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Never Stop Learning or Innovating: A Conversation with Dr. Edward M. Kraft

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Dr. Edward M. Kraft

Q: When and how did your career in Test and Evaluation (T&E) begin?

A: In 1964, I was a co-op student in aerospace engineering at the University of Cincinnati. My co-op assignment was at AEDC (Arnold Engineering Development Center, now Arnold Engineering Development Complex). Early in my co-op career I worked as a technician in two research wind tunnels. This was an excellent way to learn not only how wind tunnels work, but also how organizations work. Later I co-oped in a facilities development group where I was involved in the design and operation of major wind tunnels.

Q: You spent several years as a contractor. What lured you to join the Air Force as a civilian? What observations do you have from both sides of that relationship?

A: In my contractor career I rose from a co-op student to a test engineer, research engineer, and a number of management positions culminating in being the General Manager of one of the operating contracts at AEDC. I literally got to see every facet of a contract operation.

In 1995, AEDC recombined multiple contracts and the company I was with did not retain their contract. I went into private industry, still in the aerospace industry, as the Chief Technical Officer for a small company. This experience opened new doors in understanding management, finance, and business development. The company was responsible for building and flight testing the X-43A so I got to see the whole development and testing process from a different perspective.

By 2001, I had worked with the company owners to do strategic acquisitions to grow. They, in turn, were bought by a larger company. I decided I would like to get back to my technical roots. About that time, the Chief Technologist position at AEDC opened up. I was encouraged by Air Force (AF) leadership to apply. I did and was selected for the position and started my federal career in September 2001 just 2 weeks after 9/11.

As a contractor, one of the limitations I had was the ability to pursue visions I had for improving T&E and implementing them into policies and methods not only at the AEDC but at the AF and the Department of Defense (DoD) as well. As a senior civilian I found I had much more opportunity to shape national activities particularly in T&E as well as high performance computing. Two areas where being able to have more influence on policies and practices at the national level paid off were being one of the originators for the HPCMP (High Performance Computing Modernization Program) CREATE (Computational Research and Engineering Acquisition Tools and Environments) program in 2005 (and later its extension to hypersonics), and in 2013 working with the AF Chief Scientist and the AF Chief Engineer in parallel activities that led to the AF Digital Thread / Digital Twin. Even today I am still shaping the vision for Digital Engineering not only across the DoD but commercial industries as well.

Q: What was your role in the test process? How did that change over the years? Was testing conducted using a rigorous, well-defined,

documented process or was it based on senior tester experience and on-the-job training that adapted to each different test?

A: When I started as a young test engineer, it was primarily OJT (on-the-job training) guided by greybeards. Over the years various efforts did provide some disciplined training for new hires, but there was still a strong reliance on greybeards. As a test project engineer, I had responsibility for conducting a test from start to finish including coordination with the customer, test planning, test execution, data quality certification, data analysis, and documentation.

Q: What procedures and processes did you use early-on in your career that you would like to see come back?

A: I had the good fortune to spend my early testing career in what may have been the "golden years" of aeronautical ground testing. As I mentioned, during my co-op experience I was involved in designing new wind tunnels. In the 60's and early 70's many ground test facilities were being developed and commissioned. Several advanced concepts for hypersonic testing were in research. Today there are almost no new test facilities being developed.

The decade of the 70's marked major technical advances in aeronautical ground testing. Data acquisition systems were moving from vacuum tube technologies to digital systems resulting in increased accuracy of measurements. With better data quality, wind tunnel / flight correlations started to reveal some fundamental shortcomings in wind tunnel results, namely the effects of scale, noise effects on boundary layers, and the impact of the wind tunnel walls. The entire aeronautical community including test centers like AEDC, NASA wind tunnel centers, OEM (original equipment manufacturer) testers, and test centers from all NATO nations mobilized and collaborated on wind tunnel-to-wind tunnel as well as wind tunnel-to-flight correlations. The collective body of knowledge grew rapidly and was shared across the community. Over the last several decades, much of this in-depth knowledge has been dissipated and young engineers entering the testing community today do not have the opportunity to gain such deep knowledge of their craft. Most of the SMEs (subject matter experts) that generated that knowledge have retired; hence, it cannot be passed on through OJT.

