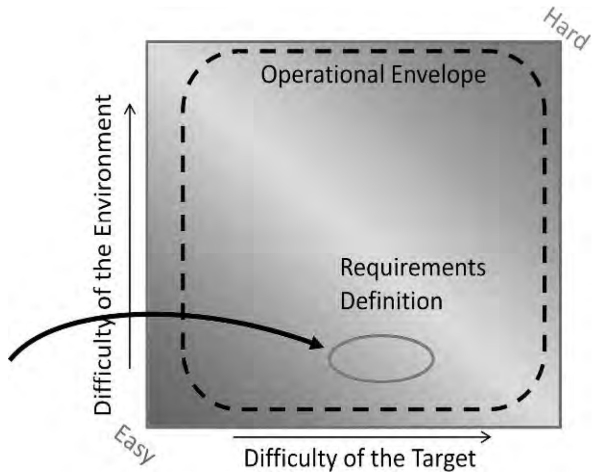

Figure 1. Notional 2-dimensional diagram of a weapon system's operational envelope.

- The operator must be able to detect 90 percent of surface ships of size X at a range of at least Y.

The first requirement is expensive to test because it is based solely on a percentile; additionally, it does not provide testers information on what defines an operationally meaningful detection. The second requirement is untestable because it implies 100-percent detection, which can never be verified via testing. The third requirement combines aspects of the two previous requirements and provides a testable, operationally meaningful requirement. Testers bring this perspective to the requirements community to improve the overall testability and feasibility of requirements.

Evaluation across the operational envelope

Another disconnect between the requirements community and the test community is that often requirements are narrowly focused and do not cover the operational envelope, as highlighted in *Figure 1*. Other times, the requirement is ambiguous and fails to specify related conditions. There is a common concern that failing to specify a certain set of conditions could lead to an unwieldy test. This is one of the reasons DOT&E is using design of experiments to efficiently span the operational envelope.

DOT&E has advocated for the use of design of experiments as a scientific methodology for approaching these aspects of test. One of the key tenets of a well-designed experiment is that all stakeholders must be engaged in the determination of the goals, metrics, operational envelope, and test risks. The requirements community is a key stakeholder in determining these test elements, and they can heavily influence testing by covering these aspects in requirements documents.

The requirements community can provide valuable input on the factors (or conditions) that should be considered in a test, and testers must select the best allocation of test resources to evaluate the requirement across the operational envelope.

In summary, through early and continuous engagement between the testing and requirements communities, we can craft requirements that are mission oriented, realistic, and testable. Additionally, the requirements community provides valuable input on the test conditions that define the operational envelope. I have made it one of my initiatives to proactively engage the requirements community and discuss how we can improve coordination and cooperation between the requirements and testing communities. I invite the rest of the test community to join me in this initiative. ❑

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References

Carter, A. B., and Gilmore, J. M. 2011. Test and Evaluation of Defense Programs. OSD Memorandum, Washington, D.C. June 3. Online at http://www.dote.osd.mil/pub/report/20110603TEofDefensePro grams(3844).pdf.

National Research Council Committee on National Statistics. 1998. *Statistics, Testing, and Defense Acquisition*. Washington, D.C.: National Academy Press.

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Air Engineering Development Center: Part I—Rising From the Ashes of World War II

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Editor's note: This two-part historical perspective is presented in recognition of last year's 60th anniversary of the Arnold Engineering Development Center dedication. In this engaging narrative, the unit historian, Mr. David Hiebert, outlines the high points of air and missile testing at the end of World War II. Enjoy, JW.

> *"Some people were convinced that rather large capital investment was required in this country if we were to get up to the position the Germans occupied. They no longer hold that position now, of course, but the Army, Navy, and Air Force had many ideas of what was to be done."*
> (Dr. Hugh L. Dryden, Director of Aeronautical Research, National Advisory Committee for Aeronautics, April 1949 testimony in support of PL 81-415)

Title II of Public Law (PL) 81-415, the enabling legislation for the Air Engineering Development Center[1] (AEDC), is short fewer than 300 words but the history it reflects illustrates a much more detailed account of the United States' efforts to counter Germany's widely perceived superiority in aeronautical test facilities at the end of the Second World War. The AEDC story is a narrative replete with international intrigue and intense technical and political battles among nations and U.S. government agencies to determine the character and site of the center battles significant enough to bring the president of the United States, for AEDC's June 1951 dedication, to a site that the German engineer and general Walter Dornberger called "a dull and boresome place far away from all centers of culture."[2]

The dilemma

The "General Statement of Purpose" for PL 81-415 clearly stated why the United States needed this legislation:

> *"The purpose of this bill is to authorize the construction of wind tunnels and other experimental and testing facilities suitable for research, development, and evaluation in the field of transonic and supersonic aeronautics. This field, covering as it does the range of very high-speed flight both by aircraft and guided missiles promises to be of the utmost importance because of the steady trend toward higher speed aerial vehicles in the development of newer and more effective types of military aircraft and missiles."*[3]

As the United States answered the German wake-up call in Europe, the National Military Establishment, National Advisory Committee for Aeronautics, industry, and other interested parties began to assess this country's aeronautical capabilities. Our near loss of the war signaled that the United States needed to develop new facilities that could handle the special challenges of the jet engine, because mass production would not win the next conflict. Harvard professor Lionel Marks led a committee to investigate the feasibility of gas-turbine propulsion for aircraft applications, concluding that it was not possible. At the same time, and unknown to the Marks group, Hans von Ohain's turbojet engine made its first successful flight in Germany. When he witnessed Frank Whittle's turbojet in test flights in 1941, Army Air Corps leader General Henry H. ("Hap") Arnold immediately ordered the concept brought to the United States for further development.

In the legislative history for PL 81-415, Congress summarized the testimony of numerous experts on this matter:

> *"American aeronautical research has been shown to have lagged dangerously behind the German advances in the fields of jet propulsion and high-speed flight prior to and during World War II.*

... It is not enough for the Congress merely to bestow money liberally upon any and all comers who apply for funds in the name of 'research and development' and thereafter wash its hands of this problem; nor can the Congress relax in the comfortable assurance that aeronautical research and development are entrusted to the NACA, an agency composed of recognized experts in the field, or to the aeronautical industry which normally develops and produces newer and better types of aircraft, or to the Air Force and Navy upon whom rests the responsibility for the conduct of aerial warfare. It is imperative that the Congress recognize that these very same responsibilities were vested in the identical agencies all of them composed of experts prior to and during World War II; yet that fact did not prevent our drifting dangerously far behind the enemy in the more advanced fields of aeronautical research and development, as exemplified by German progress with jet aircraft, V-weapons and similar types of rockets and guided missiles.

To state the foregoing facts is not to imply any unwarranted or harsh criticisms of the agencies or groups mentioned above; to fail to draw attention to these facts, however, would be inexcusable negligence on the part of the committee and would constitute a blind refusal to recognize and profit by the mistakes of the past mistakes, the more dangerous potential effects of which, we were fortunate enough to escape the last time."[4]

General Franklin O. Carroll chief of the Experimental Engineering Section at Wright Field from 1939 to 1944 faced a dilemma: How to reconcile Wright Field's limited potential for expansion with the clearly identified requirement for facilities that could test high-speed aircraft? General Carroll appointed a technical survey team from Wright Field to the European theater. The team inspected a research tunnel at Oetztal, a jet-engine test facility in full operation at the Bavarian Motor Works plant in Munich, and at Kochel, south of Munich, a 1-meter-by-1-meter hypersonic battery of tunnels capable of operations through Mach 10 that was later to shape the future AEDC.[5]

Leading the scientific advisory group, Frank Wattendorf noted that German facilities were more ambitious and forward looking than American facilities, remarking that

"there was no indication of the superiority of German engineers over United States engineers as individuals; rather, the improvements were due to more forward looking directives and freer purse strings for engineering and research matters. ... The scope of the German plans make it essential that our own plans be certainly not less ambitious in the light of our future security. It is recommended that consideration and study be given to the establishment of a new Air Forces Research and Development Center. ... This establishment should be located near a source of large power, for instance in the Boulder Dam or Grand Coulee Dam regions."[6]

Wattendorf proposed six elements that would serve as the foundation of the new center:

1. A 20 30 foot wind tunnel for throat speeds up to M 1.0 for complete airplane models, full size nacelles, and propulsion systems. Simple straightforward construction with air exchanger is recommended. Utilization of parts and equipment from the Oetztal wind tunnel should be considered. This project would utilize over 100,000 H.P.
2. A 20 30 foot wind tunnel, evacuated and refrigerated, for speeds up to M = 1. This tunnel would be used primarily for propulsive system and propeller development and testing. Such a tunnel would involve about 160,000 H.P.
3. An 8 12 foot wind tunnel for Mach numbers up to approximately 3. The purpose of this tunnel would be development and testing of supersonic aircraft and missiles, together with propulsive systems such as ram jets.
4. A supersonic wind tunnel for very high Mach numbers up to 10 primarily for the development of high altitude rocket propelled aircraft and missiles. It is recommended that utilization of parts and equipment from the 76,000 H.P. Kochel supersonic tunnel be considered. This laboratory would require about 100,000 H.P. for drive, cooling, and accessory equipment.
5. A components laboratory for developing large compressors, turbines, and component parts of gas turbines and jet engines. This project should be set up around 75,000 H.P.
6. Supporting facilities to enable development of a supersonic aircraft or missile as an integrated whole.[7]

Embedded in Wattendorf's concept was a topographic requirement a hydroelectric fall to provide sufficient electrical power that not only precluded Wright Field as a site but also severely limited the number of appropriate locations. Both Oetztal and Kochel were under construction in the Bavarian Alps, so the areas around the Boulder Dam and the Grand Coulee Dam were earmarked as logical potential sites.

The proposal also inferred re-erecting German equipment from Oetztal, Kochel, and the Bavarian Motor Works, on the assumption that German scientists and engineers would engage in both the construction and the operation of the relocated materiel. Also implicitly embedded in Wattendorf's proposal was the assumption that the process for re-erecting the German facilities could save time and money by circumventing the requirement for enabling legislation. In October 1945 the Office of Military Government for Germany's Economics Division sought to end the removal of technical equipment from Germany "pending the allocation of Reparations to the United States,"[8] but the Armed Forces Division suggested that wind tunnels be exempt from the proposed restriction.

When Wattendorf returned to Germany, he had two further missions for the Air Force: to look for significant German facilities or equipment that might be appropriated for the proposed AEDC and to list the names of German scientists who might be useful in the future design and operation of the center. As a result, several of these scientists eventually worked in the laboratories at Wright Field, and some came on loan to Sverdrup and Parcel for the preliminary engineering studies on the center.

Oetztal

Meanwhile, the status of the Oetztal tunnel had changed. Since June 1945, the scientific advisory group had proposed to use only the tunnel's drive system, balance, and associated equipment. The plan was to build a new tunnel shell, improving its design during construction. But when he returned to Europe, Wattendorf found the Oetztal site not in the U.S. occupation zone but in the French, as a result of Allied rezoning agreements. Further, some individual components of the tunnel, including balances and fans, were not on the site but in the plants of the various manufacturers.[9]

In his earlier technical report, Wattendorf had described the various contractors for the components, so in early October 1945 he visited the Voith Company in Heidenheim, where the Pelton wheels and drive-system components had been manufactured.[10] There he encountered what he called "the mystery of the freight shipments."[11] He described the apparently routine request to load "scrap steel" actually parts of the Oetztal tunnel into freight cars destined for Stuttgart. When he arrived in Stuttgart he found more than a dozen freight cars filled with most of the drive system, including fan blades and associated parts. The cars were scheduled to leave at midnight for Mainz, which lay in the French zone. Wattendorf's solution was to change the manifest destination from Mainz to Bremerhaven, in the U.S. zone, enabling later shipment to a stateside Army Air Forces (AAF) Collection storage base, pending a decision about re-erecting the tunnel.[12]

In the midst of the dismemberment and shipping of German equipment, the U.S. aircraft industry also showed intense interest in the Kochel and Oetztal tunnels for its use. Responding to a query from the Aircraft Industries Association of America, Inc., on December 4, 1945, Arnold advised:

> *"Subsequent to the visit of various West Coast aircraft industry representatives to Germany, there has been a great deal of rearrangement of the zones occupied by the Allied Powers. This, in turn, has resulted in several changes in our plans for returning German research equipment to the United States. The United States Army Air Forces in Europe have furnished the War Department with an inventory of the wind tunnels and test installations now under American control and the War Department has already allocated this equipment. ... Some of the equipment pertaining to the Oetztal 25′ wind tunnel has been packed and crated for shipment to this country. Tentative allocation of equipment for this tunnel has been made to the Army Air Forces. It is our plan to assemble and inspect these components after their arrival and, in conjunction with experts from various agencies, to determine whether or not complete reconstruction is feasible. While a definite site for this installation has not yet been selected, it appears quite probable that your suggestion concerning the Rocky Mountain district will be virtually mandatory due to the tremendous water power requirements. The Air Technical Service Command has been authorized to conduct an informal survey of possible locations for a wind tunnel of this size. ... The Aircraft Industries Association will be invited to participate in discussions of plans for location and reconstruction of the Oetztal tunnel.*
>
> *The various supersonic wind tunnels, now under American control, have been assigned to Government activities and will be reinstalled in the United States as soon as shipment is completed. Specifically, the 40 × 40 cm super-*

sonic tunnel from Kochel has been turned over to the Navy, while others have been turned over to the Army Air Forces and the N.A.C.A."[13]

Headquarters Army Air Forces believed that the Aircraft Industries Association would support their claims for the Oetztal equipment but advised that "the N.A.C.A., however, will undoubtedly make a strong bid for assignment of the Oetztal tunnel project to Langley or Ames Laboratory."[14]

By May 1946 the French government had made repeated requests to the War Department for the return of all parts and components of the Oetztal tunnel still in the U.S. zone to French territory.[15] The Air Materiel Command obtained from steel contractors an estimate of the value in time and money of using the parts of the Oetztal tunnel in the construction of one of the AEDC tunnels; they planned to bargain with the French for other equipment in the French zone. The Air Materiel Command recommended that Theodore von Karman, then serving as a representative of the Army Air Forces Scientific Advisory Board to the Sixth International Congress for Applied Mechanics in Paris, engage in preliminary negotiations with the French.[16]

As planned, von Karman met with French members of the research-and-development community, who informed him that France wished to re-erect the Oetztal tunnel at Modane in the southeast of France, a site topographically suited for hydraulic drive. The French, however, expressed concern that they had been unable to locate missing parts especially associated with the drive system that had mysteriously disappeared in October 1945. They learned, to their surprise, that Wattendorf had long ago spirited these parts away.

France and the United States reached a bilateral agreement that the United States would ship the parts of the Oetztal tunnel to France, including the drawings, and would further assist French authorities in finding other parts possibly still in the U.S. zone of occupation. In return, France would grant the United States access to information about the operation of the tunnel and favorable consideration for running special tests in the Modane Wind Tunnel.[17] A draft of the proposed agreement appeared in October 1946,[18] and included a provision

"…to admit by the French, American representatives to technical data including drawings for transmittal to Wright Field and to technical installations for inspection in all French zones. Of particular and of immediate interest in this connection are complete drawings of equipment in the French zone pertaining to the Kochel tunnel … as well as all of the design, construction and operational information concerning the Oetztal tunnel."[19]

Kochel

The development of supersonic tunnels in Germany had begun in earnest during the 1930s. With the 1936 establishment of the Peenemunde Rocket Development Station on the Baltic, the Germans began the development of a long-range guided missile, the A4 (V-2), with Dr. Werner von Braun as technical director for the project. In 1937, Peenemunde added an Aerodynamics Institute, led by Drs. Rudolph Hermann and Hermann Kurzweg, for the aerodynamic development of the V-2. By 1938 the first of two 40-centimeter-by-40-centimeter supersonic wind tunnels were operating at Mach 2.5. In 1941 the second tunnel in operation achieved Mach 3.3.[20]

Following the air raid on Peenemunde of August 17 18, 1943, the chief of the Army Weapons Office decided to move the supersonic wind tunnel to Kochel, Bavaria, where it later operated under the "camouflaged designation" *Wasserbau-Versuchs-Anstalt*. Three hundred railroad cars were needed to move the "two 40 by 40 cm tunnels, the small experimental tunnel intended for the development of higher Mach numbers, the wooden 40 by 40 cm tunnel for subsonic velocities up to Mach 0.4, the compressors, motors, the 41′ diameter sphere, and other equipment, [while the] 18 by 18 continuous tunnel went to Braunschweig."[21] At Kochel the Mach 10 tunnel required 30,000 kilowatts.

Hitler's increasing desperation in 1944 led to the appointment of Schutzstaffel (SS) general Dr. Hans Kammler, a military officer and engineer, who became the supreme commander for all rocketry efforts.[22] Werner von Braun and Walter Dornberger anticipated that the SS would destroy documents and equipment related to the tunnels rather than let them fall into Allied hands. For example, reports containing the results of Peenemunde work for the previous eight years had been moved to the "Mittelwerk" in Thuringia, which lay under the jurisdiction of General Kammler.

In March 1945, senior German scientists drove by night from Kochel to Thuringia with the objective of obtaining the secret archive reports of "series 66," contained in the files of the Peenemunde institution. Von Braun issued orders for them to enter the underground complex, although he was not authorized to do so. The Kochel scientists removed the documents in a bag, concealed them under spare tires and tools in their car, and destroyed the von Braun permit. On that same day, General Keitel issued general orders prohibiting the use of any civilian car that used gasoline, so the Kochel scientists evaded detection by driving home at night without lights. They microfilmed the documents and secured them in various places in sealed metal boxes. Meanwhile, the SS loaded the remaining documents from the Mittelwerk into trucks and dumped the trucks into the shaft of a salt mine.[23]

Illustrating the context of these times, one of the participants in the clandestine activity later wrote:

> *"We were scientists and not fighting people. We could not understand the senseless destruction of scientific equipment with which we had made so many important investigations in the supersonic field during the last years. It was absolutely of no use to anyone in Germany if we should burn all the results of our scientific work. If we did so, we would fall back in our field several years. It was not clear at this time which one of the hostile armies would occupy Kochel. However, all efforts were made to save as much as possible of the work already done and to protect the wind tunnel to use it for further work. The development of high-speed flying bodies is one of the most urgent and most interesting technical problems of the near future. The destruction of his tool for this development and the destruction of his own brain work would actually mean the suicide of the scientist."*[24]

One week before U.S. troops reached Kochel on May 1, 1945, the scientists defied German orders to destroy all secret equipment and documents. In order to protect the hidden documents and equipment from plunderers and souvenir hunters [they] kept them hidden until the arrival of the first American scientists. The first U.S. commanding officer in Kochel, one Lt. Roberts, signed the first order to protect the Wasserbau-Versuchs-Anstalt.[25]

The U.S. Joint Chiefs of Staff awarded custody of the Kochel tunnels to the U.S. Navy. Custody then passed from the Chief of Naval Operations to the Bureau of Ordnance to the Naval Ordnance Laboratory. An assessment of these tunnels at the time read:

> *"The White Oak installation will be superior to any existing American supersonic wind tunnel installation and will be capable of investigating fields not accessible to any existing installation. There are at present no tunnels operating in this country at speeds comparable to that reached by the Kochel tunnel (4.4 times the velocity of sound). Such speeds are needed for research on the aerodynamics of very high-speed guided missiles and projectiles. ... The instrumentation of the German tunnel is believed to be superior in a number of respects to that which is planned for any of the American tunnels."*[26]

Wattendorf later described the shipment of the Kochel tunnel to the United States:

> *"There, Colonel Paul Dane was crating up the main blow-down supersonic wind tunnel and had it all packed in crates. On the site was a Navy observer who was there every day. When the long dismantling and crating process had been completed, Paul Dane said to his Navy friend…"Finally, it's all wrapped up. All I have to do is put on the labels and I'm through." Whereupon the Navy officer said, "Oh, no. I can save you that trouble. ... I have the labels right here for shipment to the U.S. Navy." Unknown to us, he had obtained authority from the Navy, okayed at a higher level; and so he had the fun of watching Paul Dane of the Air Force complete the elaborate crating process, so that all he had to do was apply the labels."*[27]

The train with the tunnel equipment left Kochel in early October 1945 to be later requisitioned and set up at White Oak, Maryland, as the first increment of the new Naval Ordnance Laboratory. Wattendorf considered the tunnel a "spin-off of AEDC ... and therefore [an element that] should have honorary alumnus membership."[28] In an instance of historical irony, in 1995 the tunnel officially became part of AEDC because of the base realignment and closure.

Bavarian Motor Works

The BMW Engine Test Facility at Munich was the only facility designated for AEDC from Wattendorf's earlier memo that actually became part of AEDC. It had first been assigned to the U.S. Navy, but only for testing in Munich. The Army Air Forces requisitioned the materiel for re-erection as a first increment for AEDC.[29] The National Advisory Committee for Aeronautics' Special Facility on Supersonic Facilities decided in December 1946 that the proposed components-test facility and the special equipment required for its operation would not be included in the Unitary Plan.[30]

In February 1947 the Joint Chiefs of Staff allocated the complete Bavarian Motor Works plant, together with parts intended for its expansion, to the Army Air Forces, which shipped the materiel to the United States and stored it until the final site selection for AEDC.[31] ❑

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Endnotes

[1]Dedicated as the Arnold Engineering Development Center on June 25, 1951, and redesignated as the Arnold Engineering Development Complex on July 6, 2012.

[2]Walter Dornberger, "Incentives Within the AEDC," Wright Field, February 21, 1949.

[3]Senate Report No. 443, June 2, 1949; House Report No. 1376, October 4, 1949; Conference Report No. 1451, October 17, 1949. The House report repeats in substance the Senate report. The Conference report, also set out, outlines changes to the bill accepted by the conference. House Report No. 1376. Hereafter "Legislative History," p. 2298.

[4]"Legislative History," pp. 2300 2301.

[5]Frank L. Wattendorf, Scientific Advisory Group, "Reports on Selected Topics of German and Swiss Aeronautical Developments," n.d.

[6]Memorandum, Frank L. Wattendorf to Gen. F. O. Carroll, Chief, Engineering Division, AMC, "Proposal for a New Air Forces Development Center," June 19, 1945.

[7]Frank L. Wattendorf, "Trans Atlantic memo, June 19, 1945. See Wattendorf, Memorandum to General Carroll in references for full citation.

[8]Office of Military Government for Germany, Economics Division, [draft] "Amendment to Directive re Administration of Military Government in the U.S. zone in Germany," Oct. 1945, as cited in Gimbel, p. 115.

[9]Wattendorf, Report No. 5240, July 13, 1945; Wattendorf, "Historical Aspects of the Oetztal (Modane) Wind Tunnel," October 22, 1981.

[10]Wattendorf, Report No. 5240.

[11]Wattendorf, "Historical Aspects"

[12]Wattendorf, *ibid*.

[13]Letter, H. H. Arnold to Aircraft Industries Association of America, Inc., December 4, 1945.

[14]Memorandum, Aiden R. Crawford, Brig. Gen., USA, to Com manding Gen., Air Technical Service Command, "German Wind Tunnels for Installation Within the U.S.," December 10, 1945.

[15]Memorandum, John G. Moore, Col., Air Corps, Deputy Asst. Chief of Air Staff 4, to Commanding Gen., Air Materiel Command, "Oetztal Wind Tunnel Equipment," May 16, 1946.

[16]Memorandum, D. L. Putt, Col., Air Corps, Deputy Commanding Gen., Intelligence, T 2, to Commanding Gen., Army Air Forces, "Oetztal Wind Tunnel Equipment," May 29, 1946.

[17]Wattendorf, "Historical Aspects"; memorandum, Aiden R. Craw ford, Brig. Gen., USA, to Commanding Gen., Air Materiel Command, "Reconstruction of Oetztal Tunnel," August 15, 1946.

[18]Memorandum, I. H. Edwards, Maj. Gen., USA, to Commanding Gen., HQ U.S. Forces European Theater, "Release to the French authorities of the parts of the Oetztal Wind Tunnel still in possession of the U.S. authorities," October 4, 1946.

[19]Memorandum, Paul H. Kemmer, Col., Air Corps, to Commanding Gen., Army Air Forces, "Reconstruction of Oetztal Tunnel," July 25, 1946.

[20]Sam M. Hastings, "The NSWC/WOL Wind Tunnels: A Chro nology," August 1979.

[21]"History of the Group of German Scientists (As Recounted by Several German Scientists Who Came to NOL)."

[22]Peter P. Wegener, *The Peenemunde Wind Tunnels: A Memoir* (New Haven, CT: Yale University Press 1996), pp. 93 ff.

[23]Account taken nearly verbatim from "History of the Group of German Scientists." Unpublished.

[24]"History of the Group of German Scientists." Unpublished.

[25]*Ibid*.

[26]Cited in Hastings, "The NSWC/WOL Wind Tunnels."

[27]Wattendorf, "AEDC Early Planning," April 26, 1968.

[28]*Ibid*.

[29]*Ibid*.

[30]R. G. Robinson, Secretary, NACA Special Committee on Super sonic Facilities, "Revisions in Facilities to be Included in Unitary Plan," December 20, 1946.

[31]Historical Office, Arnold Engineering Development Center, *Chronol ogy of the Arnold Engineering Development Center: Beginning in 1944*, p. 5.

References

Arnold Engineering Development Center Historical Office. 2002. *Chronology of the Arnold Engineering Development Center: Beginning in 1944*. AECC, Arnold Air Force Base, TN: Headquarters.

Arnold, Henry H. 1945. Letter to Aircraft Industries Association of America, Inc., December 4. AEDC Archived Documents.

Crawford, Aiden R. 1945. Memorandum to Commanding General, Air Technical Service Command, "German Wind Tunnels for Installation Within the U.S.," December 10. AEDC Archived Documents.

Crawford, Aiden R. 1946. Memorandum to Commanding General, Air Materiel Command, "Reconstruction of the Oetztal Tunnel," August 15, 1946.

Dornberger, Walter. 1949. Wright Field, "Incentives Within the AEDC," February 21. AEDC Archived Documents.

Edwards, I. H. 1946. Memorandum to Commanding General, U.S. Forces European Theater, "Release to the French authorities of the parts of the Oetztal Wind Tunnel still in possession of the U.S. authorities," October 4. AEDC Archived Documents.

Gimbel, John. 1990. *Science, Technology, and Reparations*. Stanford, CA.: University Press..

Hastings, Sam M. 1979. "The NSWC/WOL Wind Tunnels: A Chronology." Unpublished paper.

Kemmer, Paul H. 1946. Memorandum to Commanding General, Army Air Forces, "Reconstruction of Oetztal Tunnel," July 25.

Moore, John G. 1946. Memorandum to Commanding General, Air Materiel Command, "Oetztal Wind Tunnel Equipment," May 16.

Putt, D. L. 1946. Memorandum to Commanding General, Army Air Forces, "Oetztal Wind Tunnel Equipment," May 29.

Robinson, R. G. 1946. "Revisions in Facilities to be Included in Unitary Plan," NACA Special Committee on Supersonic Facilities, December 20. Unpublished paper.

U.S. Congress. House of Representatives. Committee on Public Law 81-415. 1949a. *The Unitary Wind Tunnel Plan Act of 1949 and the Air Engineering Development Act of 1949*. 81st Cong., 81st sess. H. Rep. 1376.

U.S. Congress. House of Representatives. Committee on Public Law 81-415. 1949b 81st Cong., 81st sess. H. Rep. 1451.

U.S. Congress. Senate. Committee on U.S. Congress House of Representatives. Hearing on Air Engineering Development Center Act of 1949 Prior to Becoming Law (Report 1451). 81st. 1949. *U.S. Congress Senate Hearing on Unitary Wind Tunnel Plan Act of 1949 Prior to Becoming Law (Report 1451)*. S. Rep. 443.

Wattendorf, Frank L., Scientific Advisory Group. n.d. "Reports on Selected Topics of German and Swiss Aeronautical Developments." Report for Scientific Advisory Group.

Wattendorf, Frank L. 1945a. Memorandum to General F. O. Carroll, Chief, Engineering Division, AMC, "Proposal for a New Air Forces Development Center," June 19.

Wattendorf, Frank L. 1945b. Report No. 5240, July 13. Report for Scientific Advisory Group.

Wattendorf, Frank L. 1968. "AEDC Early Planning," Speech delivered at AEDC on April 26, 1968.

Wattendorf, Frank L. 1981. "Historical Aspects of the Oetztal (Modane) Wind Tunnel," Speech delivered at AEDC on October 22, 1981.

Wegener, Peter P. 1996. *The Peenemunde wind tunnels: A memoir*. New Haven, CT: Yale University Press.

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How Technology and Tools Can Improve the Development and Marketing of Products

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In today's world of instant gratification, rapid prototyping and high-speed machining technologies are becoming increasingly important to manufacturers and product designers. Three-dimensional printers have effectively redefined the prototyping phase of the design process, as complicated parts can be produced in a matter of hours or days with little to no effort. These machines have become easier to use, more accurate, faster, and more affordable within the last few years, due in part to the explosion of interest in 3-D printing within the hobbyist and "maker" communities. Never before have individuals had access to these versatile tools without spending large sums of money or being limited to a company- or school-owned machine. Rapid-prototyping machines are vital components of the modern manufacturing and product-design processes, and will definitely become even more important in the near future. In a manner similar to 3-D printers, high-speed machining centers have become instrumental parts of both manufacturing and prototyping processes. Such tools have reduced cycle times on even complicated parts to mere minutes, increasing efficiency and saving manufacturers money. Some companies, such as Apple, understand the value of a series of fast computer numerical-controlled machines for prototyping parts that need to be made of tougher materials than 3-D printers can easily or inexpensively produce. These machines are typically better suited to later phases of the prototyping process, as machining is generally a longer and more labor-intensive process than 3-D printing. Still, with proper code and process optimization, subtractive manufacturing, as seen in most machining operations, can be nearly as efficient as additive manufacturing, typical of 3-D printing, for one-off and short-run parts.

In order to truly improve the development and marketing of products, fundamental changes must occur in the prototyping process. To be effective, product designers must be able to quickly produce physical mock-ups and prototypes so that customers and managers can evaluate the status and progress of the product's design. Traditionally, this step has been "farmed out" to third-party companies that specialize in this area, but that is often plagued with high costs and unacceptably long lead times. Modern product designers and companies are turning to in-house prototyping as much as possible. This tends to substantially reduce the cost of producing a prototype, allowing more stages of a design to be translated to physical objects for easier assessment. The recent jump in the evolution and development of rapid prototyping processes is particularly conducive to an increase in in-house prototyping, as efficient and high-performance 3-D printers are widely available for reasonably low prices. Though professional-quality printers can range in price from $20,000 to well over $1 million, depending on the machine's capabilities, the printers pay for themselves over time and are effectively investments in a company's future success.

For the last 4 years, I have found myself immersed in the world of manufacturing technology. Through my school and my own personal ventures, I have gained experience in many areas of both the design process and manufacturing itself. In the learning process, I have discovered the strengths and weaknesses of many manufacturing techniques, including both machining and 3-D printing. I have seen part failures from products of both processes, though I have experienced many more breakages in the use of printed parts than machined parts. Three-dimensional printing is an inherently flawed method of part production, in that

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its products are not typically very strong. Fused deposition modeling is the most common and least expensive method of printing; it operates by stacking thin, extruded layers of plastic to build up parts. Most parts produced by this process are subject to a grain, like that present in wood, which creates a distinct strength gradient throughout the part. A designer has to be careful to orient the part properly when setting up for a 3-D print if the resulting part will be used in a functional model and subjected to significant forces. There are other methods of printing solid models, such as selective laser sintering, but those are much more expensive processes. Still, 3-D printing is a valuable and useful resource for product development and marketing, since complex models, some of which cannot be produced by traditional machining processes, can be made very quickly. A printed mock-up or scale model of a proposed design can wow a client, and will make a presentation seem very well thought out and professional. These models are also extremely useful for finding flaws in designs, as the only way to truly ensure that a part or assembly is correctly designed is to actually produce a physical product and test the parts together. Still, 3-D printing is not ideal for all stages of the prototyping process, and definitely should be integrated with machining technology in later stages.

Machining is an often-overlooked method of prototype creation in the design process. This may be due in part to many engineers' experiences with older and slower forms of machining technology, particularly those involving manual machines. Modern computer numerical-controlled machines are extremely flexible, fast, and effective at cutting stock, and they can be used to make nearly anything out of virtually any material imaginable. The integration of computer-aided machining software with computer-aided design software currently in use by most engineers enables even those with little to no machine-programming experience to generate programs for extremely complicated and otherwise labor-intensive parts in a matter of minutes or hours. Most modern computer-aided machining software includes code optimization, which increases productivity by allowing high-speed machines to operate at the upper limits of their performance. An advantage to computer numerical-controlled machines is that once the setup operations are performed and the operator proves out the program, the machines can largely be left alone to complete longer programs automatically with minimal operator interaction. This feature allows a single operator to supervise multiple machines at once, reducing the cost of prototyped parts and increasing the rate at which prototypes can be made without increasing staff. This is not the only advantage of machining for prototype purposes, though. Machined parts are much more durable and can handle loads that are orders of magnitude higher than their 3-D printed counterparts can, and they are accordingly better suited to the final prototype and test phases of product design. They can also be used to demonstrate the final appearance, weight, and rigidity of a product to a client or potential customer, a big selling point for a design.

Response and rationale

Obviously, each method of prototyping holds its own strengths and weaknesses, and both should be implemented in the design and prototyping processes to achieve maximum efficiency. In order for 3-D printing to be effective, printed parts should not be utilized for applications where another method would be better suited to the task at hand. In order to determine the suitability of a given part-production process for a particular prototype or product, engineers must be properly trained in the capabilities and correct implementations of both machining and 3-D printing. Though this step involves a significant investment of time, such an investment will easily save many hours of frustration and complications in the long run. After all, without proper training, experience, or a combination thereof, engineers will not be able to consistently produce prototypes that function as expected for a given point in the design process. Though both manufacturing processes are powerful and useful to the design and prototyping systems, without proper implementation of the technologies, peak efficiency and therefore peak profitability cannot be achieved.

Summary and conclusion

Many designers stand to vastly improve the rate at which they can produce prototype parts and assemblies while simultaneously reducing the overall prototyping cost by correctly utilizing available and future technologies for 3-D printing and high-speed machining. Both processes can be used to advance both the development and marketing of products with proper implementation of the technology. The potential boon to prototyping and product design and development is obvious, but many may not consider the possibilities for marketing presented by rapid prototyping and high-speed machining technology. Both can be used to create highly aesthetically pleasing and accurate models based on designs created in computer-aided design software quickly and painlessly. Customers are naturally drawn to more professional-looking and visually clean designs, so prototypes and mock-ups that have been produced with modern technology and are intended for exhibition are likely to be popular among clients and potential customers.

Prototyping and manufacturing technology has come a long way in a very short period of time, and there are even more developments just beginning to appear on the horizon. The future holds nothing but progress in this field, and product designers and engineers will have increasingly efficient and powerful cutting-edge technology at their fingertips. The potential for innovation is nearly limitless if companies recognize the profitability of these machines. The coming years promise to exhibit countless improvements to already-powerful technology, something that will reflect positively in product design across industries. ❑

Bradley Matheus is currently attending 12th Grade at the California Academy of Mathematics and Science. He will be applying to MIT for mechanical engineering, intends to get a master's degree or beyond in mechanical engineering. He would like to start a manufacturing company focused on the production of CNC machines and automation equipment. His main goal is to start and run a successful business.

References

Datron Dynamics. n.d. *Rapid prototyping machines from Datron! High speed CNC machining centers for rapid prototyping*. Milford, New Hampshire: Datron Dynamics. http://www.datrondynamics.com/Rapid Prototyping Machine.htm (accessed August 31, 2012).

Parrish, R. April 5, 2012. Inside Apple HQ. *Apple Gazette*. http://www.applegazette.com/feature/inside-apple-hq (accessed August 31, 2012).

Stratasys. n.d. *Dimension printing*. Eden Prairie, Minnesota: Stratasys, http://www.dimensionprinting.com (accessed August 31, 2012).

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Methods of Promoting STEM Education to Solve the T&E Workforce Problem

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This article identifies the cause of the critical workforce problem in the test-and-evaluation (T&E) industry and proposes a solution. The proposed solution is to push for education in the fields of science, technology, engineering, and math (STEM) to produce a better workforce and give students incentives to pursue STEM education. Specialized courses and hands-on training during undergraduate studies will provide students with the fundamental knowledge to handle the responsibilities of the T&E field. Scholarships provided by T&E companies to distinguished students will give the students an incentive to pursue a career in the field. Implementing these measures will result in mutual satisfaction between an industry enjoying an influx of new workers and students with reduced debt and an education they are genuinely interested in.

Key words: Defense industry training; STEM education; scholarships.

This article is presented in 4 sections: Approach, Response and rationale, Summary and conclusion, and References.

Approach

Identifying the problem

The widely accepted first step to solving any issue is identifying the problem. The workforce problem in the field of test and evaluation (T&E) is that the need for future T&E work cannot be met without making effective changes. Moreover, the workforce size is not large enough to replace the experienced workers nearing retirement. The major causes of this unstable workforce are the significant portion of T&E workers who will be at retirement age in the next 10 years and the declining interest in science, technology, engineering, and math (STEM) in the United States.

An aging workforce is not an isolated phenomenon, but part of a larger trend in the United States. Forty-seven percent of the current workforce in the United States is made up of those born after World War II: the baby boomers (United States Department of Labor 1999). By 2030, these workers will be at retirement age, between 66 and 84 years old (Halbert 2006). The decades following the baby boom experienced significantly lower birth rates (see *Figure 1*). The reduced birth rates after the later half of the 1960s will result in a reduced workforce size years later, in 2012.

Similarly, a decline in STEM interest over the past decades in the United States has contributed to an insufficient workforce. Doctoral degrees in engineering and science have experienced a 36% drop among white males between 1966 and 2000. The prestige of making millions through stock trading on Wall Street has attracted graduates from top universities, diverting their focus away from STEM. Additionally, government cuts in science research and funding have imposed an equally critical obstacle blocking students from pursuing STEM education (Knovel 2011).

Choosing the best option

Upon examining the causes, the best solution to the problem of retiring experience leaving a gap in the T&E industry is to encourage education in STEM-related fields as early as possible to attract students, rather than training the current workforce by means of the Defense Acquisition University. This is discussed under "Response and rationale."

Gathering data

Finding the best illustration of why STEM education should be encouraged was no daunting task, given the current situation in which the federal budget leaves education wanting. Regardless, a diverse array of data was drawn from journals, databases, and presentation slides in addition to interviewing an award-winning CERN researcher to create the best representation of this greatly underfunded field.

Response and rationale

Encouraging students to pursue STEM education is the best way to bring new workers into the declining T&E workforce. Pushing STEM education early in

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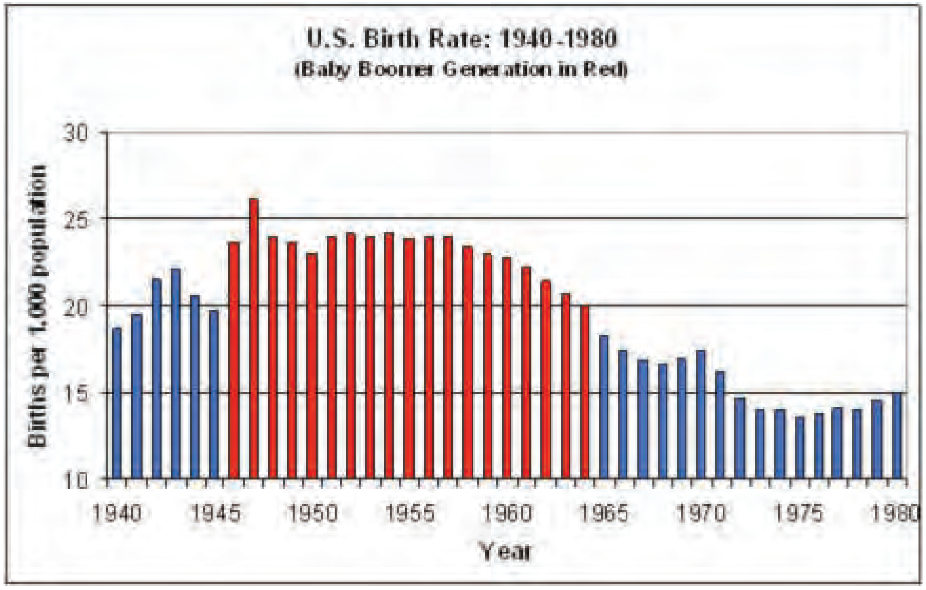

Figure 1. Baby-boomer generation highlighted in red (Halbert 2006).

undergraduate studies benefits both the industry and students in two significant ways. First, students will learn the skills necessary to perform tasks in the T&E field early on in their education, giving them a greater foundation than people of previous generations. Second, scholarships and increased funding will attract students looking to avoid debt and pursue STEM education, while serving as a worthwhile investment for T&E companies.

Early career training

Training for the T&E industry can be done as early as the undergraduate years of university education. One effective method for integrating career training in the field is to sponsor T&E-specific courses. For example, the logistics aspect of the T&E industry requires workers to be educated about operational and logistical models, as well as the properties of a representative suite of logistical models (Olwell, Johnson, & Didoszak 2007). In addition, engineers should understand basic structural mechanics, fluid dynamics with respect to weapon systems, thermodynamics, and materials science. These can be taught and promoted in undergraduate courses in major universities partnered with T&E organizations, such as Texas A&M, the University of Central Florida, George Mason University, Johns Hopkins University, and the University of California, San Diego.

Another effective method involves engaging the students through a hands-on approach that will supplement their classroom education. This allows students to work for a qualified employer doing practical work pertinent to their course studies in this case, T&E. Programs like this have proven successful, such as Northwestern University's Cooperative Engineering Education Program, available to students at the McCormick School of Engineering and Applied Science (Northwestern University n.d.). Alternatively, internships in the T&E field available to students taking T&E-specific courses would also provide the encouragement necessary to engage and prepare students for a career in the industry.

Through integrating career training into undergraduate studies by means of specialized courses and hands-on programs, the T&E industry will have a better-prepared workforce entering the field in future years.

Funding STEM education

While giving students an early foundation will benefit the T&E field with a prepared workforce, scholarships and funding for STEM education will provide an incentive for students to pursue T&E education.

Encouraging students to pursue a future in T&E is as easy as ameliorating their debt. In fact, studies show that future debt has a critical impact on a student's chosen major (Neal et al. 2012). Even engineering majors in the United States are expected to have a monthly student loan debt of $229 after graduation (Shook, Fletcher, and Neal 2012). T&E companies can provide scholarships to distinguished students who show interest in working in the industry to reduce this debt.

The need for funding of STEM education can be seen on all levels. Alex Garner, a CERN research assistant under Dr. Ivan Furic and Dr. Bobby Scurlock at the University of Florida's department of physics, is currently double majoring in physics and math. He comments on the need for greater funding for STEM education:

"Ever since I read 'Angels and Demons' in 10th grade, I knew I wanted to pursue a career in particle physics. Despite having this passion, I didn't get any scientific scholarships to attend the University of Florida. I loved it enough that I paid my own tuition and began research in particle physics my very first semester. Despite having done it for over three years now and having several publications and even an award-winning presentation, I am still financing my own education. My passion for physics keeps me in the field, but there were many times I considered switching due to the lack of support for STEM fields. If there were more funding for STEM fields, not only would more people be willing to enter, dedicated students like myself would be able to graduate without the large amount of debt I unfortunately will have to deal with." (Internet chat interview with the author, August 22, 2012)

Though his passion for particle physics has kept Garner in the field, he notes that the need for financial assistance in STEM fields has discouraged him a phenomenon that many other students experience. The United States is experiencing a decline in students pursuing engineering: what was 52 to 59 percent of 24-year-olds holding their first university degrees in engineering or natural sciences in 1996 became 27 to 46% in 2007 ("Increasing Emphasis and Funding" n.d.). T&E companies can bring these numbers back up by encouraging students to pursue STEM fields through providing yearly scholarships that allow students to explore the field and gauge their interest.

Summary and conclusion

A declining interest in STEM over the past decades pairs with the aging workforce to manifest as the T&E industry's ultimate problem: workers are needed to fill the gap left by retiring experienced workers. Current trends show that active measures must be taken to attract a sufficient number of experienced workers into the industry. The methods discussed to accomplish this are

- encouraging early career training by means of specialized courses and cooperative education programs or internships and
- providing funding for STEM education through scholarships, giving students an incentive and opportunity to explore T&E fields.

Both methods, as discussed, are investments that the T&E industry must make to ensure that the new generation entering the workforce is prepared to handle the responsibilities of the retiring experienced workers. ❑

Zaki Molvi is a senior at Troy High School in Fullerton, CA. His academic areas of interest include Environmental Remote Sensing, Geographic Information Systems, Inorganic Chemistry, and Applied Physics. A genuine interest in the sciences and engineering motivated him to enroll in STEM courses throughout high school. His plan is to double major in chemical engineering and nuclear engineering at Northwestern University's McCormick School of Engineering and Applied Science. His goal is to change the world with his ideas, whether it be through working in the industry, doing research, or philanthropic work.

References

Halbert, G. August 15, 2006. Will the baby boomers wreck the market? *Forecasts & Trends* [newsletter]. http://www.profutures.com/article.php/448/ (accessed August 20, 2012).

