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C. S. Smith

United States Department of Defense

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Criteria for Nondestructive Testing R&D

Abstract

Gentlemen, I'm probably more out of place than any of your other speakers. Some have noted that they're chemists; some have noted that they're metallurgists. I have no research results to report; I'm a bureaucrat, one of those hopefully nice, gray, faceless, beings from the Pentagon. I must ask your forbearance this morning if I seem a bit obtuse; where I work a square corner has 108 degrees. Unfortunately, listening to your meeting I quickly concluded that my initial topic for this talk was unsuitable for this occasion. What follows is a different talk. My apologies for the misleading abstract. Now, the office I work in is charged with a rather odd problem: that of somehow arranging that the necessary resources: dollars, people, spare parts, whatever, are programmed and actually delivered to make all of the various equipments which DoD buys ready to satisfactorily accomplish their purpose when they're called upon. This can be somewhat challenging at times.

Disciplines

Materials Science and Engineering

CRITERIA FOR NONDESTRUCTIVE TESTING R&D

C. S. Smith
Office of Assistant Secretary of Defense
(Installations and Logistics)
The Pentagon
Washington, D.C.

Gentlemen, I'm probably more out of place than any of your other speakers. Some have noted that they're chemists; some have noted that they're metallurgists. I have no research results to report; I'm a bureaucrat, one of those hopefully nice, gray, faceless, beings from the Pentagon. I must ask your forbearance this morning if I seem a bit obtuse; where I work a square corner has 108 degrees.

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Now, the office I work in is charged with a rather odd problem: that of somehow arranging that the necessary resources: dollars, people, spare parts, whatever, are programmed and actually delivered to make all of the various equipments which DoD buys ready to satisfactorily accomplish their purpose when they're called upon. This can be somewhat challenging at times.

In Genesis we are told that God took six days to make the Heavens and the Earth, and apparently quality assurance was satisfactory because "behold, it was very good". As Secretary Brownman pointed out on Tuesday, it takes the Army considerably more than six years to buy a tank, and there is strong reason to doubt that the resulting product is very good at all, especially when you have to persuade someone to pry enough money out of a tightly constrained defense budget to maintain the beasts. Digging up the funds becomes more difficult every year, probably because it costs so much. This year DoD is spending somewhere between \$15 and \$20 billion just to maintain airplanes, ships, tanks and those other primary equipments which we buy.

The point is that I'm one of the guys who are going to need all of those cute black boxes which you want to produce. Frankly, those devices are needed very badly. Let me talk a little about our problems. Perhaps these difficulties can serve as a challenge to some of the research managers here in thinking about their own programs and how to move them forwards.

Several presentations about such topics as x-ray diffraction methods have mentioned potential benefits. They started me thinking about the time about ten years ago when a gentleman from MIT, who shall remain nameless, was convinced that aircraft operators should apply x-ray diffraction to the turbine blades in aircraft gas turbine engines. The Air Force and several airlines sent some of their best maintenance people to talk to him, as he explained that he could save millions of dollars. After several days of meetings, it was revealed that there were only two prerequisites to using this methodology: one of them was that all turbine blades be made out of a single crystal of metal,

and the second was that each single crystal turbine blade be reinspected in the identically same place on a daily basis. He was confident that operators should start observing reproducible results after taking some 800 to 1,000 sample observations on a given turbine blade.

This process was very hard to justify to the maintainers. For some reason, DoD has not yet invested in x-ray diffraction of turbine blades. Unfortunately, this example is not untypical of the problems of bringing NDE to the field.

I got into this whole NDE business indirectly Mike Buckley, whom I don't see this morning--there he is. You made it up, Mike. Congratulations!--got his name into an Aviation Week article which claimed near-miraculous savings as a result of his efforts. These were dangerous words. If you claim savings, somebody is going to try to subtract them from the already scarce dollars which my office is paid to care about. For this reason, I promptly picked up the telephone, called Dr. Buckley, and said, "Michael, wouldn't you like to come to Washington and explain how you calculated those savings?"

