Up Close with Maj. Gen. (Ret.) Thomas C. Brandt

Thomas C. Brandt is Associate Director at the Software Engineering Institute (SEI) at Carnegie Mellon University. Appointed to that position in January 1995, he is responsible for SEI activities relating to strategic development initiatives for rapid transition of software technology. Brandt has more than 39 years experience as an engineer and senior executive specializing in the development and operation of high technology space, missile, and command and control systems. He was a test director for both the Atlas and Minuteman programs and participated in more than 40 ballistic missile launches. As an associate professor in the department of astronautics and computer science at the United States Air Force Academy, he helped develop digital-based open form solutions to complex problems in celestial mechanics.He has been associated with the military space program for more than 25 years and was responsible to the Joint Chiefs of Staff as the planner for the United States Space Command. As vice commander of the Electronic Systems Division he had a broad range of responsibilities for the research, development, and acquisition of strategic systems. He is a graduate of the United States Naval Academy at Annapolis, Md., and holds a master's degree in electrical engineering from the Air Force Institute of Technology. He is also a distinguished graduate of the Industrial College of the Armed Forces and the Executive Program of the School of Business at the University of Virginia.

Brandt: The F-22 is, at this stage, a very happy story. That is good to report because the stories that I have recently encountered generally are not in that category. Quite often when people find their program troubled they will ask for someone to come in—like an independent review group, a Tiger Team. In this circumstance you are cast in the role of the pathologist, or the coroner, or even Jack Kevorkian: 'I am here to help you, breathe deeply two times.'

That was not the case for the F-22 review late last June. It was really a risk mitigation intervention, to look at the state of the development [of the F-22 avionics]. This was late in the research and development phase to determine:

- The risks before and during the terminal phase of the Engineering and Manufacturing Development.
- The segue into low-rate initial production.
- The tradeoff between live fly testing, which tends to be very expensive, and modeling and simulation testing as an alternative.

There are two advantages to modeling and simulation, which in this program turn out to be a best practice. Modeling and simulation, with the fidelity we now have in computation, allows testing of the dynamic envelope of a product as it performs. We were focused on the avionics suite that has some unprecedented application of emerging technologies. An example is sensor data fusion—not an easy technical job—component in the avionics tend to be software-intensive, whether it is the inertial reference system or the so-called Communications Navigation and Intelligence suite. The avionics is a federated system of components, all of which must interoperate in highly complex, sophisticated ways. From the software perspective, we have made progress over the last decades. However, the continued evolution of electronics is accompanied by demands for increasing complexity and has masked progress. As our methodologies to solve complex problems have evolved, the problems tend to expand, driven by even greater complexity.

CrossTalk: What was it about modeling and simulation that made it a best practice? Did you test in real environments?

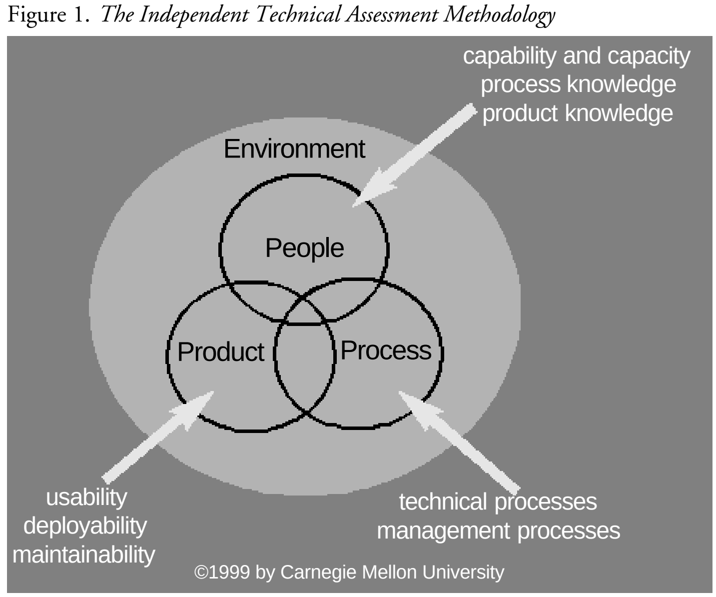
Brandt: There are two aspects that have made it so good—the maturity of the technology now, and the fact that it was employed as a strategy in the program early on and is pervasive. It is not just one model and simulation; it tends to go down and across the tiers. The F-22 is complex and employs a workforce that is creating the product. As you look at these various tiers, there are about 4,500 contractors, so the management challenge is large. The ability to have common references—sets of models and simulations—can play together and give you good information consistently. No model is perfect but some models are better than others. The ones that are repeatable and give you good fidelity are crucial. That is why this area is definitely a best practice.