Increasing emphasis and funding for technology and engineering in STEM. n.d. Reston, Virginia: American Institute of Aeronautics and Astronautics, https://www.aiaa.org/uploadedFiles/Issues and Advocacy/Education and Workforce/TE%20in%20STEM-%20030112(1).pdf (accessed August 22, 2012).

Knovel. November 7, 2011. *Now lagging in science and math, U.S. relying on top ranked engineering schools to reclaim role as global innovator*. New York: Knovel, http://why.knovel.com/all-engineering-news/997-now-lagging-in-science-and-math-us-relying-on-top-ranked-engineering-schools-to-reclaim-role-as-global-innovator.html (accessed August 25, 2012).

Neal, M., Fletcher, C., Shook, M., and J. Webster. 2012. *Balancing passion and practicality: The role of debt and major on students' financial outcomes*. Round Rock, Texas: Texas Guaranteed Student Loan Corporation, http://tgslc.org/pdf/Balancing-Passion-and-Practicality.pdf (accessed August 23, 2012).

Northwestern University. n.d. *Co-op overview*. Evanston, Illinois: Robert R. McCormick School of Engineering and Applied Science, Northwestern university, http://www.mccormick.northwestern.edu/mcd/Programs/Co-op (accessed August 26, 2012).

Olwell, D., Johnson, J., and J. Didoszak. 2007. M&S education for the acquisition/T&E workforce: Requirements analysis *10th Annual/Systems Engineering Conference* October 23, 2007, San Diego, CA. Naval Postgraduate School, http://www.dtic.mil/ndia/2007systems/Tuesday/PM/Track5/6099.pdf (accessed August 20, 2012).

Shook, M., Fletcher, C., and M. Neal. March 28, 2012. *Income by major and student loan debt: Implications* *for counseling students about choice of major, debt burden, and career choice* TG Research and Analytical Services, Texas Guaranteed Student Loan Corporation, Round Rock, TX. http://www.tgslc.org/pdf/Balancing-Passion-and-Practicality-Summary.pdf (accessed August 24, 2012).

United States Department of Labor. 1999. *Futurework: Trends and challenges for work in the 21st century*. Washington, D.C., U.S. Department of Labor. http://www.dol.gov/oasam/programs/history/herman/reports/futurework/report/chapter1/main.htm (accessed August 24, 2012).

ITEA Annual Symposium Academia Day Paper Competition

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The Importance of Test and Evaluation for Future Product Development

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With the Second Industrial Revolution, in the 19th century sometimes known as the Technological Revolution came the wider use of steel, steam and diesel engines, incandescent light bulbs, and telephones (Ryan 2012). The greater increase of manufactured goods inevitably called for a set of rules that would help protect consumers and improve manufacturers, such as the Pure Food and Drug Act (Theodore Roosevelt Association 2012). Eventually, in 1980, the International Test and Evaluation Association was founded to create and utilize a master evaluation plan to magnify the viability and sustainability of products during their development (About ITEA 2012). Test and evaluation is vital, especially for the incoming generations of manufacturers, because if it did not exist, there would be no clean-cut structure or valid organizations to verify the safety and suitability of products. This article tries to answer the question of whether test and evaluation is essential for the future of product development and ultimately, protection of consumers and improvement of manufacturers or other such businesses. Interviews with two product developers and a survey with 65 anonymous consumers are utilized.

Key words: Master evaluation plan; product development; product safety.

Test and evaluation is a system that seems to help and protect both consumers and manufacturers. In order to gain a broader perspective for this article, opinions from both sides of the topic, consumer and manufacturer, were taken through surveys and interviews. Online research to find out the history of product development and issues that arose from it was also used to substantiate the findings of this article.

A survey of six questions asking 65 participants about the importance of quality of products, pricing, and manufacturer responsibility from the standpoint of both consumer and manufacturer, was distributed. Five of the questions were answered on a scale of 1 to 5, and the remaining question was answered with either a yes or no. The survey questions included the following:

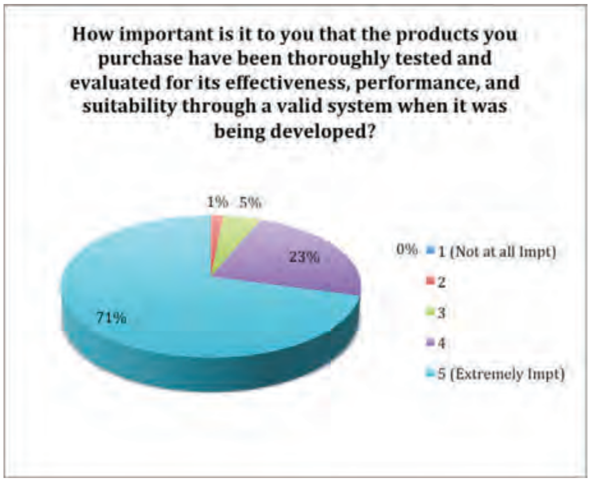
- "How important is it to you that the products you purchase have been thoroughly tested and evaluated for its effectiveness, performance, and suitability through a valid system when it was being developed?"
- "In the perspective of a manufacturer, is it worth it to spend extra time and perhaps money to have a product tested and evaluated during its development?" (This question was also asked from the perspective of a consumer.)
- "Is good pricing more important than quality of products?"
- "How important is quality of products for you?"

Some questions focused on the importance of test and evaluation directly and what consumers felt about the system, while others were more indirect and asked about how important quality and product suitability were versus the real product. The more that survey takers believe that quality and valid product descriptions are important, the more important test and evaluation is, since it is a system that helps to fortify such aspects of products.

Interviews with two software product developers from McKinsey & Company were held. Both developers have had experience in product development and at least a part of the test-and-evaluation process when they held roles in software-development projects. Five general questions were asked regarding their experience and opinions on test and evaluation. Interview questions included the following:

- "Do you think that test and evaluation is necessary? Why or why not?"
- "Have you ever been a part of or experienced test and evaluation?"

Sara Pak is the third-place winner of the ITEA Annual Symposium Academia Day Paper Competition.



Figures 1. Question 1 on survey.

- "If so, what did you think of the process and program?"

The questions asked were designed to bring out the product developers' clear opinions on the test-and-evaluation process. Some questions were also asked to see what the two interviewees thought about the primary question of this article, whether test and evaluation is necessary for the future of product development.

Response and rationale

Of the 65 people who participated in the survey, 71% indicated that it was extremely important to them that products be thoroughly tested and evaluated for effectiveness, performance, and suitability *(Figure 1)*. Fifty-four percent answered that manufacturers and product developers would not be responsible enough to make sustainable products without test and evaluation *(Figure 2)* (on a scale of 1-5, 1 meaning the participant believed manufacturers would not be responsible at all; 5 meaning manufacturers would definitely be responsible). From the perspective of a manufacturer *(Figure 3)*, 69% said that it would (definitely) be

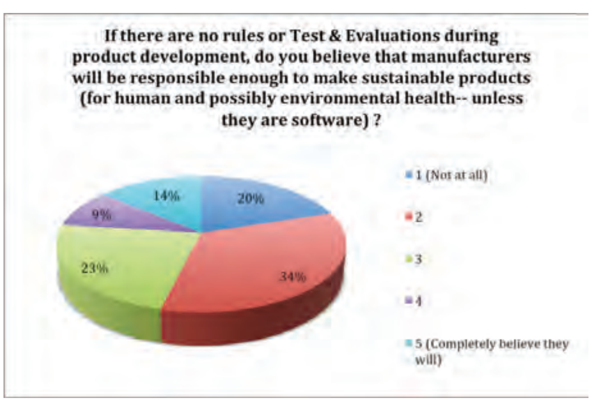


Figure 2. Question 2 on the survey.

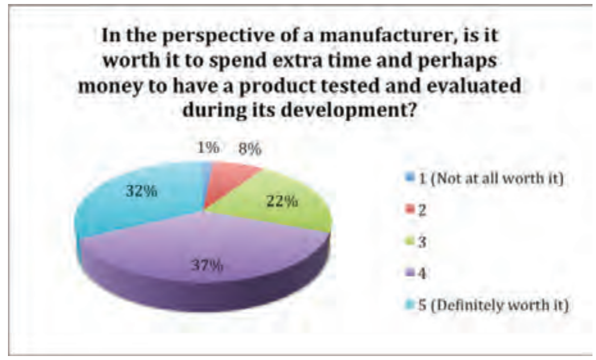


Figure 3. Question 3 on the survey.

worth the time and money for a product to be tested and evaluated. As consumers *(Figure 4)*, 78% said that test and evaluation was definitely worth the time and money spent by product developers and manufacturers. Eighty-two percent claimed that good pricing was not more important than the quality of products *(Figure 5)*, while 98% said that the quality of products was either very important or important *(Figure 6)*. Based on such results, it is clear that the majority is in support of the test-and-evaluation program.

Similar appreciation for test and evaluation was shown during the two interviews. One interviewee, who had undergone product evaluation by a quality assurance group at the company and experienced "customer beta testers," strongly believed that test and evaluation was necessary and that all products should be tested. The interviewee immediately replied with "absolutely" when I asked whether test and evaluation would be necessary during product development (Shobhit Chugh, e-mail interview with the author, July 25, 2012). The second interviewee had also received numerous items of feedback and evaluation from testers who would look for any "bug or issue" within the product and make sure "product specifications… define[d] exactly how the product would serve." In response to the question of whether test and evaluation was necessary, the second interviewee

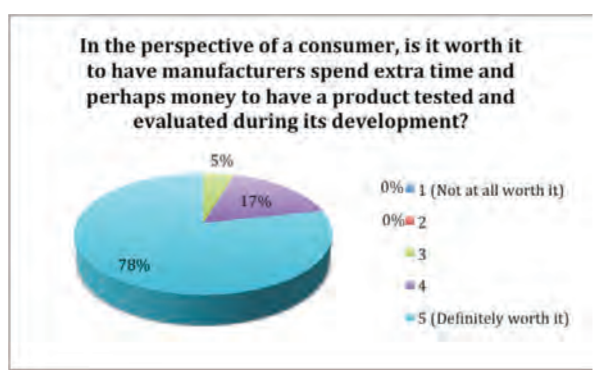


Figure 4. Question 4 on the survey.

Figure 5. Question 5 on the survey.

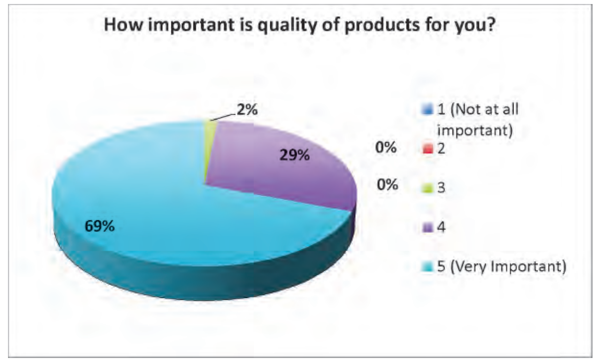


Figure 6. Question 6 on the survey.

described how "it depends" on attributes of the product such as "size of the product," "risk of failure," and "complexity". However, overall, the interviewee said, "my short answer is: Yes" (Jeff Maurone, e-mail interview with the author, July 25, 2012). Both interviewees emphasized the importance of test and evaluation in present and future product-development procedures.

Examining the results from the survey and interviews, it is apparent that both consumers and manufacturers value the current test-and-evaluation process. Without such a system, consumer satisfaction and manufacturer guarantees may be hurt. For instance, prior to the Federal Meat Inspection Act of 1906, the meatpacking industry would cheat customers into purchasing overpriced meat products that were stale, going bad, or improperly cut and cleaned (Sinclair 1971). A regulatory examination system and law became necessary to uphold a safer consumer environment. Though certainly the population can trust that manufacturers and product developers have enough education and liability issues that they will continue to make sure that products are trustworthy and sustainable, it is always better to have a set system to help both consumers and manufacturers for this matter, the test-and-evaluation master plan.

Since quality was shown to be more important than price for the majority of the surveyed consumers, test and evaluation should be maintained for the future of product development. Test and evaluation, more than being just another tedious step, serves to help manufacturers better satisfy consumers by providing feedback and encouraging the manufacturers to rebuild certain parts of products that may become problematic, thus keeping the consumers satisfied and protected.

Summary and conclusion

Based on the data and facts collected for this article, it is apparent that for both product developers and consumers, test and evaluation is something that is necessary for the best current product development and for future improvements. The history of manufacturing has shown that some structure of evaluation is vital in protecting consumers and leading manufacturers and other product-developing companies down the correct path of product creation. As product developers are given feedback on how to reinforce products and the products are made suitable for consumer needs, test and evaluation serves as a significant stepping-stone for product improvement and as a beneficial structure to keep manufacturers' and product developers' relationships with consumers strong (Daly 2012).

A further study on the question of whether test and evaluation is necessary for future product development can be done by contacting more developers of *Fortune* 500 companies that deal with more legal issues (than software development). In addition, more consumers can be surveyed to improve the validity and significance of this research project. Another question that can be asked, extending from this article, is how much influence testers and evaluators can have on product developers. ❑

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After graduating from high school, she hopes to enter a university that will allow her to develop her passions for both math and science, whether through a business or engineering program. Ultimately, she wishes to discover where her strengths and passions lie, and pursue them so

that she can give back to the community and positively impact society.

References

About ITEA. n.d. Fairfax, Virginia: International Test and Evaluation Association, http://www.itea.org/index.php/learn/10-about-itea/general-information/176-about-itea (accessed July 20, 2012).

Daly, Stephen C., Larry Miller, Ernest Seglie, and George Wauer. *The Test and Evaluation Master Plan: An Operational View.* AcqNotes, n.d. http://www.acqnotes.com/Attachments/The%20Test%20and%20Evaluation%20An%20operational%20View.pdf (accessed July 20, 2012).

Federal Meat Inspection Act of 1906. Lawyers, Legal forms, Law Books and Software, Free legal information. NOLO Law for ALL, n.d. http://www.nolo.com/legal-oncyclopedia/content/fed-meant-act.html (accessed July 29, 2012).

Ryan. February 27, 2012. *The Second Industrial Revolution, 1870 1914*. http://www.ushistoryscene.com/uncategorized/the-second-industrial-revolution-1870-1914 (accessed July 29, 2012).

Sinclair, U. 1971. *The Jungle*. Cambridge, Massachusetts: R. Bentley.

Theodore Roosevelt Association. n.d. *Pure Food and Drug Act*. Oyster Bay, New York: Theodore Roosevelt Association, http://www.theodoreroosevelt.org/life/purefooddrug.htm (accessed August 2, 2012).

Wikipedia. s.v "Test and evaluation master plan," http://en.wikipedia.org/wiki/Test and evaluation master plan (accessed July 20, 2012).

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Taking Care of Our Most Important Resource: A Human Capital Strategy for the Air Force Test Center

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The premise of this article is that human capital, embodied in our scientific and engineering professional workforce, is the core of successful developmental test-and-evaluation organizations. This article provides a short overview of existing human-capital initiatives within the Department of Defense, a summary of past and current human-capital initiatives at Air Force Test Center test organizations, and current and future workforce competencies required to achieve needed test capabilities, and then introduces a new human-capital strategy for the Air Force Test Center, followed by a conclusion and the way ahead.

Key words: Science and engineering workforce; workforce management.

Building enduring test capabilities requires that we consider all the necessary elements that make up a capability, not just the material aspects. A common way of thinking about capability elements in the Department of Defense (DoD) is the "DOTMLPF" framework doctrine, organization, training, materiel, leadership, personnel, and facilities. All of these elements must be planned and working together in unison to create both the combat and support capabilities needed to execute our missions. The employment of our existing test capabilities and the planning for future capabilities across our test enterprise can also benefit from thinking about these elements. In particular, we need to think carefully about the personnel element of our capabilities. With enough funding and priority, facilities and equipment are easily rebuilt or refurbished within a few years, but a technically competent workforce cannot be developed in that same time frame. Thus, we need an overarching strategy that ensures that we have the right people with the right set of technical skills in the right places to accomplish our mission.

The U.S. Air Force recently reorganized the Air Force Material Command into a five-center construct to gain efficiencies. As part of this reorganization, the headquarters of the Air Force Test Center (AFTC) was established at Edwards AFB as the parent unit for all developmental test activities in the Air Force Material Command, which comprise the 412th Test Wing at Edwards AFB, the newly-designated 96th Test Wing at Eglin AFB, and the newly-designated Arnold Engineering Development Complex (AEDC) at Arnold AFB. The 412th Test Wing focuses on airframe, power-plant, avionics, and electronic-warfare testing. The 96th Test Wing focuses on air-armament and command, control, and cyber testing. The 96th Test Wing is also the parent unit for the 46th Test Group at Holloman AFB, which focuses on signature-measurement, high-speed-sled, and GPS/inertial testing. The AEDC focuses on development and testing of aerodynamics, propulsion, and space systems. Although each of these subordinate organizations has a rich legacy of providing valuable test results for our customers, integrating the workforce across these three diverse, geographically separated organizations requires thinking strategically about our human capital as part of the overall test capabilities we bring to bear as partners in the current and future Air Force acquisition process.

DoD and Air Force human-capital initiatives

Over 10 years ago, the Air Force recognized the need for a strong, in-house scientific and engineering (S&E) workforce to create "overwhelming technological leadership" and "a dominant edge in technology"

(U.S. Air Force [USAF] 2001). This workforce was envisioned to include the right mix of military, civilian, and contractor personnel, along with the facilities and infrastructure needed to provide innovative solutions and technological advances to our warfighters.

In 2003, the Air Force published the *Career Development Guide for Scientists and Engineers*, which provides desired and required education, training, experience, and attributes for deliberative development of the S&E workforce in both technical depth and corporate breadth for different management and technical career paths (USAF 2003). This guide identifies eight elements of professional development: skills, competencies, values, culture, professional education, leadership, mentoring, and promotion potential. It also articulates the need for a highly skilled, multifunctional workforce that can use and adapt to information-age technologies.

Issues associated with the quality of the DoD acquisition workforce led to a DoD strategic plan to improve this workforce in 2010 (DoD 2010). This strategy focuses on hiring and in-sourcing to achieve a "right-sized, high quality, high performing acquisition workforce," which includes acquisition, technology, and logistics professionals. In particular, the DoD strategy is based on competency to promote "efficiency, effectiveness and consistency in workforce planning and development." Challenges for the test-and-evaluation workforce identified include (a) the complex planning, implementation, and execution required for planning tests in joint environments, (b) the need to identify and evaluate cyber vulnerabilities, and (c) the departure of the baby-boomer workforce that currently maintains most of the intellectual capital.

On the heels of the DoD workforce strategy, the Air Force published a strategic roadmap for its own science, technology, engineering, and mathematics (STEM) workforce (USAF 2011). This strategy recognized the need for an Air Force culture that promotes a STEM workforce engaged in the actual practice of S&E principles to develop and apply technology in a way that is "outcome oriented" and "measured by warfighter success on the battlefield." A major part of the strategy consists of defining requirements, recruiting high-quality people, and properly managing the workforce to ensure that STEM personnel are used correctly and given adequate training, education, and career-advancement opportunities in an environment that can attract and retain top talent. The desired end state is a STEM workforce that is populated with talented professionals and is "affordable, scalable, agile, and seamlessly aligned to Air Force missions and strategies" (USAF 2011). The overall strategy lays out six goals: (a) establishing requirements and inventory; (b) identifying the funding and resources required to obtain and sustain the required STEM workforce; (c) developing appropriate force-management processes; (d) establishing a continuum of learning; (e) pursuing partnerships with schools, universities, sister services, professional associations, and other federal agencies; and (f) developing measurements to drive the right behaviors across the Air Force to enable the STEM workforce.

AFTC human-capital initiatives

For the past several years, the long-term viability of the aerospace workforce in the United States has been a concern. An aging workforce coupled with predictions of a looming shortfall of skilled professionals threatens the vitality of the U.S. aerospace community, making it difficult to maintain our competitiveness and technological edge in the world.

In addition to recruiting and managing a STEM workforce, it is important to also build technical excellence in the workforce to enable the Air Force to be a "smart buyer" as well as sustain technological superiority. Having experienced scientist and engineers with testing domain knowledge is critical to increasing the effectiveness of test and evaluation (T&E). AFTC is focusing on creating a comprehensive technical environment to build the next generation of technical experts, i.e., learning by doing.

In a review of the almost six-decade history of Air Force T&E (Best, Kraft, and Huber 2008), several key attributes were identified that historically contributed to building technical excellence, namely:

1. excitement about and the innovation potential of the mission,
2. organizational and leadership emphasis on technical excellence,
3. opportunities for the staff to be technical and create knowledge,
4. technical collaboration,
5. focused emphasis on developing technical people, and
6. knowledge archiving.

AFTC has been systematically revitalizing these key elements of technical excellence. Examples of some of these activities are supplied by Huber et al. (2009).

Sans a "mission to the moon," innovation has been introduced into the T&E mission by focusing on technical approaches to increase the effectiveness and value of T&E to the acquisition process through:

1. early integrated use of high-fidelity, multidiscipline, physics-based modeling with testing to address system-development needs;
2. application of statistically defensible test methodologies to improve how test data are obtained

and to better understand the statistical significance of the data; and
3. integration of modeling, ground-test and flight-test tools, processes, and workforce to more effectively understand systems under test and impact development programs.

Through these activities, S&E workers gain insight into their craft, make personal contributions to advancing the state of the art, and can observe firsthand the positive outcomes to programs that result through application of their skills. Significant advances have been made on all three fronts through application of resources to train personnel, build tools, and create collaborative teams to effect change. In the use of high-fidelity modeling and the application of statistically defensible testing, AFTC has already established itself as a national leader.

Leadership emphasis on technical excellence starts at the top. A commitment has to be made to adequately resource critical activities for acquiring, training, and developing STEM capabilities. Beyond provisioning, however, leadership also has to set an expectation for technical excellence in the organization. Key technical positions such as technical directors or chief engineers have been elevated to positions of recognized significance in the organization to aspire younger technical talent. Career-development plans for new STEM talent include a growth path for attaining technical excellence, leading to positions as technical directors or chief engineers. Technical fellows are identified and revered as the pinnacle of technical excellence in the organization as well as vital and deep sources of knowledge. Leadership has also recognized technical accomplishments through technical-achievement awards to provide concrete evidence that technical excellence has been achieved and rewarded. Finally, leadership has set an expectation that the STEM workforce will actively engage in technical societies and publish technical papers and reports.

One of the dichotomies of STEM development in the government is, on the one hand, espousal of a critical shortage of STEM skills with, on the other hand, a squandering of STEM talent by putting government engineers and scientists in administrative and oversight roles rather than using their skills in a hands-on approach. Within AFTC, several activities have been put in place to counter this trend. In a strategic response to in-sourcing requirements, a focus was placed on hiring scientists and engineers into AFTC organizations specifically to provide independent-analysis skills in support of development programs. This has resulted in a cadre of skilled S&E workers to not only independently analyze test results but also better support early program planning, successfully troubleshooting operational technical issues. In a related activity, the role of government oversight of organic contractor technical work is evolving to use an integrated government/contractor technical team. This has been accomplished through combined test forces in flight testing for years, but is now occurring in ground testing as well. Finally, an innovative program that immerses young Air Force officers or young government civilians directly in the support of contractor technical experts is transferring important technical knowledge to new STEM talent.

Collaboration offers an important opportunity to not only share technical knowledge but to expand the viewpoint of the S&E staff members outside their own area of expertise. Collaborative efforts across AFTC have been ongoing for years. Legacy efforts such as the Modeling and Simulation Test & Evaluation Resources (MASTER) program, between AEDC and the 412th Test Wing, produced a critical understanding of the interaction between ground and flight testing, standardization of analytical tools, collaborative development of new analytical tools, and seamless access to test data, particularly for propulsion-system development. In similar activities, the Air Force Seek Eagle Office (AFSEO) within the 96th Test Wing and AEDC have collaborated on the advancement of test techniques and development of high-fidelity physics-based modeling in support of weapon-system integration for over 30 years. Development of these techniques and tools has not only established the industry's technical standards but has trained and sustained a large cadre of true technical experts. AFTC is now aggressively engaged in expanding collaboration efforts to the Air Force Research Labs, NASA, and industry.

AFTC has placed particular emphasis on the development of technical people. The development and growth of their skills is critical to advancing T&E as well as system development and sustainment capabilities for all Air Force Test Centers. This initiative has taken on greater urgency in recent years because of the aging of the aerospace-community workforce as a whole.

As subject-matter experts retire, a steady pipeline of high-quality talent must be in place to step in and take over. Considerable progress is being made on developing core-competency roadmaps. Our initiatives are addressing this issue by

1. identifying technical core competencies,
2. identifying gaps in our current staffing,
3. prioritizing the most critical needs, and
4. creating competency-development roadmaps.

Finally, the importance of knowledge capture and transfer in the T&E community has been amply demonstrated in the past. The rich history of accomplishments in AFTC has in the past been documented in technical reports generated and archived since the 1950s. However, over the last two decades, policy changes have resulted in a significant decline in the actual reporting of test results. In addition, the newest generation of S&E workers are not prone to use a library catalogue system to search for technical knowledge. They are more likely to use the Web instead. Hence an invaluable source of technical knowledge is not readily available to them. AFTC has recognized both aspects of this problem. More emphasis has been place on AFTC personnel fully documenting and archiving test and analysis results through technical reports (now in digital form). To make these and the legacy reports available to the S&E community, legacy reports have been digitized and Web-based approaches have been implemented to enable word-search interrogation of historical and current documents.

Current and future workforce competencies

The Office of the Secretary of Defense (OSD) is moving towards a competency-based approach for developing and managing the acquisition workforce (DoD 2010). The U.S. Office of Personnel Management defines the term "competency" as "a measurable pattern of knowledge, skills, abilities, behaviors, and other characteristics that an individual needs to perform work roles or occupational functions successfully" (Rodriguez et al. 2002). Competency-based approaches have become widespread in both industry and government. Instead of describing the knowledge, skills, and abilities for individual positions, a competency-based approach determines the types and levels of competencies required across the workforce as a whole. Competencies also provide a more holistic look at employees, since they can include attributes such as teamwork and values in addition to the traditional approaches using knowledge, skills, and abilities (Rodriguez et al. 2002). Competency-based approaches have been shown to improve workforce effectiveness, integrate cultures, align organizations, and drive organizational change (Gangani, McLean, and Braden 2006). Thus, a competency-based approach is ideally suited to integrating and managing the diverse workforce across the newly aligned AFTC.

OSD recently established a baseline for the general workforce competencies required for T&E personnel (Lasley-Hunter 2011). These competencies include such wide-ranging attributes as the need for customer service and the ability to identify risks. At AFTC we are augmenting these general competencies with specific technical competencies unique to the AFTC mission. These competencies include everything from measurement science to airframe testing. We are in the process of developing a survey that we will send to the supervisory workforce to establish the priorities, levels of competency required, and actual competency levels that exist in the current workforce. We also will determine what competencies we expect to be important in the future. We will then use this competency-based assessment to help us determine the best mix of training, education, and recruiting practices to improve the effectiveness of our existing workforce and ensure that we have an effective future workforce.

New AFTC Human Capital Strategy

As we developed our new AFTC Human Capital Strategy, we found this previous work to be extremely valuable. Not only did we draw overall guidance from it, but we were able to leverage many of the existing activities, programs, and partnerships already established at higher levels.

The overall AFTC Human Capital Strategy is summarized in *Figure 1*. It was developed using the framework laid out by Hall (2008). Our vision is to have a developmental T&E workforce that delivers world-class air, space, and cyberspace T&E services to our customers. To achieve this vision, we must provide T&E results that customers want, at an affordable price. Our workforce is the primary tool we have for providing these T&E results that customers want. A properly trained and motivated workforce with the right blend of technical and customer-service skills will enable us to develop enduring partnerships and relationships with our customer base. Our workforce is also the primary tool we have for determining the best mix of future investments to create and sustain the facilities and equipment needed to provide our T&E services. Our people, facilities, and equipment must also be enabled by the proper policies, organizational structures, and engaged leadership.

Our vision rests on our ability to achieve four goals that are built on a foundation made up of five objectives. The first of these goals is effective executive teams that continuously improve value for the Air Force Material Command enterprise. The second goal is leaders who deliver results by aligning leadership activities to enable a high-performing workforce. The third goal is key position excellence, through which we deliver the best value to our customers. The fourth goal is workforce performance, which is achieved through the right workforce structure, supporting systems, and overall culture to enable great performances.

The five objectives in *Figure 1* create a foundation that enables the achievement of the goals. Objective 1

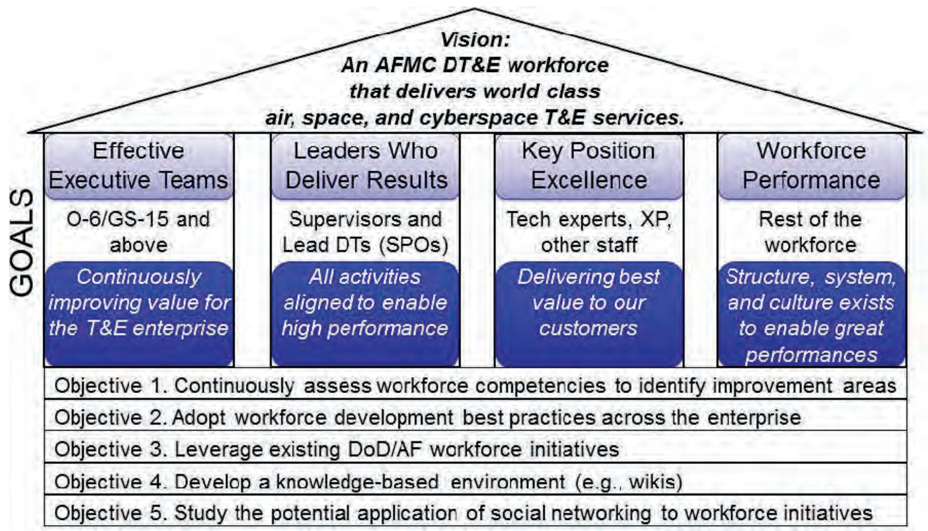

Figure 1. Air Force Test Center Human Capital Strategy.

is to continuously assess workforce competencies to ensure that we have the right level and mix of skills and to identify areas for improvement. Objective 2 is to identify best practices for workforce development and adopt them across the AFTC enterprise. Objective 3 is to leverage existing workforce initatives already in place at both the Air Force and Department of Defense level so we can maximize out available resources and be consistent with higher-level policies. Objective 4 is to develop a knowledge-based environment that enables the rapid sharing and updating of the knowledge required to execute the AFTC mission. Objective 5 is to study social-networking concepts to see if they may have application to improving existing and future workforce initiatives.

The Human Capital Strategy describes how each goal will be achieved by establishing critical success factors and the necessary conditions required to achieve them. Potential metrics for measuring the effectiveness of our workforce are also defined, including such things as investment dollars achieved per employee, customer and stakeholder satisfaction, operation T&E pass rates, and report timeliness. The document also lays out an outline for developing detailed action plans to execute the strategy, with a goal of enabling a high-performing workforce and achieving our vision by December 31, 2015.

Conclusions and the way ahead

Our experiences to date have convinced us that the best hope for the future of the Air Force Test Center is to make investment in the technical competence of its workforce a top priority on par with, if not exceeding, any test-infrastructure improvements or sustainment. As we have faced the never-ending challenge of balancing resources to provide test capabilities to our customers, we have been repeatedly reminded that test cells or test ranges without accompanying expertise to operate them and understand their interactions with systems under test are a hollow capability indeed.

Our efforts taken as a whole appear to be comprehensive enough to be having the intended effect of elevating our technical competence while instituting a culture that fosters and demands excellence. The challenge, of course, in an era of declining budgets is to continuously focus on acquiring, developing, and using a highly competent technical workforce. Air Force leadership must embrace the attitude that resources to support this activity must have nearly the status of being "fenced," and therefore cannot be compromised. So much depends on this level of commitment the future of the Air Force T&E workforce, the success of the acquisition process, and the likelihood of victory on the battlefield by our nation's warfighters. ❑

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References

Best, John T., Edward M. Kraft, and Col. Arthur F. Huber. 2008. Revitalizing the technical excellence at the Arnold Engineering Development Center (AEDC) and beyond. Presented at the U.S. Air Force T&E Days, February 5 7, Los Angeles, California. AIAA Paper 2008-1611.

Department of Defense. 2010. *DoD strategic human capital plan update: The defense acquisition workforce. The defense acquisition workforce improvement strategy*. Washington, D.C.

Gangani, Noordeen, Gary N. McLean, and Richard A. Braden. 2006. A competency-based human resource development strategy. *Performance Improvement Quarterly* 19 (1): 127 140.

Hall, B. W. 2008. *The new human capital strategy*. New York: AMACOM.

Huber, Arthur F., II, Edward M. Kraft, John T. Best, Phillip B. Stich, David A. Eldridge, William B. Baker, and Peter A. Montgomery. 2009. *Growing technical excellence in the AEDC workforce*. Presented at U.S. Air Force T&E Days 2009, February 10 11, Albuquerque, N.M. AIAA Paper 2009-1762.

Lasley-Hunter, Brooke. 2011. *Test and evaluation (T&E) workforce competency assessment report*. Center for Naval Analysis (CNA) report CRM D0025930.A1/Final.

Rodriguez, Donna, R. Patel, A. Bright, D. Gregory, and M. K. Gowing. 2002. Developing competency models to promote integrated human resource practices. *Human Resource Management* 41 (3): 309 324,

U. S. Air Force. 2001. *Concept of operations for scientists and engineers in the United States Air Force*. Washington, D.C.

U. S. Air Force. 2003. *Career development guide for scientists and engineers*. Washington, D.C.

U. S. Air Force. 2011. *Bright horizons: The AF STEM workforce strategic roadmap*. Washington, D.C.

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Elevating the T&E Profession

James M. Gaidry, CAE, BSEE, MBA

Did you happen to notice the "alphabet soup" after my name in the byline? Unless you are involved in the association management profession, chances are that you do not recognize the CAE designation. How about BSEE? I would bet that many of you hold that designation. How about MBA? That designation is probably familiar to most of you as well.

Designations such as these are used in many professions and demonstrate that the individual has the necessary qualifications to competently perform their job. But what do they really mean?

The Certified Association Executive (CAE) is a time-limited professional certification awarded by the American Society of Association Executives (ASAE) to individuals that meet the eligibility requirements and pass the CAE examination. According to the ASAE website,

> *"The Certified Association Executive (CAE) designation is designed to elevate professional standards, enhance individual performance, and identify association professionals who demonstrate the knowledge essential to the practice of association management. Founded in 1960, the CAE program stands as a mark of excellence and has evolved to reflect what it takes to manage an association in today's challenging climate. The CAE program was accredited by the National Commission for Certifying Agencies in 2010."*

Since receiving the CAE credential 3 years ago, I am currently submitting for recertification in order to maintain my certified status. I am required to demonstrate that I have maintained currency in the association management profession via full-time employment in the profession, completing the required amount of continuing education/professional development, and adherence to a code of professional ethics. This type of "professional certification credential" is quite different from many "certificate" programs that are currently available to Test and Evaluation (T&E) Professionals.

I received those other designations decades ago   the BSEE almost 30 and the MBA almost 20   and both were awarded based on my successful completion of a curriculum of study. To be perfectly honest, I would be hard pressed to pass a competency exam for either of those two credentials today, most especially in an exam based on the current electrical engineering curriculum taught at most universities.

With respect to the BSEE it has been many, many years since I have (a) been employed as an electrical engineer or (b) taken any courses or participated in any professional development activities relating to electrical engineering. I doubt many companies would hire me today as an electrical engineer just because I have the BSEE credential. Having that "one and done" certificate in no way indicates that I am as competent today as I was when it was awarded. They would be much more interested in hiring someone who has a designation that demonstrates that they are competent today, not one that shows they were competent 30 years ago!

A professional certification credential, such as the CAE, proves the following.

PROFESSIONAL CERTIFICATION CREDENTIALS, like the CAE, are awarded to individuals who successfully demonstrate that they meet the minimum level of competency in the requisite knowledge, skills, and abilities (KSAs) that have been identified by subject-matter experts (SMEs) in their profession and REQUIRE regular recertification to assess continued competency.
CERTIFICATE PROGRAMS, like a BSEE or MBA, award a "certificate of completion" based on the successful completion of a course of study and/or meeting some minimum requirements and DO NOT require regular recertification to assess continued competency.

1. It is a time-limited recognition and use of the credential's designation in conjunction with their name (e.g., CSE, CPA, or CPM) by an individual after an assessment and verification that they have met predetermined and standardized competency.
2. It confers occupational identity and provides a method for maintaining quality standards of knowledge and performance and stimulating continued self-improvement.
3. It provides differentiation among individuals in the same profession, using standards developed through a consensus-driven process and is based on existing legal and psychometric requirements.

A professional certification credential differs from a "certificate" in that the individual is required to do the following.

1. Maintain their currency, proficiency, and competency in their field through full-time active employment in the profession and completion of relevant continuing education/professional development activities.
2. Submit for recertification every few years in order to maintain their professional certification credential.
3. Adhere to a Professional Code of Ethics (see SIDEBAR 1).

Purpose of professional certification

The purpose of a professional certification credential program for those individuals who practice in disciplines involving the T&E of products and systems is to

- develop and promote professional standards and ethics;

Test and Evaluation Professional Code of Ethics

The International Test and Evaluation Association (ITEA) is dedicated to improving the principles of T&E. ITEA's heritage is built upon the commitment of each member to uncompromised professionalism and pursuit of the highest standards of business and personal conduct. The Code of Ethics sets forth the ethical principles to be observed by members of the Association. Any ITEA Member who violates any provision of the Code of Ethics will be subject to disciplinary action by a peer review panel, which may result in suspension or revocation of their ITEA membership.

ITEA Members shall, in their professional activities, sustain and advance the integrity and honor of the practice of T&E by adherence to this Code of Ethics as expressed in the following articles.

1. We accept assignments that we are qualified to perform and perform at a high level of professional competence. We present our personal qualifications and those of the organizations we represent in an accurate and complete manner so that both our capabilities and our limitations are readily apparent.
2. We use our affiliations with ITEA and other professional associations for purposes in consonance with the stated purposes of each association. We are careful not to inaccurately imply unintended endorsement of our personal actions or opinions by those associations.
3. We strive to reflect personal and professional integrity of our work in T&E.
4. We avoid situations that are a conflict of interest. If a situation could give the appearance of conflict of interest, we avoid it if practical; as a minimum, we provide full disclosure of those apparent conflicts to potentially affected parties.
5. We place a premium on the safety of people and property during T&E. We accurately present adverse conditions and expected consequences, even if such concerns have been waived or are expected to be waived.
6. We ensure that our work in T&E is reported accurately, including the methods of analysis, limitations of scope, references to other work, and conclusions drawn. We attempt to maintain the highest standards of science and engineering in T&E.
7. In publishing the results of our T&E work, we give due and accurate credit to those who have contributed to that work.
8. We accept a responsibility to call attention to possible unethical behavior in a manner appropriate to the situation. We willingly participate in investigations into unethical behavior as concerned members of the T&E community, striving to maintain the highest standards of professionalism.
9. We work to the mutual benefit of ITEA and the T&E community by openly exchanging information and sharing the lessons of study and experience with fellow professionals.

- administer credible competency examinations that provide a direct method of evaluating the knowledge, skills, and abilities (KSAs) required by the T&E professional profile;
- support professional development and education to enhance the KSAs of the current professional; and
- develop emerging KSAs that will be required by the next generation of test professionals.

T&E Professional Certification Credential

In 2013, ITEA will begin offering a professional certification credential that will provide significant benefits to T&E professionals, organizations, and their customers (see SIDEBAR 2). Over 500 T&E subject-matter experts (SMEs) have been involved in the development of this credential. These SMEs T&E executives, managers, supervisors, individual contributors, and technicians have come from a diverse cross-section of the T&E profession, representing industry, government, academia, laboratories, ranges, weapon systems, information technology, transportation, electronic communications, consumer electronics, and more.

Board of Examiners

Overseeing the certification credential's development and ongoing administration is a Board of Examiners (BOE), which is appointed by the ITEA Board of Directors. The BOE has the primary responsibility for developing and maintaining the certification examinations, as well as for working in conjunction with psychometric experts to ensure the development and administration of the certification credentialing program.

Benefits of Professional Certification

Benefits for the T&E professional

1. Provides credibility with an independent validation of their proficiency in T&E.
2. Identifies them as individuals who have demonstrated their professional qualifications and expertise required to meet the elevated standards of T&E performance and competency.
3. Provides recognition throughout the T&E community of their achievement, dedication to advancing the profession, and commitment to maintain their currency in the field.
4. Provides a differentiation from other testers that can assist their career advancement.
5. More opportunities for career and salary advancements.

Benefits for the T&E Profession

1. Helps develop and promote common standards, principles, procedures, processes, and terms for the T&E profession.
2. Elevates the T&E profession by ensuring that test engineers can demonstrate, maintain, and upgrade the skill sets required to meet the elevated standards of T&E performance and competency.
3. Ensures that T&E professionals meet global standards of performance and are held to a "Professional Code of Ethics."

Benefits for T&E Organizations

1. Provides them with a proven credential that helps them identify those individuals who have proven that they have the KSAs necessary to compete and excel in meeting the performance expectations and test specifications.
2. Helps ensure an educated and well-prepared workforce and supports the scientific outreach and education in working to develop the next generation of scientists capable of providing support to the continued development of critical technologies.
3. Provides them with a competitive differentiator by demonstrating their commitment to employing qualified test professionals who possess the competencies to produce at a higher level by working faster, smarter, and more reliably, and therefore better able to provide high quality and cost-effective products and services.

Benefits for Customers

1. Provides their customers with assurances that they are getting high quality and cost-effective products.
2. Helps them identify those organizations that employ testers who have proven they have the KSAs necessary to meet performance expectations and test specifications.

The BOE responsibilities include ensuring that the certification examination does the following:

- represents the requisite KSAs that were identified by T&E SMEs for professional competence;
- represents a valid, reliable, legally defensible, and fair measure of professional competence;
- remains current with any changes in the requisite KSAs that are required for professional competence;
- is independent of any course of study, curriculum, or test book; and
- maintains the integrity of the examination questions.

Working with T&E SMEs and personnel testing, evaluation, and measurement experts, the BOE has developed a Table of Specifications (aka "Exam Blueprint") that represents the knowledge required for proficiency in the field. The Exam Blueprint is reviewed periodically to assure that it continues to be an accurate reflection of that knowledge.

The BOE solicits examination items from individuals based on their expertise in the many diverse facets of the T&E profession. These items shall undergo detailed scrutiny by the BOE for technical accuracy, editorial soundness, and adherence to the specifications before being approved for inclusion in the Examination Item Data Bank of certification exam questions. Each certification-examination test form is constructed from the Examination Item Data Bank based on the percentage of items allocated to each category in the credential's Exam Blueprint.

The BOE ensures the reliability and validity of the certification exam by periodically evaluating the after-test score results from consolidated statistical reports. The pass/fail (cut) score for the certification exams, which also is reviewed periodically, is based upon accepted professional testing standards and determined through methods of statistical sampling and analysis of the after-test score results.

Professional certification credential development

To ensure that the Association offers a valid, reliable, and legally defensible certification credential that is a fair measure of competency, ITEA is following the ISO/ANSI/IEC 17024 global standard for accrediting personnel certification programs. This standard requires adherence to a rigorous internationally recognized process that conforms to the highest accreditation standard and represents the best practices in accreditation.

According to the ANSI website,

> *"The U.S. Government is increasingly relying on ANSI accreditation for verification of quality of certification programs and to control fraud and misuse in certain industries. In view of the proliferation of certification programs and the need to help the consumers make informed decisions, government agencies are looking to ANSI accreditation to differentiate quality programs and improve practices in industry. The ANSI accreditation process is designed to increase the integrity, confidence, and mobility of certified professionals. Some of the government agencies that are closely associated with ANSI accreditation include Food and Drug Administration, Department of Defense, State Regulation, Massachusetts Securities Commission, and the Occupational Safety and Health Administration."*

The development process for this professional certification credential includes the following stages.

1. Job/Task Analysis: A Job/Task Analysis (JTA) is performed to identify the KSAs that a test and evaluation professional ought to have in order to perform in a competent and ethical manner. The JTA contributes to test validity by ensuring that the critical aspects of the job become the domain of content that the test measures.
2. Body of Knowledge: A Body of Knowledge (BOK) is developed that identifies the primary job domains, tasks, and related KSAs that would be required to be judged as a highly competent T&E Professional.
3. Table of Specifications: A table of specifications for the certification examination (aka the "Exam Blueprint") is developed based on validation of the BOK and will be reviewed periodically to assure an accurate reflection of knowledge required for proficiency in the T&E career field (including the number of items on the exam and the appropriate weighting for each task area).
4. Examination Question Data Bank: A Data Bank of Certification Exam questions is created for the subject matter areas/modules that can be randomly used to create additional examinations that measure competency in the blueprint's job performance areas. Best practice is that the Data Bank contains three times as many items as those appearing on the examination. The number of items (or percentage of items) at each cognitive level will be written in accordance with the job/task analysis and the examination specifications. The overall Data Bank will be reevaluated every year to ensure that the questions remain valid and that new ones are added to accommodate technological equipment and tool ad-

vances within the T&E industry. All items will be maintained in a secure automatic banking system.