During the 70's I also had the good fortune to work theoretical problems in wind tunnel wall interference, apply some early computational fluid dynamics codes, and do some innovative experimental research on adaptive-wall wind tunnels. This unique opportunity to do theory, computational modeling, and leading-edge experimental research enabled me to build a strong foundation across the spectrum of digital and analog simulations that made it natural for me to automatically think of ways to integrate modeling and testing. This paid huge dividends later in my career.

Acquisition policies and budgetary challenges have all but eliminated this kind of collaborative research. I think resurrecting at least a modest investment in collaborative research would pay huge dividends in advancing the state-of-the-art in aeronautical ground and flight testing. Applications of digital engineering to ground and flight testing, which is the ultimate integration of modeling and experimental methods, could be the focal point for such a collaborative effort. Working across government, industry, and academia with a common focus could accelerate the cultural transformation and implementation of digital engineering principles, tools, and practices to T&E. I have recently written an article for *The ITEA Journal* that describes the potential future transformation of T&E using digital engineering.

Q: What was the interaction of Program Offices with your test organization? How did that change over the years?

A: In the early years, AEDC was viewed as a trusted and valued partner with the Program Offices. At that time AEDC provided world-class expertise in key ground testing methods and an independent, comprehensive data analysis and reporting of each test was provided to the Program Office. The Program Office valued these independent assessments as a quality check on the input from the OEMs. The OEMs also appreciated the technical expertise of folks at AEDC and collaborated with our experts to solve problems during testing. The emphasis by all parties was technical excellence.

There were two policy changes that, in my opinion, had a very negative effect on the effectiveness of the ground testing and analysis we were doing at AEDC. The first occurred in the early 70's when AEDC went from fully institutional funding to reimbursed budgeting. From the inception of AEDC to the mid 1970's, AEDC was institutionally funded. Program Offices could focus more on their test needs and less on having to find the budget to test. Researchers at the AF Research Laboratory (AFRL) could get access to the world-class facilities at AEDC within their limited research budgets. In the early 70's, one-third of the test workload in the AEDC wind tunnels was synergistic research with the AF Laboratories. They were doing research in the best-in-class aeronautical facilities and

the AEDC engineers were working at the leading edge of aeronautical research. The growth of technical expertise for both organizations was explosive.

Moving to a reimbursed budget authority had several negative effects that persist today. First, since the Program Office had to foot the bill, they looked for ways to reduce costs. The easy way to cut costs was to eliminate having AEDC engineers do independent analysis and reporting – pretty quickly ground testing moved toward power-by-the-hour vs. technical excellence. Also, it didn't take very long with engineers not analyzing test data for AEDC to lose its technical edge. Second, the attention of the test project engineer shifted from technical excellence and evaluating the data to tracking costs. At least 50% of the test engineers' time during a test was involved in tracking real time costs vs. working with the customer to assure the data was solving their problems. Third, the AF Research Laboratory could no longer afford to use the AEDC facilities and for the next four decades did their fundamental research in NASA facilities (which were still institutionally funded) or the Laboratory would build their own wind tunnels. Only recently have efforts been made to develop a closer working relationship between AFRL and AEDC, particularly in hypersonics.

The second major policy change which affected all of T&E was the acquisition reform "Total System Performance Responsibility" policy instituted in the early 90's. In essence, the Program Office gave all responsibility to the OEM for developmental testing. AEDC was relegated to being wind tunnel operators vice collaborating with the OEMs to assure technical excellence. Test project engineers spent almost all of their time tracking real time costs. Management attention was on costs, not technical excellence. The only reports written were Test Summary Reports which only documented a test was performed on these dates at these conditions. Even worse, the number of engineers in the Program Office was reduced as well resulting in the government not having technical experts in the Program Office or AEDC who could verify the findings of the OEMs. The AF had lost the ability to be a smart buyer.

Q: Has the role or perception of the test officer and/or evaluator changed over the years?

A: I am not sure how to answer this question. Over the last several years there has been a disciplined approach to more formally identifying and codifying the role of the Lead Development Tester and the Responsible Test Organization. This helps shape the roles and responsibilities of the test activities, but hasn't significantly changed the test activities.