In the software area in this distributive subsystem, another thing that was an excellent best practice was the early adoption of the systems software-engineering environment (S/SEE).[1] [That is] a big payoff when that happens because of the ability, in this distributive work force, to share in a proper way.

One of the key things when we do an independent technical course system is use of a consistent methodology. The paradigm is really like the Ballantine beer commercial—with the three rings, not the five. One [ring] is people, the second is process, and the third is product. (See Figure 1.)

From the people perspective we look at all of the people. What is the intellectual capital invested in creating an F-22? It is not just the primary contractor resource; it is what total resources the government brings to bear to create the system. What are the resource requirements of the government in conducting business as a better buyer vis á vis a better builder?

Figure 1. *The Independent Technical Assessment Methodology*



When you go to processes, it is not just the key process areas that are in the Capability Maturity Model®. It is all the methodologies, the procedures, and the tools linked together that gives these people, the willing workers, the wherewithal to create the product.

Finally [there is] the product. What is the corpus? What is its nature? What is its design? What are the attributes that have to be manifested for it to provide the full functionality that you will need? Underpinning all this is the ability to view operational requirements in the classic context. The program director [Maj. Gen. Michael Mushalla] is enlightened in this regard. He insists that everyone understand they are trying to produce the product with the needed operational functionality; it is the operational requirements, not just the specification, which is nothing more than trying to represent operational requirements technically. It is everyone knowing that the F-22 has to fly this fast, this high, at this degree of stealth, for this mission. That is the way this has been approached and we applaud it. It is one of the best we have seen in 30 or 40 years, and that includes the testers like Alpha Tech in the early involvement and at Langley [Va.] with its SMO22.

Even if you are the acquirer, maintain that perspective. Your job is not to satisfy a specification that has derived maybe logically, maybe illogically, from operational requirements. [Your job is] to produce the fighting machine. It is a different mindset. It is the enlightened leadership of the system program director that permeates the whole organization, both on the government side and the contractor side. Here is a best practice that has emerged out of that over the last decade.

You are creating a system that will exist beyond the middle of the new century. It is going to be here in 2050. Think of the F-15. The F-15 is not programmed out of the inventory until 2026, at which time it will have been in [the inventory] for well over 50 years. [This] creates a huge challenge.

The biggest challenge is not to get caught myopically in one program phase and begin making technical decisions or business decisions that do not consider the whole life cycle. Although they are very important, we do not do business reasons. We do not do politics. We do not do programmatics. We do *technical considerations.* We think there are plenty of other people who can do the political or programmatic aspects. It is true that occasionally business decisions or programmatics constrain a technical solution, sometimes to the degree where there is no remaining technical solution space.

> "The biggest challenge is not to get caught myopically in one phase and begin making technical decisions or business decisions that are not considering the whole life cycle."

CrossTalk: What is the underpinning of that enlightened leadership? Do you depend on a lot of research? How do you get to that stage?

Brandt: It is hard to quantify leadership. The big problem was not that they had not created a lot of intellectual capital, but to maintain that in our very fluid society.[2] You have a learning curve. The great danger is to lose momentum. There are two things that are the long-term risks, people and creeping obsolescence, as in the software-engineering environment. That has to be reinvested in and maintained because it is a needed tool from beginning to end. Also, you need simulation and modeling capability for the life of the system.

There is going to be evolution of software. Components are going to be evolving to avoid obsolescence. The long pole in the tent is not only managing the viability of the workforce but the tools, like the environment. More importantly we believe that diminishing manufacturing resources is the biggest long-term threat to this system.[3] Look at the evolution of our industrial base. What is happening beyond the millennium? The trend in the aerospace and defense industries has been one of blurring what those companies do. Many have become very large, like Lockheed Martin, for example.

What does it mean when we have vendors who are disappearing, going out of business? The challenge becomes managing the diminishing resources as vendors come and go, and the recognition that you are going to have continuous technology insertions. Do any of us have any insight into the hardware that will exist in the middle of the new century? Go back to 1950 and look at all this. There have always been prognosticators; on the scientific side they have tended to be conservative in general, and they have always pooh-poohed the likes of Jules Verne or anybody who is the out-of-the-box kind of thinker because [those types] threaten the conventional paradigm of institutions.

CrossTalk: How did you tie testing to requirements and to processes?

Brandt: You should test the requirements. You should always be geared to look at the operational performance of the system. You should not get sucked into worrying about the inner workings or hidden mechanisms. That is really the proper function for developmental testing. The ultimate in operational test and evaluation is going back and saying, 'What is this thing supposed to do? What are the operational specifications? Is it satisfying all these operational specifications?'