5. Certification Examination Pilot Test: The initial T&E Professional Certification Examination will be pilot tested, using psychometric analysis to ensure correlation with the required level of competency. A minimum of two written test forms multiple-choice examinations consisting of at least 100 items (exam format of this type are the most cost-efficient and can assess competency at a high level) constructed from the appropriate Data Bank based on the percentage of items allocated to each category in the credential's blueprint will be developed using the examination blueprint. All written test items and the examination will be written in accordance with the standards of the *Standards for Educational and Psychological Testing*, published by the American Psychological Association, Inc., and undergo a careful editorial review for grammatical content, clarity, language, cultural sensitivity (i.e., gender and ethnicity), readability, punctuation, and spelling. The cut score shall be determined through methods of statistical sampling and psychometric analysis based upon accepted professional testing standards, using the most commonly used Angoff method of standard setting in certification examinations.

6. Certification Examination Launch: The industry's first T&E Professional Certification Credential offers year-round certification examinations and uses psychometric analyses to measure the exam's reliability and making adjustments, as required, to maintain the exam's validity.

So far the T&E SMEs have completed the JTA and the BOK, with the Examination Blueprint scheduled to be finalized in October 2012. The development of examination questions for the data bank has begun with monthly Item Writing Workshops being conducted at various sites around the country. Pilot testing of the examination is scheduled to begin in January 2013, with the first examination administered in conjunction with the System-of-Systems Conference, which will be held January 22 25, 2013, in El Paso, Texas. The launch of the certification is scheduled for July 2013.

To those SMEs that have participated in the development of this certification credential, we appreciate your support of the Association, and your personal commitment to the professional excellence embodied in advancing the T&E industry. As always, please let us know what else your Association can be doing to assist your personal and professional success.

For more information on the T&E Professional Certification Credential, or to volunteer as an SME to assist in contributing questions for the examination item data bank, please visit the ITEA Web site at www.itea.org and search for "certification," or contact James Gaidry, CAE, ITEA Executive Director, at jgaidry@itea.org, or 703-631-6220, x204. ❑

James Gaidry, CAE, currently serves as the executive director for the International Test and Evaluation Association (ITEA). Previously, Mr. Gaidry served as the executive director for the Institute of Hazardous Materials Management (IHMM), vice president for the National Concrete Masonry Association (NCMA), and vice president for the Association for Services Management International (AFSMI). Prior to his career in association management, Mr. Gaidry led sales, service, and marketing operations for high technology companies including Dell Computer, Genicom Corporation, Racal-Datacom, and Texas Instruments. Mr. Gaidry previously served in the U.S. Air Force and holds a bachelor's degree in electrical engineering and an MBA in marketing, both from the University of Texas. James is proud to have two daughters currently serving in the U.S. Navy. E-mail: jgaidry@itea.org

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Investing in the Future—Building Tomorrow's Test and Evaluation Workforce Through AFOSR Sponsorship

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The technological superiority of the Air Force depends on the availability of well-trained scientists and engineers. At the Air Force Office of Scientific Research (AFOSR), we recognize that America's research and workforce challenges are best addressed by a diverse application pool from which to select the best and brightest researchers. Each year, approximately 2,000 graduate students and postdoctoral associates work on research grants under the mentorship of outstanding university researchers. The Test and Evaluation Program at the AFOSR has implemented new initiatives aimed at introducing students and faculty to Air Force test centers. One initiative sponsors university research at the test centers that leads to conference presentations and journal publications. A second initiative sponsors workshops that provide an opportunity for universities to become familiar with test centers and funding opportunities. Recent workshops at Eglin and Edwards Air Force Bases assembled university faculty and promoted direct dialogue with test-center personnel.

Key words: Workforce; Air Force; test center.

The Test and Evaluation (T&E) Program at the Air Force Office of Scientific Research (AFOSR) is responsible for basic research activities needed to develop future T&E capabilities at Air Force test centers. Three sponsored-activity components of the program are the Air Force Research Laboratory, university laboratories, and government contractors. None of these components provides a direct path to T&E workforce development, but since the university component sponsors work in the laboratories of research professors, graduate and sometimes undergraduate students are involved in T&E basic research through AFOSR funding. It is presumed that as these students graduate, some portion will remain in the T&E career path and become the cadre of tomorrow's test-center workforce.

The question remains as to the efficacy of this process and whether deliberate program action is warranted to strengthen T&E workforce development. While there have been several studies based on science, technology, engineering, and mathematics (STEM) education data from the National Science Foundation (NSF 2012), their breadth does not consider individual disciplines and the data do not contain sufficient detail for application to T&E workforce development. As part of this workforce development effort, the T&E Program at AFOSR has implemented new initiatives aimed at introducing students and faculty to T&E activities at Air Force test centers. We expect the pool of talented T&E professionals to increase as these students graduate and enter the workforce, and for the test centers to benefit from ready access to specialized courses.

T&E workforce development issues

Ongoing studies published by the National Science Foundation (NSF 2012) clearly show *(Figure 1)* that the science and engineering workforce is growing older. Unfortunately, these data do not include details for what may be occurring within the T&E workforce. The impact of this trend may be more severe for test centers, which are more susceptible to chronic hiring and workforce problems due to their remote locations. Their distance from university learning centers limits some of the professional-development opportunities readily available in urban environments. In addition, there are a scant number of programs offering degrees in T&E or test engineering, which further hinders professional-development opportunities.

Despite this trend, a recent article (Unnikrishnan 2012) characterizes the perceived shortage of engineers as more of a problem of mismatched skills rather than a true lack of engineering personnel. Other work cited in that article even suggests that there is an oversupply of S&E personnel. No evidence has been offered in any of

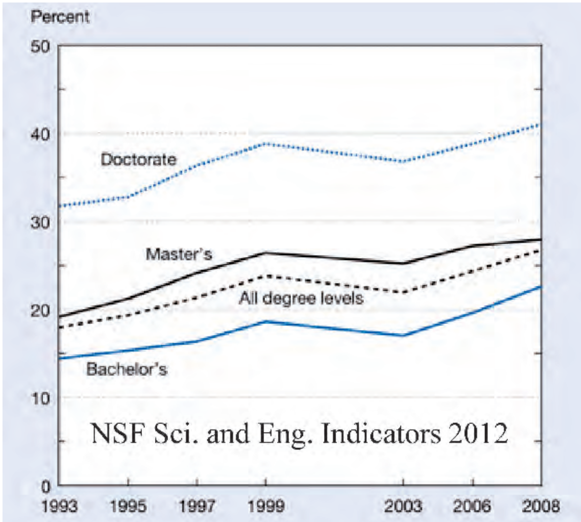

Figure 1. Workers older than age 50 in S&E occupations by highest degree level.

these studies to show that there is an abundance of qualified T&E personnel ready to enter the workforce, so the guiding forces responsible for T&E education, training, and professional development must ensure that these activities are available and appropriate to support the current and future test-center mission.

Current policies

The relevant portion of the Air Force (AF) Science and Technology Plan (AFRL 2011) developed by Dr. Steven H. Walker (deputy assistant secretary of the Air Force for science, technology, and engineering) and Ellen M. Pawlikowski (major general in the United States Air Force and commander of the Air Force Research Laboratory) outlines STEM policies and serves as a foundation for related AFOSR activities:

- Formulate Air Force S&T Program STEM-related personnel requirements in order to maintain a highly competent, diversified, and agile workforce.
- Pursue strategic partnerships and outreach activities with our schools, universities, sister services, professional associations, and other federal agencies.
- Build lasting relationships with the best university undergraduate and graduate students who are working in fields relevant to the Air Force through outreach programs.

The AFOSR's policies are identified in that organization's strategic plan (AFOSR 2009), which identifies the following goals:

- Strategic Goal 1: Identify opportunities for significant scientific advancements and breakthrough research here and abroad.
- Strategic Goal 2: Rapidly bring to bear the right researchers and resources on these opportunities in the interest of fostering revolutionary basic research for Air Force needs.
- Strategic Goal 3: Enable the Air Force to exploit these opportunities at the appropriate time, transitioning revolutionary science to the Department of Defense and industry.

Additionally, the AFOSR T&E Program supports basic research which will build the foundation for future revolutionary capabilities that address the identified needs of the T&E community. While this supporting role is focused on basic research at university and AF laboratories, the direct contact that AFOSR has with research faculty and their students provides opportunities for the T&E Program to influence S&E career-path choices through early exposure to test-center activities. This can be achieved through sponsorship of basic research activities in T&E that increase the knowledge, skills, and abilities of faculty and students in those areas most needed by the centers. This may include the development of specific courses that enhance the ability of students to engage in direct research activities at the centers. There is no single process for expanding the T&E workforce development pipeline, and AFOSR can only assume responsibility for the AF basic research component, but investment in several broad areas described in this article and appropriate partnerships with other Defense Department and government organizations will have a net positive cumulative effect over time.

This article does not address USAjobs and Air Force Personnel Center policies other than to note that they do not appear to be effective in addressing the personnel needs of the AF T&E centers.

Hypersonics revitalization efforts

The Hypersonics Workforce Revitalization project funded by the AFOSR T&E Program is with the Aerospace Engineering Department at the University of Maryland, College Park. This project addresses the problem of the aging hypersonics workforce *(Figure 2)* by building upon the relationship that the department maintains with Tunnel 9, the Arnold Engineering Development Center's hypersonic test facility located in White Oak, Maryland. Because this facility is located a short distance from the university campus, it allows for easy access by faculty and students. Facility buildings also have a surplus of laboratory and office space, allowing collocation of university and government S&E personnel. These unique circumstances put students in direct and frequent contact with the hypersonics T&E workforce at Tunnel 9 and provide

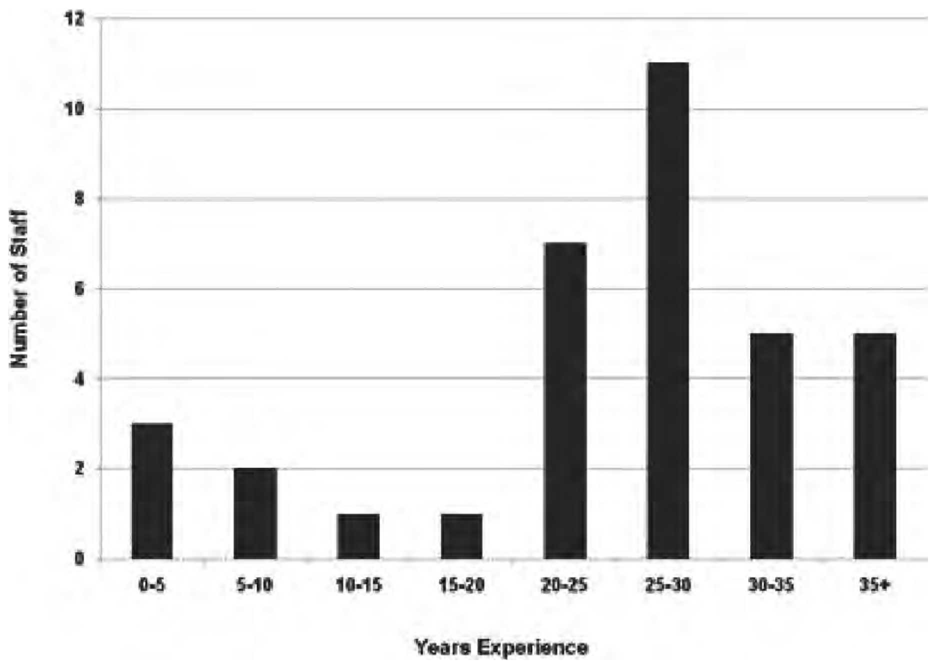

Figure 2. Hypersonic Tunnel 9 workforce experience.

continuous opportunity for technical discussion and mentoring. Additional support funds are provided by the AFOSR Hypersonics Program, and Office of the Secretary of Defense (OSD) T&E/S&T Program High Speed Systems Test activity. Together these sources provide funding for more than three research professors and 10 12 students. These investments benefit the T&E workforce by

- bringing students into T&E facilities by program design,
- coordinating collaboration of faculty, students, and mentors by establishing a direct link between T&E facilities and academic partners,
- enabling research of S&T problems with direct relevance to T&E applications,
- consolidating research priorities throughout the community while considering their relevance to T&E needs,
- educating and training students on T&E issues,
- providing a collaborative work environment at T&E facilities,
- producing new qualified engineers with adequate T&E experience,
- developing a highly skilled future T&E work-force,
- preparing for the impending transition of the aging T&E workforce while maintaining T&E expertise and experience-based reliabilities, and
- providing a pilot case in the Hypersonic Center of Testing Excellence.

Figure 3. Tunnel 9 students.

Professor Mark Lewis, the principal investigator for this T&E Program effort, has noted that the single most important aspect for success has been the long-term commitment provided by funding agencies: AFOSR for FY11-17 and OSD T&E/S&T for FY12-16. These commitments allow the university to accept graduate students *(Figure 3)* for research activities specific to Tunnel 9, thus expanding the flow of T&E career-path students in the hypersonics workforce pipeline and increasing their knowledge, skills, and abilities through direct, hands-on activities.

Air Force Institute of Technology

The Air Force Institute of Technology (AFIT) is the Air Force's graduate school of engineering and

Figure 4. (a) Air Force Flight Test Center (AFFTC) workshop; (b) site visit to the Global Hawk hangar.

management as well as its institution for continuing professional technical education (AFIT 2012), AFIT training is limited to current service and civilian-workforce members, so its role is to enhance professional workforce development. Partnerships between AFOSR, AFIT, and test centers serve to increase knowledge levels through formal programs of study, increase skill levels through mentored research activities with AFIT professors, and increase abilities and critical thinking through original research. The deputy assistant secretary of defense (developmental T&E) established the Scientific Test and Analysis Techniques Center of Excellence at AFIT on April 13, 2012. AFIT also offers a T&E Graduate Certificate Program through a regimen of graduate courses.

Although many of these AFIT-sponsored activities are stand-alone or fall under the definition of applied research, some are basic research and are funded by AFOSR. Current efforts funded by the T&E Program include a Phase 2 Small Business Technology Transfer award with AFIT as the university partner and a Laboratory Research Independent Research (LRIR) award to the Air Force Research Laboratory where AFIT is a research partner. In each of these cases, AFIT graduate students are funded to support the research activities. AFOSR can also provide core money to AFIT through the grant-award process, and the T&E Program hopes to increase its sponsorship of basic research opportunities for students from the centers through this funding process.

Workshops

The AFOSR T&E Program sponsored Research Opportunities Workshops near Edwards and Eglin Air Force Bases during the summer of 2012 (AFOSR 2012). Held at off-site locations, these workshops were organized to develop closer ties between universities, research institutions, and government organizations. Although the effort was focused on the AFFTC and 46th Test Wing, the workshop agenda was designed to include broad interests of the federal government, with representatives from the Air Force Research Laboratory, the Office of the Secretary of Defense Test Resource Management Center, the Air Force Institute of Technology, and NASA attending. Outside attendees included more than 60 research professors from 50 universities, deans and vice presidents of research, and a scattering of students, research institutions, and businesses *(Figures 4* and *5)*. The program was organized with concurrent sessions that allowed short meetings between professors and the technical leadership. It also included presentations by the AF Personnel Office, since attending professors are in close contact with university S&E students who may be seeking employment after graduation. The first two days of each workshop were devoted to government and university presentations, while day three was spent on site and facility visits.

These workshops saw good participation on the part of both university research professors and government S&T leadership. The program contained a balance of university and government speakers, and the consensus was that everyone benefited from participation. The following guidelines were given for university presentations:

> *Current plans are to allow 5 8 minutes for each speaker. The audience will be primarily interested in your institution, department, and research interests. Please refrain from providing details on any research activities, as the audience will be diverse and few, if any, will want to see more than a single summary chart.*

These guidelines were followed and seemed to be effective. The time allocated for university presentations was sufficient, and putting all speakers from a single institution in succession allowed the first speaker to talk about their university without undue repetition by the others.

Figure 5. (a) 46th Test Wing workshop; (b) site visit to the McKinley Climactic Laboratory.

Concurrent "meet the leaders" sessions were held, where attendees could schedule 10- to 15-minute meetings with government presenters and leaders. These sessions had high demand, with a total of about 30 meetings requested with the six participating leaders at Edwards and more than 50 meetings with the 12 leaders at Eglin.

The presentation by human resources was of high interest to the university faculty. Web site links and tips on searching for technical openings were provided along with information on the hiring process. Local points of contact within the AF personnel system were provided. Faculty were given electronic copies of this material and asked to distribute it to students, departments, and administrators at their institutions.

Future plans

The Hypersonic Workforce Revitalization effort has been successful at the University of Maryland, and some attributes in this approach may be broadly applicable to similar efforts at different Air Force Materiel Command (AFMC) test centers. According to the principal investigator, long-term funding commitments on the part of AFOSR and Test Resource Management Center are critical factors in attracting the best students, because that part of the pipeline requires a stable source of program funds. From the perspective of AFOSR university grants, broadly defined research programs that allow flexibility for students to pursue their own research interests are necessary if the goal is to expand the T&E student pipeline as much as possible with a manageable number of grant awards. Funded activities could also include cirriculum development to provide relevant T&E courses to students.

There are significant challenges in adapting this model to other locations, however. Physical proximity of the test facility and university center is not realized at most other test-center locations, and a solution to the logistical problem of faculty and student access to test facilities for extended periods must be found. On-site faculty mentoring need not be continuous, but any plan that assumes that test-center personnel will provide all mentoring as required does not account for test schedules and other commitments of center personnel. Successful extension of this model will likely require an off-site satellite facility that can accommodate some degree of university office and classroom activity.

One approach being considered is to provide a special distinction to faculty and students engaged in sponsored T&E research activities and thereby enable research institutions to attract AFOSR T&E research fellows and scholars, with

- senior fellows to provide leadership;
- fellows and scholars to conduct on-site Research at the AFMC test centers;
- fellows to mentor, advise, and develop associate fellows and scholars; and

Such designation would allow the necessary academic freedom for research pursuits but also place and identify T&E scholars at an early stage in their career development.

Summary

We have looked at some of the problems associated with T&E workforce development and identified various way in which the AFOSR T&E Program might help to address them. The resources available through AFOSR are determined by congressional authorization and limited primarily to university grants in support of basic research. Workforce development encompasses two main components: one that focuses on bringing new S&E personnel into the T&E workforce and another that strives to advance the professional development of the existing T&E workforce through additional training, coursework, certification, and advanced-degree awards.

Various organizations are attending to the second component through efforts sponsored by the International Test and Evaluation Association, the Air Force Institute of Technology, and the Defense Acquisition University, to name a few. Neither the International Test and Evaluation Association nor the Defense Acquisition University appear to be suitable partners for the AFOSR T&E effort. Current efforts of the International Test and Evaluation Association are more closely aligned with the Defense Department's STEM program in its outreach at the high-school and college-entry level. The Defense Acquisition University's effort is acquisition oriented and suitable for training personnel without degrees in some basic aspects of engineering management, but it lacks the academic rigor of a college-level engineering curriculum. It is possible for AFOSR to strengthen AFIT's T&E research and training through awards funding basic research when research activities occur at the centers or are directed toward identified test-center needs. Providing posthire career development and advanced-degree opportunities increases knowledge and skill levels and improves retention.

The first component of workforce development increasing the number of students who elect to pursue T&E as a career path is the one where AFOSR investment is likely to have the largest effect. We have described a sponsored effort at the University of Maryland aimed at revitalizing the hypersonics workforce and discussed how this type of research activity might be adapted to other centers. Consideration is being given to T&E Program basic-research grant awards that create a cadre of young engineers marked for a T&E career path by working as T&E scholars for university T&E fellows. Workshops were held with the AFFTC and 46th Test Wing to promote dialogue with university faculty along these lines and to strengthen the ties between university researchers, their students, and center S&E personnel. The existing pipeline for identifying qualified S&E graduates for hire at the centers relies on USAjobs and the Air Force Personnel Center to identify and filter candidates for entry to the AF T&E workforce. Appropriate allocation of AFOSR T&E Program funds can serve to influence student choices toward a T&E career path and thereby expand the pipeline of candidates. Promoting faculty and students who serve the T&E profession will likewise create an academic environment conducive to increasing T&E-specific knowledge, skills, and abilities within the university system.

Current and planned investments aimed at expanding different portions of the T&E workforce and workforce-development pipelines *(Figure 6)* are expected to have a long-term cumulative effect that benefits the profession and the ability of AF test centers to carry out their mission. ❑

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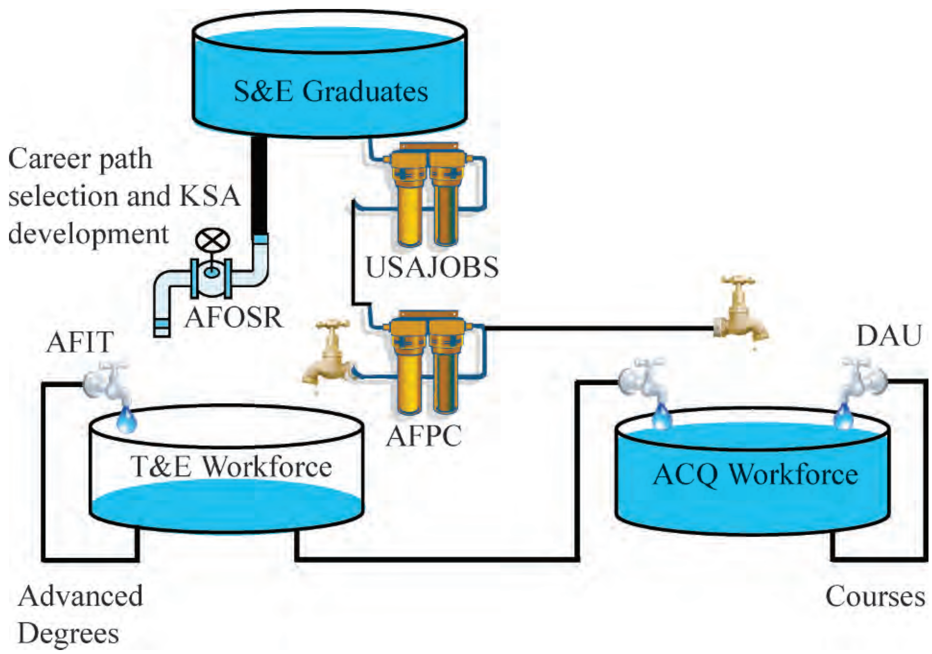

Figure 6. T&E workforce and workforce-development pipelines.

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References

Air Force Institue of Technology (AFIT). 2012. http://www.afit.edu/about.cfm

Air Force Office of Scientific Research (AFOSR). 2009. http://www.scribd.com/doc/50868798/2009-AFOSR-Strategic-Plan

Air Force Office of Scientific Research (AFOSR). 2012. https://community.apan.org/afosr/w/researchareas/7582.test-and-evaluation-research-opportunities-workshop-26-28-june-2012-edwards-afb-ca.aspx

Air Force Research Laboratory (AFRL). 2011. www.dtic.mil/dtic/tr/fulltext/u2/a550600.pdf

National Science Foundation (NSF). 2012. "Science and Engineering Indicators 2012." http://www.nsf.gov/statistics/seind12/

Unnikrishnan, Madhu, "What Shortage of Engineers?", Aviation Week and Space technology, 9 April 2012.

Air Force Research Laboratory (AFRL). 2011. www.dtic.mil/dtic/tr/fulltext/u2/a550600.pdf

Air Force Office of Scientific Research (AFOSR). 2009. http://www.scribd.com/doc/50868798/2009-AFOSR-Strategic-Plan

Air Force Office of Scientific Research (AFOSR). 2012. https://community.apan.org/afosr/w/researchareas/7582.test-and-evaluation-research-opportunities-workshop-26-28-june-2012-edwards-afb-ca.aspx

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Preparing the T&E Workforce for the Speed of Need

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Systems Testing Excellence Program (STEP)

Given the goal of testing at the speed of need which requires agility, flexibility, and accelerated testing by the test-and-evaluation (T&E) workforce a critical enabling factor is the advancement of capabilities of key T&E organizations. The goal is to shift from a strong focus on managing people and projects to one on strategically measuring and maintaining a bundle of organizational technical skills and competencies that ensure future success. It is a modern strategic imperative that an organization fully understand its pre-existing skills-and-competencies profile and develop consensus around a targeted skills-and-competencies profile for future success. A deep appreciation of the gaps between these two profiles must then systematically drive all training, hiring, work allocation, contracting, and related human-resource management decisions over an extended period of time.

As the Department of Defense moves away from system-centric development and relies more heavily on software-driven services offered at the enterprise level, both the speed and accuracy at which these services are delivered become key value factors for the users. Recognizing this evolution in need is paramount to developing the workforce; such a recognition led the Defense Information Systems Agency (DISA) and the Joint Interoperability Test Command (JITC) to conduct an internal review of skills and competencies as they relate to T&E. This effort would lay the foundation for additional work required at the management and supervisory levels of the organizations.

Approach

To accomplish this effort, DISA/JITC T&E leadership engaged the FedEx Institute of Technology's Systems Testing Excellence Program (STEP) at the University of Memphis. In line with their work in supporting private industry, the STEP team was contracted to complete a competency assessment and skills-gap analysis. They established a phased approach:

- **Phase 1: Conduct preliminary research.** Conduct site surveys, hold individual and group meetings, and administer employee questionnaires to fully understand the mission, scope, and context of the work being performed by the T&E workforce.
- **Phase 2: Survey the workforce.** Develop, execute, and analyze the results of a customized skills-and-competencies (S&C) survey.
- **Phase 3: Postsurvey analysis.** Analyze survey data and provide a comparison of current skills inventory against the organizationally submitted TO-BE S&C profile, with recommend courses of action.

Phase 1 (preliminary research) included research into the roles, responsibilities, skills, and competencies of the DISA/JITC T&E workforce. This effort included the iterative development of skills-and-competencies analysis categories for use in a customized online questionnaire, through the use of data collected using a paper-based questionnaire from identified workforce members. The primary goal was to develop the categories for an online survey to provide an AS-IS competency portfolio to serve as the basis for a customized training program for skills improvement based on the development of a TO-BE skills-and-competency portfolio for future success. While the team projected a TO-BE profile at the data-analysis stage, this must ultimately be defined at both organizational and suborganizational levels and must be clearly aligned with the roles and responsibilities of the unit whether at the division, portfolio, branch, or team level.

During Phase 2 (survey), the STEP team used data collected during the site visits to narrow the scope and customize the questions covering the skills and competencies that pertain directly to the DISA/JITC mission space. While these questions were applicable to the organization as a whole, there were cases where specific survey items did not apply to specific subelements (e.g., security-related questions outside of the core information-assurance team). This presents a small challenge in looking at the aggregate data. Those who are not familiar with the organizational construct and skills aligned with each internal unit will attempt to apply the aggregate profile to the smaller units. However, the level of detail provided by the survey team enabled drill-down capability and allowed DISA/JITC to not only create the required lower-level TO-BE profiles but also generate the associated AS-IS profiles for comparison a key element in the postsurvey analysis.

During Phase 3 (postsurvey analysis), the STEP team conducted a detailed examination of the data collected providing organizational leadership with a snapshot of overall skills inventories and, more importantly, information on what attributes may be associated with higher skill and competency levels. Determination of these associated data points provided the organization with a list of key elements to look for during the hiring process. Some of the findings from the DISA/JITC survey not directly associated with the skills-profile target include the following:

- Defense Acquisition Workforce Improvement Act T&E certification (in its current form), while adding some marginal value, is not addressing the S&C gaps for T&E of information-technology systems.
- Having a degree makes a difference in T&E S&C regardless of the degree focus area.
- Those with engineering qualifications possess a skills profile similar to those with information-technology, information-systems, and information-assurance qualifications (this suggests similar duty assignments).
- Workers with more than 15 years of experience may be stagnating, with respect to S&C.

While these three elements were somewhat unexpected, the following elements were not:

- The more senior the employee, the higher the S&C level.
- Security-related skills are lacking in all but information-assurance employees.
- T&E management employees possess a more rounded S&C profile.
- All groups share the same knowledge gaps.

While this article uses the detailed results for the DISA/JITC T&E workforce members as a framework for the discussion, detailed data presented throughout are generalized and not directly indicative of details of the individual surveys. *Figure 1* demonstrates the key elements of the team's analysis.

The overall profile suggests that the organization is strong in skills and competencies related to managing test resources and relationships, such as project management and other professional competencies. The workforce also is reasonably knowledgeable about the big picture of T&E, including test-cycle activities, as well as about T&E documentation, evaluation criteria, and configuration management. Targeted focus areas include such topics as core testing techniques, test-coverage factors, and technical areas focusing on test automation, processes, operational analysis, agile, and network testing.

This analysis allows an organization to target scarce training dollars on specific needs. When applied down to the branch or team level, it also allows managers to map required skills to specific mission areas, such as network testing, information assurance, or software-application testing. When used properly, this knowledge can be applied to changes in position descriptions, individual development plans, and job announcements. Ultimately, the use of data collected during the S&C survey and skills-gap analysis process provides information that DISA/JITC management can use to raise the overall S&C benchmark through training programs targeted at specific skills and competencies, hiring of a capable workforce in critical areas, and skills-based work rebalancing. Through improvement of the performance of the DISA/JITC T&E workforce, its professionals will be better equipped with the skills and competencies required to conduct timely, effective, and efficient actions.

Lastly, efforts undertaken as part of this focus area will be incorporated into the organization's annual skills survey, whereby employees self-assess their abilities, supervisors conduct an independent assessment, and the two results are compared and discussed between supervisor and employee. The outcome of this session includes a list of skills gaps on which the employees can focus their efforts. The overall benefit to the organization is a recurring review process that allows employees to consistently measure their success and managers to adjust their staffing profile to meet the T&E needs of the department. ❑

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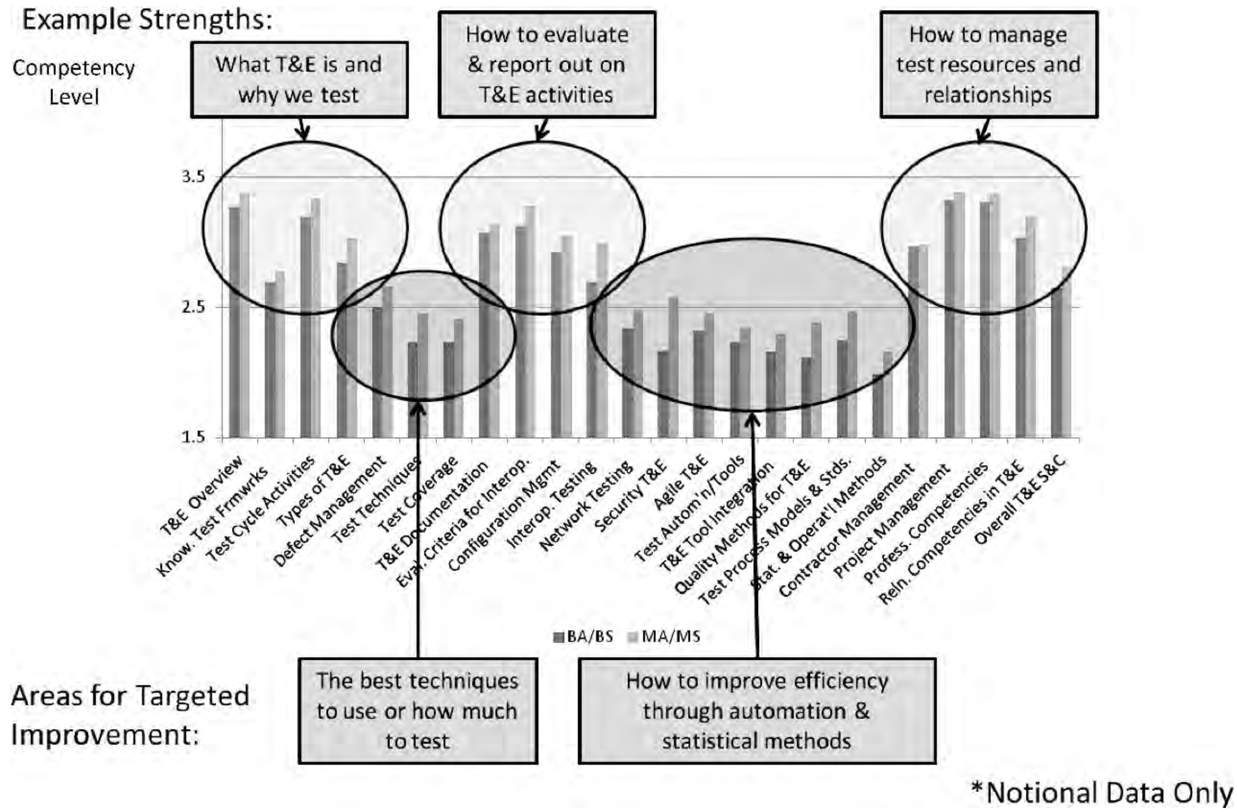

Dr. Robin Poston is a systems-testing research fellow and associate director of the System Testing Excellence Program for the FedEx Institute of Technology at the University of Memphis, and she is an associate professor of management information systems at the Fogelman College of Business and Economics at the University of Memphis. Dr. Poston is a recipient of the Memphis Alumni Association Distinguished Teaching Award and an associate editor for the highly ranked Decision Sciences Journal *and* European Journal of Information Systems. *She also serves as the organizing chair for the International Research Workshop on Advances and Innovations in Software Testing. Dr. Poston's current research focuses on understanding the alignment within the IT unit among developers and testers, client managers' responsibilities and governance especially in mitigating vendor silence and managing vendors in outsourcing of software-testing projects and online security threats. Dr. Poston has over 15 years of experience in the information-systems field, working for KPMG Consulting, Educational Computer Corporation, Meta Group Research, and Convergys, as well as consulting with several* Fortune *500 companies and government agencies. Today, she works with organizations such as the Defense Information Systems Agency of the Department of Defense, FedEx Corporation, First Tennessee Bank, St. Jude/ALSAC, Pinnacle Airlines, and others to conduct projects and educational programs. Dr. Poston received her bachelor's degree in computer science from the University of Pennsylvania (1987), master's degree in accounting from the University of Central Florida (1992), and doctorate in management information systems from Michigan State University (2003).*

Dr. Jasbir Dhaliwal is a professor of information systems and serves as associate dean at the University of Memphis. He is also the founding director of the Systems Testing Excellence Program (STEP) at the university's FedEx Institute of Technology. STEP represents the largest interdisciplinary group of academic researchers working to advance both the theoretical science of software testing and empirically validated test-and-evaluation best practices in industry. It also serves as the research and training partner of the Global Testing Center of Excellence at the FedEx Corporation. Starting with his early work in the late 1980s on the validation of knowledge-based systems in artificial intelligence, Dr. Dhaliwal has published more than 60 research articles and made numerous keynote and other presentations to industry audiences all over the world. His recent ideas about software testing have been presented at STAR-EAST and the International Conference on Software Testing, while his latest research on systems testing is being published in the European Journal of Information Systems, *the* Journal of Strategic Information Systems, IEEE Software, *and the* Journal of Database Management. *He is also active as an angel investor in technology start-ups from his home in Germantown, Tennessee.*

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Preparing Today's Department of Defense Test-and-Evaluation Professionals for Tomorrow's Challenges

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The greatest asset we have is our people. Divided into five sections, this article examines the many facets of preparing today's Department of Defense test-and-evaluation (T&E) professionals for tomorrow's challenges: (1) the T&E workforce, (2) T&E competency development, (3) T&E certification standards, (4) T&E education and training, and (5) taking the DoD T&E workforce to the next level.

There has never been a greater need than there is now for professionals in test and evaluation (T&E) to strive for increased knowledge within their chosen profession to keep pace with our increasingly complex environment. We are living in a world in which technology is changing by an order of magnitude every 10 years. Coupled with the Department of Defense's (DoD) and industry's desire to deliver highly complex products and systems of systems at the very tip of technology development to the customer more efficiently, this environment creates a challenge for our T&E professionals that stresses their ability to keep current.

There are many challenges confronting our T&E workforce today. We understand that T&E is conducted throughout the life cycle, from program initiation through sustainment, to reduce design and programmatic risks. That sounds easy, right? Now let's add to this challenge that the key T&E technical requirements need to be traceable to objectives during preparation of the T&E master plan and the T&E strategy needs to be effective, efficient, and defensible. As chief developmental testers, our ultimate requirement is to provide critical information for use in the acquisition decision process. This information may include assessment in areas such as the following:

- specification compliance;
- capabilities, limitations, and deficiencies;
- system safety;
- compatibility with legacy systems;
- certification and accreditation of information assurance;
- certification of joint interoperability;
- characterization of system functionality with information for cost, performance, and schedule trade-offs;
- documentation of the achievement of contractual technical performance; and
- verification of incremental improvements and system corrective actions.

To meet these important challenges, the DoD T&E workforce must be prepared and confident in its abilities. This preparation, leading to increased professional capability, is accomplished through numerous education and training opportunities. These opportunities should be appropriately sequenced and available throughout the careers of workforce members.

Description of the T&E workforce

The T&E acquisition workforce is made up of civilian and Service members from each of the military departments Army, Navy and Air Force as well as civilian members of the DoD Fourth Estate, which includes defense agencies such as the Missile Defense Agency and Defense Information Systems Agency. *Table 1* shows the current numbers of T&E workforce positions under the Defense Acquisition Workforce Improvement Act.

Table 1. T&E acquisition workforce positions as of the second quarter, fiscal year 2012 (source: AT&L Datamart)

	Civilian	Military	Total
Army	2,181	46	2,227
Navy	2,570	482	3,052
Air Force	1,675	1,322	2,997
Fourth estate*	346		346
Total	6,772	1,850	8,622

*Military positions assigned to fourth estate defense agencies are tracked by Service.

The T&E workforce is made up of engineers, mathematicians, physicists, chemists, biologists, etc. During their careers, T&E professionals may hold a variety of billets such as the following:

- chief developmental tester,
- chair, T&E working-level integrated product team,
- assistant program executive officer for T&E,
- assistant program manager for T&E,
- chief test engineer,
- chief test pilot,
- test director or manager,
- test engineer,
- acquisition T&E department head,
- T&E department head,
- chief test officer,
- test officer,
- lead experimentation engineer,
- T&E executive, or
- lead test engineer.

Typical T&E activities include the following:

- serving as chief developmental tester for a major defense acquisition program or major automated information system;
- serving as the chair of a T&E working-level integrated product team or as a member representing the materiel developer, tester, or system evaluator;
- analyzing requirements or capabilities documents to determine testability and measurability;
- planning, organizing, managing, or conducting test or evaluation associated with equipment or materiel throughout all acquisition phases;
- determining scope, infrastructure, resources, and data-sample size to ensure that system requirements are adequately demonstrated; analyzing, assessing, and evaluating test data or results; and preparing reports of system performance and T&E findings;
- developing T&E processes and modifying, adapting, tailoring, or extending standard T&E guides, precedents, criteria, methods, and techniques to include design of experiments, modeling and simulation, and information-assurance T&E and certification;
- designing and using existing or new test equipment, procedures, and approaches;
- writing, editing, and staffing a T&E strategy or T&E master plan, as well as system-level or individual-element test plans;
- conducting developmental T&E (DT&E), supporting operational tests, evaluating or analyzing test results or test data, and preparing and presenting evaluation or assessment results; and
- categorizing test data, equipment, materiel, or system deficiencies and certifying readiness for operational test and evaluation.

A key member of the T&E workforce is the chief developmental tester required by the National Defense Authorization Act for fiscal year 2012. The chief developmental tester is a part of the program office and is responsible for the following:

- coordinating the planning, management, and oversight of all DT&E activities for the program;
- maintaining insight into contractor activities and overseeing the T&E activities of other participating government activities; and
- helping program managers make technically informed, objective judgments about contractor DT&E results.

T&E competency development

In fiscal year 2008, the T&E Functional Integrated Product Team (FIPT) formed a group of subject-matter experts to develop the T&E competency model. The subject-matter experts defined the seven units of competency with 25 competencies and 66 competency elements. Completed during 2011, the T&E workforce survey analysis of the results was presented to the T&E FIPT. Based on the results a review of the competencies against the Defense Acquisition University (DAU) curriculum, the competencies were updated by the T&E FIPT with additional elements being added, bringing the total competency elements to 69. *Table 2* shows the high-level competencies.

T&E certification standards

The Defense Acquisition Workforce Improvement Act delineated the establishment and management of the DoD acquisition workforce. *Table 3* depicts the 15 acquisition career fields, with T&E listed as the sixth largest career field (6 percent of the acquisition workforce).

Table 2. T&E competency model

Unit of competence	Competencies
Planning	**(1)** Risk identification
	(2) Capabilities assessment
	(3) Program T&E strategy development
	(4) Test cost estimating
Preparation	**(5)** Coordination of T&E activities and events
	(6) Test readiness
Test execution	**(7)** Risk management
	(8) Test control management
	(9) Data management
Analysis	**(10)** Data verification and validation
	(11) Data reduction and assimilation
Evaluation	**(12)** Determination of test adequacy
	(13) Validation of test results
	(14) Evaluative conclusions
Reporting	**(15)** Technical reviews
	(16) Lessons learned
	(17) Documentation
Professionalism	**(18)** Customer service
	(19) External awareness
	(20) Flexibility
	(21) Communication
	(22) Technical credibility
	(23) Critical thinking
	(24) Professional ethics
	(25) Leadership and management

Certification within the T&E career field requires (a) a technical degree (bachelor's or graduate degree from an accredited university), (b) at least 2 years of appropriate work experience in the field, and (c) successful completion of required professional courses. The courses are established by the T&E functional leader, the deputy assistant secretary of defense for developmental test and evaluation (DASD(DT&E)). The DASD(DT&E) and staff work closely with the military Services, defense agencies, and DAU through the T&E FIPT to determine the required set of courses and experience for each level of certification. Most of these courses are offered by DAU, but Service-equivalent courses are acceptable substitutes. These courses can be formal in-residence (classroom) courses, computer-based continuous learning modules, or online Web-based courses. The levels of certification are as follows:

Table 3. Defense acquisition career fields

Acquisition career field	Positions
Systems Planning, Research, Development, and Engineering – Systems Engineering	39,071
Contracting	30,271
Life Cycle Logistics	17,218
Program Management	15,840
Production, Quality, and Manufacturing	9,313
Test and Evaluation	**8,622**
Facilities Engineering	7,329
Business – Financial Management	6,864
Information Technology	5,645
Auditing	4,273
Systems Planning, Research, Development, and Engineering – Science and Technology Manager	3,206
Purchasing	1,274
Business – Cost Estimating	1,271
Systems Planning, Research, Development, and Engineering – Program Systems Engineer	482
Industrial/Contract Property Management	465

- Level I entry level,
- Level II journeyman level, and
- Level III senior or executive level.

DAU offers three designated T&E courses, with one course specifically required for each certification level. Prerequisite courses must also be completed. The three designated T&E courses are as follows:

- Level I: TST 102, Fundamentals of Test and Evaluation, is an online Web-based course that takes about 6 to 8 weeks to complete. This course provides the basic tenets of T&E and introduces the DoD T&E organizational structures and oversight offices within the Office of the Secretary of Defense. Service T&E organizations and infrastructure are also discussed. TST 102 has 17 lessons, with an exam at the conclusion of each. Also, two homework assignments must be submitted and graded. The first assignment covers test planning, and the second covers data analysis and test reporting.
- Level II: TST 203, Intermediate Test and Evaluation, is currently a 1-week resident course. This course is offered at DAU regional sites. TST 203 closely examines the requirements process and the T&E documents required for management of a program's engineering development throughout the life cycle. The course covers modules on a variety of subjects, such as current events in T&E, reliability, T&E master plan, test requirements, test planning, test execution, data analysis and evaluation, test reporting, test ranges and resources, statistical methods (design of experiments), and ethics. TST 203 has daily work-group exercises or case studies and two written exams (midweek and final). Plans are under way to increase the scope of TST 203 in fiscal year 2013 and add 1 week to the course in fiscal year 2014. The intent is to provide more in-depth coverage of T&E topics and a greater opportunity for students to participate in practical applications, such as case studies, research projects, or student briefings, and lessons learned.

Table 4. T&E Level I core certification standards

Acquisition Training	• **ACQ 101** Fundamentals of Systems Acquisition Management
Functional Training	• **CLE 023** Modeling and Simulation for Test and Evaluation • **CLE 025** Information Assurance (IA) • **CLE 035** DTEPI Introduction to Probability and Statistics • **SYS 101** Fundamentals of Systems Planning, Research, Development, and Engineering • **TST 102** Fundamentals of Test and Evaluation
Education	• Baccalaureate or graduate degree in a technical or scientific field such as engineering, physics, chemistry, biology, mathematics, operations research, engineering management, or computer science
Experience	• 1 year of experience in test and evaluation

- Level III: TST 303, Advanced Test and Evaluation, is a 1-week senior-level resident course. This course covers T&E from a management level with emphasis on critical thinking and higher-learning proficiency. Case-study methods and student presentations are used for evaluation. Executive-level guest speakers from the Office of the Secretary of Defense and the Components (military services, DoD agencies, and DoD organizations) present examples of the highest levels of decision making.

Table 4 shows the requirements for Level I certification and the flow of courses. DAU provides the basic certification courses, but certification is managed by each Component's defense acquisition career manager, who acts as the certification agent for that Component's members. The remaining certification requirements can be found at the DAU website.