Well, Mike came. And, we found that perhaps there were some serious questions as to whether such savings would be realized. This disconnect resulted from assumptions being made which might seem perfectly reasonable to a laboratory scientist, but which don't match operating and financial realities.

For example, Mike pointed out how many dis-assemblies and inspections he was going to get rid of. Well, my office has recently been engaged in a very small exercise to apply what the airlines call MSG-2--it stands for the Maintenance Steering Group 2--methodology to aircraft maintenance. There is, in fact, a textbook in preparation; I have here Volume III, our "cookbook" in manuscript form. Applying MSG-2 has reduced the preventive maintenance on a typical military airframe by 50 percent and the total depot maintenance on aircraft engines to which it has been applied by more than 50 percent. Thus, MSG-2 eliminated many of the tasks Mike's improved NDE was going to do more efficiently.

How was this done? MSG-2 does only three things. It asks the questions: (1) Will doing this task improve safety? (2) If it won't improve safety, is there an economic benefit? (3) If there is neither a safety nor an economic benefit, why do it all?

Well, this seems a very simple form of discipline to apply. However, it took a certain amount of formalization--if we could show the first view-graph, please. (Figure 1) I'll see if I can get over there without tripping over myself.--This example is that for the formal evaluation of aircraft structures. All the discipline that was

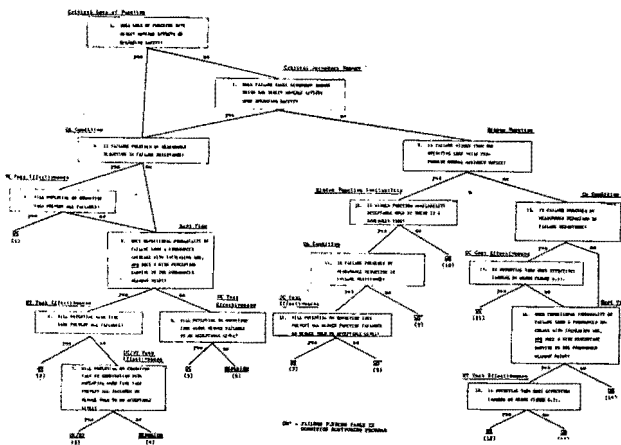


Figure 1. Reliability centered maintenance - Decision diagram

applied was to ask maintenance planners to ask themselves these questions in an organized manner. As you look at them you say, "You've got to be more quantitative than that." I wish we could be; I'd be very happy if we were. Perhaps you gentlemen can help us in becoming more quantitative.

More importantly, an analogy to this simple discipline should be applied to NDE development. One of the things that has been much reduced as a result of MSG-2 has been "on-condition" maintenance tasks, that is, tasks related to tests for reduced resistance to failure. Why has on-condition maintenance suffered? For one reason. It couldn't pass the test of simple questions.

First question, can the test detect reduced resistance to failure for some specific failure mode? Simple, but a very strong implication. You've not only got to detect something but you should also be able to relate what you detect to some failure mode. Many of the tasks didn't meet this criterion. They might detect something, but no one had any idea how to interpret or act upon the results.

Second question, can the test anticipate that failure far enough in advance to permit effective response to correct the problem before actual failure? This is an important question. For example, there is the, perhaps apocryphal, proposal for an acoustic emission nondestructive test to warn the pilots of one well-known aircraft when the wings start cracking. Its only serious drawback was that the warning would occur only 8 to 20 seconds before the pilot had to bail out. Fortunately, that device has been removed from modification planning.

We are still suffering from another device, somewhat the opposite, which is known as the helicopter chip light. This marvelous nondestructive evaluator is installed in helicopter transmissions to measure whether metallic particles are being accumulated. There are only two problems with the helicopter chip light. First, its frequency

of Type II error (false accusal) is approximately 20 times greater than its actual identification of real problems. Second, it gives you a minimum of ten hours warning before you should take corrective action.