Q: Has your perception of T&E changed as you have served in a spectrum of roles, contractor and civilian, within the Air Force?

A: As I progressed in my career from contractor to civilian, I have gained a more comprehensive view of the relevance and impact of T&E. I have also gained more insight into how the policies of T&E as well as acquisition impact the outcomes of programs. When I was a young engineer, I could barely see past the day-to-day duties of executing a test.

Q: Have the multitude of changes in acquisition reform had an impact on how testing is perceived by Program Offices? Has testing become just a compliance step instead of a valuable asset to a Program Office? If yes, what led to this? How can we reverse it or what actions or policy changes would reverse it?

A: As I outlined above, acquisition reform has had a significant impact on how testing is perceived and more importantly executed. I think aeronautical ground testing is done more by rote than by using the knowledge generated to reduce risks to the system. As an example, I compared the wind tunnel campaigns for two aircraft development programs separated by a decade. During that decade wind tunnel efficiency increased by a factor of 4-6 and major advances in computer modeling resulted in very efficient and accurate computer simulations. However, the respective wind tunnel campaigns for the two systems took nominally the same amount of test hours and calendar time. Also, over the years I have informally asked wind tunnel users how much of the data was actually used. Anecdotally only a modest fraction of the data is used directly – the rest is acquired "just in case there is a problem."

It has also influenced the test organizations as well. Instead of constantly pushing innovations in testing, I have seen testers pretty much resigned to doing what the OEM or Program Office requests. More than once I have suggested how to push the state-of-the-art only to get a response "that is not our job."

Q: Were there any landmark events that shaped or changed T&E from your perspective?

A: In the mid-80's, I was the Branch Manager for a Technology and Analysis Branch in the wind tunnels at AEDC. I had an outstanding CFD (computational fluid dynamics) group led by Dr. Jack Benek, an equally outstanding group in flight mechanics analysis led by Dr. Bill Baker, and a state-of-the-art flow diagnostics group lead by Mr. Donnie Williams. Our Branch was

physically located with the test branch for the transonic wind tunnels at AEDC.

The CFD group developed and introduced a major innovation (referred to as the Chimera zonal decomposition method) into modeling complex aircraft geometries with limited computer resources. At the time, the AEDC "supercomputer" was an IBM 360, a scalar machine with a single CPU and about 1 megabyte of RAM. Through application of the Chimera scheme, the CFD group was able to model the emerging F-15E aircraft and the interactions between stores separating from the conformal fuel tanks. At the same time, the flight mechanics group introduced a next generation, nonlinear 6-DOF trajectory generation program that could predict store separation trajectories of non-symmetric or tumbling stores. They also introduced the innovative use of a CAD workstation to present a wireframe image of a store separating from an aircraft in close to real time as the data was coming out of the wind tunnel. With my background in integrated analog and digital approaches to problems, it was natural to put the pieces together to invent a new way of analyzing weapon separation using CFD, the wind tunnel, and the new 6-DOF capability referred to as "Integrated T&E" (IT&E) at AEDC. We briefed the F-15E System Program Office (SPO) who invested in proving our new concept for the F-15E which was just entering into its air armament certification process. We successfully demonstrated the new, integrated approach and were off and running expanding the IT&E methodology.

Serendipitously, the AF SEEK Eagle Office (AFSEO) was being formed at Eglin AFB and put out a call for new approaches to safely testing air armament carriage and release. Dr. Baker and I briefed the AFSEO folks on the new IT&E concept. Jim Robinson was the lead technical expert at AFSEO and immediately saw the value of what we were doing. Over the next decade, AFSEO and AEDC collaborated to revolutionize the safe certification of air armament carriage and release. The new approach had a significant effect on the integration of weapons for the F-22 program which was just getting started. All subsequent aircraft weapons integration programs including the F-18E/F, F-35, B-2, and even the venerable B-52, which was retrofitted with small diameter bombs, benefitted from the integrated methodology.

At the same time, the High Performance Computing Modernization Program was initiated with the mission to provide high performance computing capability for the DoD. Initially, it was focused on providing HPC resources to the research community. Symbiotically, our need for more computer capability to expand the applications of IT&E to more and more programs intersected the HPCMP's need to justify their budget by demonstrating relevance to the warfighter. The AFSEO/AEDC application of IT&E to weapons integration became an important demonstration of applications of HPC capabilities to support the warfighter. In the early 90's, the HPCMP formally expanded their Charter to include T&E with their original S&T (science & technology) mission. Applications to air armament integration was the poster child for applications.