Opportunities for T&E education and training

In addition to the three T&E courses described in the previous section, there are other opportunities for education and training. Each certified member of the acquisition workforce must maintain professional competency. The minimum requirement for training and education is 80 hours within the last 24 months. After completing TST 303, there are no additional T&E courses to take at the level of the Office of the Secretary of Defense; however, DAU does offer many continuous learning modules with associated academic credit that can count toward the 80-hour requirement. Component T&E training courses and college-level courses related to testing (such as statistical analysis, program management, engineering management, logistics, or budgeting) can count toward the 80-hour requirement.

In addition, many associations such as the International Test and Evaluation Association, National Defense Industrial Association, and National Contract Management Association provide professional activities applicable to the T&E career field. These types of organizations also sponsor seminars, workshops, and conferences to support career development.

Taking the DoD T&E workforce to the next level

Based on the increasing complexity of systems being developed, the DASD(DT&E), in coordination with DAU, recommended revision of the core education requirements to advance our technical proficiency within the T&E profession. Among those initiatives are the following:

- T&E education requirements: Beginning October 1, 2012, the T&E career field requires a baccalaureate or graduate degree in a technical or scientific field such as engineering, physics, chemistry, biology, mathematics, operations research, engineering management, or computer science. The rationale for the change is the increasing complexity of systems and the need to develop more rigorous, scientific, and statistically based T&E design and methodology. The technical or scientific degree will provide the foundation necessary for T&E professionals.
- DAU T&E curriculum update: The DAU T&E curriculum is being revised to include increased rigor within the courses, increased student application through practical-application exercises, and additional critical thinking within student exercises. The intent is to provide a robust training curriculum that takes the T&E professional from entry level to senior level as shown in *Figure 1*.

The DASD(DT&E) has a roadmap to assist in T&E workforce development through improvement blocks each year, culminating in fiscal year 2015. The goal is to develop T&E professionals capable of performing their critical roles throughout the acquisition life cycle. *Figure 2* depicts the DASD(DT&E) roadmap.

Conclusion

Today's T&E professionals make up the sixth largest career field in the DoD acquisition community and will continue to have a major impact on weapon-system assessment. Today's T&E arena has become increasingly more complex and challenging. It is

Entry Level
Laying the foundation
Providing the nuts and bolts of T&E

Journeyman Level
Hands-on application and exercises
Implementation and execution

Senior Level
Critical Thinking
Higher level of proficiency

Figure 1. T&E progression from entry through senior level.

imperative that T&E professionals of today leverage every opportunity to maintain and increase their intellectual capital within the T&E profession.

T&E professionals should maintain professional standards and growth throughout their career by taking advantage of available educational and training opportunities. This concept will maximize the effectiveness of the T&E workforce while ensuring the necessary growth to keep up with advancing technologies. ❑

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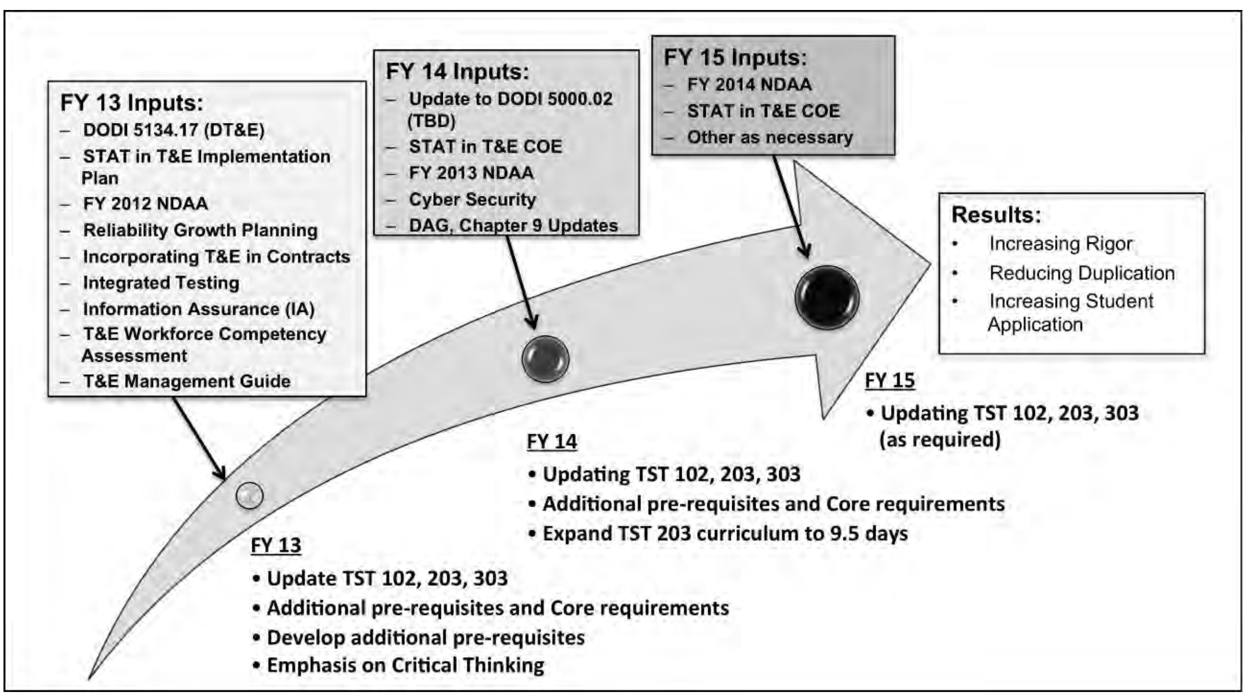

Figure 2. T&E workforce-development roadmap from the Deputy Assistant Secretary of Defense for Developmental Test and Evaluation for fiscal year 2013 through fiscal year 2015.

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References

National Defense Authorization Act for Fiscal Year 2012, Section 835, *Management of Developmental Test and Evaluation for Major Defense Acquisition Programs, Chief Developmental Tester*, December 12, 2011

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T&E Workforce Development—Do Not Forget Education

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The Department of Defense is pushing hard to include statistical rigor as part of defense test and evaluation. Workforce development is a component of this initiative. An overreliance on training avenues of workforce development has the potential to leave the overall workforce lacking in the deep knowledge needed for statistical rigor. These training avenues should be augmented with graduate-level educational avenues to help the test-and-evaluation workforce achieve the deeper level of statistical knowledge needed for the statistical-rigor initiative. This article discusses the levels of learning associated with training, argues for considering concepts from statistical engineering, and lays out an existing example of a graduate certificate course focused on the deeper statistical knowledge the Department of Defense is likely to need for the test-and-evaluation workforce.

Key words: Education; statistical engineering; statistical thinking; training; workforce development.

All tests are experiments, and all experiments are planned (Montgomery 2011). Not all experiments are planned using statistical thinking. Tests include demonstrations, envelope expansions, full factorial experiments, and various other types of tests. These may not be classical examples of experimental design (see the nice summary in Johnson et al. 2012). However, statistical thinking and statistical rigor should be a component supporting the planning, execution, analysis, and evaluation of every type of test.

Past articles in this journal have more than adequately discussed the recent emphasis by the Department of Defense (DoD) on improving the statistical rigor associated with test and evaluation (T&E). Dr. Gilmore's update (2011) and Greer's overview (2010) well summarize these initiatives. Dr. Warner (2011), in addressing the need for statistical rigor to meet T&E challenges, even states, "We must use statistical tools." (Such tools are not necessarily computer based.) The statistical-rigor initiatives are essential, but eventual success in these endeavors requires a T&E workforce that is ready and well prepared to make the initiatives work. Clearly, workforce development must play a key role in the DoD's goal to improve the statistical rigor across the range of T&E efforts. Training will be an important element in workforce development, since training programs focus on personnel knowing how to do things. However, education, which focuses on the "why" of the things that need to be done, must be part of the workforce-development solution as well.

Nearly all new initiatives involve a quick infusion of training. Some individuals may fondly recall the quality initiatives from 20 years ago and the various courses in topics ranging from continuous process improvement to Taguchi robust-design methods. I recall that some common metrics of the time were courses offered, personnel trained, and improvement teams chartered. The lean and Six Sigma initiatives are now in full stride, and there is no shortage of training and certification opportunities. However, there are problems with reliance on training along, a topic succinctly brought out by Goh (2010). Among these problems are trained (and sometimes fully expert) personnel's unawareness of the limitations of what they know and their rigid application of methods and tools even when the applicability of those methods and tools may be tenuous. Many statistical methods beneficial to test are beyond the scope of training programs. Such limitations in the breadth of expertise among personnel are often inherent in a reliance on training and should not be repeated in the statistical-rigor initiatives for DoD test.

Training versus education

Training focuses on familiarization of concepts while emphasizing processes to complete tasks or duties. It emphasizes the application of tools to somewhat specific contexts. Training is typically of very short duration but quite often will cover a broad range of topics.

Consider, for instance, a 2- or 3-day training course in experimental design (of which there are many). Such a course may cover the material in a full text on the subject during those few days, but everything is addressed at a very aggregate, high level. There is simply no time for learners to become acclimated to the material. A daily analogy might be covering all aspects of a modern automobile engine and how to repair it via PowerPoint presentations and then declaring the attendees qualified mechanics. They know of and are aware of the concepts, but they really are not fully aware of what they do not know.

Education is about the underlying principles of the techniques and methods and is more focused on the rigor of the coverage. The time frame for educational courses is much longer, providing that acclimation period and time for reflection on the material and how it all fits together. While there may be an emphasis on tool or method application, particularly with the wonderful computer tools currently available, there is time and motivation to understand why the tool or method applies, how it applies, and more importantly, when it may not apply. As Dr. Bjorkman (2012) discusses, it is useful to understand the fundamental assumptions of statistical methods, because there may be times when those assumptions fail to hold. In cases where statistical assumptions fail to hold, our test workforce must be in a position to recognize the fact and employ the correct test methods.

Consider again the analogy of the automotive-engine mechanic. We are apt to be more comfortable with that mechanic knowing that he or she has legitimate educational credentials, often supplemented by credits for focused continuing educational learning.

So what is the distinction for T&E workforce development? An answer is that statistical rigor means applying the correct techniques for the current context based on what is known (or assumed) about that context and what the test needs to achieve. The success of this approach requires a deeper understanding of statistical methods, coupled with the practical knowledge of test execution and the engineering knowledge of the system under test, to provide a cross-domain, multifunctional team. Training alone will not provide this expertise; the training should be augmented.

Everything covered so far in this article has been acknowledged in some fashion. However, implementation strategies are still lacking, and should be adjusted to explicitly consider education and the expertise gained through it and to not only acknowledge but accommodate the shortfalls inherent in training.

The deputy assistant secretary of defense for developmental T&E notes that changes underway are "ensuring the Department recruits and retains a skilled T&E workforce supported by professional education, training and certification" (n.d.). An important component of this change is the requirement of baccalaureate or graduate degrees in technical fields (Greer 2012). This degree requirement is also moving into Defense Acquisition University (DAU) requirements for T&E certification. The question is whether this move and updates to the DAU training curriculum are sufficient. Our claim is that the changes are necessary but not necessarily sufficient to achieve the requisite workforce statistical expertise.

Levels of learning

To help explain why training will likely not fully support the statistical-rigor initiative's requirements, consider personal levels of learning. There are a variety of learning taxonomies; one well-known one is Bloom's taxonomy, specifically the cognitive-skills component (see *Table 1*). The fundamental premise is that humans learn at various levels and need knowledge at differing levels depending upon the scope and complexity of the tasks they must perform. Properly understanding and considering those levels allows educational designers to focus their instructional material to the targeted level of learning.

For instance, an educational effort focused on the Remembering or Understanding level of learning targets the attainment of basic knowledge of a subject. Successful completion of such material provides personnel with familiarity with or recognition of key concepts. Such efforts are typical of introductory-level courses but do not provide a deep understanding of the concepts.

Applying statistical principles to new problems, devising new methods to handle nonroutine problems, or interpreting results from complex system testing requires knowledge at the Analyzing or Evaluating level of learning, perhaps even the Creating level. These levels of learning are typically found at the graduate level of education, where again rigor is emphasized along with independent, systematic thinking and the learning horizon is longer, to accommodate assimilation of the material.

To reinforce the need for higher levels of learning and for the educational component of workforce development for T&E, consider the DAU certification process for Test and Evaluation Levels I, II, and III. A fundamental course TST 102, "Fundamentals of Test and Evaluation" has 19 areas of learning

Table 1. Bloom's revised taxonomy (from http://www.nwlink.com/~donclark/hrd/bloom.html).

Category	Example and keywords (verbs)
Remembering: Recall previous learned information.	**Examples**: Recite a policy. Quote prices from memory to a customer. Know the safety rules. **Keywords**: Defines, describes, identifies, knows, labels, lists, matches, names, outlines, recalls, recognizes, reproduces, selects, states.
Understanding: Comprehend the meaning, translation, interpolation, and interpretation of instructions and problems. State a problem in one's own words.	**Examples**: Rewrite the principles of test writing. Explain in one's own words the steps for performing a complex task. Translate an equation into a computer spreadsheet. **Keywords**: Comprehends, converts, defends, distinguishes, estimates, explains, extends, generalizes, gives an example, infers, interprets, paraphrases, predicts, rewrites, summarizes, translates.
Applying: Use a concept in a new situation or unprompted use of an abstraction. Apply what was learned in the classroom to novel situations in the workplace.	**Examples**: Use a manual to calculate an employee's vacation time. Apply laws of statistics to evaluate the reliability of a written test. **Keywords**: Applies, changes, computes, constructs, demonstrates, discovers, manipulates, modifies, operates, predicts, prepares, produces, relates, shows, solves, uses.
Analyzing: Separate material or concepts into component parts so that its organizational structure may be understood. Distinguish between facts and inferences.	**Examples**: Troubleshoot a piece of equipment by using logical deduction. Recognize logical fallacies in reasoning. Gather information from a department and select the required tasks for training. **Keywords**: Analyzes, breaks down, compares, contrasts, diagrams, deconstructs, differentiates, discriminates, distinguishes, identifies, illustrates, infers, outlines, relates, selects, separates.
Evaluating: Make judgments about the value of ideas or materials.	**Examples**: Select the most effective solution. Hire the most qualified candidate. Explain and justify a new budget. **Keywords**: Appraises, compares, concludes, contrasts, criticizes, critiques, defends, describes, discriminates, evaluates, explains, interprets, justifies, relates, summarizes, supports.
Creating: Build a structure or pattern from diverse elements. Put parts together to form a whole, with emphasis on creating a new meaning or structure.	**Examples**: Write a company operations or process manual. Design a machine to perform a specific task. Integrate training from several sources to solve a problem. Revise and process to improve the outcome. **Keywords**: Categorizes, combines, compiles, composes, creates, devises, designs, explains, generates, modifies, organizes, plans, rearranges, reconstructs, relates, reorganizes, revises, rewrites, summarizes, tells, writes.

objectives. Each starts with the keyword "identify," "recognize," or "describe." This places the course firmly in the Remembering level of Bloom's taxonomy. CLE 301, "Reliability and Maintainability," is required for Level II; its objectives involve defining, distinguishing, understanding, and outlining. This is still largely in the first two levels of the Bloom's taxonomy, with some Analyzing-level learning as well. Finally, TST 303, "Advanced Test and Evaluation" required for Level III certification defines 14 learning-objective areas, involving 128 specific learning objectives (for a 4.5-day course). These outcomes fall largely in the Applying and Analyzing levels of Bloom's taxonomy. Of real concern for T&E is that the introductory module in probability and statistics is just 2 hours long, not nearly enough on its own to prepare the individual for the statistical rigor of advanced concepts for test.

This is not a complete course analysis and thus is not meant to displace the role of training in workforce development. Training is important, and the T&E certification process includes experience and job components that are difficult to pigeonhole into learning levels. However, with regard to the overall goals and objectives of workforce development for the complex environment that is T&E, that workforce needs deeper knowledge of the statistical concepts to support future T&E efforts. Thus, the leadership and those charged with devising the workforce-development programs should reconsider their overall approach, recognize the inherent limitations of training and certification, and incorporate education components into these programs.

Statistical engineering for the DoD

Statistical engineering is an exciting new topic of discussion and should be adapted to the statistical-rigor requirements for T&E. "Statistical engineering" is not a new term; Hare (2012) quotes an Eisenhart definition from 1963. Its most recent formalization is from Hoerl and Snee (2010). Hare (2012) defines it as "statisticians working with scientists and engineering … to produce results that none of these people could produce singly or without statistical methods and thinking." This aligns quite well for the new DoD paradigm in testing called for by Cohen, Rolph, and Steffey (1998), in which the role of statistical and quality-management principles would be expanded to effectively all of test. The Director of Operational T&E has already formally adopted the paradigm. The director's guidance on design of experiments in operational T&E is to "increase use of scientific and statistical methods in developing rigorous, defensible test plans in evaluating their results" (Gilmore 2010).

Extending statistical-engineering principles into the DoD T&E context may not require the use of just pure statisticians (as suggested in Cohen, Rolph, and Steffey 1998), but rather a workforce with key personnel who are deeply knowledgeable in statistical principles and an overall workforce with more than just a passing appreciation of how statistical thinking underlies all of test.

The Eisenhart definition (as quoted in Hare 2012) probably best fits DoD use: "Statistical engineering is the name given to that phase of scientific research in which statisticians advise, guide, and assist other scientists in the conduct of experiments and tests." An achievable goal for the DoD is to realize a workforce aligned with the statistical-engineering vision.

Anderson-Cook et al. (2012a) clearly note that the success of the broader statistical-engineering initiative will require a cultural change. A similar cultural change will facilitate the success of the statistical-rigor initiatives in the DoD. The climate in the DoD is ripe for such changes as we face reduced resources for test coupled with increasing system complexity, increasing operational complexity, and reduced acquisition timelines. In addition, as Simpson notes (Anderson-Cook et al. 2012b), we have challenges in DoD test for which current statistical methods require retooling or intelligent adaptation. Such challenges include life-cycle test planning, implementation of early involvement in test and requirements definition, integration of all test data, and integration of modeling results with live test results for decision making. Cohen, Rolph, and Steffey (1998) have also called for research in statistical methods to meet the challenges in test. Excellent discussions and examples of statistical engineering are available in the special issue of *Quality Engineering*, volume 24, issue number 2, which is freely available for download.

Test and Evaluation Certificate Program—an educational initiative

In late 2008, the Department of Operational Sciences of the Air Force Institute of Technology (AFIT) was asked to put together a graduate-level certificate program to help increase the statistical competencies of the Air Force T&E workforce. This was largely motivated by development efforts for the Air Force T&E workforce. The Test and Evaluation Certificate Program (TECP) began in January 2009 with 17 members in the cohort from across the components of Air Force test, including the major test centers.

The dispersed nature of the TECP enrollees dictates a distance-learning format. To retain the educational rigor, the format used is taped lectures (in studio or live from a classroom) in asynchronous delivery mode, using the same texts, homework assignments, projects, and exams as are found in our resident master's-degree program in operations research. Weekly synchronous sessions via Defense Connect Online provide the interaction between instructor and students to further discuss and master the concepts. Further, to maintain that rigor, every enrollee applied for and was evaluated for entry into the AFIT graduate school using the same admissions criteria as applied to our resident students.

The TECP consists of four graduate courses, each 10 to 11 weeks in duration, and a capstone (it is soon to have an optional fifth course in lieu of the capstone for selected students). Course 1 is graduate probability and statistics. This course provides the foundational material for subsequent courses and gives enrollees basic insight into statistical thinking. Course 2 is an in-depth examination of empirical modeling (regression modeling). This is not a data-fitting course focused on black-box output from a statistical-software package. This course provides a rigorous study of the fundamental concepts underlying empirical modeling.

Course 3 covers design of experiments, to include not only the usual designs and how to analyze them, but also how to plan for the experiments (see the excellent paper by Coleman and Montgomery [1993]). More of the advanced designs, particularly useful to DoD test due to the various constraints that must be considered, are covered as well. Course 4 was included specifically for the T&E customer: reliability and maintainability. While it is primarily focused on design considerations for reliability and maintainability, important topics such as reliability growth and the handling of censored data are covered as well.

We are adding a fifth course to substitute for capstone projects as appropriate. This course will cover quantitative forecasting techniques (to provide a grounding in handling time-series data) and advanced experimental-design methods as well as response surface methods, all of which are gaining favor in the T&E world.

The TECP is now in its fourth cohort and is programmed for support for the next three fiscal years. While the program's enrollees are primarily from the Air Force (due to funding, not limitations on the program), we have had Navy and Marine Corps civil servants in the program. The program is open to active-duty and defense employees, and we are expanding capacity to include more enrollees from throughout the DoD.

The point of the discussion, and our motivating rationale for the TECP, is to focus on education and the statistical rigor that statistical education can provide, in this case to the T&E workforce. Training courses do not substitute for graduate courses, and we do not provide such credit for them, even when the training courses are conducted by AFIT. Students gain familiarity via the training but garner the understanding with the longer-duration graduate education. My favorite comment, from an unattributed TECP graduate, was that he had been doing "this stuff" (statistical analysis) for years, but now he finally understood the how and the why of what he was doing.

Concluding remarks

The AFIT TECP is unique to DoD education but is not the only viable source for graduate education to support the DoD T&E workforce. Local universities will often offer graduate-level courses in statistics. There are many distance learning offerings as well. I will not advertise them here, but will note that some are good, some not so good. When examining such programs, consider the following:

- Avoid training-course-based certificates; they are costly and generally not rigorous enough.
- Avoid any course where all the student does is read Web sites and associated test books with little to no homework, projects, or instructor interactions.
- Ensure that the distance programs are affiliated with legitimate resident programs, and the courses are based on those programs.
- Scrutinize carefully those programs run out of research institutes or by nonregular faculty members; in general, their motivation is profit rather than content.

The future for DoD T&E is filled with challenges. Statisticians and engineers who are comfortable with statistical thinking can and will help the DoD meet those challenges. Training and DAU certification is and should remain an important part of T&E workforce development. However, the collective enterprise should recognize the limitations of those venues and work to include rigorous educational components into workforce-development programs.

Disclaimer

The views expressed in this article are those of the author and do not reflect the official policy or position of the United States Air Force, the Department of Defense, or the U.S. government. ❑

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References

Anderson-Cook, C. M., L. Lu, G. Clark, S. P. DeHart, R. Hoerl, B. Jones, R. J. MacKay, et al. 2012a. Statistical engineering forming the foundations. *Quality Engineering* 24 (2): 110 132.

Anderson-Cook, C. M., L. Lu, G. Clark, S. P. DeHart, R. Hoerl, B. Jones, R. J. MacKay, et al. 2012b. Statistical engineering role for statisticians and the path forward. *Quality Engineering* 24 (2): 133 152.

Bjorkman, E. 2012. The science of testing: It's not just about statistics. *ITEA Journal* 33 (2): 115 118.

Cohen, M. L., R. E. Rolph, and D. L. Steffey, eds. 1998. *Statistics, testing, and defense acquisition: New approaches and methodological improvements*. Washington, D.C.: National Academy Press.

Coleman, D. E., and D. C. Montgomery. 1993. A systematic approach to planning for a designed industrial experiment. *Technometrics* 35 (1): 1 12.

Deputy Assistant Secretary of Defense for Developmental Test and Evaluation. n.d. *Office of the DASD for Developmental Test &Evaluation/Dir, Test Resource Management Center*. Washington, D.C.: Department of Defense, http://www.acq.osd.mil/dte-trmc (accessed August 7, 2012).

Gilmore, M. J. 2010. *Guidance on the use of design of experiments (DOE) in operational test and evaluation*. OSD(DOT&E) memorandum. October 19.

Gilmore, M. J. 2011. Rigor and objectivity in T&E: An update. *ITEA Journal* 32 (3): 237 240.

Goh, R. N. 2010. Six triumphs and six tragedies of Six Sigma. *Quality Engineering* 22 (4): 299 305.

Greer, E. R. 2010. Developmental test and evaluation is back. *ITEA Journal* 31 (3): 309 312.

Greer, E. R. 2012. Briefing to 2012 NDIA T&E Conference, May 14, 2012. Available at http://www/dtic.mil/ndia/2012test/greer.pdf.

Hare, L. B. 2012. Statistical engineering: Principles and examples. *Quality Engineering* 24 (2): 153 161.

Hoerl, R. W., and R. D. Snee. May 2010. Closing the gap: Statistical engineering links statistical thinking, methods, tools. *Quality Progress* 43 (5): 52 53.

Johnson, R. T., G. T. Hutto, J. R. Simpson, and D. C. Montgomery. 2012. Designed experiments for the defense community. *Quality Engineering* 24 (2): 60 79.

Montgomery, D. 2011. The principles of testing. *ITEA Journal* 32 (3): 231 234.

Warner, C. 2011. Continuing the emphasis on scientific rigor in test and evaluation. *ITEA Journal* 32 (1): 15 17.

3-D Computational Analysis of the Turbulent Mixing of an Angled Jet in Cross Flow

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Computational results are compared to experimental data for the scalar mixing of two fluids in an incompressible turbulent flow. The apparatus investigated consists of an angled jet entering a cross flow with a 49.3-mm square cross section. The jet ejects from a single elliptical hole with a length-to-diameter ratio of 6.0 into a cross flow at 30 degrees pitch and zero skew, with a jet-to-mainstream velocity ratio of 1.0. The elliptical hole is of minor diameter 6 mm in the spanwise direction and of major diameter 12 mm in the streamwise direction. A counterrotating vortex pair emerges from the feed hole and is sustained through the end of the measurement region over 10 hole diameters downstream. The three-dimensional, three-component velocity and scalar concentration fields are compared to Reynolds-averaged Navier Stokes simulations of the tested geometry using an unstructured grid. Detailed analysis of the similarities and differences between the computational results and experimental data is presented for the flow in the film hole, the cross-flow velocity, and the cross-flow concentration of the converged flows. A discussion of improvement of the simulation is presented through the implementation of a modified constant turbulent Schmidt number, improved turbulence intensity, or an improved boundary condition of the inlet plane of the water channel. The simulations are developed using CFD++11.1.1 with support from the Army Research Lab at Aberdeen Proving Grounds, Maryland. High-performance computing capabilities facilitated by a partnership between the United States Military Academy and the Army Research Lab are required for the computer-intensive Reynolds-averaged Navier Stokes simulations. One salient, focused application of this research is the model improvement of fluid flow over gas-turbine engine blades. Continued subsequent research provides immense potential in improving simulations of complex turbulent-mixing flow fields.

Key words: magnetic resonance velocimetry and concentration techniques; computational fluid dynamics; turbulent diffusivity.

Gas-turbine engines reach very high temperatures that endanger their blades by exceeding their natural melting points. These blades are successfully cooled through jets of air derived from film-cooling holes within the blade. The interaction of the cooling jet through the holes and across the surface of the blade demonstrates the mixing of two converging flows. Bunker (2005) provides an extensive survey of shaped film-cooling technology used to cool gas-turbine airfoils. He concludes that shaped film cooling can have many benefits, including low sensitivity to variations in free-stream turbulence intensity, low susceptibility to film blow-off under typical conditions, and little variation of effectiveness given a variety of blowing ratios. An optimization in the design of shaped film-cooling holes can only strengthen the technology and lead to better performance when applied to high-temperature airfoils. A greater understanding of the inherent complexities of the mixing of fluids in turbulent flow can greatly improve computer-modeling capabilities. These enhanced simulation capabilities will only further strengthen industrial design and manufacturing abilities.

A computational analysis of turbulent mixing of an angled jet in cross flow is performed using the 3-D geometry displayed in *Figure 1*. This geometry displays an elliptical red tube dispersing a fluid into a highly

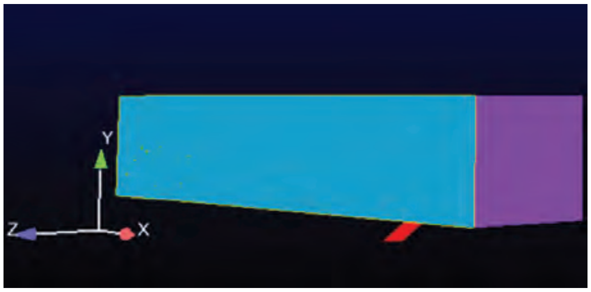

Figure 1. 3-D geometry of converging flows. The turbulent cross flow moves in the positive x-direction exiting through the purple face. The red elliptical tube ejects a fluid jet.

turbulent, larger cross flow with a 49.3-mm square cross section. The coordinate system has its origin at the center of the elliptical tube exit along the floor of the square cross-section channel. The direction of streamwise flow is designated the x-direction, spanwise movement is designated the z-direction, and movement normal to the floor of the channel is designated the y-direction. The fluid dispersed from the tube is referred to as the coolant flow. A more thorough understanding of turbulent mixing will improve the capabilities of computer simulations and subsequently benefit the design capabilities of the engineering community. Improved modeling capabilities reduce the need for long and costly fluid-dynamic experimentation. The value of computer simulations is judged by their ability to replicate validated experimental results.

The emergence of modern computational fluid dynamics (CFD) has provided greater opportunities for scientists and engineers to conduct significant research into turbulent mixing. These CFD capabilities are aided by modern high-performance computing capabilities. A fundamental understanding of flow physics allows for model improvement. Research into various CFD simulation techniques provides an understanding of typical modeling techniques.

A thorough discussion of diverse modeling techniques is provided by the work of Acharya and Hoda (2000). They analyze seven different turbulence models against a contemporarily valued experimental standard. They state that many models give overly simplistic conclusions regarding the highly complex fluid field being considered. They also explain that the most common approach is the use of the Reynolds-averaged Navier Stokes (RANS) Solver, which requires a turbulence model. They suggest that Claus and Vanka fail to predict proper vortex nature due to the inability of the high-Reynold-number model (HRE) to solve complex turbulence fields. The HRE overpredicts the spanwise jet penetration. Additionally, the HRE is said to be unsuited for the experimental flow situation, since it does not resolve the near-wall region properly.

Leylek and Zerkle (1994) model the uses of gas-turbine cooling parameters for airfoil applications. Their work is a beneficial resource because the authors explain the details of the computational model, including the method of applying a grid mesh in three dimensions. They also explain the use of applying boundary conditions for the six boundary surfaces to most closely replicate the experimental work. Their simulation inputs also included a turbulence intensity of 0.2 percent and a velocity profile using "plug-flow," since the inlet plane was placed at the leading edge of the test plate, where a new boundary layer was triggered. They finally explain that the pressure level was also specified at the exit plane along with zero streamwise gradient for all other dependant variables. Leylek and Zerkle also mention that their cross stream and film hole were initialized separately and as accurately as possible. These topics served as a beneficial means to better understand the requirements of completing a comprehensive list of CFD inputs into numerical-simulation software programs.

The work of Bai, Liu, and Zhu (2011) is also of immense benefit. Although they address new developments regarding the turbulent Prandtl number, their explanation of CFD methodology was quite beneficial in the experimental work for this article. They show that a body-fitted multiblock grid allows the highest quality in all regions with the fewest number of cells. This supports the use of unstructured meshing to better fit the desired needs of precision for various locations within the flow's geometry. The domain was partitioned into subsections as follows: the cooling hole, the jet plenum, and three subsections of the main channel. A large amount of information regarding the construction of mesh data from previous work is then referenced from six unique publications. One of the listed tests utilizes a row of cylindrical holes with compound angle orientation, and another utilizes a row of double-fan-shaped holes. Two others that are more closely related to the simulated geometry are those completed by Goldstein, Eckert, and Ramsey (1968) and Sinha, Bogard and Crawford (1991). Goldstein and colleagues measured the film-cooling effectiveness downstream of a long cylindrical hole inclined at 35 degrees in the streamwise direction. They completed computations at the three blowing ratios of 0.5, 1.0, and 1.5. Bai explains that Sinha conducted similar tests utilizing a row of cylindrical holes inclined streamwise at an angle of 35 degrees with a blowing ratio of 0.5. Experimental setup strongly validates the testing methodology of the chosen geometry to undergo simulation in this article.

Upon completion of research into the construction of a CFD simulation utilizing a RANS simulation with a k-ε turbulence model, research into the turbulent

Schmidt number (Sc_t) is conducted. Stathopoulos and Tominaga (2007) completed an extensive literature review of the various turbulent Schmidt numbers used within CFD analysis for varying flow fields. They explain that no universal value of the turbulent Schmidt number has been established, and many different values are utilized given the scenario. These values range as widely as 0.2 to 1.3, even though they can have a significant impact on computational predictive results. For the specific case of predicting the turbulent scalar fields in jet-in-cross flow with a standard k-ε model, Yimer, Campbell, and Jiang (2002) conclude that a turbulent Schmidt number of 0.7 should be recommended for use in CFD applications that "involve axisymmetric free-jet flows". They explain that such is done through consideration of "the consistency with the prediction accuracy of the velocity field." Stathopoulos and Tominaga suggest that the work of Yimer, Campbell, and Jiang maintains a much stronger argument than the 1999 work of He, Andrew, and Hsu, which recommends a turbulent Schmidt number of 0.2. Although this low value best matches the experimental data set used by He, Andrew, and Hsu, it may very well be a product of a large underestimation of the predicted turbulence intensity around the jet. To further support the work of Yimer, Campbell, and Jiang, the later work of Huai, Sadiki and Wegner (2004) displays the use of a constant turbulent Schmidt number of 0.7 between the turbulent diffusion coefficient and the turbulent viscosity.

A literature review of the jet-in-cross-flow scenario strongly shows that the turbulent Schmidt number is often chosen to be 0.7 for CFD applications, but highly optimized simulations may better replicate experimental data if the turbulent Schmidt number is found to be a more precisely defined constant or possibly even spatially variable throughout the 3-D geometry to be modeled. The use of highly precise flow-dependent constant values is seen in the 2002 work of Baurle and Eklund, which recommends $Sc_t = 0.5$ for the simulation of reacting scramjet flows. Sturgess and McManus (1984) display the range of variation of the Sc_t from 0.2 to 0.7 for use in a diffusion flame combustor. Batten, Goldberg, Gupta, and Palaniswamy (2010) explain that in the case of large variations, the Sc_t may be modeled as a function of the k-ε turbulence model, which is "modified by sensitizing the parameter, $C\mu$, to the ratio P_k/ε (ratio of turbulence kinetic energy production and its dissipation rate) with a similar treatment of the eddy diffusivity." This work is also beneficial because it explains the benefits of using a spatially varying Schmidt number to increase model precision, yet its explanation of implementation does not cover the case of incompressible fluids. Such a limitation proved to greatly limit the capabilities of simulations of incompressible flow using software from Metacomp Technologies.

Objectives of work

The initial objective was the completion of a 3-D velocity and concentration field, accounting for the fluid movement of the cross-flow jet, assuming steady flow and no slip condition on the apparatus boundary. A further objective of the work was the iterative process of improving the initial completed simulation. This was attempted through the implementation of more accurate turbulence intensity or the use of an improved boundary condition of the inlet plane of the water-channel geometry. A detailed explanation can be found under "Simulation procedures." The final objective is to further improve the simulation through the determination of the scalar isotropic diffusivity to a much higher level of precision for an angled jet in cross flow, ultimately allowing for needed improvements with respect to the film cooling of turbo jet engines.

This final objective may be completed through further use of Reynolds-averaged Navier Stokes equation modeling to gain a greater understanding of the turbulent Schmidt number (Sc_t):

$$Sc_t = \frac{\mu}{\rho D}. \tag{1}$$

Equation 1 defines the turbulent Schmidt number, which is simply a ratio of the viscous diffusion rate to the molecular diffusion rate. This parameter is useful in considering a conservation of momentum, as done in the simulations for this article. The value of the turbulent mass diffusivity can be calculated throughout the 3-D flow field from experimental results using partial differentiation of the scalar concentration throughout the experimental geometry. Additionally, the momentum diffusivity can be determined by obtaining the eddy diffusivity, at the same discrete points, as a function of the k-ε turbulence model used within CFD++11.1.1. The use of these values may lead to the determination of a more accurate constant Schmidt number to be used in CFD simulation. This may allow an improvement of the simulation capabilities to replicate the experimental results (Benson 2011).

Simulation procedures

The simulations for this article were compared to experiments that used measurement techniques of magnetic resonance velocimetry and magnetic resonance concentration at a resolution of 0.24 mm^3. The experiment with magnetic resonance velocimetry utilized a single fluid of copper sulfate mixture and was used to obtain velocity data for the fluid within the tested region. The experiment with magnetic resonance

Table 1. Simulation parameters for velocity and concentration.

Q_{main}	71 L/min
Q_{cool}	0.79 L/min
m_{main}	1.18 kg/s
m_{cool}	0.0126 kg/s
Re_{main}	98,400
Re_{cool}	2,900
$\mu_{vel,fluid}$	0.00091 kg/ms
$\rho_{vel,fluid}$	1008 kg/m^3
$M_{vel,fluid}$	41.2 kg/kmol
$\mu_{con,main}$	0.00111 kg/ms
$\mu_{con,cool}$	0.0009 kg/ms
$\rho_{con,main}$	998 kg/m^3
$\rho_{con,cool}$	1002 kg/m^3
$M_{con,main}$	18.0 kg/kmol
$M_{con,cool}$	26.7 kg/kmol

L/min liters per minute; kg/s kilograms per second; kg/ms kilograms per millisecond; kg/m^3 kilograms per cubic meter; kg/kmol kilograms per kilomole.

concentration used two fluids and was used to obtain concentration data for the fluids within the tested region. The mixed fluids for the concentration measurements were plain de-aerated water in the mainstream and water with copper sulfate at a concentration of 0.015 mol/L for the jet (Benson 2011). Data used in these simulations are provided in *Table 1*.

The CFD simulations were done using the fundamental Navier Stokes equation, which represent the conservation of linear momentum. An in-depth analysis of this law is not undertaken in this analysis; rather, a fundamental understanding of its concepts validates the testing for conservation of linear momentum used to support the simulation results.

$$\rho\bar{u}_j\frac{\partial\bar{u}_i}{\partial x_j}=\rho\bar{f}_i+\frac{\partial}{\partial x_j}\left[-\rho\delta_{ij}+\mu\left(\frac{\partial\bar{u}_i}{\partial x_j}+\frac{\partial\bar{u}_j}{\partial x_i}\right)-\rho\overline{u_i'u_j'}\right] \tag{2}$$

Equation 2, known as the Reynolds-averaged Navier Stokes (RANS) equation, is a time-averaged solution to the Navier Stokes equations and is applied to a turbulent, incompressible flow, which is characteristic of the experimental work. The RANS equation is a powerful tool because it allows for the unknown Reynolds stresses to be modeled in terms of the known mean flow. The simulated steady-state flow is thus able to gain closure. RANS requires the implementation of a turbulence model. This simulation used the HRE (high-Reynolds-number model).

The creation of the simulations required a systematic process that included replication of the experimental geometry, discretization of that volume, input of the experimental physical conditions, application of the turbulence modeling, and iterative improvements of the simulation through comparison with experimental results.

The simulation replicated those geometric dimensions provided by LTC Michael Benson to model previously highly validated experimental work (Benson 2011). The interior of the channel was modeled as a solid and was meshed for computer calculation of the fluid behavior. A quick orientation to the coordinate system first displayed in *Figure 1* will reveal the cross-flow direction of travel in the positive x-axis. The positive y-axis is oriented normal to the floor of the channel. Finally the z-axis moves in the spanwise direction, from side to side of the water channel. It is a body-fixed coordinate system with the origin at the center of the coolant exit tube.

An anisotropic discretization of the water channel and feed pipe containing 1.3 million control volumes resulted from the meshing process. An unstructured mesh was utilized to allow greater precision in the discretization of the coolant tube and the portion of the main channel where the fluids would converge. The benefit of unstructured meshing is apparent in the separation of the entire geometry into six components for designation of grid shape and resolution. The mesh shape chosen for the walls parallel to the fluid flow was quadrilaterals; whereas the mesh shape chosen for inlet and exit planes orthogonal to the fluid flow was triangles. The literature supports the use of the finest discretization of the geometry near to and directly downstream of the hole exit where the mixing occurs.

The physical conditions of the experiment were inputted through the use of boundary and initial conditions. Boundary conditions were assigned for each component of the complete geometry to define their interaction with the moving fluids. The portions of the geometry that had the fluids flow across their surface were designated as wall-boundary conditions, and boundary layers of the proper height were assigned. Those portions of the geometry that had fluid flow through their surfaces were assigned conditions characteristic of 2-D inlet and exit planes. The initial conditions were used to define the characteristics of the fluids as they entered the mesh, before convergence. These were satisfied through the fluid properties for the one fluid within the velocity simulation and the two fluids within the concentration simulation. These properties are listed in *Table 1*. The simulation utilized pressure parameters during the input of the inlet-plane characteristics.

The turbulence initialization used the RANS model, as previously mentioned. As a high-Re model, the turbulence of the free-stream velocity was set at 0.01, a value suggested for internal flows using the *k*-ε model chosen, where *k* is the turbulent kinetic energy and ε is the turbulent energy dissipation rate. Such input is likely compatible with the inherent nature of the k-ε model providing isotropic diffusivity. Turbulence initialization proves to be largely a characteristic of the nature of the flow and the dimensions of the geometry. Convergence of the simulation occurred after an iterative input of up to 500 time steps achieved a predetermined negligible residual value of less than 1.0×10^{6}. This requirement is met when the combined error for a given variable changes to such a small amount between iterations that further iteration is deemed unnecessary.

The simulation was compared to the experimental data in regard to the nature of the flow in the film hole as well as the velocity and concentration of the cross flow after convergence of the two fluids. This analysis was focused along the z-plane in the middle of the channel and on the x-plane at distances of one diameter and 10 diameters downstream of the jet exit of the film hole. Improvements upon the initial completed simulation were attempted in the three areas of implementation of an improved turbulence intensity value, an improved boundary condition of the inlet plane of the water channel, and a more accurate, modified constant turbulent Schmidt number.

The turbulence level can be adjusted to more closely model the experimental results. The free-stream turbulence level typically varies from 0.01 to 0.05 for incompressible flow. Such an input is needed in CFD unless there are experimentally provided data for the turbulent kinetic energy and its dissipation rate. The initial simulation utilized a free-stream turbulence level of 0.01, and various levels to a maximum of 0.05 were utilized in simulation.

The boundary condition for the inlet of the fluid flow through the simulation geometry was a function of the mass flow rate in the initial completed simulations. The implementation of a 2-D velocity profile at this boundary condition has the potential to improve the accuracy of the simulation. This velocity profile had a high potential because it was experimentally obtained from highly precise experimental work. Implementation of this 2-D velocity profile was completed as an inlet boundary condition at 64.5 mm upstream of the film hole, causing the use of a shortened geometry for simulation. This alternative boundary condition was implemented for all test cases used, but verifiable high-quality results could not be repeatedly obtained.

Given the inability of Metacomp software to utilize a spatially varying turbulent Schmidt number in incompressible flows, various constant turbulent Schmidt numbers were implemented from a range of $Sc_t = 0.5$ to 0.9, utilizing a cubic k-ε turbulence model (Batten, Goldberg, Gupta and Palaniswamy 2010; Stathopoulos and Yoshihide 2007). Use of the wider range of turlulent Schmidt numbers did not produce high-quality, verifiable results.

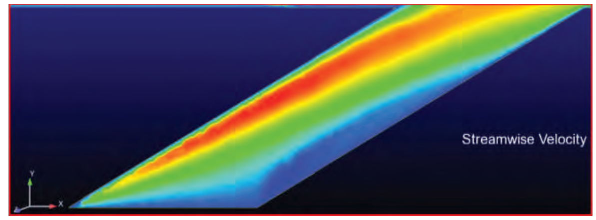

Figure 2. Streamwise velocity profile in film hole. The red fluid at the top of the tube is of the highest velocity, representing the jetting effect.

The inability to achieve verifiable results utilizing the entire range of 2-D velocity-profile inlet-plane boundary conditions and the entire range of constant turbulent Schmidt numbers during simulation provided an improved simulation through the optimization of the free-stream turbulence level within the CFD simulations. This improvement is referred to as the improved simulation within the subsequent discussion of results.

Results and discussion

The simulation resulted in the completion of a 3-D velocity and concentration field for the entire geometry. Use of the postprocessing software Ensight 9.2 provides clear visualization of the required fluid properties throughout the geometry, allowing for accurate analysis of the validity of the simulation results. Results are also presented for an improved simulation utilizing a free-stream turbulence level of 0.04 to more closely model the behavior of the experimental fluid convergence.

Details of flow in the film hole

The flow within the film hole displayed the jetting effect repeatedly seen in the literature for the 30-degree angle of discharge. *Figure 2* displays this phenomenon through the coolant, with the highest streamwise velocity moving toward the cross flow at the top of the tube. The method of feeding was parallel to the center line of the tube, a stark difference from the method in the experimental data of side feed from a plenum. A predicted sharp transition of coolant flow direction upon interaction with the cross flow was also validated within simulation results.

Details of cross-flow velocity analysis

The streamwise velocity field was analyzed by examining the 2-D streamwise profiles of the velocity from the floor of the channel to a height of 20 mm. This was done along the xy-plane at $z = 0$. This profile was taken at a distance of one hole diameter

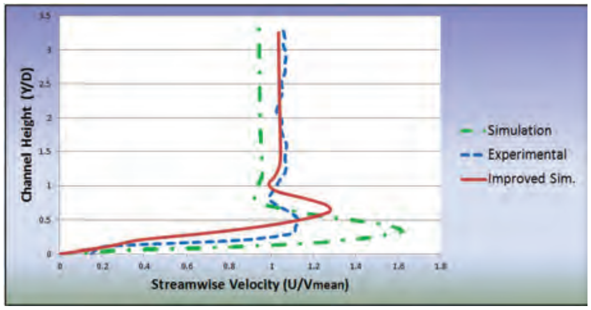

Figure 3. Streamwise velocity profile at x/D 1.

