TRI-SERVICES NDE CAPABILITIES REQUIREMENTS
AIR FORCE/ARMY/NAVY

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D. M. FORNEY, JR.: I imagine that most of you would agree that it is a very difficult task to conclude what the military services—the Army, Navy and Air Force—have established as their major NDE requirements toward which research projects could be focused. What we are going to try to do in the next few minutes is present a short view of what, in our best judgment, these requirements are and what are the range of capabilities we would like to see developed. We hope that by doing this, you will get a better picture of the key NDE research objectives within the DoD.

First let me put the NDE activity in the Air Force into perspective. While both daily in-service NDE support activity and R&D work have been ongoing for many years, these functions were not described as a formal Air Force program activity until the issuance of Air Force Regulation 66-38, "Nondestructive Inspection Program," in 1966. AFR 66-38 established the authority and assigned responsibilities for various NDE functions to specific commands as outlined in Fig. 1 and detailed in Ref. 1.

The Air Force Logistics Command (AFLC) oversees a worldwide NDE laboratory system with inspection groups at over 195 bases and at the 5 Air Logistics Centers (maintenance depots). Furthermore, AFLC establishes inspection schedules and approves NDE procedures and equipment, and finally, identifies personnel training needs. An Air Force NDE Program Manager is assigned to coordinate all of these activities. The R&D responsibility is assigned to the Air Force Systems Command (AFSC). The program is conducted through two organizations primarily: the Air Force Office of Scientific Research (AFOSR) which manages the 6.1 Basic Research and the Air Force Materials Laboratory (AFML) which conducts the 6.2 Exploratory Development and 7.8 Manufacturing Technology NDE efforts.

A key advantage in the USAF program lies in the fact that all NDE R&D and Manufacturing Technology work is planned and conducted by two specific compatible organizations (AFOSR and AFML) within one single command.

The USAF NDE development program performs two major types of functions:

1. Research and Development
   - New Fundamental Technology
   - Manufacturing Technology

2. Quick Reaction Engineering Support to other USAF organizations.

The major thrusts in these two functions will be reviewed in a moment.

Program activities are focused on several types of problems:

- Specific problems—solution of a special problem and specific requirements. For example, improved techniques and instrumentation tailored to solve the C-5A wing fastened joint inspection problem.

- General problems—solution of a specific type of problem with application to hardware in general. For example, the early detection of hidden corrosion.

- Generic problems—development of new technology to increase NDE capabilities to apply to a wide range of requirements. For example, improvements in the various aspects of the ultrasonics method to increase the probability of detection of flaws in hardware under field conditions—a fairly general but serious problem.

The 6.1 Basic Research program being conducted by AFOSR is concentrating on two particular areas which are shown along with several examples of specific programs therein:

- Advanced Acoustics Science
  - EM Acoustic Transducer Concepts
  - Acoustic Emission
  - Particle Emission
  - PVF2 Film Transducers
Optical Signa

The number of development needs have grown to the ducted by AFML, has undergone a change in overall development requirements.

OSR is concentrating on the development of new knowledge of acoustics which may lead to fundamental improvements in the ultrasonics NDE method. The thrust on new physical methods is exploring phenomena which may offer new ways to detect flaws early in their formation by measuring subtle physical changes that can be related to the fracture process. The remaining part of the USAF NDE R&D program (6.2 and 7.8) which is conducted by AFML, has undergone a change in overall philosophy which is summarized below:

1. Concentrate resources on a few key development requirements.
2. Emphasize improvement in in-service NDE reliability.
3. Include field implementation phase in development programs.
4. Continue focussed fundamental NDE program--initial thrust: ultrasonics.

The number of development needs have grown to the point where resource availability is far outstripped. Thus, rather than attempt to deal with most of the problems, many inadequately, a few of the most critical problems will receive proper resourcing to assure timely results and lesser priority programs will be postponed.

A significant portion of program resources will be assigned to increase the reliability, sensitivity, and general flaw detection capabilities of the major techniques. Current emphasis is on the improvements of ultrasonic equipment capabilities during the next 2-3 years. The next major emphasis will probably be on eddy current techniques.

As Dr. Kelly mentioned earlier, the weakness of many past programs has been due, in part, to an inadequate job of technology transfer to the field, including the development and testing of prototypes and/or procedures and the reworking of prototype designs or procedures as part of the program to yield a well engineered model truly ready for routine productions. Present and future programs will, therefore, feature a strong phase to complete this development cycle.

Finally, we consider the continuation of the strong fundamental NDE program, epitomized by the ARPA/AFML program being reviewed at this conference, to be a vital step toward the creation of sensitive, accurate and reliable NDE.