Giving so much notice is fine except that some pilots, God bless them, get all kinds of distraught the moment that light goes on. They ground their airplanes immediately wherever they are. Sometimes in the middle of South or North Viet Nam. Some have crashed, killed themselves. The chip light has cost DoD at least 10 times as much damage as it has averted according to the best analysis I've seen. And, so far as can be determined, it has little or no safety benefit.

Now, it was good of the nondestructive evaluation community to provide such a device. However, it would have been better if someone had thought enough to locate the readout someplace off the instrument panel so as to preclude accidents because the pilot had an unreliable ten hour warning that someone should inspect his transmission for possible problems.

After that digression, we get to the last question about on-condition tests. Does the task have a greater likelihood of doing good than harm? This was certainly a problem with the chip light. Let me give you another example.

For the C5A, the Air Force decided to do all kinds of performance trend analysis. To this end they installed a monitoring system called MADARS-GPS on every C5. At Dover, where the greatest number of C5s are based, the principal cause of aircraft being "down" was failure of the monitoring system. Now, for every hour of tapes of the numerous variables which this monitoring system records on the airplane, it takes 16 hours of computer analysis time on a rather large machine. But, there is no evidence that anyone has ever taken an effective action as a result. The fact that this expensive airplane is now being grounded because an unproductive monitoring system isn't working well frightens me a little.

Okay. Those are the prerequisites to get monitoring which works satisfactorily or, at least, is such that someone should be willing to pay for it. Those prerequisites are, as the gentleman who preceded me pointed out, going to be applied in an environment quite hostile to any device requiring sophisticated operators. As a result, I have gotten rather fatalistic. Dearly as I would like to see the daily maintenance burden reduced, most of the benefits of your work are going to be seen (and hopefully should be seen) in applications before the equipment is ever accepted.

Now, we DoD logisticians have another small problem. Materials quality assurance is black magic to many, if not most, managers. Perhaps enough of us are not technically qualified to understand the answer when we ask the question, "Will it do any good?" before spending money for NDI or NDE. We often are forced to act through mist or mystification.

However, I for one, am still curious why dye penetrant inspection, which detects flaws less than 1/16" deep, is performed on billets before a half inch is shaved off each side. I'm equally unclear as to why, of the numerous metallurgical tests required by MILSPEC, almost none seems to be related to any of the specific failures that we experience. Frankly, we need not only tests, but we need tests that we can soundly and tightly relate to something that is failing or that will cause a failure.

To be direct: Please, before you go out and design a 35-pound black box that will do acoustic holography of titanium parts, think about how to relate the resulting acoustic holograms to something, anything. If you can't, don't really count on a market. Even DoD isn't dumb all of the time.

Unfortunately, I'm not sure a disciplined answer to the questions I've raised is at all easy to arrive at. I think that it involves a lot of work; and it's going to take people in a number of fields talking to each other to get those answers.

In essence, that's my message. Before quitting, I would like to tell another horror story, because I think it says something important.

I was approached recently by a gentleman with a marvelous inspection technique that eliminated all disassemblies in inspecting the outer skin panel of a wing. There is only one problem with this application. One still has to inspect the inner skin panel; thus, disassembly is still required anyway, and the new technique saves nothing. It would probably cost an additional \$10,000 per airplane. If, like DoD, you have a 25,000 airplane fleet, 10,000 of which are potential users, that would get expensive fairly fast.

In spite of all these horror stories, DoD needs nondestructive evaluation. In proposing NDE applications, however, you should bear in mind that the armed forces are not run by engineers, they are run by people who have been operators. Operators usually do not understand the technologies embodied in their weapons systems and, as a result, are often

very much afraid of technological change. In a number of studies, we have clearly documented their great hesitation to engage in anything that looks like it might be riskier. For example, even though, on an engineering basis, it was clear that the Navy should overhaul an F-4 aircraft at 48 month intervals rather than every 24 months, it took 14 years from the time the engineers reached that conclusion to the time pilot managers were willing to accept it and permit it to happen. In short, your case had better be good, and you may need a bit of patience.