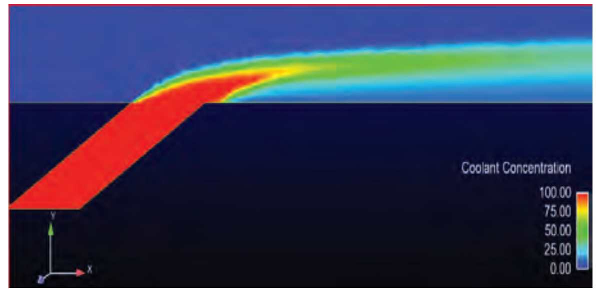

Figure 5. Initial simulated streamwise concentration profile.

downstream in *Figure 3* and at a distance of 10 hole diameters downstream in *Figure 4*. Both axis measurements are nondimensional. The streamwise velocity is presented as (U/V_{mean}), a ratio of streamwise velocity to average velocity over the plotted domain. The channel height is presented as (Y/D), a ratio of the height to the diameter of the film hole. At one hole diameter downstream, Figure 3 shows that the improved simulation more closely models the fluid-mixing behavior than does the initial simulation, which has a large velocity difference near the floor of the channel. At a distance 10 diameters downstream, as seen in Figure 4, the improved simulation appears to overpredict the fluid velocity within the first 5 mm from the floor of the channel. The improved simulation's results appear to be reasonably valid, but further improvement is possible.

Details of cross-flow concentration

The concentration analysis may best be understood by an initial look at a 2-D profile of the length of the cross flow downstream of the coolant tube in the streamwise direction when $z = 0$. This reveals that the flow in the simulation did not reattach to the floor of the channel like the experimental result appeared to do successfully. *Figures 5* and *7* display this disparity in coolant travel downstream. It is also apparent that the simulation's coolant requires a longer distance of travel downstream before it mixes to the same extent as that witnessed in experimental work, yet the higher turbulence level of the improved simulation, as displayed in *Figure 6*, promotes a higher level of mixing that more closely replicates the experimental data. Closer analysis of the concentration is conducted through analysis in the spanwise direction.

Analysis of a 2-D profile of the spanwise direction when viewing the x-plane provides the most analytically profitable information within comparison of data sets. Further regional analysis occurs at a distance of one diameter downstream of the film hole as displayed in *Figures 8, 9,* and *10* as well as 10 diameters downstream of the film hole, as displayed in *Figures 11, 12,* and *13*. A keynote is the isotropic nature of mixing of the experiment, compared to the largely anisotropic mixing of the coolant in the initial simulation. The improved simulation provides a more even distribution of mixing that closely replicates the nature of the experimental data. This improvement is much better than the complete lack of isotropic mixing shown 10 diameters downstream in the initial simulations. This isotropic mixing is not directly sought, but it is desired given the experimental mixing's characteristics of appearing generally isotropic. The isotropic nature of the RANS k-ε model is successfully displayed given the optimum turbulence level. An insufficient turbulence level appears to more closely model the excessive spanwise spreading mentioned in the work of Acharya and Hoda (2000). A removal of any excessive spanwise spreading in the

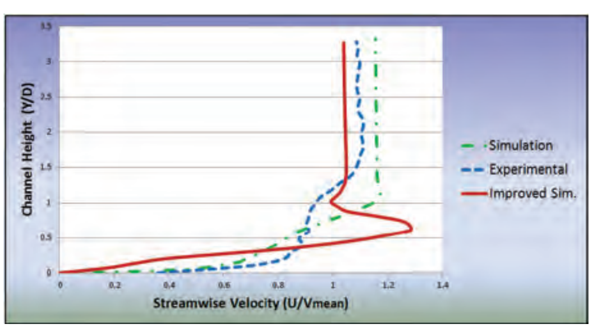

Figure 4. Streamwise velocity profile at x/D 10.

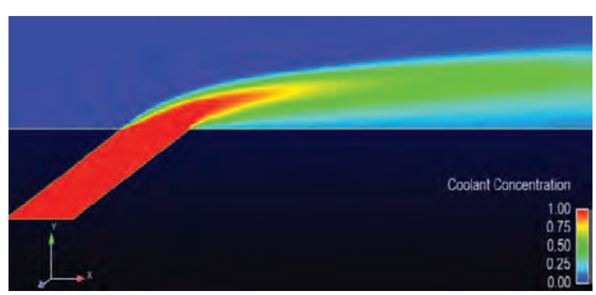

Figure 6. Improved simulation streamwise concentration profile.

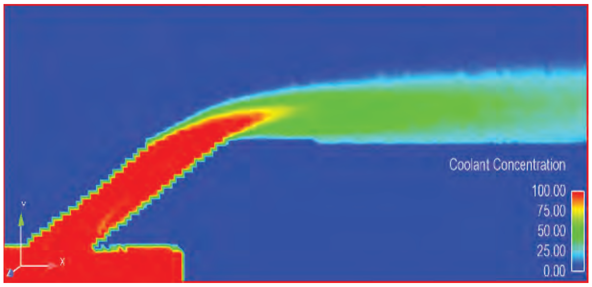

Figure 7. Experimental streamwise concentration profile.

improved simulation is indicative that the simulation successfully displays a properly oriented counterrotating vortex pair at lengths of at least 10 diameters downstream.

The improved simulation, shown in *Figures 9* and *12*, also appears to provide a higher level of mixing than the initial simulations, although it still does not meet the higher levels of mixing displayed in the experimental profiles of *Figures 10* and *13*. At a distance of $x/D = 1$, the experimental data display only a small level of pure coolant, yet the improved simulation still maintains a larger section that has yet to mix with the cross flow. At a distance of $x/D = 10$, this phenomenon is again witnessed. The highest level of coolant concentration in the experimental data is approximately 30 percent, yet the improved simulation maintains a coolant fluid concentration as high as approximately 50 percent.

Implications

The improved simulation proved to be a much stronger match to the experimental data set. Implementation of a free-stream turbulence level of 0.04 was much more appropriate to replicate the necessary higher level of mixing inherent in the experiment. This improved simulation proves to be a positive gain because it more closely resembles the isotropic nature of the experiment and more closely mirrors its level of mixing than did the initially completed RANS

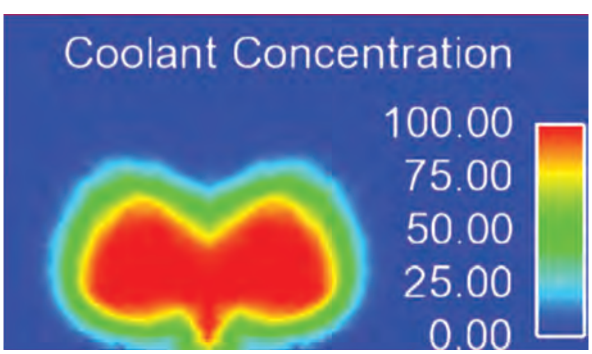

Figure 8. Initial simulated spanwise concentration profile at x/D 1.

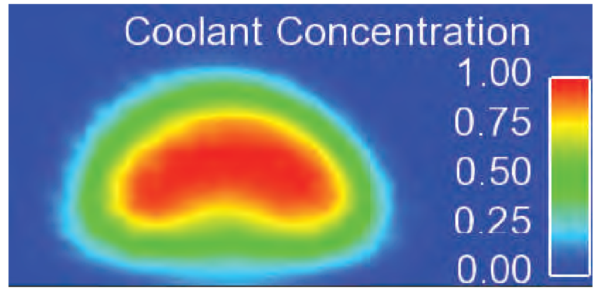

Figure 9. Improved simulation spanwise concentration profile at x/D 1.

realizable k-ε turbulence model simulations. There is room for improvement in the area of simulating a greater level of mixing of the converging fluids. It would also be very beneficial to create simulated results that allow the coolant jet to reattach to the floor of the channel. This additional mixing and reattachment of the coolant jet to the channel floor are both necessary tools to more closely simulate the useful industrial application of cooling air inciting heat transfer away from the surface of very hot gas-turbine engine blades.

Conclusion

The simulated results made gains in replication of experimental results throughout the period of CFD study and implementation. The high-Re turbulence model chosen may not have had the level of documented historical success as a more computationally intensive Large Eddy Simulation, but it is most commonly used and has provided reasonable results (Acharya and Hoda 2000). Velocity analysis along the x-plane demonstrates that the simulation is not greatly different from the experimental work downstream of the coolant hole. Improved simulation replicates the isotropic nature of fluid mixing, as displayed in the spanwise concentration profiles of *Figures 9* and *12*. Improvements must be made to more closely replicate the reattachment of the coolant jet to the channel floor, as well as promote more mixing of the fluids downstream of the film hole. Additional work may be continued to properly implement a 2-D

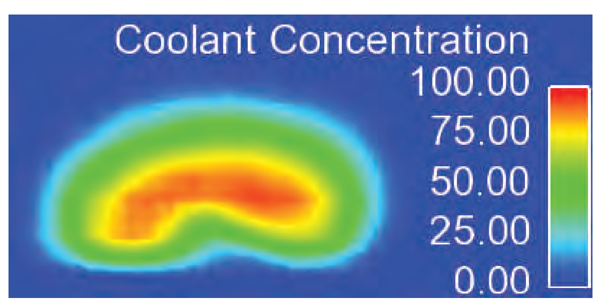

Figure 10. Experimental spanwise concentration profile at x/D 1.

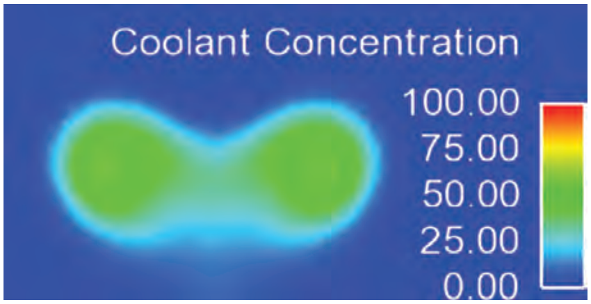

Figure 11. Initial simulated spanwise concentration profile at x/D 10.

velocity profile as the boundary condition of the inlet plane of the channel or to determine the optimal Sc_t for the flow properties, to fulfill the final objective of the work. Use of magnetic resonance velocimetry and magnetic resonance concentration measurements (Benson 2011) to obtain the turbulent diffusivity to generate a regionally specific averaged optimal Schmidt number represents a powerful tool to improve simulations of complex turbulent-mixing flow fields.

Nomenclature

$C\mu$	coefficient in eddy viscosity formula
Sc_t	turbulent Schmidt number
D	mass diffusivity (m^2/s)
m	mass flow rate (kg/s)
Q	volumetric flow rate (L/min)
Re	Reynolds number $= VD/\mu$
M	molecular weight (kg/kmol)
ρ	density (kg/m^3)
μ	dynamic viscosity (kg/ms)

Subscripts

main	cross flow
cool	coolant
vel	fluid, fluid used in the velocity simulation
con	main, water used as cross flow in the concentration simulation
con	cool, fluid used for coolant in the concentration simulation ❑

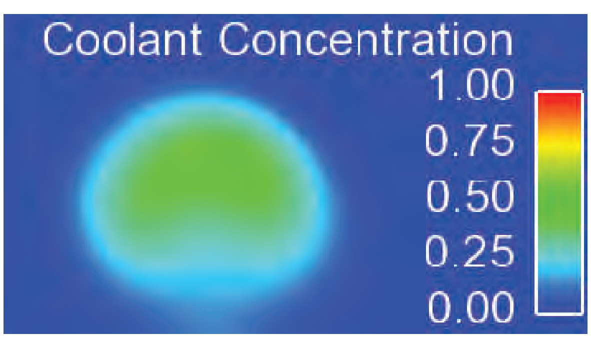

Figure 12. Improved simulation spanwise concentration profile at x/D 10.

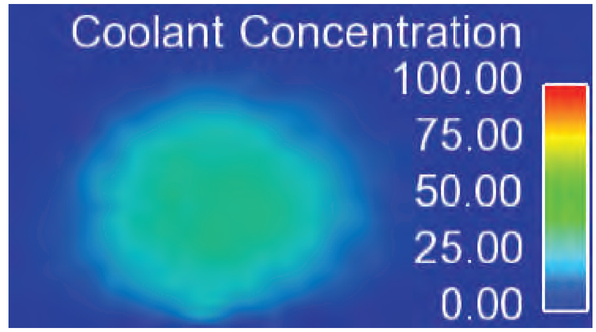

Figure 13. Experimental spanwise concentration profile at x/D 10.

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References

Acharya, S., and A. Hoda. 2000. Prediction of a film coolant jet in crossflow with different turbulence models. *Journal of Turbomachinery* 122 (3): 558 568.

Bai, J.-t., C.-l. Liu, and H.-r. Zhu. 2011. New development of the turbulent Prandtl number models for the computation of film cooling effectiveness. *International Journal of Heat and Mass Transfer* 54 (4): 874 886.

Batten, P., U. C. Goldberg, V. Gupta, and S. Palaniswamy. 2010. Variable turbulent Schmidt and Prandtl number modeling. *Engineering Applications of Computational Fluid Mechanics* 4 (4): 511 520.

Baurle, R. A., and D. R. Eklund. 2002. Analysis of dual-mode hydrocarbon scramjet operation at Mach 4 6.5. *Journal of Propulsion and Power* 18 (5): 990 1002.

Benson, M. 2011, May Experimental work completed during research at Stanford University, provided to the author through Ensight 9.2 data files of flow characteristics, October 2011.

Bunker, R. S. 2005. A review of shaped hole turbine film-cooling technology. *Journal of Heat Transfer* 127 (4): 441 453.

Goldstein, R. J, et al. 1968. Film cooling with injection through holes: Adiabatic wall temperature downstream of a circular hole. *Journal of Engineering Power* 90 (4): 384 395.

He, G., Y. G. Andrew, and T. Hsu. 1999. The effect of Schmidt number on turbulent scalar mixing in a jet-in-crossflow. *International Journal of Heat and Mass Transfer* 42 (20): 3727 3738.

Huai, Y, et al. 2004. Comparative study of turbulent mixing in jet in cross-flow configurations using LES. *International Journal of Heat and Fluid Flow* 25 (5): 767 775.

Leylek, J. H., and R. D. Zerkle. 1994. Discrete jet film cooling: A comparison of computational results with experiments. *Journal of Turbomachinery* 116 (3): 358 367.

Sinha, A. K, et al. 1991. Film cooling effectiveness downstream of a single row of holes with variable density ratio. *ASME Journal of Turbomachinery* 113 (3): 442 449.

Stathopoulos, T., and Y. Tominaga. 2007. Turbulent Schmidt numbers for CFD analysis with various type of flow field. *Atmospheric Environment* 41 (37): 8091 8099.

Sturgess, G. J., and K. R. McManus. 1984. *Calculation of turbulent mass transport in a bluff-body diffusion-flame combustor*. AIAA Paper 84-0372. American Institute of Aeronautics and Astronautics Aerospace Sciences Meeting, 22nd, Reno, NV, January 9 12.

Yimer, I., I. Campbell, and L. Y. Jiang. 2002. Estimation of the turbulent Schmidt number from experimental profiles of axial velocity and concentration for high-Reynolds-number jet flows. *Canadian Aeronautics and Space Journal* 48 (3): 195 200.

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CFD Calculation of Aerodynamic Indicial Functions for a Generic Fighter Configuration

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A reduced-order modeling of nonlinear and unsteady aerodynamics based on indicial (step) response functions and Duhamel's superposition integral is presented. These time-domain models could predict the unsteady aerodynamic responses of an aircraft performing any arbitrary motion over a wide range flight regime, but require calculating a large number of response functions. A method to efficiently reduce the number of indicial response calculations is tested. This method uses a time-dependent surrogate model (input/output mapping) to fit the relationship between flight conditions and response functions from a limited number of response simulations (samples). Each sample itself is directly calculated from unsteady computational fluid-dynamic simulations and a grid-motion tool. An important feature of this approach is uncoupling the effects of angle of attack and pitch rate from pitching motions. The aerodynamic models are then created with predicted indicial functions at each time instant using the surrogate model. This model is then applied for aerodynamics modeling of a generic fighter configuration performing arbitrary pitching and plunging motions at various Mach numbers. Results presented show that reduced-order models can accurately predict time-marching solutions of aircraft for a wide range of motions, but with the advantage that reduced-order model predictions require on the order of a few seconds once the model is created. The results also demonstrate that the surrogate model being tested aids in reducing the overall computational efforts to develop reduced-order models.

The unsteady aerodynamic forces and moments acting on a fast-maneuvering fighter aircraft can have a significant effect on the aircraft's calculated stability and control characteristics. Some observed unsteady aerodynamic phenomena include aircraft buffeting, wing rock, roll reversal, and directional instability (Pamadi 2004). The aeroelastic instabilities of flutter or limit-cycle oscillations are also associated with unsteady aerodynamic loads (Wright and Cooper 2008). Despite great efforts using the best available predictive capabilities, nearly every major fighter program since 1960 has had costly issues with nonlinear aerodynamic or fluid structure interactions that were not discovered until flight testing (Chambers and Hall 2004). Some recent aircraft that have experienced unexpected characteristics are the F/A-18, F-18E, and F-22 (Chambers and Hall 2004; Hall, Woodson, and Chambers 2005). The lack of a full understanding of unsteady aerodynamics typically leads to "cut and try" efforts, which result in very expensive and time-consuming solutions (Hall 2004). Current tools of computational fluid dynamics (CFD) have recently become credible for modeling unsteady nonlinear physics and hence would help to reduce the amount of wind-tunnel and flight testing required (Silva 1993). With advanced computing techniques, one straightforward way to calculate unsteady aerodynamics of a maneuvering aircraft is to develop a full-order mathematical model based on direct solution of the discretized Navier Stokes equations coupled with the dynamic equations governing the aircraft's motion (Ghoreyshi, Jirásek, and Cummings 2011). A full-order model for stability-and-control analysis is a computationally very expensive approach, since such a model requires a large number of coupled computations for different values of motion frequency and amplitude. An alternative approach to solving the full-order model is to develop a reduced-order model (ROM) that seeks to approximate CFD results by extracting information from a limited number of full-order simulations. Ideally, the specified ROM can predict aircraft responses over a wide range of amplitudes and frequencies in a fraction of a few seconds of computational time without the need of running CFD tools again.

This article considers the development of ROMs based on indicial functions that allow the prediction of pitching and plunging responses of a fighter aircraft within the space of frequency, amplitude, and Mach number. The transient aerodynamic response to a step change in a forcing parameter, such as angle of attack or pitch rate, is an indicial function. Assuming that the indicial functions are known, the aerodynamic forces and moments induced in any arbitrary maneuver can be estimated in the time domain by means of the well-known Duhamel's superposition integral (Leishman and Nguyen 1989). The indicial functions can be derived from analytical, CFD, or experimental methods (Librescu and Song 2006). Limited analytical expressions of indicial functions exist for two-dimensional airfoils. For incompressible flows, Wagner (1925) was the first to detail the analytical unsteady lift of a thin airfoil undergoing a plunging motion using a single indicial function (the so-called Wagner's function), with its exact values known in terms of Bessel functions. For unsteady, compressible flows past two-dimensional airfoils, Bisplinghoff, Ashley, and Halfman (1996) have also described an exponential approximation to the exact solutions of indicial functions at different Mach numbers. However, these analytical expressions are not valid for aircraft configurations.

The efforts to estimate the indicial functions for aircraft configurations can be classified into two groups: the direct and the indirect methods. Leishman (1993) has presented an indirect technique for identifying indicial functions from aerodynamic responses due to harmonic motions. However, the derived indicial functions using indirect methods depend largely on the quality of motion, e.g., amplitude, Mach number, and frequency. Experimental tests are limited for high frequencies and Mach numbers, and practically nonexistent for direct indicial-function measurements. An alternative is to use CFD, but special considerations are required to simulate step responses in CFD. Singh and Baeder (1997) used a surface-transpiration approach to directly calculate the indicial response due to angle of attack using CFD. Ghoreyshi, Jirásek, and Cummings (2012) have also proposed an approach based on grid motion for CFD-type calculation of indicial functions. In this article, the indicial functions of aircraft are calculated using the CFD and grid-motion approach. For motions at low angles of attack and assuming incompressible flow, only a single indicial function with respect to each forcing parameter needs to be generated (Leishman and Crouse, 1989). For compressible and high-angle-of-attack flows, many indicial functions need to be generated for different Mach numbers and angles of attack. The generation of all these functions using CFD is expensive and makes the creation of ROMs time consuming. Note that these models are still much cheaper than a brute-force approach, because the ROMs based on indicial functions eliminate the need to repeat calculations for each frequency.

A cost-effective unsteady-aerodynamic model needs a mathematical description of indicial functions as a function of angle of attack and Mach number. However, this model is often unavailable for three-dimensional configurations. It is more common to use surrogate models, which are mathematical approximations of the true response of the system built using some observed responses. By building surrogate models using a few observed responses, the total cost of modeling is reduced. In this article, a surrogate model is used based on the kriging technique to model indicial functions as a function of angle of attack and Mach number. In this article, the creation of reduced-order unsteady-aerodynamic models using indicial functions is reviewed. Next, the flow solver and an approach for CFD calculation of indicial functions are described. A surrogate model, built using some observed responses, is then described to approximate indicial function at new Mach numbers and angles of attack. The created ROM and the surrogate model are then used for aerodynamic predictions of a generic fighter configuration. The aircraft geometry and validation of CFD predictions are presented. Finally, the validity of ROMs is assessed by comparison of the model output with time-accurate CFD simulations.

Formulation

Reduced-order aerodynamics modeling

The problem of predicting unsteady lift and pitch moment responses of a generic fighter to pitching and plunging motions is considered. Assuming these motions could be started from different Mach numbers, the Mach number is held constant during each motion i.e., $\dot{V} = 0$. The unsteady and nonlinear aerodynamic models used in this work are based on aerodynamic indicial functions by using superposition integrals. Tobak and colleagues (Tobak and Chapman 1985; Tobak, Chapman, and Schiff 1984) and Reisenthel (Reisenthel 1997; Reisenthel and Bettencourt 1999) have detailed the superposition process for the modeling of unsteady lift and pitch moment from angle-of-attack and pitch-rate indicial functions. Following their work, the time responses in lift due to the step changes in angle of attack α and normalized pitch rate q are denoted as CL_α and C_{Lq}, respectively.

The unsteady-lift coefficient at time t is obtained by

$$C_L(t)=C_{L_0}(M)+\frac{d}{dt}\left[\int_0^t C_{L_\alpha}(t-\tau,\ \alpha,\ M)\alpha(\tau)d\tau\right]+\frac{d}{dt}\left[\int_0^t C_{Lq}(t-\tau,\ \alpha,\ M)q(\tau)d\tau\right], \tag{1}$$

where C_{L_0} denotes the zero-angle-of-attack lift coefficient (found from static calculations) and M denotes the free-stream Mach number. Note that the indicial response function with respect to the rate of change of velocity i.e., $\dot{V}$ is assumed to be small and is not modeled. Likewise, the time responses in pitch moment due to the step changes in α and q are denoted as $C_{m\alpha}$ and C_{mq}, and the pitch moment is estimated as follows:

$$C_m(t)=C_{m0}(M)+\frac{d}{dt}\left[\int_0^t C_{m\alpha}(t-\tau,\ \alpha,\ M)\alpha(\tau)d\tau\right]+\frac{d}{dt}\left[\int_0^t C_{mq}(t-\tau,\ \alpha,\ M)q(\tau)d\tau\right]. \tag{2}$$

The unsteady effects in drag force are assumed to be small and therefore are not discussed here. The response function due to pitch rate i.e., $C_{jq}(\alpha, M)$ for $j = L, m$ can be estimated using a time-dependent interpolation scheme from the observed responses. This value is next used to estimate the second integrals in Equations 1 and 2; however, the estimation of the integral with respect to the angle of attack needs more explanation. Assuming a set of angle-of-attack samples of $\alpha = [\alpha_1, \alpha_2, \ldots, \alpha_n]$ at free-stream Mach numbers of $M = [M_1, M_2, \ldots, M_m]$, the pitch moment response to each angle of α_i, where $i = 1, 2, \ldots, n$, at Mach numbers of M_j, where $j = 1, 2, \ldots, m$, is denoted as $A_\alpha(\mathrm{t}, \alpha_i, M_j)$. In these response simulations, $\alpha(t) = 0$ at $t = 0$ and is held constant at α_i for all $t > 0$. For a new angle of $\alpha^* > 0$ at a new free-stream Mach number of M^*, the responses of $A_\alpha(t, \alpha_k, M^*)$ are interpolated at $\alpha_k = [\alpha_1, \alpha_2, \ldots, \alpha_s]$, such that $0 < \alpha_1 < \alpha_2 < < \alpha_s$ and $\alpha_s = \alpha^*$. These angles can have a uniform or nonuniform spacing. The indicial functions of $C_{j\alpha k}$ for $k = 1, \ldots, s$ at each interval of $[\alpha_{k\ 1}, \alpha_k]$ are defined as

$$C_{j\alpha_1}=\frac{A_\alpha(t,\ \alpha_1,\ M^*)-C_{j0}(M^*)}{\alpha_1} \tag{3}$$

and

$$C_{j\alpha_k}=\frac{A_\alpha(t,\ \alpha_k,\ M^*)-A_\alpha(t,\ \alpha_{k\ \ 1},\ M^*)}{\alpha_k-\alpha_{k\ \ 1}}, \tag{4}$$

where C_{j0} denotes the zero-angle-of-attack pitch moment coefficient. The interval indicial functions are then used to estimate the values of the first integrals in Equations 1 and 2. These steps can easily be followed for a negative angle of attack, i.e., $\alpha^* < 0$. The functions of $C_{L\alpha}(t, \alpha, M)$, $C_{m\alpha}(t, \alpha, M)$, $C_{Lq}(t, \alpha, M)$, and $C_{mq}(t, \alpha, M)$ are unknown and will be determined in this article using CFD with a grid-motion approach, along with a time-dependent surrogate model.

CFD solver

The flow solver used for this study is the commercially-available flow solver Cobalt (Strang, Tomaro, and Grismer 1999), which solves the unsteady, three-dimensional, and compressible Navier Stokes equations in an inertial reference frame. These equations in integral form are

$$\frac{\partial}{\partial t}\iiint \mathbf{Q}\,dV+\iint\left(\mathbf{f}\hat{i}+\mathbf{g}\hat{j}+\mathbf{h}\hat{k}\right).\hat{n}\,dS=\iint\left(\mathbf{r}\hat{i}+\mathbf{s}\hat{j}+\mathbf{t}\hat{k}\right).\hat{n}\,dS, \tag{5}$$

where V is the volume of the fluid element; S is the surface area of the fluid element; $\hat{n}$ normal to S; $\hat{i}, \hat{j}$, and $\hat{k}$ are the Cartesian unit vectors; and $\mathbf{Q} = (\rho, \rho u, \rho v, \rho w, \rho e)^T$ is the vector of conserved variables, where ρ represents air density, u, v, and w are velocity components, e is the specific energy per unit volume, and the superscript T denotes the transpose operation (Da Ronch et al. 2012). The vectors of $\mathbf{f}$, $\mathbf{g}$, and $\mathbf{h}$ represent the inviscid components:

$$\begin{aligned}
\mathbf{f}&=\left[\rho u,\rho u^2+p,\rho uv,\rho uw,u(\rho e+p)\right]^T,\\
\mathbf{g}&=\left[\rho v,\rho v^2+p,\rho vu,\rho vw,v(\rho e+p)\right]^T,\\
\mathbf{h}&=\left[\rho w,\rho w^2+p,\rho wu,\rho wv,w(\rho e+p)\right]^T.
\end{aligned} \tag{6}$$

The vectors of $\mathbf{r}$, $\mathbf{s}$, and $\mathbf{t}$ represent the viscous components:

$$\begin{aligned}
\mathbf{r}&=\left(0,\tau_{xx},\tau_{xy},\tau_{xz},u\tau_{xx}+v\tau_{xy}+w\tau_{xz}+kT_x\right)^T,\\
\mathbf{s}&=\left(0,\tau_{xy},\tau_{yy},\tau_{yz},u\tau_{xy}+v\tau_{yy}+w\tau_{yz}+kT_y\right)^T,\\
\mathbf{t}&=\left(0,\tau_{xz},\tau_{zy},\tau_{zz},u\tau_{xz}+v\tau_{zy}+w\tau_{zz}+kT_z\right)^T,
\end{aligned} \tag{7}$$

where τ_{ij} are the viscous stress tensor components, T is the temperature, and k is the thermal conductivity. The ideal gas law and Sutherland's law close the system of equations, and the entire equation set is nondimensionalized by free-stream density and speed of sound (Strang, Tomaro, and Grismer 1999). The Navier Stokes equations are discretized on arbitrary grid topologies using a cell-centered finite volume method. Second-order accuracy in space is achieved using the exact Riemann solver of Gottlieb and Groth (1998) and least-squares gradient calculations using QR factorization. To accelerate the convergence solution of the discretized system, a point-implicit method using analytic first-order inviscid and viscous Jacobians is used. A Newtonian subiteration method is used to improve the time accuracy of the point-implicit method. Tomaro, Strang, and Sankar (1997) converted the code from explicit to implicit, enabling Courant Friedrichs Lewy numbers as high as 10^6. The Cobalt solver has been used at the Air Force Seek Eagle Office and the United States Air Force Academy for a variety of unsteady nonlinear aerodynamic problems of maneuvering aircraft (Forsythe, Hoffmann, et al. 2002; Forsythe, Squires, et al. 2004; Forsythe and Woodson 2005; Jeans et al. 2009; Morton et al. 2002).

CFD calculation of indicial functions

In this article, the indicial functions are directly calculated from Unsteady Reynolds-Averaged Navier Stokes (URANS) simulations using a grid-motion tool. Cobalt, the flow solver used, uses an arbitrary Lagrangian Eulerian formulation and hence allows all translational and rotational degrees of freedom (Ghoreyshi, Jirásek, and Cummings 2012). The code can simulate both free and specified motions with six degrees of freedom. The rigid motion is specified from a motion input file. For the rigid motion, the location of a reference point on the aircraft is specified at each time step. In addition, the rotation of the aircraft about this reference point is also defined using the rotation angles of yaw, pitch, and roll (bank). The aircraft reference-point velocity V_a in an inertial frame is then calculated to achieve the required angles of attack and sideslip, and the forward speed. The velocity is then used to calculate the location. The initial aircraft velocity V_0 is specified in terms of Mach number, angle of attack, and sideslip angle in the main file. The instantaneous aircraft location for the motion file is then defined from the relative velocity vector V_a V_0. For CFD-type calculation of a step change in angle of attack, the grid immediately starts to move at $t = 0$ to the right and downward, as shown in *Figure 1*. The translation continues over time with a constant velocity vector. Since there is no rotation, all the effects on aerodynamic loads are from changes in the angle of attack. For a unit step change in pitch rate, the grid moves and rotates simultaneously. The grid starts to rotate with a unit pitch rate at $t = 0$. To hold the angle of attack at zero during the rotation, the grid moves right and upward in *Figure 1*. All indicial function computations started from a steady-state solution and then advanced in time using second-order accuracy with five Newton subiterations. The steady-state solutions correspond to a zero-degree angle of attack and sideslip for the Mach number of interest.

Surrogate-based modeling of indicial functions

Having an ROM to predict the aerodynamic responses to any arbitrary motion over a wide flight regime could become a very expensive approach, because a large number of indicial functions need to be computed. In order to achieve a reasonable computational cost, a special time-dependent surrogate-based modeling approach is adapted to predict indicial responses for a new point from available (observed) responses. These observed responses are viewed as a set of time-correlated spatial processes where the output is considered a time-dependent function. Romero et al. (2004) have developed a framework for multistage Bayesian surrogate models for the design of time-dependent systems and tested their model for free vibrations of a mass-spring-damper system assuming the input parameters of stiffness and damping factor at different initial conditions. This framework is examined for reduced-order modeling of nonlinear and unsteady aerodynamic loads. Assume an input vector of $\mathbf{x}(t) = [x_1(t), x_2(t), \ldots, x_n(t)]$, where n represents the dimensionality of the input vector. To construct a surrogate model for fitting the input output relationship, the unsteady aerodynamic responses corresponding to a limited number of input parameters (training parameters or samples) need to be generated. Design-of-experiment methods, for example, can be used to select m samples from the input space. The input matrix $\mathbf{D}(m \times n)$ is then defined as

$$\mathbf{D} = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix}, \tag{8}$$

where rows correspond to different combinations of the design parameters. For each row in the input matrix, a time-dependent response was calculated at p discrete values of time; this information is summarized in the output matrix of $\mathbf{Z}(m \times p)$ as

$$\mathbf{Z} = \begin{bmatrix} y_{11} & y_{12} & \cdots & y_{1p} \\ y_{21} & y_{22} & \cdots & y_{2p} \\ \vdots & \vdots & \ddots & \vdots \\ y_{m1} & y_{m2} & \cdots & y_{mp} \end{bmatrix}, \tag{9}$$

where for modeling of aerodynamic loads, p equals the number of iterations used in time-marching CFD calculations. The objective of surrogate modeling is to develop a model that allows prediction of the aerodynamic response of $\mathbf{y}(\mathbf{x}_0) = (y_{01}, y_{02}, \ldots, y_{0p})$ at a new combination of input parameters $\mathbf{x}_0$. To

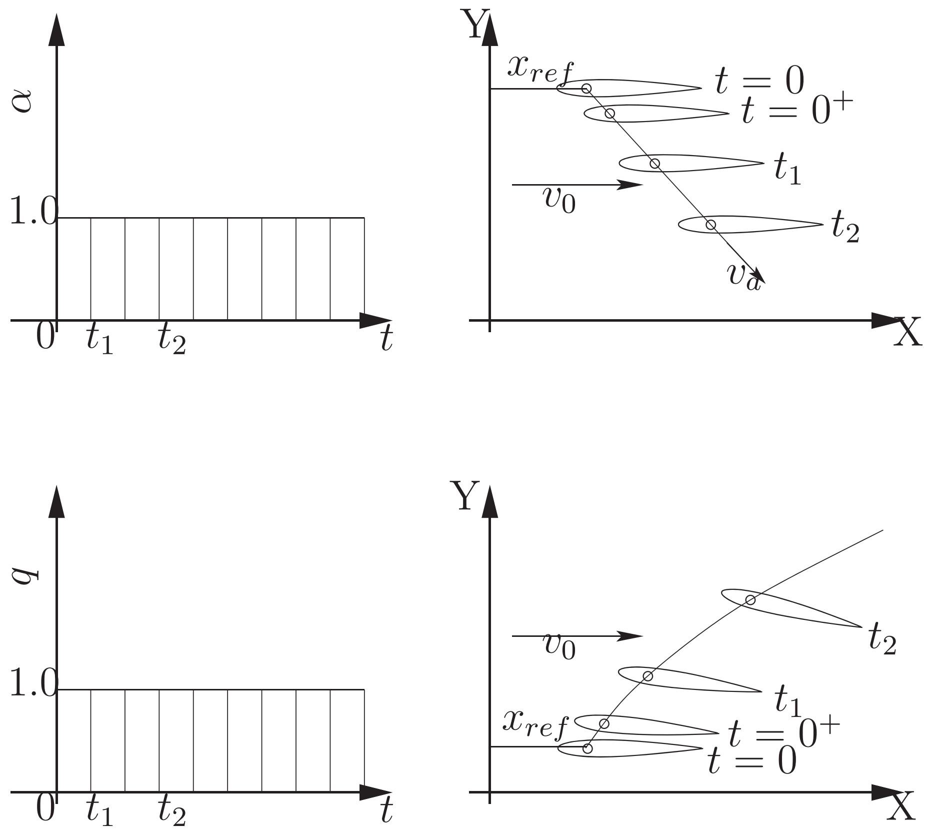


Figure 1. The grid motion for modeling a step change in angle of attack and pitch rate.

construct this surrogate model, the responses at each time step are assumed as a separate set, such that each column of the output matrix is a partial realization of the total response. In this sense, p surrogate models are created; they are denoted as $\mathbf{Z}_i(\mathbf{D})$ for $i = 1, 2, \ldots, p$. A universal-type kriging function (Ghoreyshi, Badcock, and Woodgate 2009) is used to approximate these models. Each $\mathbf{Z}_i(\mathbf{D})$ function can be approximated as the sum of a deterministic mean (trend) μ and a zero-mean spatial random process of ε with a given covariance structure of σ^2; therefore each function value at the new sample of $\mathbf{x}_0$ is

$$\tilde{\mathbf{Z}}_i(\mathbf{x}_0) = \mu + \epsilon, \tag{10}$$

where the tilde shows that the surrogate model is an approximation of the actual function. Universal kriging, which is used in this article, assumes that the mean value μ is a linear combination of known regression functions of $\mathbf{f}_0(x)$, $\mathbf{f}_1(x)$, . . . , $\mathbf{f}_n(x)$. In this article, the linear functions are used; therefore, $\mathbf{f}_0(x) = 1$ and $\mathbf{f}_j(x) = x_j$ for $j = 1, 2, \ldots, n$. This changes Equation 10 to

$$\tilde{\mathbf{Z}}_i(\mathbf{x}_0) = \sum_{j=0}^{n} \beta_{ij} \mathbf{f}_j(\mathbf{x}_0) + \epsilon, \tag{11}$$

where β_{ij} represent the regression coefficient for the jth regression function of the response function at time step $i = 1, 2, \ldots, p$. To estimate the spatial random process of ε, a spatially weighted distance formula is defined between samples given in matrix $\mathbf{D}$ such that for sample $\mathbf{x}_i$ and $\mathbf{x}_j$, the distance is written as

$$d(\mathbf{x}_i, \mathbf{x}_j) = \sum_{h=1}^{n} \theta_h \left| x_h^{(i)} - x_h^{(j)} \right|^{p_h}, \tag{12}$$

where the vertical bars indicate the Euclidean distance, the parameter $\theta_h \geq 0$ expresses the importance of the hth component of the input vector, and the exponent p_h ($\in [0, 1]$) is related to the smoothness of the function in the coordinate direction h. A correlation matrix $\mathbf{R}(m \times m)$ with a Gaussian spatial random process is then defined as

$$\mathbf{R} = \begin{bmatrix} \exp\left[\frac{d(\mathbf{x}_1,\mathbf{x}_1)}{\sigma^2}\right] & \exp\left[\frac{d(\mathbf{x}_1,\mathbf{x}_2)}{\sigma^2}\right] & \cdots & \exp\left[\frac{d(\mathbf{x}_1,\mathbf{x}_m)}{\sigma^2}\right] \\ \vdots & \vdots & \ddots & \vdots \\ \exp\left[\frac{d(\mathbf{x}_m,\mathbf{x}_1)}{\sigma^2}\right] & \exp\left[\frac{d(\mathbf{x}_m,\mathbf{x}_2)}{\sigma^2}\right] & \cdots & \exp\left[\frac{d(\mathbf{x}_m,\mathbf{x}_m)}{\sigma^2}\right] \end{bmatrix}. \tag{13}$$

To compute the kriging model, values must be estimated for β_{ij}, α, θ_h, and p_h. These parameters can be quantified using the maximum-likelihood estimator, as described by Jones, Schonlau, and Welch

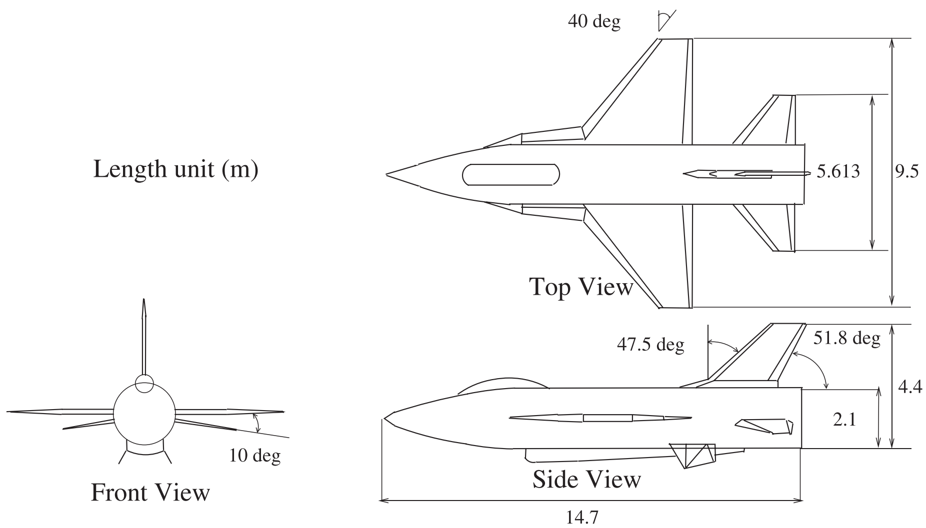


Figure 2. Standard Dynamic Model (SDM) layout (Huang 2000).

(1998). Next the vector of $\mathbf{R}(m \times 1)$ is defined from correlations between the new design parameter $\mathbf{x}_0$ and the m sample points, based on the distance formula in Equation 12:

$$\mathbf{r} = \begin{bmatrix} \exp\left[-\dfrac{d(\mathbf{x}_1,\mathbf{x}_0)}{\sigma^2}\right] \\ \exp\left[-\dfrac{d(\mathbf{x}_2,\mathbf{x}_0)}{\sigma^2}\right] \\ \vdots \\ \exp\left[-\dfrac{d(\mathbf{x}_m,\mathbf{x}_0)}{\sigma^2}\right] \end{bmatrix}. \tag{14}$$

Now $\widetilde{\mathbf{Z}}_i(\mathbf{x}_0)$ can be estimated as

$$\widetilde{\mathbf{Z}}_i(\mathbf{x}_0) = \sum_{j=0}^{n} \beta_{ij}\mathbf{f}_j(\mathbf{x}_0) + \mathbf{r}^T\mathbf{R}^{-1}[\mathbf{Z}_i(\mathbf{D}) - \mathbf{F}\beta], \tag{15}$$

where β is the $n + 1$ dimensional vector of regression coefficients; $\mathbf{Z}_i(\mathbf{D})$ is the observed responses at time step $i = 1, 2, \ldots, p$; and matrix $\mathbf{F}$ is

$$\mathbf{F} = \begin{bmatrix} \mathbf{f}_0(x_1) & \mathbf{f}_1(x_1) & \cdots & \mathbf{f}_\mathbf{n}(x_1) \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{f}_0(x_m) & \mathbf{f}_1(x_m) & \cdots & \mathbf{f}_\mathbf{n}(x_m) \end{bmatrix}. \tag{16}$$

The total response at $\mathbf{x}_0$ is then a combination of the predicted values of each surrogate model:

$$\tilde{\mathbf{Z}}(\mathbf{x}_0) = \left[\tilde{\mathbf{Z}}_1(\mathbf{x}_0), \tilde{\mathbf{Z}}_2(\mathbf{x}_0), \ldots, \tilde{\mathbf{Z}}_p(\mathbf{x}_0)\right]. \tag{17}$$

Test case

The Standard Dynamics Model (SDM) is a generic fighter configuration based on the F-16 platform. The model includes a slender strake-delta wing, horizontal and vertical stabilizers, ventral fins, and a blocked-off inlet section. The three-view drawing is shown in *Figure 2*. This geometry has been tested extensively at various wind-tunnel facilities to collect wind-tunnel data (Balakrishna and Niranjana 1987; Beyers 1984; Jermey and Schiff 1985). Note that slightly different geometries were used in previous studies.

The lifting surfaces (strake, wing, and tail) have a thin airfoil with sharp leading edges. This enforces a fixed separation point in the leading edge and the formation of vortices over the surface. The vortex-induced suction pressure accounts for the additional lift, named vortex lift, which helps to delay stalling. The complex interaction of strake and wing vortices creates very nonlinear aerodynamic characteristics. Also, at high angles of attack, these vortices break down and cause a sudden reduction in lift. The forward

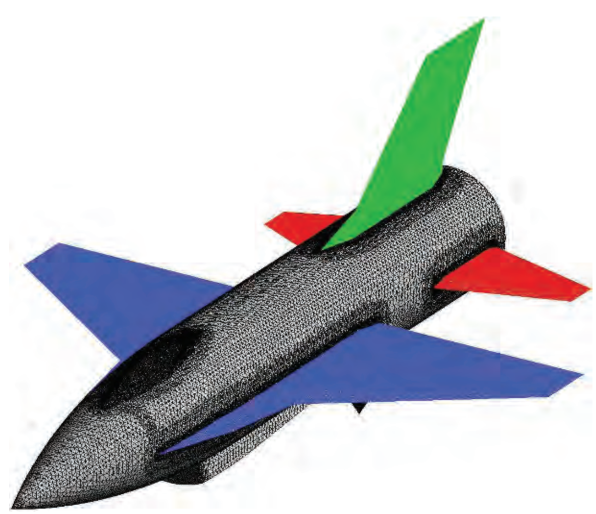


Figure 3. The SDM aircraft-surface mesh model.