The AFML program is organized into two program areas: The Technology program using 6.2 funding plus some 6.1 funding from AFOSR; and the Applications program using 6.2 and 7.8 funds. The program thrusts of each program area are shown in general order of priority:

• New Physical Methods
  - Fositron Annihilation
  - Optical Detection Methods
  - X-Ray Strain Probes for Composites
  - Nuclear Magnetic Resonance Techniques

Technology

• Quantitative Ultrasonics
  - Transducers
  - Signal Acquisition
  - Signal Processing

• Quantitative NDE of Surface Flaws
  - Surface Wave Ultrasonics
  - Electromagnetics
  - Optical

• NDE of Advanced Materials
  - Composites
  - Adhesive Bonds
  - Ceramics

Applications

• NDE of Fastened Joints
• Field NDE Reliability Improvement
• Composite In-Service Inspection Methods
• NDE of Complex Shapes
• Adhesive Bond Evaluation Methods

Discussion

The details of the Technology program thrusts are being covered in these proceedings. In the Applications program, the NDE of Fastened Joints thrust contains work to develop instrumentation capable of detecting 0.1 inch radial length cracks from fastener holes, both in outer and interior joint layers, without fastener removal; The Field NDE Reliability thrust deals with the design and manufacturing technology of new, advanced state-of-the-art ultrasonic equipment (pulser-receiver, transducers, signal processing) capable of higher reliability flaw detection under in-service conditions; the Composites In-Service Inspection Methods thrust will produce improved, semi-automated inspection processes/equipment for reliable composite structure NDE under service conditions; the NDE of Complex Shapes thrust supports NDE equipment/technique developments for computer-aided flaw and metrology evaluation of complex-shaped airframe structures and engine hardware (disks and blades); the Adhesive Bond Evaluation thrust is completing work on NDE methods to assess pre-bonding surface conditions and to detect strength-degrading disbands in high performance bonded structure.

In the area of Quick Reaction NDE Engineering Support (Systems Support) the AFML provides several types of technical service including:

• NDE advice to Weapon System Program Offices (SPO's)
• Technical aid to field organizations with NDE problems
• Development and improvement of USAF NDE specifications
• Special NDE method improvement projects and new method evaluations

One final word on some projections of the future technology requirements of interest to the USAF. Among the more important ones are:
Automation and computer-aided decision processes
• Major advances in eddy current capabilities
• New/improved radiography capabilities and roles (e.g., neutron radiography if an on/off generator is developed)
• Improved ultrasonic techniques useful in finding interior layer defects
• "Clean", consistent transducers
• Detection methods for small, tight surface flaws
• Quantitative flaw growth monitoring in a real time

One last comment. The AFML is conducting a detailed program roadmap review for all interested groups--industry, academia, government--in Dayton, Ohio, on 19-21 July 1977. At this review, the FY77, FY78 and FY79 program activities will be described in detail. Attendees will receive a report of the details discussed.

In the short space available, I have attempted to summarize the main features of the USAF NDE development program and plans, highlighting the factors shaping the major thrusts. I shall be happy to elaborate further upon request.

Reference
S. LORBER: Good morning, gentlemen--lady and gentlemen, Nancy. It's indeed a pleasure to be here and your agenda is very impressive. I wish I could understand it. The coffee breaks I understand, and the lunch. The money and the other subjects are indeed interesting to you, I'm sure, but I'm on the other end of the stick. I'm the Director of Product Assurance in the Readiness Command--Material Development and Readiness Command, and my purpose is to use the results of your experiments and that's what they are, experiments. Until they are applied, practically, repeatably, and in the field, they are just experiments. I need solutions, I need them today. Now my objective is very simple. Now this is an old chart (Fig. 1), but I always use it to remind myself what my job is. And that's to satisfy that man, a very simple man, a soldier. Last Tuesday I received a flasher report from Europe; we had a premature in an 81 mm mortar shell, two soldiers were killed, several injured seriously. We make millions of 81 mm mortar shells, it's fired by an infantry man, he carries it around with him, puts it in the back of his truck. Fortunately or unfortunately, depending on your point of view, one in a million might be good or bad, but that's my job and I'm looking for the techniques that you are developing that will at least assure that man that the material I'm fielding will not premature, that it will work as intended. That's my job and I need your help to do it but I need your help today. I need your help today to find a way that I can solve that problem today because we're making them today--we're issuing today in large quantities.

Figure 1. The user that must be satisfied.

Okay, now let's look at the Materiel Command briefly and what are our problems. This is the way we approach our problem. I use the Army's Materials Mechanics Research Center (AMMRC) spider chart technique (Fig. 2) and this is to show you the mission areas that we're concerned with in DARCOM. It covers the whole gamut of Army material, anything you would expect the Army to have. We carry out our program through eight development commands, about forty project managers, two laboratories, and five readiness commands--about 101,000 civilians and 16,000 military. Incidentally, there are twelve depots involved where we do our overhaul work towards the issue. So you see, the areas that we are concerned about--everything--and some of it rather exotic, some of it rather simple. For example, road wheels--rubber on aluminum, on tanks--well you know if you lose your road wheel on a tank, the tank is immobile and that's almost as bad as a premature in combat and if you've ever been in combat... I've had the bad fortune or misfortune of looking at all the tanks that were killed in Israel during the 1973 war. It's quite frightening when you look at what happens to a tank crew when their tank is immobile. When you're hit by one of the shells, you're just literally cooked inside that tank. So just losing something like a road wheel can be very serious to a tanker. Not as exotic as some of the aircraft, but a very real problem for us in the Army and we need your techniques to make sure that we can produce those road wheels so that they meet our needs. That's just one item. Talk about fuzes...that's the front end of the 81 mm mortar. It's a probable cause of that premature. You make fuzes for rounds of ammunition anywhere from the smallest round, 20 mm, on up to the largest. What can I do to make sure that those fuzes are assembled properly? Simple, something as simple as that--assembled properly, that's what causes premature. What techniques can you give me to solve that problem? Well, the way we go about trying to identify problems--and this is what Dr. Kelly, I think, was driving at--I'm on the other end; I have to identify the problems and find some way to force your fraternity to help me solve them. But I can't blame you unless I can identify them and force you to look at them. That's my job and I'm not doing it too well--I'm not doing it too well.