I have had one other difficulty with what I have heard here. Everyone has talked about costs; everyone talks about savings; occasionally, we talk about reliability. Reliability needs to be discussed.

We're buying new weapons. We have to buy new weapons. Unfortunately, it's a competitive world, and in a society which seems to find it very difficult to produce non-military work, the Soviets are beginning to produce very good weapons these days.

Building those new weapons has all kinds of interesting implications. For example, to build a really effective VTOL aircraft, we will need gas turbine hot stages which operate 500 to 600 degrees Fahrenheit hotter than present designs. I don't think anyone understands enough about how the materials that work at those temperatures fail. We're going to need means of testing new materials just to find out what their characteristics are and how they fail. Then we're going to need means of evaluating production materials to be sure they are within meaningful quality standards.

Again and again when considering use of a material we must think not merely of its cost, but also of its reliability and how that reliability impacts on design capability. The real benefits from NDE, I'm convinced, will often not be cost savings; in fact, almost never cost savings. But, hopefully, NDE will benefit effectiveness, the ability to make the equipments we have work. As has been frankly discussed, they don't always work well now. And, NDE is clearly pre-requisite to the ability to design and manufacture equipments with new capabilities that really do work. That's a very different set of benefits than people have been talking about.

Thinking about the likely pay-offs suggests that some variation in present development plans might be helpful. For example, much as it may be painful, researchers should start looking at titanium instead of just aluminum. I was fascinated with the number of papers about aluminum. I have asked several speakers afterwards, "Why don't you look at titanium?" Their uniform reply was, "Well, it's difficult." It's difficult, but that's where the problem is.

DISCUSSION

DR. GEORGE MARTIN (UCLA): You mentioned the Russian equipment as being rather superior. How do the Russians handle their equipment inspection problems?

DR. SMITH: Sir, I did not mention it as superior; I mentioned it as improving rapidly, as becoming competitive. The Department of Defense would be loathe to admit that the Russian equipment was superior, and if I were to make such a statement I should promptly and deservedly be shot by my bosses.

The problem of poor quality assurance in the Soviet Union has been well publicized. It is very clear that in certain of their newer weapons systems they are addressing the issue much more effectively than they ever have in the past. One can see this in the fact that we now actually worry about the counterforce effectiveness of their strategic missiles which suggests that they have met a very tight assurance equipment. And, one sees it in the fact that we begin to think the armor plate on their tanks might be good, which implies they have solved another quality assurance problem.

The question is a different one. I think, than your rephrasing, and one would not wish to be quoted otherwise. I was noting that we find ourselves in a competitive environment. I would not want to evaluate, but certainly we are feeling the hot breath of competition much more strongly. We are feeling it for a number of reasons. One of them is that you are now defended by an all volunteer force. In 1962 with many more men in uniform, the U.S. could devote more than 70 percent of its defense monies to new procurement, R and D, etc. Defense now devotes over 55 percent of its monies to personnel. That leaves less than 45 percent for procurement, R and D, etc.

DR. GEORGE MAYER (Army Research Office): I guess I don't understand your objection to the chip detector. The question, number one, is: does it work?

DR. SMITH: Very serious questions on that. The work I'm quoting, in fact, was done by and for Army's Air Mobility Research and Development Lab at Fort Eustis.

DR. MAYER: Yes, but the point is, if it does work, then the factor of your warning light making your pilots crash--

DR. SMITH: Okay, but let's go the other way.

DR. MAYER: --is simply a psychological one.

DR. SMITH: That psychology may be lovely. It's a lovely black box, but if that psychology does me harm, sir, I don't want it. New York Airways took on this same problem and solved it very nicely. They took the chip detector off of the instrument panel, put it on a servicing panel that had to be checked every time the helicopter landed. Helicopters don't have 10-hour flights so they had plenty of warning. By making this change, they produced a situation where chip detectors stopped frightening the pilots, without preventing action from being taken where it needed to be, by the maintenance personnel.