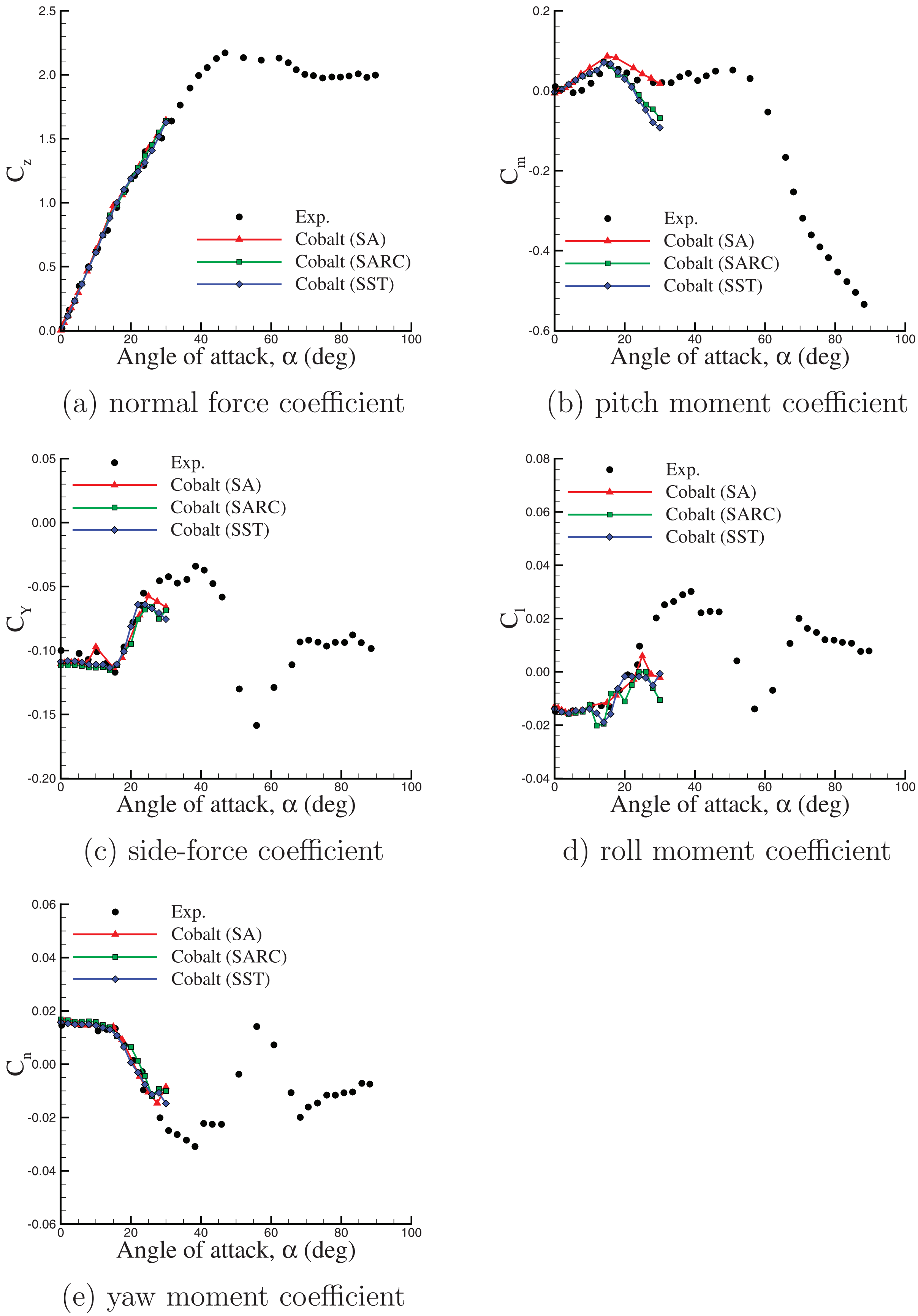
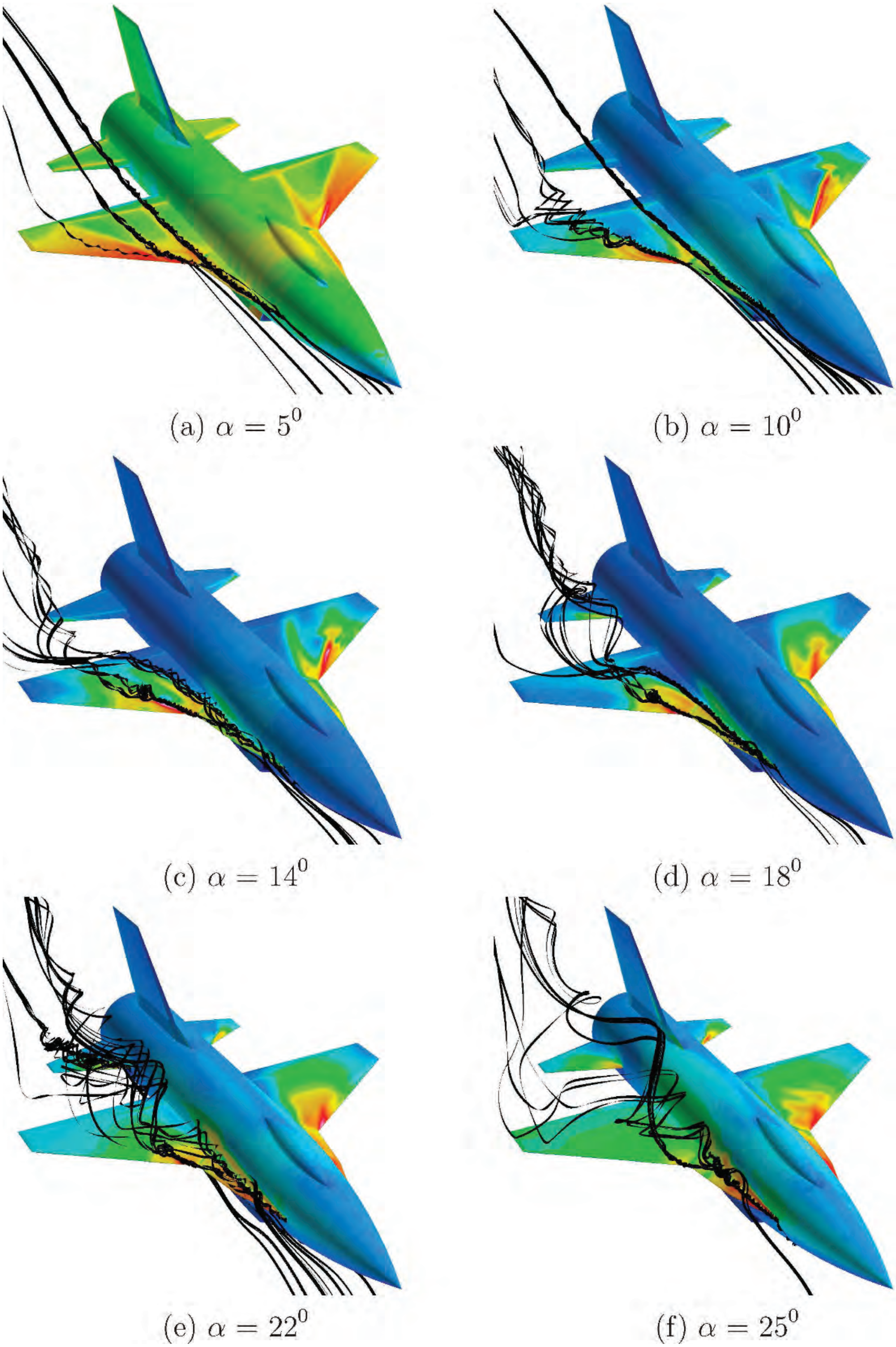


Figure 4. Static aerodynamic predictions at V_0 100 m/s and β β is side-slip angle.



(a) $\alpha = 5^0$ (b) $\alpha = 10^0$

(c) $\alpha = 14^0$ (d) $\alpha = 18^0$

(e) $\alpha = 22^0$ (f) $\alpha = 25^0$

Figure 5. SDM flow-field visualization. The calculations are for a Mach number of 0.3 and β 5 using the SARC turbulence model.

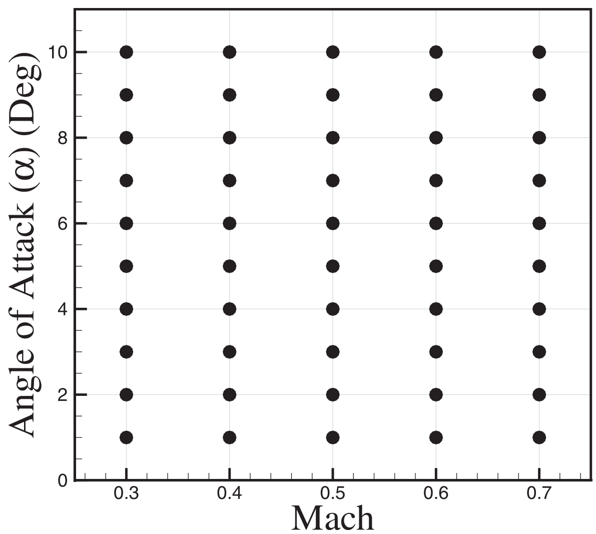


Figure 6. Design samples.

movement of vortex breakdown has significant effects on the pitching moment. Validation of CFD codes for predicting these effects can be a very challenging task.

In this article, only unsteady RANS calculations are used. A full-span geometry mesh is available, shown in *Figure 3*. The mesh was generated in two steps. In the first step, the inviscid tetrahedral mesh was generated using the ICEM CFD code. This mesh was then used as a background mesh by TRITET (Tyssel 2000a, 2000b), which builds prism layers using a frontal technique. TRITET rebuilds the inviscid mesh while respecting the size of the original inviscid mesh from ICEM CFD. The full-span geometry mesh consists of a nine-million-point mesh and 19.5 million cells.

Results

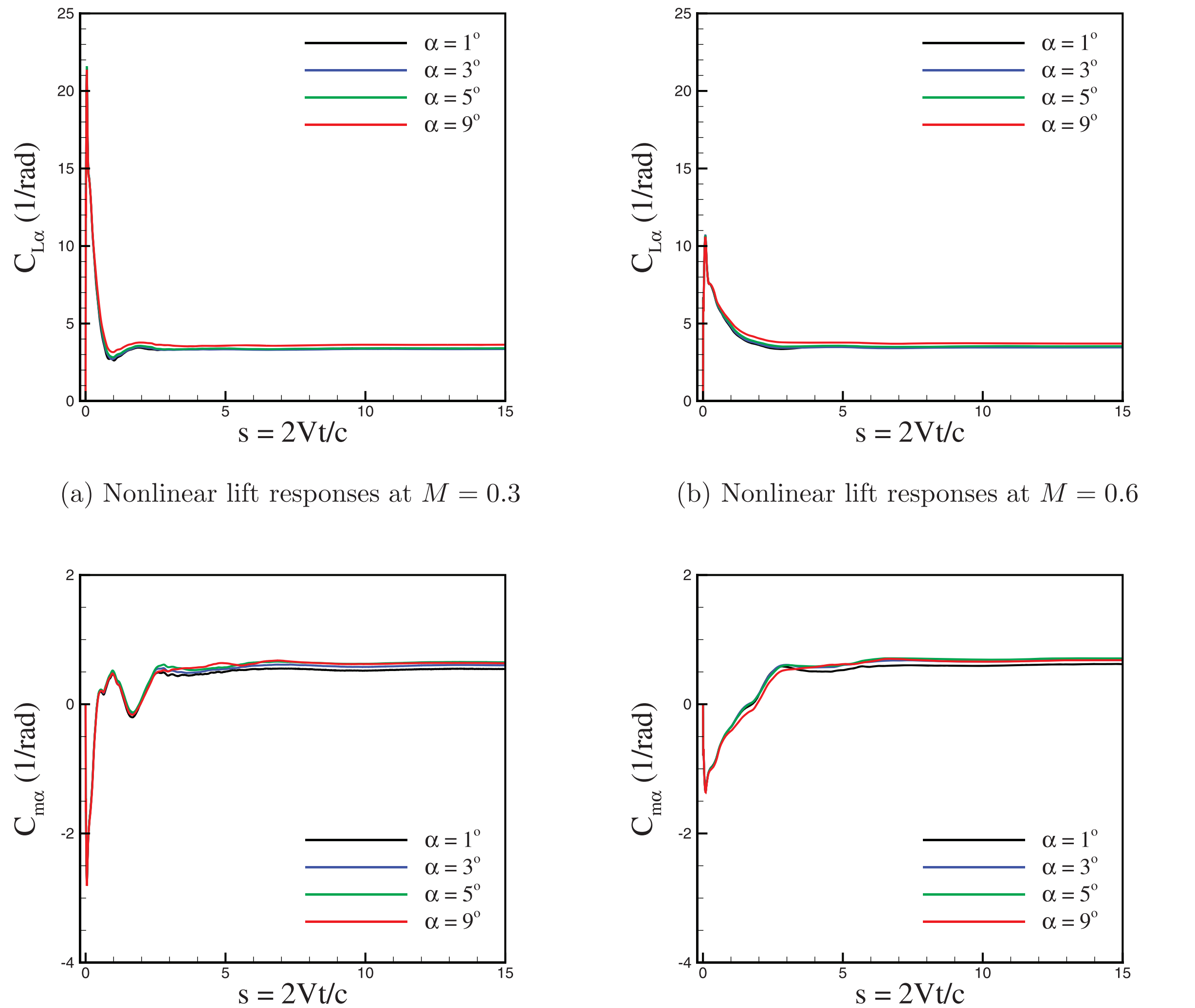
Static predictions

Wind-tunnel experiments (Huang 2000) were first used to validate the CFD predictions at low speed. The conditions of the tests were $V = 110$ m/s, Re = 0.57 million (Re=Reynolds number), and $\beta = 5^\circ$ for $\alpha = 0$ to 90°. All CFD simulations were run at free-stream conditions consistent with flow conditions in wind-tunnel tests. For the flow solution, RANS equations are discretized by second-order spatial and temporal operators. The turbulence models used are Spalart Allmaras (Spalart and Allmaras 1992), Spalart Allmaras with rotation/curvature correction (SARC; Spalart and Schur 1997), and Menter's (1994) shear stress transport (SST). The relatively low-cost Spalart Allmaras model is the most popular one-equation turbulence model for flows with an attached boundary layer (McCallen, Browand, and Ross 2004), but the model has a large viscosity in the core of vortices that results in diffusion of the vortex structure (Schröder 2010). On the other hand, the SARC model provides a lower eddy viscosity for vortical flow predictions (Schröder 2010). The SST model is a hybrid k ε and k ω turbulence model (Morton, Cummings, and Kholodar 2004). Typical ε ω models are well behaved in the near-wall region, where low-Reynolds-number corrections are not required. However, they are generally sensitive to the free-stream values of ω. On the other hand, k ε models are relatively insensitive to free-stream values, but behave poorly in the near-wall region. The SST model uses a parameter F_1 to switch from k ω to k ε in the wake region to prevent the model from being sensitive to free-stream conditions (Morton, Cummings, and Kholodar 2004).

All simulations were computed on an unstructured mesh with prisms in the boundary layer and tetrahedra elsewhere on full-span geometry. The cases were run on the Cray XE6 and Cray XE6 (open system) machines at the Engineering Research Development Center (Garnet, with 2.7 GHz core speed, and Chugach, with 2.3GHz core speed), which have approximately 20,000 and 11,000 cores, respectively. The total run times of 1,000 iterations using 128 processors for the SARC and SST turbulence models were 5 and 6 hours, respectively. The static force and moment coefficients are compared with experiments in *Figure 4*.

The comparisons show that there is a good agreement between RANS predictions and the measurements for angles of attack below 25 degrees. However, all turbulence models predict a positive pitch moment slope at zero degrees, while experiments show a falling trend at this angle. This is likely due to different inlet geometries in wind-tunnel and free-flight models. At five degrees, a pair of vortices emanating from strake and wing leading edge have formed, as shown in *Figure 5(a)*. These vortices do not exhibit breakdown and do not interact over the airframe. The vortex formation causes additional increase of lift and pitch moment coefficients. In experimental tests, the sign of pitch moment is reversed at this angle, while CFD shows a jump in the moment rate of increase. No significant changes in lateral force and moment coefficients were observed at this angle.

The vortices grow in size and strength with increasing angle of attack. At 10 degrees, the center of a vortex of the wing is shifted laterally while the shedding point is moved forward, as shown in *Figure 5(b)*. There are still no signs of vortex breakdown. The lateral moments slightly change due to the movement of the wing vortex. Around 14 degrees, the two vortices wind around each



(a) Nonlinear lift responses at $M = 0.3$

(b) Nonlinear lift responses at $M = 0.6$

(c) Nonlinear pitch moment responses at $M = 0.3$

(d) Nonlinear pitch moment responses at $M = 0.6$

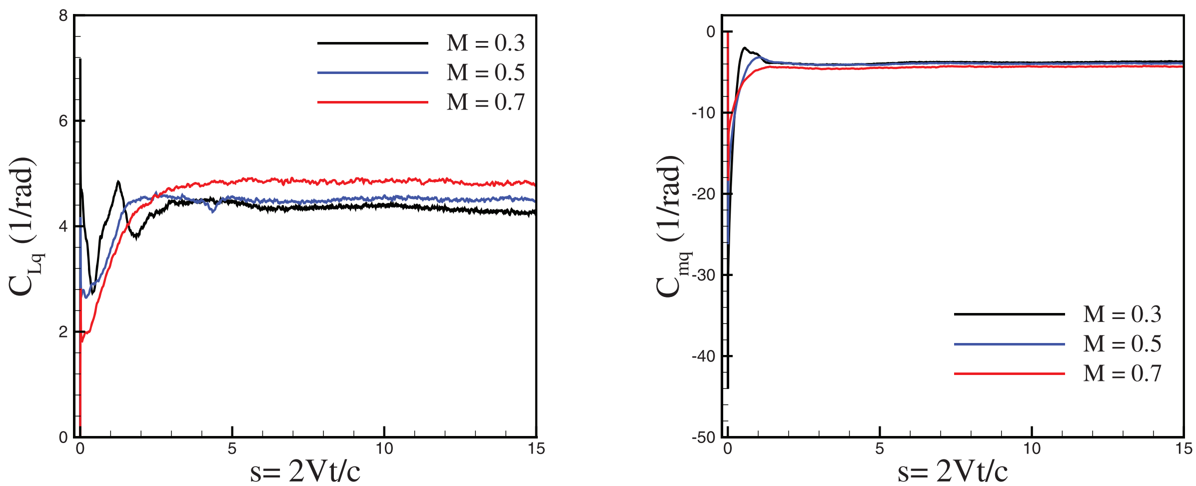
Figure 7. Nonlinear lift and pitch moment indicial solutions due to angle of attack for M 0.3 and 0.6.

other toward the trailing edge of the wing, as shown in *Figure 5(c)*. With a slight increase in angle of attack, the wing vortex appears to break down quickly, as shown in *Figure 5(d)*. The vortex breakdown leads to a smaller rate of increase in lift and a negative pitch moment slope.

The vortex-breakdown phenomenon is asymmetric, and hence the lateral force and moment coefficients suddenly start to change very fast. At 22 degrees, the strake vortex is also burst, as shown in *Figure 5(e)*. Finally, at 25 degrees there is no sign of a wing vortex, as shown in *Figure 5(f)*.

Calculation of indicial functions

The indicial response functions in this article are interpolated from some available samples in the space of angle of attack and free-stream Mach number. Note that these functions only need to have dependency on angle of attack and Mach number, and once they have been calculated they can be used to predict the aerodynamic response to any frequency of interest. The samples could be generated using methods of factorial designs, Latin hypercube sampling, low-discrepancy sequences, or designs based on statistical optimality criteria (A-, D- and G-optimal designs; Mackman et al 2011). Factorial designs are extremely simple to construct and have been used in this work. The considered SDM motions encompass α and M values in the ranges of [10°, 10°] and [0.3, 0.7], respectively. Assuming symmetrical flow solutions with respect to the angle of attack, the indicial functions are only calculated for positive angles of attack. A set of samples including 50 points is defined on the α and M space



(a) Pitch rate lift indicial functions (b) Pitch rate pitch moment indicial functions

Figure 8. Lift and pitch moment indicial solutions due to pitch rate for α $0°$. The pitch axis and moment reference point are located at 35 percent Mean Aerodynamic Center (MAC).

using factorial design; these points are shown in *Figure 6*. The indicial functions are calculated using the CFD and grid-motion approach for each sample condition. All these calculations started from a steady-state solution such that the Mach number in the steady-state simulations corresponds to each sample Mach number. For the indicial functions due to angle of attack, the steady-state angle of attack is set to zero degrees, but for the indicial functions due to pitch rate, the steady angle of attack

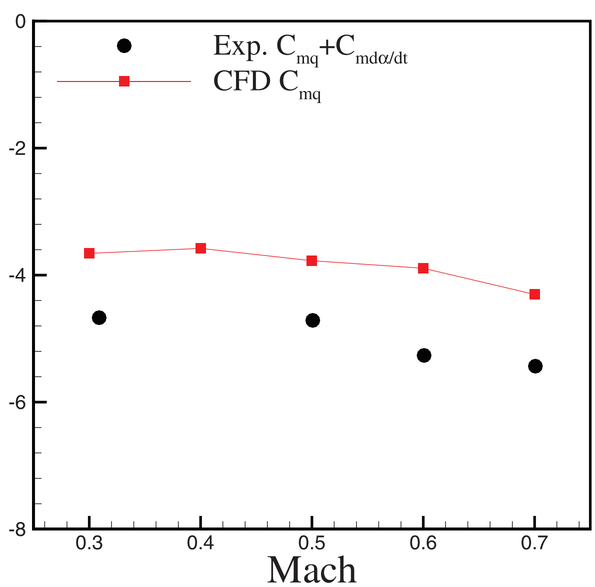


Figure 9. Validation of C_{mq} values calculated from pitch-rate indicial functions. Experimental data are from Da Ronch et al. (2012).

corresponds to each sample α. The step-function calculations are second order in time with a nondimensional time step of $\Delta t^* = \Delta t.V/c = 0.01$. For more details on time-step selection, the reader is referred to the work of Cummings, Morton, and McDaniel (2008).

The calculated indicial functions due to angle of attack are shown in *Figure 7* for $M = 0.3$ and $M = 0.6$. *Figures 7(a)* and *7(b)* show that the indicial lift has a peak at $s = 0$ followed by a rapidly falling trend. The lift again builds up and asymptotically reaches the steady-state value. The pitch moment has a negative peak at $s = 0$, as shown in *Figures 7(c)* and *7(d)*. The initial peak can be explained based on the energy of acoustic-wave systems created by the initial perturbation (Ghoreyshi and Cummings 2012). The most obvious difference between responses at low and high speeds is that the initial peak becomes smaller for higher speeds. An explanation is given by Leishman (1993): this is due to the propagation of pressure disturbances at the speed of sound, as compared with the incompressible case, where the disturbances propagate at infinite speed. *Figure 7* also shows that the initial values of the indicial functions are invariant with angle of attack, but the intermediate trend and steady-state values change depending on the angle of attack. Although the final values of indicial lift are nearly unchanged for angles of attack below five degrees, the pitch moment's final values are different even at small angles of attack, due to vortices on the wing.

The effects of Mach number on the lift and pitch moment indicial functions are shown in *Figure 8*. As with angle-of-attack response, the lift and pitch

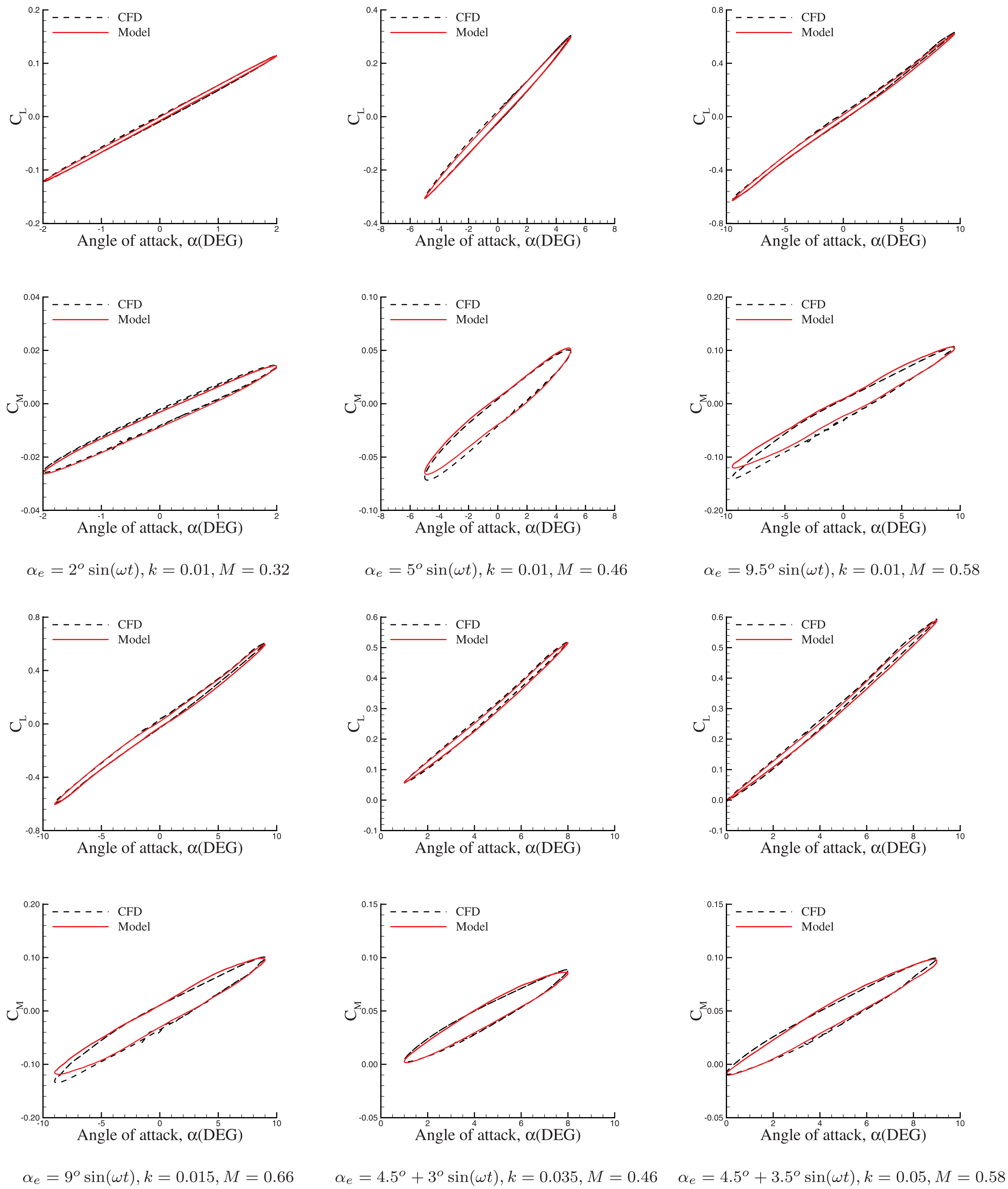
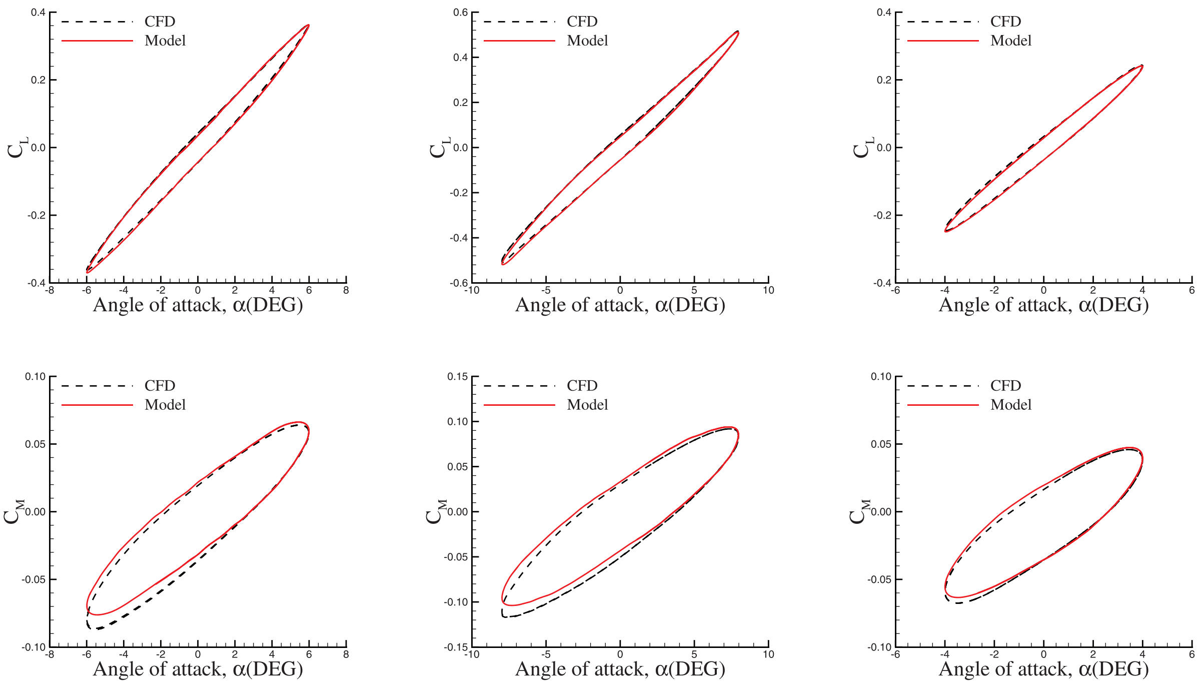
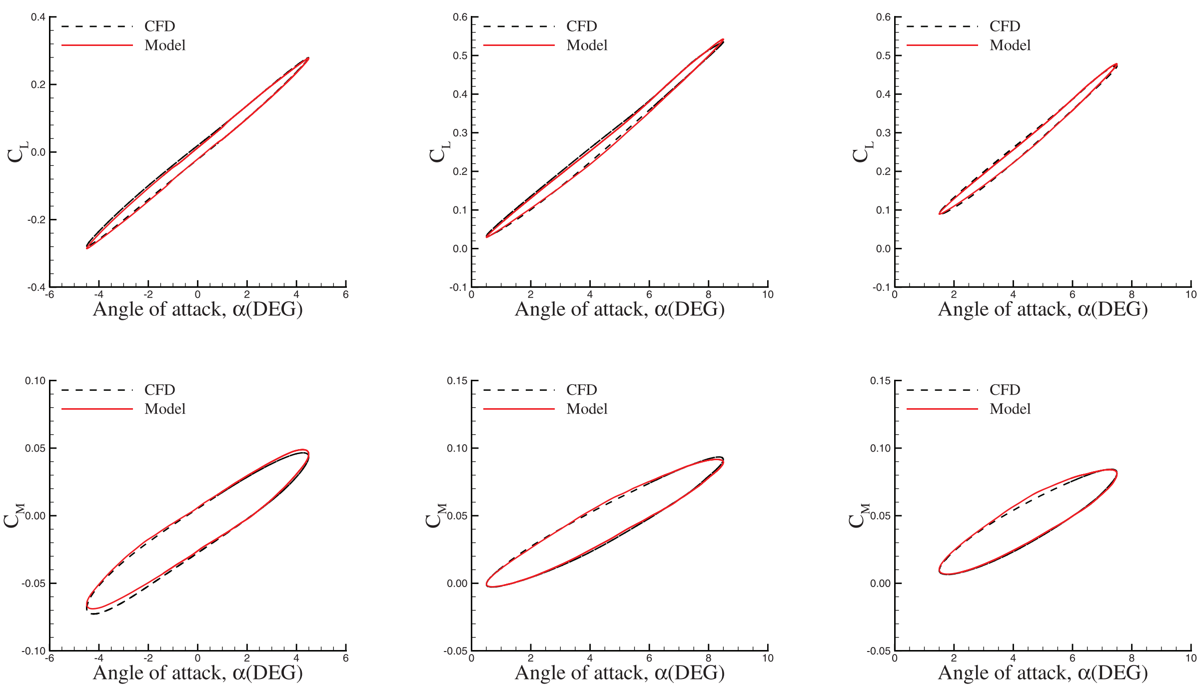


Figure 10. ROM prediction of plunging motions. In above ω is angular velocity and k is reduced frequency.

moment have initial peaks due to the initial perturbations and asymptotically reach the steady-state value. *Figure 8* shows that increasing Mach numbers result in the increase of steady-state C_{Lq} and the decrease of steady-state C_{mq} (the so-called pitch-damping derivative). *Figure 9* compares the steady-state C_{mq} values calculated from the CFD code with the out-of-phase components of pitch moment derivative i.e., $C_{mq} + C_{m\dot{\alpha}}$ measured at different Mach numbers and zero angle of attack; these experimental data are detailed by Da Ronch et al. (2012). Like the static predictions, the CFD values slightly underestimate



$\alpha = 6^o \sin(\omega t), k = 0.02, M = 0.32$ $\alpha = 8^o \sin(\omega t), k = 0.025, M = 0.46$ $\alpha = 4^o \sin(\omega t), k = 0.05, M = 0.58$



$\alpha = 4.5^o \sin(\omega t), k = 0.015, M = 0.66$ $\alpha = 4.5^o + 4^o \sin(\omega t), k = 0.02, M = 0.37$ $\alpha = 4.5^o + 3^o \sin(\omega t), k = 0.035, M = 0.46$

Figure 11. ROM prediction of pitching motions.

the experimental pitch moment data, although the CFD data do not include the effects of rate of change of angle of attack, i.e., $C_{m\dot{\alpha}}$. Typically, C_{mq} is the largest factor in the sum $C_{mq} + C_{m\dot{\alpha}}$, typically accounting for 90 percent of the sum. Again, the underestimation of experimental data is likely due to different inlet geometries in the wind-tunnel and the SDM geometry used. Note that the indicial-function approach allows the direct calculation of pitch-damping derivatives, but extraction of dynamic derivatives from harmonic motions results in the in-phase and out-of-phase components (Leishman 1993), requiring additional work to separate each derivative from these components.

ROM predictions

A ROM is now created along with a time-dependent surrogate model to determine the terms in Equations 1 and 2 at each time step. The validity of the ROM is tested for several arbitrary pitching and plunging motions. These motions start from different steady-state conditions (not being used at sample design) and run for different amplitudes and frequencies. Note that the plunge motions have no rotation, but the angle of attack changes due to the vertical displacements of the grid; this angle is named the effective angle of attack, denoted by α_e:

$$\alpha_e = \tan^{-1}\left(\frac{\dot{h}}{V}\right), \tag{18}$$

where $\dot{h}$ shows the vertical displacement of the grid and V is the free-stream velocity. The maximum effective angle of attack for a plunge starting at a zero-degree angle of attack is determined by the Strouhal number, St $= 2fH/V$, such that $\alpha_e^{\max} = \tan^{-1}(\pi \mathrm{St})$, where f is the frequency and H is the plunge amplitude. The ROM predictions are compared with time-accurate CFD simulations in *Figures 10 and 11*. The time-accurate solutions are labeled as "CFD" in the plots. *Figures 10 and 11* show that the ROM lift and pitch moment predictions agree well with the full-order CFD simulation values. Small discrepancies are found in the pitch moment predictions at negative angles of attack. This is likely due to the fact that SDM pitch moment is not symmetric with angle of attack, and hence the response functions generated at positive angles cannot predict the slope changes correctly. Note that the average cost of generating each full-order simulation is around 1,280 CPU hours, while the ROM predictions require on the order of a few seconds.

Conclusions

The use of indicial functions for unsteady- and nonlinear-aerodynamics modeling of a generic fighter configuration was investigated in this article. Only the longitudinal aerodynamic forces and moments were considered; thus, the aircraft responses corresponding to a step change in angle of attack and pitch rate were found. The step functions were calculated using a CFD and grid-motion approach for a set of samples defined in the space of angle of attack and Mach number. The results show that indicial functions have a peak response at initial time steps. This is related to a traveling acoustic wave formed by the flow disturbance. At higher Mach numbers, the peak values are diminished due to compressibility. A time-dependent surrogate model was used to interpolate these functions for the new conditions. The ROMs were tested by comparison of the model output with time-accurate CFD simulations for several motions. The results show that predictions agree well with full-order CFD simulation values. Future work will extend this study to include samples generated by Latin hypercube sampling and generate ROMs for maneuvers with six degrees of freedom. ❑

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References

Balakrishna, S., and T. Niranjana. 1987. *Wind tunnel dynamic flying study of the pitching moment derivatives of the Standard Dynamics Model in active control. AIAA Atmospheric Flight Mechanics Conference,* 17 19 August 1987, Monterey CA. AIAA Paper 87-2626.

Beyers, M. E. 1983. Subsonic roll oscillation experiments on the Standard Dynamic Model. *AIAA Atmospheric Flight Mechanics Conference,* 15 17 August, Gatlinburg, TN. AIAA 83 2134.

Bisplinghoff, R. L., H. Ashley, and R. L. Halfman. 1996. *Aeroelasticity*. Mineola, N.Y.: Dover Publications.

Chambers, J. R., and R. M. Hall. 2004. Historical review of uncommanded lateral-directional motions at transonic conditions. *Journal of Aircraft* 41 (3): 436 447.

Cummings, R. M., S. A. Morton, and D. R. McDaniel. 2008. Experiences in accurately predicting time-dependent flows. *Progress in Aerospace Sciences* 44 (4): 241 257.

Da Ronch, A., D. Vallespin, M. Ghoreyshi, and K. J. Badcock. 2012. Evaluation of dynamic derivatives using computational fluid dynamics. *AIAA Journal* 50 (2): 470 484.

Forsythe, J. R., K. A. Hoffmann, R. M. Cummings, and K. D. Squires. 2002. Detached-eddy simulation with compressibility corrections applied to a supersonic axisymmetric base. *Journal of Fluids Engineering* 124 (4): 911 923.

Forsythe, R., K. D. Squires, K. E. Wurtzler, and P. R. Spalart. 2004. Detached-eddy simulation of fighter aircraft at high alpha. *Journal of Aircraft* 41 (2): 193 200.

Forsythe, J. R., and S. H. Woodson. 2005. Unsteady computations of abrupt wing stall using detached-eddy simulations. *Journal of Aircraft* 42 (3): 606 616.

Ghoreyshi, M., K. J. Badcock, and M. A. Woodgate. 2009. Accelerating the numerical generation of aerodynamic models for flight simulation. *Journal of Aircraft* 46 (3): 972 980.

Ghoreyshi, M., and R. M. Cummings. 2012. *Challenges in the aerodynamics modeling of an oscillating and translating airfoil at large incidence angles.* 50th AIAA Aerospace Meeting, 9 12 January 2012, Nashville, TN. AIAA Paper 2012-0690.

Ghoreyshi, M., A. Jirásek, and R. M. Cummings. 2011. *CFD modeling for trajectory predictions of a generic fighter configuration. AIAA Atmospheric Flight Mechanics Conference,* 19 21 August, Portland, OR. AIAA Paper 2011 6523.

Ghoreyshi, M., A. Jirásek, and R. M. Cummings. 2012. Computational investigation into the use of response functions for aerodynamic loads modeling. *AIAA Journal* 50 (6): 1314 1327.

Gottlieb, J. J., and C. P. T. Groth. 1998. Assessment of Riemann solvers for unsteady one-dimensional inviscid flows of perfect gasses. *Journal of Fluids and Structure* 78 (2): 437 458.

Hall, R. M. 2004. Overview of the Abrupt Wing Stall Program. *Progress in Aerospace Sciences* 40 (7): 417 452.

Hall, R. M., S. H. Woodson, and J. R. Chambers. 2005. Accomplishments of the Abrupt-Wing-Stall Program. *Journal of Aircraft* 42 (3): 653 660.

Huang, X. Z. 2000. *Wing and fin buffet on the Standard Dynamic Model.* RTO Technical Report RTO-TR-26. Quebec, Canada: The Research and Technology Organization (RTO) of NATO.

Jeans, T., D. McDaniel, R. M. Cummings, and W. Mason. 2009. Aerodynamic analysis of a generic fighter using delayed detached-eddy simulations. *Journal of Aircraft* 46 (4): 1326 1339.

Jermey, C., and L. B. Schiff. 1985. Wind tunnel investigation of the aerodynamic characteristics of the Standard Dynamics Model in coning motion at Mach

0.6. *12th AIAA Atmospheric Flight Mechanics Conference*. 19 21 August, Snowmass, CO. AIAA 85 1828.

Jones, D. R., M. Schonlau, and W. J. Welch. 1998. Efficient global optimization of expensive black-box functions. *Kluwer Academic Publications* 13: 455 492.

Leishman, J. G. 1993. Indicial lift approximations for two-dimensional subsonic flow as obtained from oscillatory measurements. *Journal of Aircraft* 30 (3): 340 351.

Leishman, J. G., and G. L. Crouse. 1989. *State-space model for unsteady airfoil behavior and dynamic stall. 30th AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics & Materials Conference,* 19 22 April 2004, Palm Springs, CA. AIAA Paper 89-1319.

Leishman, J. G., and K. Q. Nguyen. 1989. State-space representation of unsteady airfoil behavior. *AIAA Journal* 28 (5): 836 844.

Librescu, L., and O. Song. 2006. *Thin-walled composite beams: Theory and application*. Dordrecht, Netherlands: Springer.

Mackman, T. J., C. B. Allen, M. Ghoreyshi, and K. J. Badcock. 2011. *Comparison of adaptive sampling methods for generation of aerodynamic models for flight simulations. 49th AIAA Aerospace Meeting,* 4 7 January, Orlando, FL. AIAA Paper 2011 1171.

McCallen, R., F. Browand, and J. Ross. 2004 *The aerodynamics of heavy vehicles: Trucks, buses, and trains*. Berlin, Germany: Springer-Verlag.

Menter, F. 1994. Two-equation eddy-viscosity turbulence models for engineering applications. *AIAA Journal* 32 (8): 1598 1605.

Morton, S. A., R. M. Cummings, and D. B. Kholodar. 2004. *High resolution turbulence treatment of F/A-18 tail buffet. 45th AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference,* 19 22 April, Palm Springs, CA. AIAA Paper 2004-1676.

Morton, S. A., J. R. Forsythe, A. M. Mitchell, and D. Hajek. 2002. Detached-eddy simulations and Reynolds-averaged Navier-Stokes simulations of delta wing vortical flowfields. *Journal of Fluids Engineering* 124 (4): 924 932.

Pamadi, B. N. 2004. *Performance, stability, dynamics, and control of airplanes.* AIAA Education Series. Reston, VA: American Institute of Aeronautics and Astronautics.

Reisenthel, P. H. 1997. *Development of a nonlinear indicial model using response functions generated by a neural network. 35th AIAA Aerospace Science Meeting,* 6 9 January, Reno, NV. AIAA Paper 97 0337.

Reisenthel, P. H., and M. T. Bettencourt. 1999. *Data-based aerodynamic modeling using nonlinear indicial theory. 37th AIAA Aerospace Science Meeting,* 11 14 January, Reno, NV. AIAA Paper 97 0763.

Romero, D. A., C. Amon, S. Finger, and I. Verdinelli. 2004. Multi-stage Bayesian surrogates for the design of time-dependent system. In *Proceedings of ASME 2004 Design Engineering Technical Conference and Computers and Information in Engineering*, September 28 October 2, Salt Lake City, UT 405 414, DETC 2004-57510.

Schröder, W. 2010. *Summary of flow modulation and fluid-structure interaction findings*. Berlin, Germany: Springer-Verlag.

Silva, W. A. 1993. Application of nonlinear systems theory to transonic unsteady aerodynamics responses. *Journal of Aircraft* 30 (5): 660 668.

Singh, R., and J. Baeder. 1997. Direct calculation of three-dimensional indicial lift response using computational fluid dynamics. *Journal of Aircraft* 34 (4): 465 471.

Spalart, P. R., and S. R. Allmaras. 1992. *A one equation turbulence model for aerodynamic flows.* AIAA Paper 1992 0439. *30th AIAA Aerospace Science Meeting*, 6 9 January 1992, Reno, NV.

Spalart, P. R., and M. Schur. 1997. On the sensitisation of turbulence models to rotation and curvature. *Aerospace Science and Technology* 1 (5): 297 302.

Strang, W. Z., R. F. Tomaro, and M. J. Grismer. 1999. *The defining methods of Cobalt: A parallel, implicit, unstructured Euler/Navier-Stokes flow solver. 37th AIAA Aerospace Science Meeting,* 11 14. AIAA Paper 1999 0786.

Tobak, M., and G. T. Chapman. 1985. *Nonlinear problems in flight dynamics involving aerodynamic bifurcations.* NASA TN-86706. Moffet Field, CA: National Aeronautics and Space Administration.

Tobak, M., G. T. Chapman, and L. B. Schiff. 1984. *Mathematical modeling of the aerodynamic characteristics in flight dynamics.* NASA TN-85880. Moffet Field, CA: National Aeronautics and Space Administration.

Tomaro, R. F., W. Z. Strang, and L. N. Sankar. 1997. *An implicit algorithm for solving time dependent flows on unstructured grids. 35th AIAA Aerospace Science Meeting,* 6 9 January, Reno, NV. AIAA Paper 1997 0333.

Tyssel, L. 2000a. Hybrid grid generation for complex 3D geometries. In *Proceedings of the 7th International Conference on Numerical Grid Generation in Computational Field Simulation,* 25 28 September, Whistler, Canada, International Society of Grid Generation.