When I took the position of Chief Technologist at AEDC in 2001, I was appointed as the AF T&E representative to the HPC Advisory Panel. It was one of the most fruitful appointments I have had in my career. In June of 2005, several folks met during a side bar discussion during the HPC User Group annual meeting in Nashville. The question at hand was how could the HPCMP justify investments in more computer capability for the DoD. The answer was to expand the HPCMP mission to the support of the life cycle of weapon systems. Within a couple of years, the HPCMP again expanded their Charter to formally include acquisition to Science and Technology (S&T) and T&E.

Also at the 2005 sidebar discussion, the realization that the HPCMP needed to do more than just provide computers led to the initial realization that better modeling tools would be needed. Dr. Doug Post, the HPCMP Chief Scientist, and I facilitated a meeting at AEDC in September of 2005 and birthed the concept of the Computational Research Engineering Acquisition Tools Environment (CREATE) Program. Doug accomplished the impossible by selling the concept to senior leaders in the DoD and securing an unheard of 12-year Program Objective Memorandum (POM) budget for implementing and fielding CREATE. By FY2008, we had funds in hand and were off and running on developing what I believe is probably the most successful large scale, wide ranging software development program in the aerospace industry. The fixed- and rotary-winged version, CREATE-AV, provides an integrated modeling capability that includes the airframe aerodynamic performance, fluid/structure interactions, integrated propulsion systems, weapons integration and separation, as well as inner- and outer-loop control of moving control surfaces. The CREATE program not only has developed an advanced capability for modeling air vehicles but also ships, land vehicles, and RF antennae. These capabilities have had a major impact on T&E across the DoD, including ship-shock tests for the Navy.

Q: You were an early and vocal proponent of modeling & simulation and high performance computing, and it has had a significant impact on

testing at AEDC. Do you see the role and impact of Modeling and Simulation (M&S) and HPC in testing continuing to grow?

A: I see a much bigger impact of M&S and HPC, as we refer to them today, on testing in the future. However, it will require a major cultural transformation and rethinking of what we mean by M&S and HPC and how they interact with T&E using digital engineering principles and practices. M&S has already become an arcane term overtaken by model-based engineering (MBE) and the development and application of authoritative digital surrogates through a disciplined application of uncertainty quantification methods. HPC will take on added dimensions not only for running big computer codes, but for handling high-volume, high-velocity data from cloud computing, big data analytics, artificial intelligence, probabilistic analyses, and edge computing for digital twins.

The current idea of testing being the source of data for Verification, Validation, and Accreditation (VV&A) of a computer code will give way to a full integration and continuous recalibration of an authoritative response surface models generated from any and all heterogeneous data sources such as low fidelity models, high fidelity models, experiments, tests, and operational data. The authoritative digital surrogate model will enable quantifying margins and uncertainties for key technical performance measures (TPM) to enable risk informed decision analytics. Using statistical inference, the ability and cost of a test to reduce uncertainty in a key TPM can be evaluated leading to the selection of a best course of action to meet requirements.

T&E will further transform using models and high speed, high volume data applications to automate many of the test activities and introduce agile test and evaluation innovations. Instead of following a predetermined, rigid test plan, an agile strategy of using HPC high speed applications of authoritative digital surrogates will enable creating knowledge in real time and using that knowledge to determine the next test point to automatically optimize the test program. Automatic evaluation will use the authoritative digital surrogates to perform probabilistic analyses to forecast impact on performance and cost leading to best value in mission utility and reliability at the minimum total ownership cost.

Q: Do you think testing has become too dependent on technology; are we using enough of it?

A: On the contrary, I find the current testing community to be a conservative community slow to engage new technologies. This has been further exacerbated by the policy changes that suppressed innovation and has moved testing more to a commodity. An example is the challenge of introducing statistically defensible testing through applications of design of experiments. Although required by DOT&E (Director, Operational Test and Evaluation), the testing community found many reasons, some legitimate, for not using DOE (design of experiments). Implementation of digital engineering to testing will require a comprehensive, integrated use of statistical engineering tools including not only DOE, but Gaussian methods and Bayesian inference. Based on the DOE and STAT (scientific test and analysis techniques) experience, I expect the full integration of uncertainty quantification to manage risks in T&E will be a challenge.