In our car, there is plenty of software. Do we care about that or do we care about the car's performance? We care if someone says the brakes went out because of the software. You need to do rigorous engineering during engineering and manufacturing development and development test and evaluation. But as you phase over to operational testing and evaluation your mantra has to be the requirements that were stated by the operator. You are delivering capability to him. You are delivering not just a piece of hardware but a weapon system that is conforming to the requirements that the Air Force has to fly and [use to] fight.

CrossTalk: What made that F-22 testing successful?

Brandt: It is the early involvement and the ability to stabilize these requirements. Any requirement will evolve. There has always been a lot of negative thinking attached to the term 'requirements.' The plain fact is every system as it evolves has technology inserted, or as new missions emerge you discover more about the system's potential. It simply evolves. There is hardly anything anymore that would be

The Capability and Maturity Model and CMM are registered in the U.S. Patent and Trademark office to Carnegie Mellon University.

considered a static or set piece system.

The B-52 is going to have been in the inventory nearly 100 years. Does it look anything like the original avionics suites that were inside the airplane or even the engines? I don't think so. It has had this long century of evolution as a platform. The F-22, even though it is going to be the most capable fighter aircraft we have ever fielded, would be nothing more than good for air shows if it did not have this highly capable avionics suite where the heart of the aircraft resides and where the ability to deploy weapons is focused.

You must maintain capacity, capability, and full commitment of your workforce. It must be continuously managed —the keeping of the experience, the intellectual capital, all that you would need to prosecute the rest of this program because we will be tending this system for another 50 years.

Adopt that mindset when it comes to the evolution of hardware. That makes the issue of process, and institutionalizing good practice, so important because you know those who are here today are not going to be here 50 years from now. How do you carry forward the legacy of understanding? Sometimes you carry it through highly defined processes that have matured over time, and the accompanying documentation, so when you lose good ol' Charlie you do not lose a huge chunk of your memory and your experience, creating a void and therefore creating problems.

[Regarding Integrated Product Teams], we found them relatively mature across this program, beginning with Lockheed Martin.[4] As we went out and across the next tiers, they actually do exist. It is not the government over here pretending they are integrated, or the contractors, or the vendors. They are truly integrated and that is a great risk mitigation strategy because what it gains is better understanding overall of exactly the condition and state of the program. This intercommunication that goes through IPTs is quite mature.

There is a special kind of integrated product and process development, a Software Engineering Integration and Test Team. That is crucial when you come to this phase in a program [that is] highly complex; lots of things have to fit together, lots of contractors [are] involved, and now you are going to try to prove out this highly complex article.

CrossTalk: How do you handle discrepancies between testing and requirements?

Brandt: Sometimes it depends on when a discrepancy is known or not known, how you can or cannot recover. Often you have to do some negotiation and do that up front. The tester, if he is the operational tester, is constrained. I do not think you can negotiate a lot. [The tester] has the operational requirement; he is trying to validate that. What if there is some variance? There would have to be negotiation between the requirements persons—the combat command—and the development persons. It is always good to have a good understanding of what things are so sacrosanct that they could not change—the degree of stealthiness; performance parameters related to the aircraft; or more importantly, performance parameters that focus around the avionics and the functionalities you need to deliver weapons.

The evolution of complex systems, especially knowing that they are going to be legacies for a long time, is the proper mindset—nothing is totally static and all things become negotiable. They are negotiable in the sense you are resource-constrained, you are mission-constrained. There are various constraints that need to be looked at. You probably, over time, come to these suboptimal solutions that are at least within the solution space where you have a minimal satisfaction of all of these considerations.

CrossTalk: Which did you consider the greatest challenge—testing the hardware or the software?

Brandt: It is not an either/or situation because these are all software-intensive components. When you have embedded software, it is increasingly difficult to rationalize separation of pure hardware and software. You do not separate them. You make sure you have plenty of testing in the systems component area.

I have found those who have experience with software tend to make better systems engineers than those who came solely up the hardware route. I suspect that not all engineers agree with this finding.

Notes

1. See page 9 and 14 for more on the Independent Technical Assessment of the F-22 as it relates to the S/SEE.
2. See page 10 for comments by Ron Dubbs of Wright-Patterson AFB on engineer turnover.
3. See page 9 for Dubbs' comments on diminishing manufacturing resources.
4. See page 4 for Maj. Gen. Bolton's comments and page 9 for more on how the IPTs were found to be highly effective in the F-22 program.

Web Addition

F-22 Avionics Integration On Track

Boeing vice president and F-22 program manager Robert Barnes discusses how the company is reducing avionics risks and development costs by using both its ground-based lab and 757 Flying Test Bed to evaluate and troubleshoot the integrated avionics software long before it is installed on the F-22 Raptor. Barnes explains the software integration process and says that the F-22's avionics already have been through more rigorous testing than any previous fighter at a similar stage in its development.

by Robert Barnes
Boeing Vice President and F-22 Program Manager

Available online at www.stsc.hill.af.mil