DR. MAYER: I think that's fine, but this community here is mainly composed of R and E engineers and they're not going to determine where you put your warning lights.

DR. SMITH: Sir, with all due respect, the real problem is that nobody seems to determine those things. If the instrument designer doesn't think about the user of his product, who else should?

DR. KIRK RUMMEL (Boeing, Vertol): You threw some rather interesting challenges out to this group of engineers and scientists. I guess more than most of these I'm one of those people who try to make the system evaluations for those systems. Let me throw a challenge back to you. Given that we've done our homework, and maybe in many cases we haven't, and we've tried to do those evaluations rigorously, once we've reached that point and have great factors missing in our equation such as the cost of a maintenance man hour or where the problem is, there's many things that we certainly can't come up with that the operator can. Perhaps you could give us some advice of how we've run that system, and we've got a course of action which we feel we've done the right way and come up with the right answer, how do we tackle that red tape, that bureaucracy whose, I guess, inaction can best be described as inertia parading as caution?

DR. SMITH: Fair question. Two answers. You're from Boeing, Vertol; you know Tom House?

DR. RUMMEL: I'm giving his paper.

DR. SMITH: That's what I thought. Okay. One way to get action is to find an effective and interested agent in the bureaucracy and work through that office. Many of us bureaucrats really do care.

In the helicopter business in the Army, the USAAMRD at Fort Eustis, especially the group that Tom is associated with, probably has done a better job of looking systematically at the relationship of design to operating and support costs than anyone else in DoD. In fact, I think the results coming out of that shop do tell us things like where the failure modes really are, where costs are, what we can do about them. That's where you get some of the answers you need to change your designs. In fact, some of those answers are reflected in your new designs, for example, the UTTAS which is really a remarkable aircraft from a support point of view, as is SIKORSKY's.

Where I work, many people are trying very hard to put it in rather clear and stringent criteria on how to select a maintenance program. I've talked about some of these. It's a very simple set of criteria, and we are trying to take a number of steps to see that these are carried out and that the theoretical improvement will be realized.

Fort Eustis, for example, is being listened to more now. Secretary Brownman, in fact, has had one briefing from Tom House and is due for more. We are making some headway there.

I think the AF will have some dollars for emergent problems in its FY 78 budget. They even have a little bit of this kind of money in FY 1977. The revolution that is implied in that statement probably seems very small to you gentlemen; however, I am wearing a suit partially because I have to cover the scars. Believe me, it is a very hard thing to do and the battle is only begun. At least, we're trying.

If there is no friendly pocket of bureaucrats, you try to educate one. The Air Force now has a focused place for a man with a solution to contact, the PRAM SPO. Similarly, for Navy ships, the "RED/E" effort has a charter to change things. The Army is moving in a very positive direction right now. They are starting to apply some of the research results which we had all wondered if anybody ever read. Your best bet there is probably USAAMRD.

Maybe that's part of an answer. You asked a tough question. With an organization as big as DoD, you don't try to control very many details. I don't even think that approach is possible. Management of such a large organization has to be thought of in terms of entropy and thermodynamics. -- I'm not sure I want to be quoted and I wish the tape recorder weren't running, but -- when you need to do something quickly in an organization like DoD you start by asking, "Well, where are we falling on our faces and what's going to make a difference?" Then you try to design short circuits around the system so as to do what needs to be done until the system catches up several years downstream.

The Russians have a worse problem than we do on this. I have occasionally muttered that we should look at Lieberman's writings on putting incentives into the Soviet economy. Perhaps we could find something useful to DoD there.

It is a problem; it's often not going to be solvable. If all else fails, give me a ring. My telephone number is (202) 697-6079. If you've got a case, I'll be happy to hear from you; maybe I'll know someone who can help.

DR. C. MOW: I'm sorry I have to cut the interesting discussion off. You can continue during the coffee break. Thank you, Dr. Smith.

DR. SMITH: Thank you.