Q: How has the T&E workforce changed? What can T&E organizations do to continue to attract, motivate, and retain an excellent, highly skilled, and vibrant technical workforce while competing with industry and higher grade government organizations?

A: Attracting a highly skilled workforce to T&E has never been about pay or location but about the nature of the work. To be involved at the earliest stages from development through introduction of the most advanced weapons system in the world using the best-in-class test capabilities should be a major attraction. Also to be involved with almost every system as it goes through the T&E cycle as compared to working on a single weapon system for most of your career should add more interest in working in T&E. The problem is policy reforms over the years have turned many T&E jobs into repetitive tasks with little incentive to innovate. Testing today is a commodity. Many testers across the MRTFB (Major Range and Test Facility Base) are contractors. In today's contracting world, competitive pricing usually translates to lower salaries and little to no financial support for gaining higher education and expanding your skills. Contracting language usually indicates the government expectation that a contractor employee will meet the job description and no more. The best and brightest coming out of colleges today will be turned off by lower salaries, repetitive tasks, and limited technical growth. They may accept a lower salary if they can innovate and contribute.

Reflecting on my own career, I was highly encouraged and supported to get my M.S. and Ph.D. The research I was doing at AEDC was the basis for my thesis and dissertation. AEDC got the benefit of the additional hours I spent at home completing my degrees. The AF and my contractor leadership highly encouraged

and supported pursuing innovative new ideas. This was a rich environment for doing exciting work and constantly growing technically. If I came to work today at AEDC, I would likely move on in 2-3 years vs. spending more than 50 rewarding years in and around AEDC.

Q: Your successful career has centered around AEDC, holding leadership positions as a contractor and later as an Air Force Scientific and Professional (ST). You were elected a Fellow of AEDC and a Fellow of the American Institute of Aeronautics and Astronautics (AIAA). What do you consider to be some of your other career highlights? What advice do you have for those employees just entering federal service?

A: My career highlights were the introduction of Integrated T&E at AEDC, shaping and helping lead the HPCMP CREATE program development and application, and early formulation and selling of the AF Digital Thread / Digital Twin initiative. All of these built off my early insights into the synergistic use of modeling and testing and have had impact far beyond my activities at AEDC.

My advice to not only those entering federal service, but to anyone entering into the Aerospace and Defense community is threefold; don't stop learning, always look for innovative ways to improve what you are doing, and develop deep insight into the context and purpose of what you do. Avoid staying focused on the narrow sliver directly in front of you. The first two came naturally through my early research activities. The third came later in my career, particularly after I assumed my role as the AEDC Chief Technologist. Recognizing that further budget cuts to T&E were on the horizon, I systematically studied the role and relevance of T&E to the entire life cycle of a weapons system as justification for T&E. I organized and facilitated several lean/six sigma workshops looking in detail at the acquisition cycle for programs like the F-22 and several turbine engine development programs. I also explored the interactions between budget cycles and the growth of acquisition cycle times across essentially all DoD acquisition programs. In 2013, when working with the AF Chief Scientist and Chief Engineer, I was quickly able to connect all of the functional activities over the entire life cycle of a system and how model-based engineering could improve the total process. This was the innovative foundation for the AF Digital Thread / Digital Twin concept which was the initial foundation for the DoD Digital Engineering Strategy. ❑

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EDWARD M. "ED" KRAFT, Ph.D., is an independent consultant to the Aerospace and Defense industry. He has more than 50 years' experience in testing and evaluation in the government, industry, and academia. He recently retired as a member of the federal Senior Executive Service as a Senior Leader serving as the Chief Technologist for ground testing in the Air Force Test Center. He is a nationally recognized leader in the innovative integration of high-performance computing with testing to improve defense acquisition. He is one of the initiators and principal architects for the Air Force Digital Thread/Digital Twin initiative and a strong advocate for the applications of Uncertainty Quantification in developing the digital authoritative truth source in support of decision-making.