Tyssel, L. 2000b. The TRITET grid generation system. In *Proceedings of the 10th International Conference on Numerical Grid Generation in Computational Field Simulations,* 16 20 September, Forth, Crete, Greece, eds., International Society of Grid Generation.

Wagner, H. 1925. Über die Entstehung des dynamischen Auftriebes von Tragflügeln. *Zeitschrift für Angewandte Mathematik und Mechanik* 5 (1): 17 35.

Wright, J. R., and J. E. Cooper. 2008. *Introduction to aircraft aeroelasticity and loads*. Chichester, U.K.: John Wiley.

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Combining Simulation With Flight Test Through Bayesian Inference

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The number of test points performed in a flight test is often limited due to many factors, including cost and schedule. Having only a small number of open-air-range test points can make statistically relevant data analysis challenging. Using simulation results as prior information, Bayesian techniques can generate statistically significant results from only a few flight-test data points. This article presents fictitious simulation data from electronic-attack test points and representative flight-test data for test points run at the same conditions. The simulation and flight-test data are then combined using Bayesian techniques to generate a posterior probability density function. The posterior probability density function shows the effects of electronic attack and the associated credible intervals (somewhat similar to a frequentist confidence or prediction interval). The results demonstrate that Bayesian techniques can provide a way to obtain meaningful results, even with limited flight-test data.*

Key words: Bayes's theorem; Bayesian inference; credible interval; flight test; Gibbs sampling; simulation.

Flight testing is a vital aspect in the development of operational aircraft, but due to constraints such as cost and schedule, the number of test points may be severely limited. This restriction on the number of test points can make statistically significant data analysis challenging. For example, a binomial nomograph can be used to gauge reliability and confidence for a missile in live-fire testing. To be 80 percent confident that there is a reliability of 90 percent, 16 test points would be required with no failures. If one of those 16 test points results in a failure, then at least 30 test points for the same confidence and reliability are needed. If only 5 live-fire tests can be executed, the confidence of a 90 percent reliability would only be about 45 percent, assuming no failures (Kececioglu 2002). Simply put, it is challenging to have high statistical confidence when the number of test points is limited.

Due to increasingly available computational power, current simulation capabilities are of sufficient fidelity to bring additional information to the flight test. Simulations have the benefit that hundreds or thousands of test points can be performed in a relatively short amount of time for a comparatively low cost. Bayesian inference can be used to combine simulation data with flight-test data to generate a joint distribution. If the simulation data is of sufficient fidelity and is appropriate for the specific situation it is being applied to, then the combination of flight test and simulation can result in increased confidence in the final data products.

This article first gives a brief history of Bayesian inference and its application today. An example is then shown to illustrate the differences between frequentist and Bayesian statistics. Finally, an example is given to show how Bayesian inference is being used at the Air Force Test Center to increase test-result confidence when test points are limited.

Background on Bayesian inference

The reverend Thomas Bayes was a mathematician and minister who studied logic and theology in the 1700s. The first appearance of any form of Bayes's theorem was in his posthumously published work *An Essay Towards Solving a Problem in the Doctrine of Chances* (Bayes 1763). Soon after, Laplace pioneered a more rigorous treatment of what is now known as

*Fictitious data is presented due to releasability restrictions

Bayes's theorem (Laplace 1774). Bayesian inference and Bayesian probability theory are still widely studied and have a vast number of applications (Agresti and Hitchcock 2005). Bayes's theorem has been applied to machine learning (Tipping 2004), neuroimaging (Friston et al. 2002), infectious-disease models (O'Neill 2002), and the historical method (Carrier 2008), to name just a few examples.

Bayesian inference is analogous to the scientific method. With the scientific method, after a process is observed or understood, a hypothesis of how it works is posited, usually as a model by which predictions of outcomes can be made. The model typically depends on a set of parameters, noted here as θ, which scientists attempt to quantify and determine. The model is tested by conducting an experiment to collect data, denoted y, analyzing how well the data fits the current hypothesis, and updating the model parameters if necessary.

In the Bayesian lexicon, the initial hypothesis is referred to as the "prior." The name references the fact that this is the hypothesis about the system that is held prior to conducting the current experiment, and it represents the knowledge of the system up to, but not including, the current experiment. How well the data fits this hypothesis is called the "likelihood," referencing how likely is it that the current hypothesis is to have generated the data observed in the experiment. The updated model is referred to as the "posterior," as it represents the knowledge about the model parameters held after the experiment has been conducted and its results have been analyzed. The prior, likelihood, and posterior are quantified as probability density functions and are related to each other through Bayes's rule:

$$f(\theta|y) = \frac{f(\theta)f(y|\theta)}{f(y)}.$$

According to Bayes's rule, $f(\theta|y)$ is the posterior (conditional) distribution of θ given the data, $f(\theta)$ is the prior distribution of θ, $f(y|\theta)$ is the likelihood of observing the data y for a given value of the parameter θ, and $f(y)$ is the distribution of the observed data. In words, Bayes's rule states that the posterior distribution $f(\theta|y)$ of θ given the data y is equal to the product of the prior distribution $f(\theta)$ of θ and the likelihood $f(y|\theta)$ of the data y given θ, normalized by the distribution $f(y)$ of the observed data.

The prior distribution of a parameter θ may be formulated in many different ways. Historical data, subject-matter expert opinion, and simulation data may all be quantified as probability density functions representing the knowledge and belief regarding the possible values of θ.

In general, the way to implement Bayesian techniques (to calculate the expected value of a parameter of interest θ) is to integrate the equation

$$\int \theta f(\theta|y)\,d\theta.$$

This integral may not have a closed-form solution, so numerical integration techniques are typically used. The post popular techniques are Markov-chain Monte Carlo methods. These algorithms are used to sample probability distributions based on constructing a Markov chain that has the desired probability distribution as its equilibrium.

One popular technique for implementing Bayesian inference through Markov-chain Monte Carlo algorithms is using a Gibbs sampler. Gibbs sampling generates a sequence of samples from two or more random variables to create an approximation of the joint distribution of the variables in question (Geweke 1995). The joint distribution that is created is an approximation for $f(\theta|y)$.

Bayesian versus frequentist statistics

Frequentist statistical analysis is an inference framework featuring hypothesis testing and confidence intervals. The key feature of frequentist inference is that population parameters, unknown to the investigator, are constants. Inferences then are made relative to these unknowns. Errors wrong assertions about the unknown constants are classified as Type I or Type II, depending upon the true state of nature. In a similar manner, confidence intervals are estimates of location for an unknown constant. A 95 percent confidence interval has the property that, with repeated tests, 95 percent of the 95 percent confidence intervals generated would contain the true mean, but the probability that a specific interval contains the true mean is either 0 or 1, since the parameter is assumed to be an unknown constant. This is in stark contrast to Bayesian statistics, which views the unknown population parameter as a random variable, and hence a statement about 95 percent probability of the random variable being in a specific interval makes sense.

Although Bayesians and frequentists have often been at odds, both approaches have advantages, depending on the setting. In a case where large quantities of data exist, frequentist methods are straightforward and practical (Vallverdu 2008). On the other hand, Bayesian techniques have the advantage of incorporating prior information into statistical analysis. It is important to note that this prior data can have a significant impact on the final data product, so using prior information of sufficient fidelity under the direction of a subject matter expert (SME) is important to ensure credible results.

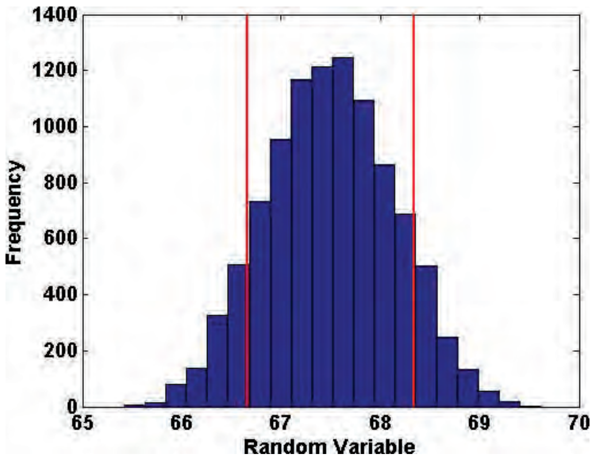

Figure 1. 80% credible interval for posterior distribution.

Additionally, Bayesian methods can incorporate hierarchical models which are vastly more complex than those that can appear in frequentist methods.

Bayesian inference begins with a prior distribution of a variable of interest and combines that with observed data to provide a revised estimate of the probability distribution. The goal is to use this revised (posterior) distribution for statistical inference. One difference to note is the fact that in Bayesian statistics, the term "confidence" is not used. Instead, credible intervals are used. For example, given the hypothetical posterior distribution shown in *Figure 1*, an 80 percent credible interval is shown by the two vertical lines.

This credible interval can be interpreted to mean that there is an 80 percent probability that the parameter of interest is within the interval. This is one key distinction between frequentist and Bayesian statistics: An 80 percent confidence interval implies that with a large number of repeated samples, 80 percent of the confidence intervals would contain the mean value of the parameter. This gives no indication as to whether or not the current interval contains the mean. An 80 percent credible interval, on the other hand, means that the probability that the mean is within the interval is 80 percent.

The following hypothetical example demonstrates some of the differences between Bayesian and frequentist methods of statistical analysis: A new radar warning receiver (RWR) is being tested by the Air Force. The RWR manufacturer has provided expected values for response time against a surface-to-air missile system (the SA-X). The expected values for mean, standard deviation, and distribution type are shown in *Table 1*. These expected values are based on historical data and modeling and simulation results.

Table 1. Manufacturer-provided specifications for RWR.

Mean	3 s
Standard deviation	1 s
Distribution type	Log normal

RWR radar warning receiver; s seconds.

A test is performed to verify that the RWR has a mean response time of no more than 3.5 seconds against the SA-X. The data from the test is shown in *Table 2*.

Table 2. Test data to validate RWR specifications.

Response time (s)	
2.98	2.70
2.79	2.35
3.86	2.28
3.87	4.52
2.52	2.31

RWR radar warning receiver; s seconds.

Using frequentist techniques, an estimated mean ($\bar{x}$) and 95 percent confidence interval can be calculated using the equations

$$\bar{x} = \frac{\sum_{i=1}^{N} x_i}{N}$$

and

$$\mathrm{CI}(95\%) = \bar{x} \pm \frac{t_c s}{\sqrt{N}},$$

where N is the number of samples, x_i is the ith sample from the test data, t_c is the upper 2.5 percent critical value for a t distribution with N 1 degrees of freedom, and s is the estimated standard deviation from the test data.

Using Bayesian techniques, a 95 percent credible interval can be calculated. The test data is used as the likelihood, as shown in *Figure 2*. The information provided by the RWR manufacturer can be used as a

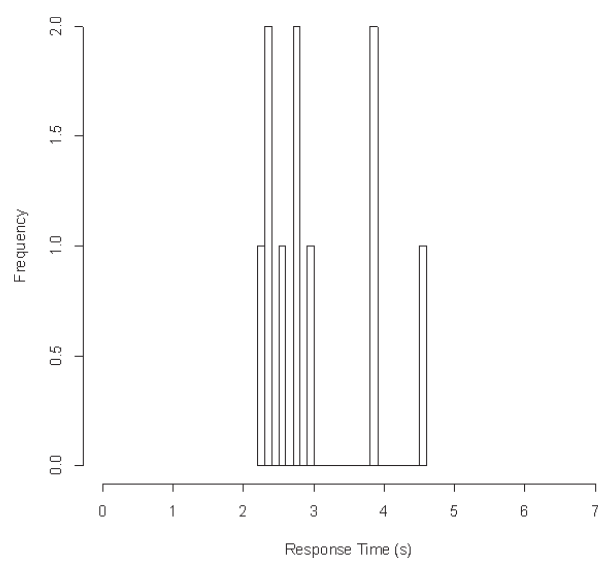

Figure 2. Test data used as the likelihood.

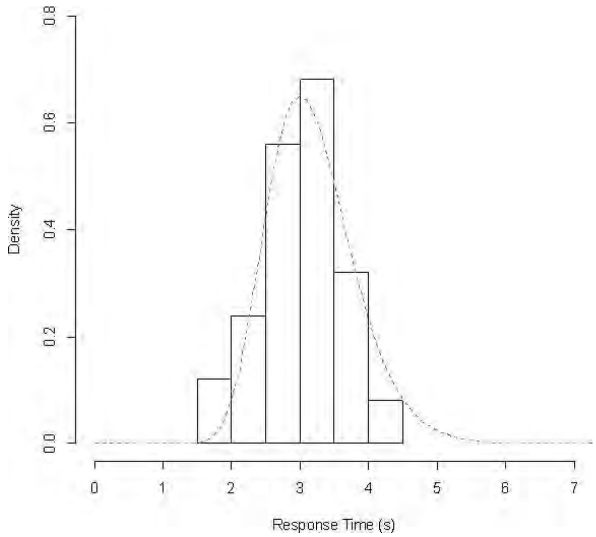

Figure 3. Manufacturer specifications used as the prior.

prior, as shown in *Figure 3*. That figure shows theoretical lab data and the fitted distribution used for the Bayesian analysis. For the purposes of this article, the data shown in *Figure 2* was actually randomly generated from the same distribution as the data shown in *Figure 3*. This insures that the prior is an appropriate model for this example. Using Gibbs sampling, a posterior distribution can be created. The posterior distribution with its 95 percent credible interval and the mean with its 95 percent confidence interval are shown in *Figure 4* and *Table 3*.

Table 3. Mean, 95% confidence interval, and 95% credible interval for RWR data.

Estimated mean (x)	3.0 s
Confidence interval (95%)	2.45–3.58 s
Credible interval (95%)	2.66–3.32 s

RWR radar warning receiver; s seconds.

In this case the results were similar, but the credible interval was about 40 percent smaller than the confidence interval. This is partially due to the fact that the frequentist approach is unable to make use of the prior, which in this case is the predicted distribution generated from lab data provided by the manufacturer. Using Bayesian analysis, it can be said that there is a 95 percent probability that the mean response time is between 2.66 and 3.32 seconds.

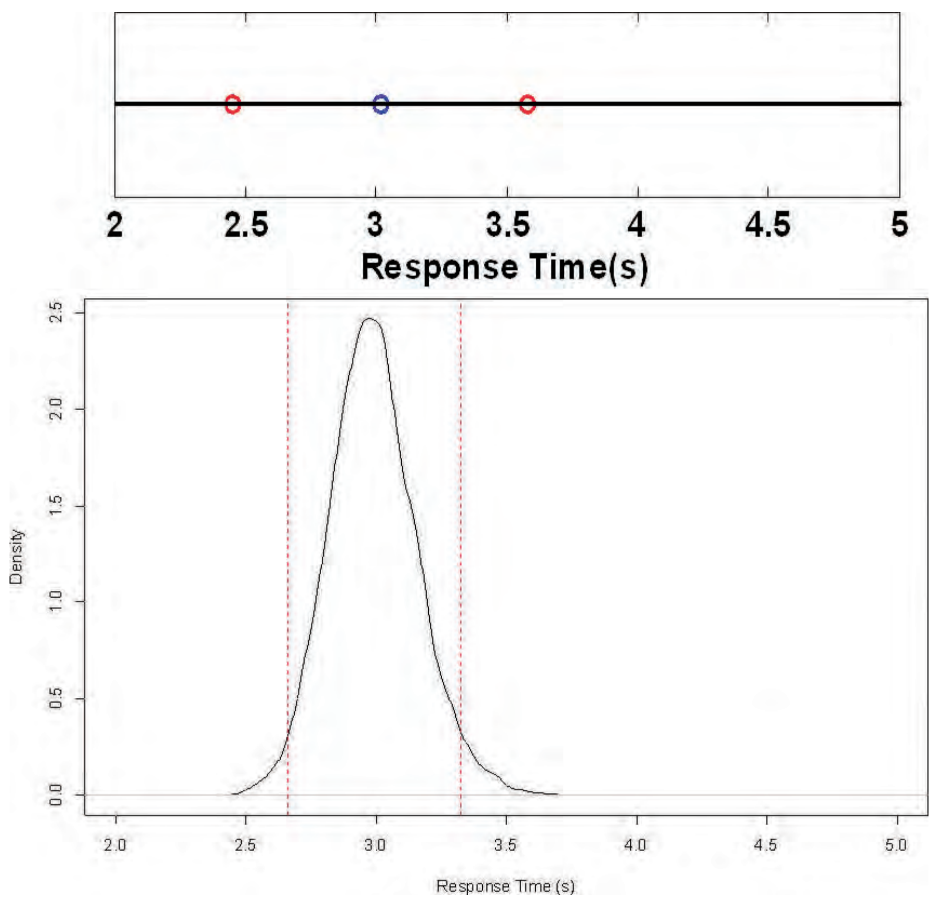

Figure 4. Top plot: Mean and 95% confidence interval; bottom plot: Posterior distribution and 95% credible interval.

Table 4. Flight-test dry and wet engagement ranges, measured in cubits.

Dry				Wet				
100.21	98.18	104.26	97.24	78.26	69.75	73.41	74.22	77.94
				79.23	75.23	76.31	74.16	71.16

Additionally, it can be said that there is a 95 percent probability that the required reaction time of 3.5 seconds was met. Using the frequentist technique, the 95 percent confidence interval extends beyond the 3.5 second mark. Disregarding the specification, it can still be said that the 95 percent confidence interval is from 2.45 to 3.58 seconds. The interpretation of this result is that if this test were repeated a large number of times, 95 percent of the confidence intervals would contain the true mean, but nothing can be said of this particular confidence interval specifically. The interpretation of the Bayesian results is clearly more straightforward than with the frequentist technique.

Bayes's theorem in flight test

In current testing at the 412th Test Wing, data is being gathered to determine the percent reduction in engagement range (RER) due to electronic attack. The RER can be calculated using the equation (R_{Dry} R_{Wet})/R_{Dry}, where R_{Dry} is a dry run (a run without electronic attack) and R_{Wet} is a wet run (a run with electronic attack).

A problem lies in the fact that flight test is limited due to budget and schedule constraints. Fortunately, there are several venues where these test points have been simulated at varying levels of fidelity. Data has been collected at hardware-in-the-loop and software-in-the-loop facilities under conditions that are representative of flight-test conditions. This section presents fictitious data analogous to the data acquired from simulation and from flight test. These sets of data are then combined through Bayesian inference to generate a posterior distribution of the RER. Credible intervals on that distribution are also given that show the probability that the platform meets the RER required in the specifications for the aircraft platform.

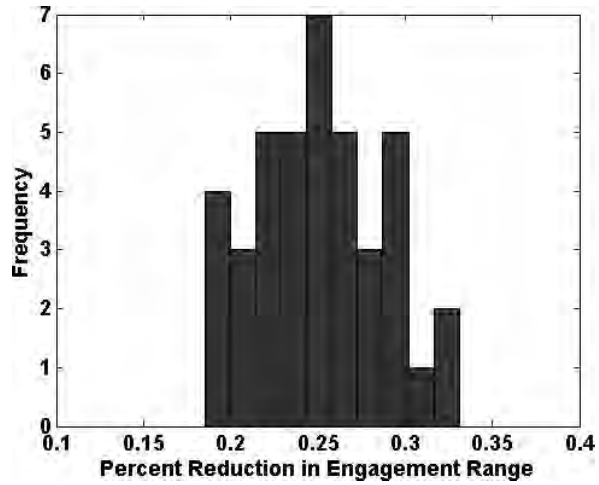

Figure 5. Distribution of percent reduction in engagement range from flight-test data (likelihood).

The variable being measured in flight test, as mentioned previously, is the RER. The distributions in Bayes's theorem as applied to this flight-test scenario can be defined as follows: The variable θ is the distribution of the RER using the simulation data. The variable y is the distribution of the RER using the flight-test data. The function $f(\theta|y)$ is the joint distribution of the RER, combining simulation and flight-test data through Bayesian inference using Gibbs sampling.

Results

Although the actual simulation and flight-test data are not provided, the principles of using Bayesian inference to create a joint distribution of two random variables still remain the same for the fictitious data presented here. *Table 4* shows theoretical engagement ranges from flight-test data, and *Table 5* shows theoretical engagement ranges from simulation data.

Figure 5 shows the distribution of the percent RER from the flight-test data. *Figure 6* shows the distribution from the simulation data. These distributions were created by matching all dry runs with all wet runs from *Table 4* and *Table 5* and then using the previously defined RER equation.

Table 5. Simulation dry and wet engagement ranges, measured in cubits.

Dry simulation					Wet simulation				
106.14	100.76	102.47	101.69	99.79	74.87	77.31	75.61	74.89	73.99
103.20	100.93	97.15	101.01	96.34	73.18	75.11	76.64	75.86	70.13
100.30	104.80	105.71	98.84	102.37	79.87	78.02	74.28	74.31	73.18
103.61	97.16	100.72	99.14	98.52	81.42	79.57	72.08	76.26	78.40
99.18	96.63	101.75	100.35	100.57	74.13	76.64	77.17	74.59	76.63
104.07	99.41	102.91	101.74	97.82	74.05	71.89	72.76	70.22	71.72
103.61	103.36	100.10	105.13	95.65	72.52	72.18	76.85	78.80	68.98
104.79	95.28	102.39	100.08	102.43	78.53	76.38	75.91	72.63	70.88
100.10	98.23	101.04	95.58	102.89	78.51	74.70	77.33	74.90	77.21
102.63	96.44	99.48	100.68	97.06	75.29	77.21	70.29	76.12	76.50

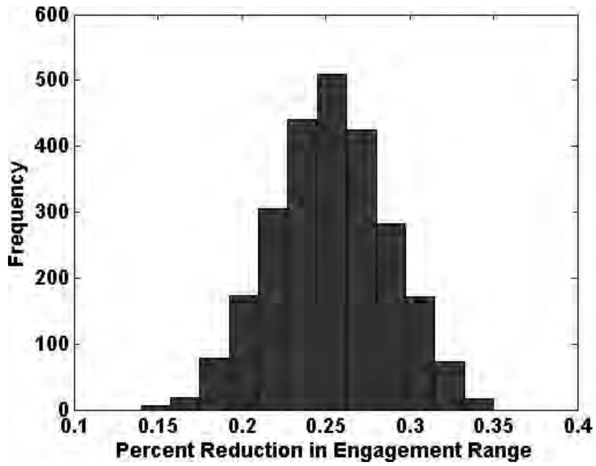

Figure 6. Distribution of percent reduction in engagement range from simulation data (prior).

Using Gibbs sampling to create a joint distribution of random variables, the posterior distribution shown in *Figure 7* was generated. The two vertical lines around the curve in *Figure 7* mark the 95 percent credible interval (23.9% to 26.1%). In other words, there is a 95% chance that the mean RER is greater than 23.9 percent and smaller than 26.1 percent. The vertical line at the left in *Figure 7* marks a theoretical specification requirement for the aircraft platform. This specification would represent the contract requirement between the contractor and the government, and is not generated from the data. If the requirement were for the RER to be greater than 20 percent, as in this case, then it could be said with more than 95 percent certainty that the RER meets the requirement, since more than 95 percent of the distribution is greater than 20 percent.

Conclusion

Test and evaluation will continue to face tough budget and schedule restrictions in the future; subsequently, the number of test points flown at open air ranges will likely continue to be reduced. Frequentist methods are well understood and can be applied to flight test, but confidence in their results is generally low when test data is limited. Bayesian techniques offer an alternative approach. Under suitable conditions and under the direction of a SME, lab data can be used in conjunction with flight-test data to get a better understanding of aircraft performance than can be obtained from a meager number of flight-test data points alone. ❑

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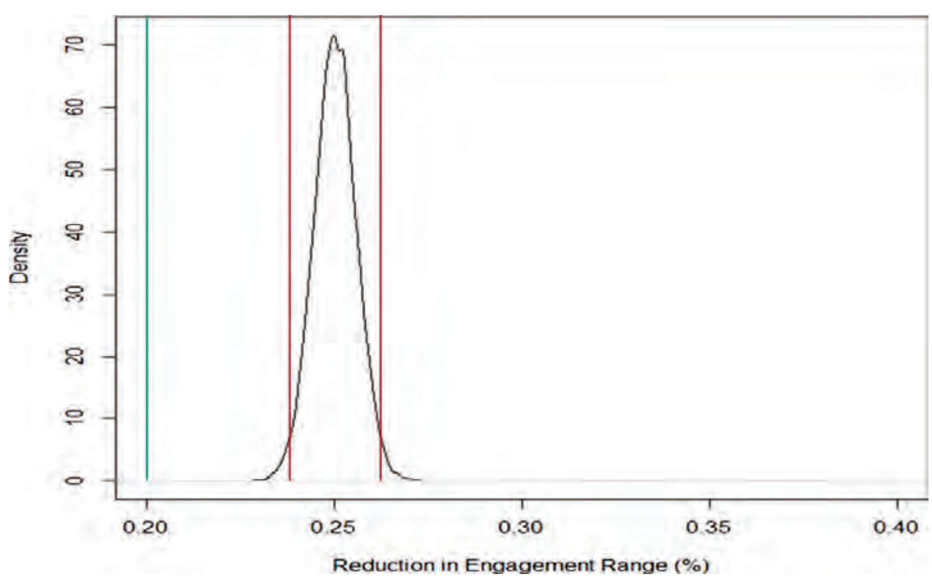

Figure 7. Posterior distribution generated through Bayesian analysis.

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References

Agresti, A., and D. B. Hitchcock. 2005. Bayesian inference for categorical data analysis. *Statistical Methods and Application (Journal of the Italian Statistical Society)* 14 (1): 297 330.

Bayes, T. 1763. An essay toward solving a problem in the doctrine of chances. *Philosophical Transactions of the Royal Society* 53 (1): 370 418.

Carrier, R. C. 2009. Bayes' theorem for beginners: formal logic and its relevance to historical method. Caesar: A journal for the critical study of religion and human values, 3 (1): 26 35.

Friston, J. K., W. Penny, C. Phillips, S. Kiebel, G. Hinton, and J. Ashburner. 2002. Classical and Bayesian inference in neuroimaging: Theory. *NeuroImage* 16 (1): 465 483.

Geweke, J. 1995. *Posterior simulators in econometrics* Research Department, Federal Reserve Bank of Minneapolis, Working Paper 555.

Kececioglu, D. 2002. *Reliability & life testing handbook*. Lancaster, PA: DEStech Publications.

Laplace, P. S. 1774. Mémoire sur la probabilité des causes par les evénements. *Mémoires de l'Académie Royale des Sciences* 6 (1): 621 656.

O'Neill, P. D. 2002. A tutorial introduction to Bayesian inference for stochastic epidemic models using Markov chain Monte Carlo methods. *Mathematical Biosciences* 180 (1): 103 114.

Tipping, M. E. 2004. Bayesian inference: An introduction to principles and practice in machine learning. In *Advanced Lectures on Machine Learning*, ed. O. Bousquet, U. von Luxburg, and G. Ratsch 41 62, Cambridge, U.K.: Springer.

Vallverdu, J. 2008. The false dilemma: Bayesian vs. frequentist. *Electronic Journal for Philosophy* ISSN 1211 0442.

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Transitioning Emerging Microsystem Technology Into Test and Evaluation

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Virtually unnoticed, microsystems are taking over sensitive tasks in our everyday lives. Microsystems provide the ability to sense, process, and act on their environment in an integrated reduced Size, Weight, and Power (SWaP) footprint, in essence a "platform on a chip." In this article we investigate what microsystems are and what technologies are applied to them, we look at present trends in microsystem research and development, define players associated with this technology and its development, define candidate technologies applicable to the Department of Defense (DoD) Test and Evaluation (T&E) community. Secondly, we define a mechanism through which the Test Resource Management Center (TRMC) T&E/Science and Technology (S&T) Advanced Instrumentation Systems Technology (AIST) Test Technology Area (TTA) can develop a current perspective of where the state of the art lies in this technology, define a methodology for how the T&E community can evaluate this technology, validate the applicability and refine the scope of the T&E use cases for this technology, and define a mechanism for how we work this technology into the AIST T&E roadmap and ultimately into broad agency announcements to move promising technologies towards maturation.

Key words: Micro-Electro-Mechanical System (MEMS); micro systems; Nano-Electro-Mechanical System (NEMS); test and evaluation applications.

Microsystems are being applied to a wide variety of sensitive tasks that affect our everyday lives. For example, automotive manufacturers use microsystems to help control the vehicle, make it safer, or make our experience more comfortable. In medicine, they are used in operating rooms to help doctors perform complicated procedures, to pace your heart or deliver the right dose of medication unobtrusively. In manufacturing process control, they provide the means to accurately fabricate a component repetitively. In the information and communication sectors, they make many of our ubiquitous devices operate smoothly. Microsystems provide the ability to sense, process, and act on their environment in an integrated footprint with reduced Size, Weight, and Power (SWaP).

The Advanced Instrumentation Systems Technology (AIST) program's aim is to develop Test and Evaluation (T&E) technology from Technology Readiness Level 3 (TRL3) through TRL6 in the instrumentation area by funding and managing projects that address Department of Defense (DoD) T&E needs. These T&E needs are captured in the AIST Broad Agency Announcement (BAA), the most recent of which (FY 2013) includes six technology areas of interest as described in *Table 1*. Microtechnology can assist the AIST goal of improved T&E capability by capitalizing on development in industry and academia in the microtechnology field, particularly via decreases in SWaP. The AIST program plans to incorporate the benefits of microsystems into T&E by applying this technology to use cases, outlining where such technology is pertinent, and guiding the AIST and roadmap Test Technology Area (TTA).

*Table 1. Test Resource Management Center Advanced Instrumentation Systems Technology FY 2013 Broad Agency Announcement technology areas of interest.**

Area	Description
1. TSPI	High accuracy and continuous TSPI for high speed/high dynamic, and GPS degraded environments
2. Advanced sensors	Miniature and hardened sensors for harsh environments
3. Advanced energy and power systems	Next generation fuel cells and power harvesting techniques for data collection
4. Nonintrusive instrumentation	Advanced data acquisition and processing components designed to be embedded within the SUT
5. Range, environmental encroachment	Technologies to mitigate impact to test range operations
6. Human systems	Technologies to assess the human–machine interface, including improved methods to measure warfighter workload

*TSPI, time, space, position information; GPS, global positioning system; SUT, system under test.

Microsystem defined

There seems to be no single definition to describe a microsystem. An initial definition can be constructed by looking at the roots of the word "microsystem." The first part, "micro," is derived from the Latin word *parvi*, meaning "small" or "little." The second part, "system," is derived from the Latin word *systēma,* meaning a set of interacting or interdependent components forming an integrated whole. Taken together, the term can be decoded as *a set of small interacting or independent components forming an integrated whole*. This definition starts to get at the core meaning of microsystems as a collection of small components that have *structure*, *behavior*, and *interconnectivity* aimed at meeting the *needs* of a specific application (e.g., measuring acceleration and responding by altering orientation). The technology aspect includes concepts involved in the design, production, and application of microsystems.

Terminology varies across the globe, but the underlying function remains constant: all definitions require a mixture of microelectronics, some form of processing, and a form of actuation having an effect on the system sensed. Microsystems consist of elements drawn from either functional or form elements, components, or composite subsystems. Functional or form elements represent fundamental structures fabricated at the nano- or micrometer level, such as cantilever beams, permeable membranes, stoppers, bearings, gears, channels, piezo-electric, piezo-resistive, piezo-capacitive, thermal-resistive, conductors, logic gates, or other low-level functional elements.

In Europe, the term "microsystem technology" is defined as an "*intelligent miniaturized system comprising sensing, processing and/or actuating functions*" (Fatikov 2010); or microsystems are described as "*microstructure products [that] have structures in the micron range and have their technical function provided by the shape of the microstructure* (Gerlach, Dotzel, and Muller 2008). In Japan, the term used is "micromachines": "*Micromachines are composed of functional elements only a few millimeters in size and are capable of performing complex microscopic tasks*" (Howe et al. 2003). In the U.S., the term initially used was Micro-Electro-Mechanical system, or MEMS, defined as "*integrated micro devices or systems combining electrical and mechanical components fabricated using integrated circuit (IC) compatible batch-processing techniques and [varying] in size from micrometers to millimeters*" (Fatikov 2010).

A National Institute of Science and Technology (NIST) advanced technology program study defines a microsystem as "*a collection of highly integrated devices that contains transducers along with appropriate interface circuitry and is capable of performing multiple tasks autonomously as well as responding intelligently to various commands from a host system*" (Boudreaux 1999). Other terms that refer to microsystems include System On a Chip (SOC) and System In a Package (SIP) (Voda 2010). Microsystems are aimed at nano- and micrometer-embedded systems, where SWaP is very important, and autonomy is often also of concern.

For the AIST TTA, the definition of microtechnology is based on the end need as opposed to the components. AIST defines microtechnology as the blending of many technologies combined in a systematic way (e.g., miniaturization, microelectronics, micromechanical components, nanotechnology) to realize an end-to-end solution to some physical need. A typical microsystem device may include a sensing element, a processing element, an actuation element, and supporting services (e.g., power management, interfacing), all existing in a single entity called a system *(Figure 1)*. For example, a microsystem can be envisioned that provides sensors to sense a person's brain waves in real time with autonomous processing resources that look for signs of cognitive overload and provide actuation such as removing load that can be handled by autonomous artificial intelligent agents (Moore 2006). From this definition, a microsystem

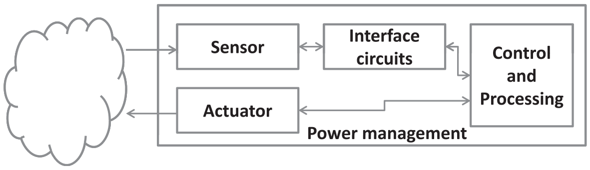

Figure 1. Elements of microsystems.

consists of integrated elements to sense, process, and respond to some physical system.

Functional or form elements, in turn, can be used to construct components such as an electric circuit, a microfluid pump, a micromotor, and other such composite elements. Components are then used to design and fabricate a microsystem that meets some end user need. For example, a complete microsystem may be an air bag system (that senses pressure and deploys an air bag if there is sufficient force), an intelligent sensor system, a micro-analysis and compensation system, and so forth. Such systems are composed of a hierarchy of technologies used to construct more complex elements, components, and ultimately systems *(Figure 2)*.

Present trends in microsystem Research and Development (R&D)

Most microsystem R&D efforts are being performed at University research centers, government research laboratories, and industrial R&D centers worldwide. Four primary technology areas appear to have the bulk of research efforts aimed at them *(Figure 3)*. The research areas are (a) Nano-Electro-Mechanical (NEMS) and MEMs electrical and computing, (b) structural and materials, (c) power, and (d) sensors. These research areas have a variety of academic, industrial, and governmental facilities involved in basic and applied research to move the technology forward to where applications can be developed.

Like research in basic technology, there are organized efforts taking the results of basic and applied research and moving them into the area of applications development. From this perspective, there appears to

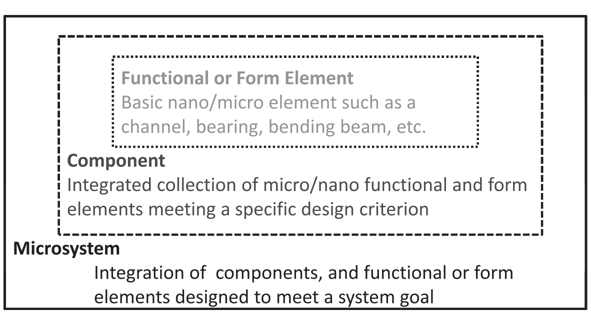

Figure 2. Microsystem technology hierarchy.

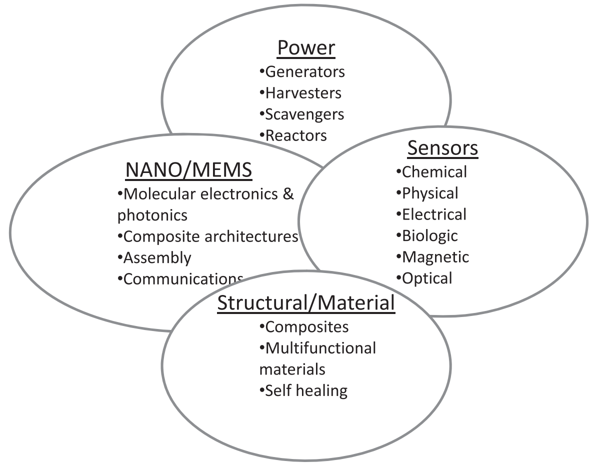

Figure 3. Nano-/micro-electro-mechanical system (MEMS) technology major research and development sectors.

be an emphasis on developing microsystem technology focused on four primary applications areas: the environment, mobility, human health, and industrial processes. Within the realm of the environment, microsystems are seen as a means to more closely monitor and react to our physical environment while at the same time avoid impacting the environment as present systems do. Some efforts derived from this area include development of micro-energy harvesting systems and micro fuel cells, which limit adverse effects on the environment. Mobility does not simply imply communications. Microsystem R&D applied to mobility looks towards developing microsystems that support and enhance the movement of people and goods. Examples include technology applied to smart roadways, driver assistance, automotive control and optimization, tracking systems (e.g., Radio Frequency Identification [RFID]), and optimization applications. Microsystems applied within the realm of human health include technology to aid in preventative health care, innovative diagnostics, microsurgery, implant technology, and intelligent living environments, to name a few. In the field of industrial processes, microsystems are being applied to aid in solving numerous problems with the manufacturing, implementation, and application of microsystems to new domains. Some interesting research includes microprocess technology, organic microsystems, magnetic nano- and microsystems, micro- and nanosystem integration, micro- and nanopower systems, measuring and testing technologies, autonomous sensor networked systems, intelligent technical textiles, and applications centers that aid in movement of technology into customer application needs.

One reason that microsystem technology and its applications have not been highly pervasive is because of the initial cost associated with low production numbers. Since much of this technology is new and has not been applied to high-volume production runs outside of the automotive arena, it has not been easy to apply this technology into new areas. To be cost-effective, microsystems must be applied to applications having large production numbers. One reason for this is the reliance of microsystems manufacturing on technology used in commercial semiconductor processes. New technologies specific to microsystems are only possible when either large production numbers support the development of new fabrication processes, or there are no alternatives and a higher cost can be forced onto the application users. A case in point is found in the domain of specialized medical applications. The economic forces often dictate which integration and production technologies will be used. There are, however, numerous R&D activities ongoing that look to developing new monolithic and hybrid integration methods that may improve the cost point for microsystems applied to smaller application domains. The dominant method driving microsystem developments are microelectronics, micromaterials and integration methods. A few issues are mentioned below.

Microprocess technology research is aimed at the development of reactors, mixers, and heat exchangers with structure sizes of a few micrometers, and it is increasingly important for the chemical and pharmaceutical industry as well as for biotechnology and nanotechnology industries. Organic functioning systems enable various combinations of individual components in complex microsystems; for example, through the printing of polymer electronics or the simple integration of various functionalities, free-forming, and the use of technologies with low-cost production processes that are sustainable for mass production. Magnetic-based microsystems offer many possible applications in biologic sensors and where low power and interference persists. Integration technologies will aid in the fields of automobile technology, medical technology, and in the development of autonomous, networked sensor systems, also known as "e-grains."

Improved methods for sensing and testing will evolve from smaller, more powerful micro- and nanosensors and systems. Improved wireless microsystems will provide for a wide variety of environmental monitoring on a scale that is not physically possible today. Intelligent textiles will only become a reality through the use of microsystem technology and the emerging nanotechnology that can support weaving sensors and actuators into fibers that can then be woven into fabrics for smart clothing or coverings for numerous items. Finally, the development of application centers to improve the movement of technology into products is an important element in the evolving area of microsystem technology. One important function for application centers is supporting quick and cheap prototype production for researchers to allow for additional experimentation and evolution of application solutions using the technology. Fast prototype capabilities are similar to what is available today for companies, universities, or government agencies to have components fabricated in small lots for experimental use at a relatively low cost.

Who is involved in microsystem technology?

The variety of organizations involved in microsystem technology initiatives is as diverse as the possible applications for these devices. One of the industries most heavily involved is the automotive industry, which is driven by an increasing need to sense and control more aspects of vehicle operations than ever before as vehicles rely more heavily on drive-by-wire technology. Another major player is the European Union, whose members are driven by organizations partially funded by their governments and by industries benefiting from developments to foster advancement of microsystem technology. A third application area in which microsystems are finding an increasingly larger role is in health care. MEMS and nano-based devices have demonstrated their potential in applications for detecting and treating neurologic disorders, epilepsy, seizures, and Parkinson's disease to name a few (Moore 2006). A promising area for microsystems in health care is in drug therapies and delivery systems, which could benefit the warfighter.

In the U.S., national research agencies such as Defense Advanced Research Projects Agency (DARPA), Sandia National Laboratory, the Defense Microelectronics Activity (DEMA), and the national Nanotechnology Initiative (NII) support 25 federal agencies. Other major players are National Science Foundation (NSF)-supported R&D centers of excellence such as Berkley's Berkley Sensor Actuator Center (BSAC), Cornell's Nanofabrication Facility, Louisiana State Universities Institute for Micromachining, Caltech's Micromachining Laboratory, MIT's Micro Systems Technology (MST) Laboratory, and the University of Minnesota's Optical Microsystems Group. A detailed list can be found within the Emergency Microsystems Technology Transfer (EMTT) white paper developed by the Test Resource Management Center (TRMC), AIST TTA area (Fortier 2012).

There are a variety of private organizations and industries involved in the design and manufacturing of microsystems. The U.S. has initiated national financed research in microsystem technology through DARPA; the EU, through consortia such as Network of Excellence in Multifunctional Microsystems (NEXUS); and Japan, through the Ministry of International Trade and Industry (MITI).

Many engineering technical organizations (e.g., Institute of Electrical and Electronics Engineers (IEEE), International Conference on Nanoscience and Nano Technology (ICNN), International Academy, Research, and Industry Association (IARIA), Society of Photo-Optical Instrumentation Engineers (SPIE) are supporting conferences, workshops, seminars, tradeshows, and educational seminars dealing with microsystem technology and related technologies. Many of these organizations publish journals (both online and in print) dedicated to this technology. For example, the IEEE/American Society of Mechanical Engineers (ASME) publishes the *Journal of Microelectromechanical Systems*, advances in microsystems. The journal is jointly sponsored by the IEEE Electron Devices Society (EDS), IEEE Industrial Electronics Society (IES), and IEEE Robotics and Automation Society (RAS). The *Sensors and Transducers Journal* is an excellent source of current, relevant information on sensors, transducers, and microsystems. One special issue was dedicated to microsystem technology and innovations. Springer-Verlag publishes the *Microsystem Technologies* journal providing important and timely results on electromechanical, materials science, design, and manufacturing issues of microsystems and their components. SPIE publishes the *Journal of Micro/Nanolithography, MEMS, and MOEMS*.

Candidate technologies

The T&E community needs to take advantage of evolving microsystem technology, therefore potential candidate technologies must be identified for more detailed assessment. Some of the technologies of interest include SOC (e.g., Time, Space, Positioning Information (TSPI) chip, lab on a chip), micropower reactors, micro-antennas, voltage imagers for bioelectronics, silicon-on-insulator, flexible covert electronics, quantum-limited Charge-Coupled Device (CCD) imaging, advanced microwave photonic subsystems, electro-wetting microfluidic devices, passive wireless sensors (e.g., RFID-based), printed circuit technologies, and subthreshold-optimized ultralow-power electronics. Others related to the automotive industry, and also applicable to many of the AIST applications, include fuel-mixture management, exhaust-gas management, chassis management, drive differential gears, steering gears, brake management, suspension management, light management, navigation management, motor controls, and ignition management.

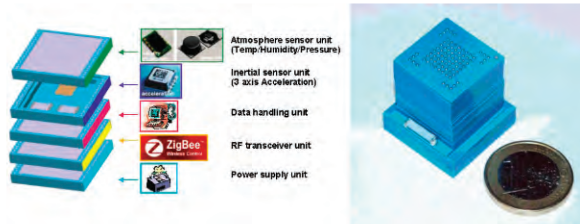

Figure 4. EADS micropack technology concept (Moore 2006).

The European Aeronautic Defense and Space Company's (EADS) micropack technology concept (*Figure 4*) is a packaging concept that provides the capability to integrate many general purpose elements with special purpose elements as needed (Coumar 2005). Possessing such a capability would provide opportunities for vendors to develop and test new pack components without the need for developing a new host environment. In addition, moving towards such a modular architecture allows for standardized interfaces and metadata specifications to be developed, tested, and possibly adopted, even further enhancing their utility to the T&E community.

Establishing current State-Of-The-Art (SOTA) in microsystem technology

Determining the SOTA in microsystem technology requires a review of current R&D being performed, along with evaluation of current products and applications. Many companies, research laboratories, and universities involved in this technology must be interviewed and their capabilities assessed to accomplish this review; an alternative is to attend conferences, workshops, and tradeshows where this technology is highlighted. The latter option offers the capability to review many organizations involved in technology development in one place in an efficient manner. A common means of determining the SOTA is to review the current literature on a topic. This literature includes textbooks, reference books, journals, research publications, and position papers. This approach offers the quickest means for a snapshot view of a technology and is proposed as the first method to be applied in developing the microsystem technology SOTA. This approach combined with attendance at upcoming conferences and workshops dedicated to relevant technologies and the findings from these meetings will be used to further refine the SOTA status.

References supporting the initial SOTA assessment effort include the following: Boudreaux 1999; De Micheli et al.; 2009; Fatikov 2010; Gerlach 2008; Hsu 2008; Jha 2008; Leondes 2006; Lyshevski 2002; Madou 2011; Pelesko and Bernstein 2003; and Zhou, Wang, and Lin 2012. As part of this effort, a taxonomy of

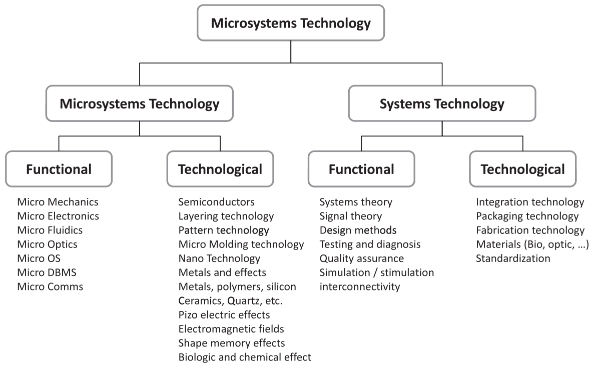

Figure 5. Microsystems taxonomy.

microsystem technology is needed. One such taxonomy was developed by J. C. Boudreaux of the National Institute of Science and Technology (Boudreaux 1999), which defines microsystem technology taxonomies using formalized semantics (Naur 1960).

To develop an initial taxonomy requires that a decomposition of the technology elements forming the microsystems be performed, and that all the components be completely and clearly defined. A typical microsystem is composed of transduction elements, processing elements, actuator elements, possibly storage elements, product delivery storage reservoirs (fluidic devices), and power-management elements, as well as actuator material production and storage elements. Following such an approach, *Figure 5*, depicts an introductory taxonomy for microsystem technology developed by decomposing the fundamental elements within the technology's name, "micro" and "systems." Each of these definitions is then decomposed into functional and technological items that define or support the area.

Fundamental to the realization of microtechnology is the development of functional elements for micro-mechanics, micro-electronics, microfluidics, and micro-optics. In turn, none of these technologies would have been possible without improvements in semiconductor technology, layering technology, and pattern specification and synthesis technologies. Some key aspects for manufacturing include micromachining, functional thin films, and wafer-stacking capabilities.

Microsystems benefit from low production costs and high volumes possible through manufacturing techniques used. The extremely small size and low power requirements of microsystem components support stand-alone, portable, and implantable systems. Additional benefits owing to size, power, and integration are reduced external connections and new concepts for control architecture and signal processing, which result in improvements in system reliability.

A leading driver of microsystem SOTA is the automotive industry because of the large volume of units needed. Typical microsystems include accelerometers, micropressure sensors, microgyroscopes, micro mass flow sensors, control systems, and microflow devices (e.g., pumps and valves); these are but a few amenable to the warfighter T&E domain.

Figure 6. Example autonomous platforms.

Method for evaluating microsystem technology for T&E applications

Ivar Jacobson introduced the concept of use cases in the context of his work on large telecommunication systems in 1992 (Jacobson 1992). The behavior of large systems is complicated and may be analyzed at many levels. Jacobson had the idea of describing a system's desired behavior by telling a story at a single level of detail; from the point of view of the end user. This process helped to manage the complexity. In most cases, the story, or scenario, must be supported by subsidiary scenarios and associated technical information. Use case analysis has become a staple in the DoD T&E requirements development process. The advantages of use case analysis include

- identification of the stakeholders,
- facilitation of discussion across disciplines (e.g., program acquisition, test instrumentation, data analysis),
- identification of core needs and requirements,
- identification of technology shortfalls through systems engineering and analysis, and
- use of a scenario to create full understanding.

Some initial use case application domain possibilities include autonomous surface, airborne (Forrest 2000), space (Altman 2005), and subsurface vehicle testing *(Figure 6)*, as well as soldier systems testing *(Figure 7)*, where the platforms are highly space, weight, and power limited for test equipment. Other good use cases may be derived from replacing existing range T&E infrastructure, or components thereof (e.g., radars, communications, sensors), with microtechnology. It is important to note that microtechnology can be applied to both assist new requirements for the T&E of these uses cases and to improve existing infrastructure of the current ranges where these use case Systems Under Test (SUT) are to be tested. One of the desired outcomes of use case development is to ascertain where existing infrastructure can be improved by microtechnology advances.

Figure 7. Soldier system sensors and testing.

In the autonomous vehicle application, sensors are required to assess SUT position, motion, propulsion performance, vehicle stresses and strain, and environmental parameters, as well as platform applications performance such as video clarity and sensor fidelity. In the soldier system application, sensors are needed to test soldier posture, eye focus, hand gestures, soldier and equipment location, movement, physiologic stresses, weapon position, weapon targeting, defensive systems performance, and communications, as well as situational awareness, tactical planning, and decision support systems that may come into play.

Sensors will be needed to identify all elements of interest in a test and to possibly keep track of them in time and space for the duration of a test.

In all of these examples, in order to assess a potential microsystem that could meet some testing need, the first requirement is defining the testing need (what must be tested? what physical phenomena will be used to acquire a given measurement?), followed by a definition of possible existing sensors that could meet the need. With this information, an examination of potential microsystems that could provide the same if not superior (fidelity, accuracy, etc.) performance could then be researched, selected, designed, developed, and fabricated into a system. Or, if none are available, this may point to an opportunity to develop or repurpose some microsystem to meet the testing need.

T&E case study development

The role of the TRMC T&E/S&T program and the AIST TTA is to develop cutting-edge technology to support DoD T&E.

The first step to advancing the use of microsystems in transition to T&E is to develop and verify pertinent use cases. These will be used to determine the technology gaps that might be addressed by innovative microsystem technology. Initial discussions with government test range personnel show promise for using microsystem technology. *Table 2* describes the types of data used to define use cases for further development.

The AIST TTA is focused on capturing test requirements from system developers, designers, and testers who define test applications (e.g., air, sea, land), their specific application (e.g., testing an Unmanned Micro Autonomous Vehicle [UMAV], soldier weapon, soldier system), the type of testing required, the types of measurements needed, etc.

One potential use case could examine numerous types of test requirements for UMAVs used in surveillance applications (Beard et al. 2005; Michelson 2008; and Petricca et al. 2011). In UMAV applications, the percentage of overall platform weight and mass reserved for guidance, navigation, and control may be less than 20 percent, with the majority of weight and mass (60 percent plus) reserved for propulsion and overall airframe components, leaving the remaining 15 to 20 percent for payloads related to the function of surveillance and information collection, as well as for platform and system T&E elements.

This application may seem like an extreme use of microsystems as applied to T&E from the perspective of weight, space, and power limitations. In addition, the platform still requires all of the traditional testing that would be done for an avionics platform plus added testing for the autonomous nature of the system and testing for the platforms application (e.g., surveillance).

The authors invite feedback concerning requirements related to the initially defined use cases related to air, sea, and land testing. Queries can be sent to the lead author at Dr. Paul Fortier, Electrical and Computer Engineering Department, University of Massachusetts-Dartmouth, 285 Old Westport Road, North Dartmouth, MA 02747-2300, email: pfortier@umassd.edu.

Microsystems transition to T&E roadmap

Results from use case definition, requirements definition, and gap analysis will feed into the existing AIST technology roadmap. With this information, the AIST program team will examine what technologies exist using present SOTA, what technologies are at the appropriate stage of development (TRL2/3), and what technologies could be moved towards TRL6 with sufficient support. This analysis must take into account what industry is doing, so that the DoD does not invest in areas where industrial concerns will move the technology along without assistance. Once accepted, defined technologies must be mapped to existing and or forecasted technology gaps and estimates made on

*Table 2. EMTT use case survey.**

1.	On your range, or test facility, are you presently using microsystem technology? If so, what technology?
2.	What equipment, subcomponents, or infrastructure do you see as a potential candidate for microsystem technology insertion?
3.	Do you see advantages for use of microsystems in T&E? If so, what are they?
4.	Do you think microsystem technologies can reduce T&E infrastructure operating costs?
5.	Are you aware of equipment or subcomponents that pose reliability issues and that, if replaced by microsystem technology, might be improved?
6.	Do you use data acquisition or processing technology that would benefit from the SWaP reduction that could be offered by microsystem technology? If so, please identify.

*T&E, test and evaluation; SWaP, size, weight, and power.

the development time for new and evolving microsystems to be available for future T&E needs.

Summary and closing

Microsystems technologies offer the ability to perform functions we do today in better ways. Microsystems applied to a conventional problem may require less weight, space, and power, or provide a capability that could not be done on platform to now be accomplished easily and with possibly excess capacity. In addition, this technology may offer a means to perform tasks we cannot do today with conventional technology or allow the community to develop new capabilities not possible before microsystems. The AIST TTA will capitalize on these developments by (a) creating use cases to feed the AIST roadmap and BAA, (b) engaging with the T&E community to develop these use cases and identify low-hanging fruit for application of existing microtechnology, and (c) remaining engaged in microtechnology development to further the SOTA for T&E, ensuring the AIST BAA reflects needs that can be addressed via investment in TRL3 through TRL6 S&T. Ultimately, developments in microsystem technology will be driven by application demands, such as in the automotive industry (e.g., microtriggers for airbag deployment) and the automated manufacturing industry, as well as in environmental monitoring, medical monitoring and management, and aerospace and defense. The AIST TTA is not involved in duplicating development efforts led by industry to develop microtechnology but rather is focused on applying proven components to T&E. ❑

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JAMES E. HOOPER is owner and president of Sakonnet Technology Group, a consulting firm he founded in 1993 to provide management and engineering services. He has over 29 years experience working in the Department of Defense on various undersea warfare programs, surface missile systems, and new technology programs. He has supported advanced program development for both government and industry clients in undersea warfare and information technology; including, Intelligent Transportation Systems (ITS). His current interests are in requirements definition and assessment of emerging technologies for test and evaluation of military systems. He received a master of marine affairs degree in 1981 from the University of Rhode Island and holds a bachelor's degree from the University of North Carolina at Chapel Hill. Mr. Hooper retired as a Captain in the U.S. Navy Reserves and is a member of the International Test & Evaluation Association (ITEA), the National Defense Industrial Association (NDIA), the

Naval Institute, and the Association of the United States Navy (AUSN).

Benjamin Viall is a doctoral student in the electrical and computer engineering department at the University of Massachusetts-Dartmouth. His research interests are in synthetic sensors and their application to health monitoring.

References

Altman, J. 2005. *Nanotechnology and preventative arms control.* Deutsche Stiftung Friedensforschung, http://www.bundesstiftung-friedensforschung.de/pdf-docs/berichtaltmann.pdf (accessed July 21, 2012).

Beard, R., D. Kingston, M. Quigkey, D. Snyder, R. Chiristiansen, W. Johnson, T. McLain, et al. 2005. Autonomous vehicle technologies for small fixed-wing UAV's. *Journal of Aerospace Computing, Information, and Communications* 2 (January 2005): 92 108.

Boudreaux, J. C. 1999. *A practical taxonomy for microsystems applications.* NIST Advanced Technology Program. Gaithersburg, MD.

Coumar, O. 2005. *Potential applications of micro and nano technologies on space transportation systems.* ADA446756. European Aeronautic Defense and Space (EADS ST) conference paper. Les Mureaux Cedex, France: 2005.

De Micheli, G., Y. Leblebici, M. Gijs, and J. Voros. 2009. *Nanosystems design and technology*. New York: Springer Verlag.

Fatikov, Sergei. 2010. *Microsystems technology and micro robotics*. New York: Springer Verlag.

Forrest, F. 2000. MEMS technology transition opportunities for gas turbine engines. IDA Paper P-3482. Institute for Defense Analysis, Alexandria, VA.

Fortier, P., T. Fueton, J. Hooper, and B. Viall. 2012. An assessment of emerging microsystems technology and transition possibilities for use in test and evaluation. AIST White paper. Newport, RI: Naval Undersea Warfare Center: Newport, RI.

Gerlach, G., W. Dotzel, and D. Muller. 2008. *Microsystems technology: A guide for students*. Hoboken, NJ: Wiley Publishing.

Howe, R., M. Allen, A. Berlin, E. Hui, D. Monk, K. Najafi, and M. Yamakawa. 2003. *WTEC panel on microsystems research in Japan*. Baltimore, MD: World Technology Evaluation Center, Inc.

Hsu, T. 2008. *MEMS and microsystems: Design, manufacture and nanoscale engineering*. New York: John Wiley and Sons.

Jacobsen, Ivar, Magnus Christerson, Patrik Jonsson, and Gunnar Övergaard. 1992. *Object-oriented software engineering: A use case driven approach*. Wokingham, England: Addison-Wesley.

Jha, A. 2008. *MEMS and nanotechnology-based sensors and devices for communications, medical and aerospace applications*. Boca Raton, FL: CRC Press.

Leondes, C., ed. 2006. *MEMS/NEMS: (1) handbook techniques and applications design methods, (2) fabrication techniques, (3) manufacturing methods, (4) sensors and actuators, (5) medical applications and MOEMS*. New York: Springer Verlag.

Lyshevski, S. 2002. *MEMS and NEMS: Systems, devices and structures*. Boca Raton, FL: CRC Press.

Madou, M. 2011. *Fundamentals of microfabrication and nanotechnology.* 3rd ed. 3 vols. Boca Raton, FL: CRC Press.

Michelson, R. 2008. Test and evaluation of fully autonomous micro air vehicles. *ITEA Journal* 29 (4): 367 374.

Moore, Samuel. 2006. Transcranial magnetic stimulation and therapy for seizures. *IEEE Spectrum* 43 (3): 28 30.

Naur, Peter, ed. 1960. Revised report on the algorithmic language ALGOL 60. *Communications of the ACM* 3 (5): 299 314.

Pelesko, J., and D. Bernstein. 2003. *Modeling MEMS and NEMS*. Boca Raton, FL: CRC Press.

Petricca, L., P. Ohlckers, and C. Grinde. 2011. Micro and nano-air vehicles: State of the art. *International Journal of Aerospace Engineering*. http://www.hindawi.com/journals/ijae/2011/214549/ref/ (accessed June 12, 2012).

Voda, A. 2010. *Micro, nanosystems and systems on chips: Modeling, control and estimation*. New York, NY: Wiley-ISTE.

Zhou, Z., Z. Wang, and L. Lin. *Microsystems and nanotechnology*. New York, NY: Springer Verlag.

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Chapter News

Emerald Coast Chapter

The Emerald Coast Chapter is pleased to announce that the 2nd quarter winner for "Tester of the Quarter" was the F-35 Block 2A Support Testing Team of the 513th Electronic Warfare Squadron, 53rd Electronic Warfare Group. This team of extraordinary professionals was assembled to help stabilize crucial JSF Developmental Test and Evaluation software. The team corrected software errors by implementing a root cause analysis, resulting in the on-time delivery of a modeling and simulation software package. The team's diligent efforts streamlined the process for data analysis and reduced the time to review test data by an astonishing 66 percent. The team not only reduced the time required for analysis, but also reduced the number of tests required by implementing new, real-time data monitoring tools and techniques. The hard work demonstrated by the team, resolved an urgent program requirement and reinforced the engineering relationship between government and private industry personnel.

In other news, the Emerald Coast Chapter hosted the Eglin Professional Consortium Guest Speaker Event on Sep 10, 2012. The guest speaker was **Brigadier General David Harris**, who was recently assigned as the new 96th Test Wing commander. The 96th Test Wing was activated in July 2012, combining the 46th Test Wing with the 96th Air Base Wing under Air Force Materiel Command's reorganization. Brigadier General Harris addressed the audience on the mission of the newly established 96th Test Wing. The Eglin Professional Consortium is comprised of the local chapters of ITEA, INCOSE, AFA, and NDIA.

The Emerald Coast Chapter also participated in the 29th Annual ITEA Symposium. **Mr. Robert J. Arnold**, Technical Advisor for the 96th Test Wing, Eglin AFB, presented "Strengthening and Shaping the T&E Workforce for the Future: A View from the Field". His presentation brought forth recommendations for strengthening recruitment, retention, and development of the Science and Engineering workforce in support of T&E activities. He also discussed the importance of identifying the correct skill sets necessary to shape the Science and Engineering workforce in support of future DoD T&E requirements. While at the Symposium, Mr. Arnold also served as moderator on the Future Workforce Development panel.

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Francis Scott Key Chapter

The Francis Scott Key Chapter is having a great month of October. **Mr. Joseph Wienand**, the Technical Director of the Edgewood Chemical Biological Center was the guest speaker at our luncheon. Mr. Wienand shared ECBC's Mission and Vision and also provided the assembled body with some insight on several of the Centers current projects. We provided an opportunity for two Harford County Science and Mathematics Academy seniors to share progress with their senior capstone research project. Both students gave well organized, informative presentations and thoughtfully answered questions. Next month on November 7th, we will be pleased to host **Dr. Forest Crain**, the Director of U.S. Army Materiel Systems Analysis Activity, as our guest speaker. The Francis Scott Key Chapter is excited to host the Cyber Conference on November 27 – 30, at Baltimore's fabulous Inner Harbor. We expect that many members of the T&E community will join us to discuss the need to meet the advanced persistent cyber threat.

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George Washington Chapter

At its monthly luncheon on September 13th at the Fort Myer Officers Club, the George Washington Chapter heard **Dr. J. Michael Gilmore**, the Director of Operational Test and evaluation (DOT&E) in the Office of the Secretary of Defense give his views on tester involvement in system requirements and design of experiments.

Dr. Gilmore said that testers have a role to play in the setting of requirements for systems acquisition. When it is a matter of requirements that cannot realistically be achieved, it is also a matter of testability. For example, a 99.9% requirement not only needs extensive testing, it probably also needs to be changed from a test of a binomial probability answer to a test of a continuous variable with operational meaning. He also pointed out that the F-35, as is the case with all weapons systems, must be tested against operationally realistic threats because the warrior would be badly served if realistic threats were not included in testing. Another example of requirements that were problematic was the Army's Future Combat System. About $20B was invested before the program was cancelled when

New chapter officers elected during the summer started their two-year terms in September. The four new officers are pictured here are (from left) Treasurer Erika Chan Gillian, President Lee Schonenberg, Vice President Tony Garces, and Secretary Cynthia Lindberg-Ross.

developmental and operational testing showed the requirements were impossible to meet.

The Director went on to say that testers should use statistical tools in planning tests because they are key to explaining and defending the content of testing; each test must have its own rationale based on the system, its environment, associated systems, and the threat. He said both engineering and operational expertise are needed to apply statistical tools and DOT&E will continue to emphasize this in reviewing Test and Evaluation Master Plans. Unless the operational and developmental sections of those plans are substantive, the DOT&E will not approve them.

In a Q&A session, Gilmore said there is no problem of evaluator independence with involvement in requirements because the T&E role is advisory. That said, he stated that T&E advice is critically important to the decision maker. He also said that the Department's leadership seeks DOT&E comments and those comments are often accepted. He also discussed the interaction of DOT&E and AGILE software development processes.

After the talk, chapter president **Lee Schonenberg** thanked Dr. Gilmore and presented him with an ITEA inscribed crystal paperweight as a memento of the occasion.

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Penn State Chapter

The Penn State Chapter is pleased to report that its first workshop on *Underwater Acoustics for Test and Evaluation* was a great success. The workshop took place on April 26th, 2012, at the Penn Stater Conference Center and Hotel in State College, PA. Featured speakers included **Mr. Christopher Paust**, Deputy Program Manager for the Central Test and Evaluation Investment Program (CTEIP) at the Test Resource Management Center (TRMC), **Dr. George Shoemaker**, executing agent for

Dr. Gilmore receives memento from chapter president Lee Schonenberg.

Mr. Christopher Paust, Deputy Program Manager for CTEIP at TRMC.

the Advanced Instrumentation Systems Technology (AIST), TRMC Test and Evaluation/Science and Technology (T&E/S&T), and **Mr. Clarence Ching**, Test and Evaluation Readiness Technical Program Manager, Naval Undersea Warfare Center (NUWC), Keyport Division. Presenters gave talks in the areas of Automatic Classification of Marine Mammals, Unmanned Underwater Vehicles, and Precision Tracking. The workshop attendance included members of industry, government, and academia.

The Penn State Chapter meets

Dr. George Shoemaker, Executing Agent for AIST at TRMC T&E/S&T.

Mr. Clarence Ching, T&E Readiness Technical Program Manager, NUWC Keyport.

the first Tuesday of every other month and has grown rapidly since its inception in May 2011. The chapter anticipates continued membership growth and plans to host a second workshop focused on undersea technologies for testing and evaluation in June 2013 at the Penn Stater Conference Center and Hotel in State College, PA.

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Valley of the Sun Chapter

The leadership team for the Valley of the Sun Chapter is finishing paperwork for funding its first scholarship, sending funds by November 1, 2012, to the Arizona State University (ASU) College of Technology and Innovation (CTI) at ASU's Polytechnic Campus. Meanwhile, the chapter is holding a meeting at ASU's SkySong Campus in Scottsdale, AZ, and establishing plans for a tour of the ASU's Polytechnic Campus in Mesa, AZ. The tour allows chapter members to see several on-going projects run by students, and to check on opportunities with the Collaboratory (a gateway for industry to readily access the assets of ASU's CTI). Working through the Collaboratory can further enable us to extend our collaborations amongst students and professionals.

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Western Europe Chapter

Forthcoming European test events that may be of interest to ITEA members are:

Training, Simulation, Evaluation & Test Event (TSET), 6-7 February 2013, University of West England, Bristol, England – see http://www.adsgroup.org.uk/articles/27623

European Test & Telemetry Conference (ETTC), 11-13 June 2013, Pierre Baudis Conference Centre, Toulouse, France – see www.ettc2013.org

Trade Fair—The Education Show 14-16 March 2013, National Exhibition Centre, Birmingham, England. This event is the UK's leading education event for the promotion and development of all learning and teaching—see www.education-show.com

The above and other future events will be posted onto the ITEA events calendar on the itea.org web site.

Special Section

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29th Annual International Test and Evaluation Symposium Highlights

The 29th Annual International Test and Evaluation (T&E) Symposium was held September 17 – 20, 2012 at the Hyatt Regency Conference Center in Huntington Beach, California.

Track Chair Pete Crump and presenters, Robin Poston, Tony Stout, and Mike Kendra.

This Symposium, "Testing at the Speed of Need," was designed to address the current concerns of the international T&E community; provide a platform for open dialogue to work together on solutions for future T&E challenges; and to build on the successes of previous Symposia. The Symposium, chaired by **Mr. Randy Surch**, Boeing Test and Evaluation, formed a team of dedicated volunteers 15 months prior to the event. The Technical Co-Chairs, **Dr. Steve Gordon**, Georgia Tech Research Institute and **Mr. Mike Lockard**, EMC Corporation, worked diligently to incorporate the subthemes, Policy, Processes, Procedures, and Facilities for Future T&E; Government, Industry, and Academic Partnerships to Share and Improve the T&E Infrastructure; T&E in an Agile Environment; Improving T&E through Integrated, Accelerated, and Innovative Processes; Scientific Principles to Improve the Speed of Testing; and Recruiting and Training the T&E Workforce into the entire program.

The theme and subthemes were used to plan tutorial topics for Monday's sessions, develop themes for the technical tracks held on Wednesday afternoon, and to synchronize the topics for the plenary speakers and the three panels scheduled on Tuesday, Wednesday morning, and Thursday morning. The Call for Papers attracted nearly 70 abstracts that were incorporated into 8 technical tracks, 8 tutorials, and 12 poster paper. By the time the Symposium started, several poster papers had been selected to fill-in for technical track presentations, and the remaining seven poster papers were displayed in the hallway just outside the plenary session and the exhibit hall.

The goal of the Symposium was to "Stimulate Partnerships and Inspire Solutions for Testing at the Speed of Need." With 420 registered attendees, 5 countries represented, 50 exhibitors, several outstanding guest speakers, 3 impressive panel discussions, and 24 technical presentations on Wednesday afternoon, the week definitely provided the forum for stimulating partnerships and inspiring solutions. Monday proved to be a very busy day filled with training and educational tutorials being offered, attracting over 100 students to attend classes on the Fundamentals of Design of Experiment, Test and Evaluation, and Agile T&E; and courses on T&E of Cyber Systems; Math, Probability, and Statistics for T&E; Mission Based T&E Strategy; Testing Future EW Systems; and Enabling Integrated Distributed

Poster papers had a lot of traffic.

Pete Nikoloff, Board Member, President of the Southern Cross Chapter in Australia, and lifetime member, addresses the audience.

Randy Surch presenting a big check to Norbie Lara on behalf of the Wounded Warrior Project.

Testing with TENA and JMETC. That evening, ITEA sponsored a Welcome Ice-Breaker with wine and cheese to bring our attendees together to kick off a week of technical sessions, open dialogue, and a gathering of T&E colleagues and friends.

On Tuesday, after the Presentation of the Colors by the **Magnolia High School JROTC** and the classic rendition of the National Anthem by **Mrs. Cindy Surch**, the ITEA leadership welcomed a slate of informative and thought-provoking speakers.

Mr. Norbie Lara, Wounded Warrior Project, after his briefing, accepted a check from Mr. Surch in the amount of $1,000 to the Wounded Warrior Project (WWP) on behalf of all our speakers in lieu of a gift of appreciation. The WWP programs are uniquely structured to nurture the mind and body and encourage economic empowerment and engagement for our severely injured service members who incurred service-connected injuries or illness on or after 9-11-2001. We could not think of a better way to acknowledge our outstanding speakers while joining them to support our wounded warriors.

The morning continued with briefings from **Mr. Rick Baily**, Senior Vice President of Engineering, Boeing Defense, Space, and Security, **Mr. Edward Greer**, Deputy Assistant Secretary of Defense for Developmental

A side bar with a few students after a tutorial.

Edward Greer accepting his certificate from Randy Surch acknowledging the donation to the WWP has been made on behalf of all our speakers.

Test and Evaluation, **Mr. David Gruel**, Mars Science Laboratory Assembly Test and Launch Operations, NASA Jet Propulsion laboratory, **Air Commander, Noel Derwort**, Aerospace Operational Support Group, Australia, and **Brigadier General Arnold Bunch**, Commander, Air Force Flight Test Center, headquartered at Edwards Air Force Base.

The afternoon of day one was highlighted by two panels, both moderated by outstanding leaders with their discussions addressing a variety of perspectives. The first panel, led by **Dr. Wilson Felder**, Director of the FAA Technical Center, created the momentum for the panelists to identify and talk to 'Future Opportunities to Develop a More Integrated Government/ Industry T&E Team.' The panel consisted of **Mr. Marshall Short**, Boeing Vice President of Lab Test Operations, **Mr. Mike McLendon**, Associate Director, Interagency Programs, Software Engineering Institute, Carnegie Mellon University, **Dr. Edgar Waggoner**, Director of the Integrated Systems Research Program, NASA, and **Mr. Marty Arnwine**, Test Resource Management Center.

Dr. Steve Hutchison, Principal Deputy, Developmental Test and Evaluation, emphasized "Testing at the Speed of Need; Agile Development" by bringing together representatives from the services, agencies, industry and academia to have an open dialogue on the challenges of agile development. Dr Hutchison suggested that agile development is the acquisition approach that is most likely to deliver enhanced capabilities at the speed of need, but that it would require change in acquisition and test processes, and that we could apply lots of lessons-learned from industry and academia. His panel consisted of **Mr. Terry Simpson**, Chief Technology Officer, Intelligence, United State Marine Corps, **Mr. David Jimenez**, Senior Executive Service, Executive Director, Army Test and Evaluation Command, **Mr. Gary Carter**, Director, Operational Test and Evaluation, Department of Homeland Security, **Mr. Jamie Masterson**, Air Warfare Destroyer System Acceptance and Verification Manager, Techport, Australia, and **Dr. Robin Poston**, University of Memphis, Systems Testing Excellence Program.

At the conclusion of day one, The Boeing Company sponsored a Grand Reception providing an opportunity for networking and fellowship to continue the dialogues from earlier in the day. The exhibit hall was filled with industry, academia and government partners sharing their products and services with T&E leadership, engineers, and managers, to ensure they are aware of the best and newest opportunities being offered.

The Vice President of ITEA, **Mr. Charles McKee**, kicked-off Wednesday morning with the announcement of the ITEA Chapter of Excellence Awards. The Chapter of Excellence Award is presented to Chapters that are vibrant and contributing effectively to ITEA's mission and goals to help ITEA in furthering the professional and technical interests of the Test and Evaluation community. These Chapters met stringent guidelines intended to measure their level of effectiveness and are recognized at this time for their excellence. Congratulations to the leadership and membership of these Chapters. 2012 Chapters of Excellence are: Antelope Valley Chapter (Edwards AFB, California), **Mr. Doyle Janzen**, President; Emerald Coast Chapter (Eglin, Florida), **Mr. Doug Davis**,

Networking.

President; Francis Scott Key (Aberdeen, Maryland), **Mr. John Schab**, President; Rocket City Chapter (Huntsville, Alabama), **Major Cornelius Allen**, President.

The Board of Directors also recognized the **Rocket City Chapter** as Chapter-of-the-Year for 2012, which is awarded to Chapter that provides outstanding opportunities for test and evaluation professionals to learn from others and share their own experiences, as well as facilitates the peer networking that test professionals require to expand their knowledge, skills, and abilities, and advance themselves and their profession. Along with the recognition, the Chapter of the Year will receive $500 for their Scholarship Fund. The ITEA Scholarship Program is designed to foster interest and education in technical fields that may benefit the test and evaluation profession. The program furthers the goals of ITEA by providing financial aid to qualified students.

The morning continued with outstanding guest speakers who took questions from the audience, including, **Mr. Tom Wissink**, Director of Integration, Test and Evaluation, Lockheed Martin, Dr. J. Michael Gilmore, Director for Operational Test and Evaluation, **Major General David Eichhorn**, Commander, Air Force Operational Test and Evaluation Center, and **Mr. Pete Christensen**, The MITRE Corporation.

After the ITEA T&E Professional Awards ceremony and luncheon, the afternoon was impressive as the 8 technical tracks made way for 24 presentations to be briefed, in some cases, to a standing room only crowd. The tracks were chaired by dedicated volunteers working with Dr. Gordon and

Chapter of Excellence recipients, Jim Brock, Mike Bell, John Schab, Sean Dobbin, and President of ITEA Chas McKee.

Mr. Lockard to create stimulating technical sessions for the attendees. The leads for this portion of the program were, **Mr. Ben Castillo**, 412 TENG/ENI, Edwards AFB; **Mr. Pete Crump**, **Mr. John Schab**, and **Mr. Miles Thompson** Georgia Tech Research Institute; **Ms. Souzane Tacawy**, **Mr. Greg Gocal**, and **Mr. Joe Bilodeau** , The Boeing Company.

On Thursday, the attendees continued to be enlightened by the panel entitled, "Future Workforce Development" moderated by **Mr. Robert J. Arnold**, Technical Director, 46th Test Wing, Air Armament Center. He, along with his panelists, Dr. Steve Hutchinson**, Mr. Jeff Moulton**, Information Operations and Program Development Director, Georgia Tech Research Institute, **Mr. Peter Nikoloff**, Director/ Senior Weapons System Engineer, Nova Systems, Australia, and **Mr. Gordon Eldridge**, Vice President and General Manager, BAE Systems provided their views of this continuing workforce development challenge faced by the Department of Defense T&E organizations. The panel members covered areas such as the aging workforce, a restricted flow of STEM graduates into the T&E workforce, and the changing needs of T&E, including cyber systems testing.

After the panel, **Major General (Retired) John Custer**, Director, Federal Missions and Programs, EMC Corporation, spoke about the problems connected to "big data" and the need to develop and test systems that sift through the increasing mountains of data generated every day. Our fully net-connected life and the net-centric challenges of warfare are shifting to what could be called a

J. Michael Gilmore, PhD. answers questions from the audience.

Track Chair, Souzane Tacaway presents certificate of appreciation to presenter, Eric Greene.

John Custer, MG (Retired) speaking to the attendees.

data-centric world. His bottom line was that the challenges of big data demand a new T&E paradigm.

And at the conclusion of the program, the much-anticipated and traditional final briefing 'A Call to Action' by **Mr. David Duma**, Principal Deputy Director, Operational Test and Evaluation, gave the attending T&E community an overview of the speakers during the Symposium and a restatement of many of their key points and bottom lines. Mr. Duma challenged the audience to work together to help solve the issues presented where possible.

The benefit of a sponsorship not only defers the costs associated with hosting this premiere event, but it allows ITEA to continue its mission to *advance the field of Test and Evaluation worldwide in government, industry and academia*. ITEA provides scholarship dollars throughout the year to deserving students in their pursuit of academic disciplines related to the T&E. We would like to express our sincere appreciation to our generous sponsors who invest in the future of the T&E workforce. Platinum Sponsors: **Scientific Research Corporation** and **TASC**; Gold Sponsors: **ALION Science and Technology, CALCULEX**, **EWA Government Systems Inc.**, **General Dynamics, C4 Systems**, **ManTech International Corporation**; Silver Sponsors: **ASD**, **Jacobs**, **CSC**; and Bronze Sponsors: **Georgia Tech Research Institute**, **ISTEMS**, **JT3**, **Rockwell Collins**, **TRAX International**.

The entire symposium is planned and executed by volunteers and it is their unwavering dedication to the T&E community and to ITEA that leads to the success of this premier T&E event. Logistics coordinator, **Ms. Suzanne Hammond**, The Boeing Company, led the efforts on-site for a seamless production. The support of the audio visual/speaker ready team from Georgia Tech Research Institute, **Ms. Doresa May** and **Ms. Julie Fenger**, along with the much appreciated support at the registration desk from Boeing employees, **Ms. Amy Azpeitia** and

Dave Duma in the audience preparing for his briefing on a call to action.

Ms. Laura Brewster. The official photographer**, Ms. Kelli Seten-Coolidge,** as well as many others who supported 'behind the scene,' were recognized in person by Mr. Surch during the symposium.

During the Symposium, ITEA offers a private meeting room for sidebar meetings for our attendees to increase their productivity. This year we had over 10 meetings taking place during the week and received feedback from one of our attendees, "Thank you for arranging for this meeting room for us on Monday afternoon. It was exactly what we needed, and I was able to bring together the T&E Test Center stakeholders for a very productive technical interchange meeting." We encourage our attendees to take advantage of this opportunity next year.

Some other notables from the Symposium include the commitment to nurturing the T&E workforce. In addition to the "Future Workforce Development" panel, the planning committee made sure that subtheme, "Recruiting and Training the T&E Workforce," was stressed by encouraging early career T&E professionals to participate. We challenged the T&E leaders to ask their early career T&E professionals to submit an abstract for consideration and to attend the Symposium. An independent committee reviewed the papers and attended their sessions and were pleased to announce the following individuals won a monetary award for their presentations: **Mr. Daniel Carlson**, Air Force Flight Test Center at Edwards Air Force Base; **Mr. Eric Greene** of Raytheon Missile Systems; and **Ms. Gina Parodi de Reid** of The Boeing Company. And finally, ITEA incorporated the subtheme on the future T&E workforce by hosting the Academia Day Program on Thursday morning.

Technical co-chair, Steve Gordon presenting Daniel Carlson his monetary award for best presentation.

As we prepare for the 30th Annual International Test and Evaluation Symposium the week of September 16th in Denver, Colorado, we are reviewing the surveys you provided us with at the conclusion on the event. Comments such as "outstanding event," "best conference attended in 10 years," and "academia day was a big success" are much appreciated. The best things from this year are being considered for next year, and less popular aspects of this Symposium are being evaluated for improvement or elimination. Our goal is to design and deliver the best mile-high training and idea-exchange event of 2013. We encourage you to submit an abstract for a presentation, suggest a tutorial topic, or consider volunteering. It is a commitment of your time and talent, it is rewarding, and after all was said and done this year; some members of the planning committee for 2012 have a measure of sadness and withdrawal from the planning process, as they question "What, no Symposium planning teleconference on Monday afternoon?" Visit the ITEA website for more details on the 30th Annual International T&E Symposium and to learn how you can become involved.

The Academia Day Program at the Annual Symposium

Since 2009, ITEA has been developing an annual program dedicated to high school students participating in the science,

Academia Day Students.

technology, engineering and mathematics (STEM) initiative. The program consists of highly recognized speakers and panelists engaging and encouraging students as they make plans for undergraduate studies and their future in the workforce. The event took place on Thursday, during the Annual International Test and Evaluation Symposium with time allotted for the students to engage with our attendees, sponsors, and exhibitors to learn about the opportunities in the test and evaluation community as they thought about their future college choices, summer internships, and potential career fields.

One of the best ways to motivate STEM students and promote their entry into the T&E field is for students to see and touch the systems used in T&E and to talk to the T&E professionals. Some of the students we met at the Symposium this year will be young T&E professionals in the next decade, and they will be ITEA Symposium attendees and planners within a few years after that.

The 2012 program, chaired by **Mr. Michael Bell**, Army Test and Evaluation Command, together, with the exceptional support of the planning committee, **Ms. Villy Angelico**, The Boeing Company and **Ms. Catherine Reich**, Scientific Research Corporation, exceeded all expectations as over 250 students from nine schools across the Los Angeles and Orange County districts emerged from the busses. In addition to the students, several school district administrators and educators came to check out the event and decide if they would support future events.

New to the program this year, ITEA introduced its first student paper competition which required the students to work on the papers during their summer vacation. Anyone who works on a paper over summer break automatically deserves points for being passionate about the subject.

From the seven submittals three winners received an iPad, a one year ITEA membership, and their papers are published in the December issue of *The ITEA Journal*. The winners are **Mr. Bradley Matheus**, a 12th grader at California Academy of Mathematics and Science with 36/36 points; **Mr. Zaki Molvi**, a 12th grader from Troy High School with 36/36 points; and **Ms. Sara Pak**, a 12th grader from Diamond Bar High School with 34/36 points. The three iPads, along with lunch for all the students, were generously donated by **Mr. Albert Sweets**, President, ISTEMS. The Boeing Company and Georgia Tech Test and Evaluation Research and Education Center (TEREC) were also proud sponsors for this outstanding program.

The keynote speaker, **Mr. Kyle Bridgeo**, an early career Boeing

Students enjoyed a full day of activities at The Academia Day Program at the Annual Symposium.


Best paper competition participants.

engineer, opened the day by sharing what worked for him in securing internships and gaining visibility in the workplace – "take the initiative." The interaction with the students was a highlight and the students asked impressive questions. Bridgeo was followed by a high caliber panel facilitated by Mike Bell. The students had tough, thoughtful questions for the panel, consisting of Al Sweets; **Mr. Albert Sciarretta**, PE., President, CNS Technologies, Inc.; **Mr. James Hutchinson**, Program Manager; **Ms. Christa Rogers**, government contractor supporting the U.S. Naval Air Warfare Center (NAVAIR) and former intern; and **Mr. Gary Estep**, Broad Area Maritime Surveillance; ITT Interoperability/ T&E Networks Lead, NAVAIR. At the conclusion of the panel, the students had the opportunity to meet with **Mr. Marshall Short**, Vice President, Boeing Laboratory Test and Evaluation; **Mr. Tom Wissink**, Senior Fellow and Director of Integration, Test and Evaluation Corporate


Bradley Mateus, 1st place winner with Al Sweets.

Engineering and Technology, Lockheed Martin; and **Dr. Steve Gordon**, Georgia Tech Research Institute. Afterwards, the students filled the Exhibition Hall. The Academia Day program is geared to the motivated and passionate students all over this country. The students were provided sound advice, guidance, and opportunities

Zaki Molvi, 2nd place winner receives an iPad from Al Sweets.

Sara Pak, 3rd place winner.

to be integrated into the technology community. The interchange and ongoing conversations that ensue are essential to realizing the significance of this program and the future of our workforce – a fifteen person student team designing autonomous robots requesting subject matter experts to review their online survey, a student interested in developing apps for military systems, and a student interested in becoming a Navy officer with a technical background were pointed in the right direction.

The 2012 ITEA Academia Day program certainly set the bar high for the 30th Annual International Test and Evaluation Symposium. If you are interested in volunteering or supporting the program with a sponsorship, please contact us at AcademiaDay@itea.org.

The ITEA T&E Professional Awards at the Annual Symposium

ITEA annually presents seven Professional T&E Awards to individuals and groups that have made significant contributions to advancing the test and evaluation profession. The awards luncheon that took place on Wednesday, September 19, recognized the recipients of 2012 ITEA Awards.

The ITEA Board of Director's Award was presented to **Steven J. Hutchison, Ph.D.** The award, established in 1997, is presented to an individual who has contributed to the growth, development, goals, and mission of the Association.

The ITEA President's Award, presented to **Gary L. Bridgewater**, established in 1996 to give the president of ITEA the prerogative of acknowledging individuals whom he or she deems worthy of recognition. The President's Award is reserved for an individual who selflessly steps up to assist the president in the execution of the organization's goals and missions. Mr. Bridgewater was unable to attend the ceremony. **Mr. Edward Garza** accepted on his behalf.

The Allen R. Matthews Award was presented to **Mr. Thomas R.**

Academia Day Chair, Mike Bell and panelists, Gary Estepl, Christa Rogers, Kyle Bridgeo, Al Sweets, Steve Hutchinson, and Al Sciarretta.

Back row: T&E Professional Award recipents: President of ITEA Chas McKee, Sub-Committee Chair, Larry Leiby, Eileen Bjorkman, Steve Hutchison, Michael Modia, Kate Aggas, Paul Cast, and ITEA Awards Chair, Al Sciarretta. Seated: Jim Brock, Greg Glenn, Bruce Einfalt, Ed Garza, and Marty Arnwine.

Berard, recently retired SES from AFFTC, Edwards AFB. Named after Dr. Allen R. Matthews, founder and first president of ITEA, it is presented to an individual for a lasting, significant contribution to the field of T&E, such as the cumulative effect of a distinguished career. The Allen R. Matthews award is the highest award bestowed by ITEA. Mr. Berard was unable to attend the ceremony. **Col Eileen Bjorkman USAF**, **Retired**, accepted on his behalf.

The Special Achievement Award, presented to **Mr. Shane Esola**, U.S. Army Aberdeen Test Center, was given for an exceptional special act of achievement in T&E, such as the solution of a major problem, or a notable project success for which there is evidence that tangible benefits have accrued. Mr. Esola was unable to attend the ceremony.

The Richard G. Cross Award was given to the **Naval Aviation Test and Evaluation University**. Named after the late Major General Richard G. Cross, Jr., USAF, a highly respected figure in T&E and one of the first directors of ITEA, it is presented to an individual, team, or organization for a significant contribution to education for T&E in teaching, administration, or research.

The Publications Award was presented to **Mr. Bernard "Chip" Ferguson**, **Dr. Michael G. Lilienthal**, **Mr. Christopher Yglesias**, **Mr. David Brown**, and **Ms. Natalie Apuzzo**, of the OSD Joint Mission Environment Test Capability (JMETC). The Award recognizes outstanding contributions to test and evaluation literature, and is given for a book, technical paper, or article that improves or increases the body of knowledge and understanding of T&E. The authors were unable to attend the ceremony. **Mr. Marty Arnwine** accepted on their behalf.

The Technical Achievement Award, presented to the **413th FLTS Instrumentation Team**, recognizes an individual or group for outstanding achievement in applying instrumentation, information technology, modeling and simulation, time-space-positioning information, electro-optics technology, or other T&E technology to cause a test and evaluation program to be better, faster, and less expensive.

The Junior Achiever Award was presented to **Mr. Michael Modica**, U.S. Army T&E Command. The award recognizes a young professional who, during his/her first 5 years of practicing in the T&E field, has accomplished a significant achievement(s) which enhances and strengthens the T&E profession.

The Energizer Award, presented to **Mr. Bruce Einfalt**, Applied Research Laboratory, The Pennsylvania State University, recognizes behind-the-scenes volunteer contributions that have supported the test and evaluation community and/or member organizations.

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Association News

ITEA AND DEPS ANNOUNCE CO-LOCATION OF 2013 EVENTS

ITEA's Test Instrumentation and DEPS's Directed Energy Test and Evaluation Workshops to be Jointly Held May 14–17, 2013, in Las Vegas, Nevada.

The International Test and Evaluation Association and the Directed Energy Professional Society have announced they have reached an agreement to co-locate two of their most successful annual events beginning in 2013. This agreement expands a partnership that the two organizations formed over a decade ago to bring high-value workshops presenting state-of-the-art technologies, techniques, and best practices for test and evaluation professionals involved in the research and development of directed energy technologies.

The Directed Energy Test and Evaluation Workshop, which previously has been held each August in Albuquerque, New Mexico, will be co-located with ITEA's Test Instrumentation Workshop in odd numbered years, and co-located with DEPS's Directed Energy Systems Symposium in even numbered years. In 2013, the Directed Energy Test and Evaluation Workshop will be held May 14-17 in Las Vegas, Nevada, at the Tuscany Suites Hotel, and then in 2014, it will be held in the April timeframe in Monterey, California.

At the May 2013 co-located events, each workshop will have dedicated general and track sessions, but participants will be able to "cross-over" and attend sessions in either workshop. The exhibit hall will also be open to all attendees and showcase organizations from both the directed energy and the test instrumentation industries.

For more information and to register for these two workshops, please visit www.itea.org/directed-energy or www.deps.org and click on "Events."

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2013 PRODUCTION SCHEDULE

Issue	Space Reservation Due	Ad Material Due
March	12/27	1/11
June	3/28	4/12
September	6/27	7/12
December	9/27	10/11

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