I am not identifying the needs. For some reason we think that we have to have a solution before we can identify the needs. I'm not satisfied about that anymore. I am looking just for the problem so that I can force you to address those issues. And what I've tried to do is get the people you see in the center here, our project managers and our development managers, to set up a program for each of their major systems; a review at the beginning of the development. I'm talking about the XM-1 tank, I'm talking about the new ammunition, the new mortar, the new artillery piece. The project manager who is responsible for developing and fielding that item as a part of his development effort to identify the issues concerning inspection and test that he faces so that he can force the community to solve those problems as part of his development effort. And I'll show you one example at the end. But we're asking him to do it so he can force the laboratories and force the people in technology fields to help him solve his problem--bring the needs to you and help you solve them.
Within the second area, what are my drivers? (See Fig. 4.) They are twofold and very simple. One I have already mentioned (to assure the reliability and safety of Army material) and, second, obviously, I think, to increase the productivity of the industry that supports us and I think NDE does both and does it well if we apply it properly. Third, we are on our way to trying to identify the needs so that we can put our money to solving our most pressing problems. One other approach that we are using is trying to marry NDE with our reliability effort. What we are trying to find out is whether there is some way that we can improve the life of our end items in our major components and we believe that by the application of proper reliability techniques coupled with the NDI techniques we can actually: (1) predict more accurately the life; (2) properly monitor our equipment and extend life without going into planned overhaul. So that's another effort, and you can see some of the efforts underway.
ins is a somewhat similar chart (Fig. 5) I think I've seen earlier, but this is the approach we are using: determine the wear and failure mechanisms as part of our development effort; use the techniques that we can for proper determination and for proper monitoring in the field (you see it here); continue the selected techniques, confirm them in our depots and manufacturing plants, and as our confidence increases, increase the life of our equipment. But this is an approach we're trying to get together on with the experts in the field. I have only one example (Fig. 6) of how this can be used and we have high hopes for this application—the screening of 105 shells. We make about 60,000 shells a day when we are in production on this item and we have about 15 plants making these shells. Obviously, we are not making that many now; we're not at war, thank God. But when we are, we have 15 plants making shells, loading, and inspecting. Why do we inspect them? A crack in the metal parts or an improper fill leads to a premature that I mentioned earlier. We have a technique that is almost real time now which we'll put into our production line and it will actually screen these shells 100% for this defect. No plates. This is some of the work that you have been doing and I think some of the people here could talk to you about it. I'm not really that much of an expert in the technique used, but it's very promising. It will be going into our first modern plant, I think, in about six months. This will give us greater assurance that the ammunition is safe. It is a natural output of some of the work that has been done by your people. Now the one point problem I have with this system—I'm not satisfied yet. It solves my reliability problem and it solves my safety problem, but what I need to do now is find some way to couple that with the manufacturing process so that I really can adjust the process properly and not make bad materials. It doesn't solve many problems to sort if the output isn't great. I've got to find a way of putting this kind of equipment into the line to manage the line; actually manage the line to preclude the manufacture of bad materials. That's the next step, but I have a good screening technique. Now, I have some advice for you—I use it quite often but it helps. Thank you very much.
J. J. KELLY: The Navy is a multi-mission type of service and uses a variety of platforms to accomplish these missions. As you can see, we are in the air with aircraft, and using conventional warships like a carrier, and have an advanced type of high performance craft like a hydrofoil. For those of you who are not familiar with these crafts, we also have submarines which we saw before and also have surface effect type ships, and amphibious craft operating over the waves. We also have platforms from at least two points of view. One, from the concept of these craft and their detection in these platforms from an operational and maintenance phase with the equipment. I will discuss the major NDE requirements for each platform in terms of these two categories. However, since the Air Force and Navy requirements in aircraft construction are very similar, I've eliminated that slide for the sake of time and will go on to the operational and maintenance requirements for Navy aircraft which are somewhat different than those of the Air Force.

The Navy is definitely concerned with flaws and their detection in these platforms from at least two points of view. One, from the concept of the construction and repair phase - what do we have to detect at that stage; and secondly, during the operation and maintenance phase with the equipment.

Naval aircraft perform very high impact takeoffs and landings on a moving landing field which is an aircraft carrier; we have different loadings and operate in a marine environment which is highly corrosive. This latter consideration is common to all of our naval platforms and is one of the driving forces for our programs, either in materials or NDE. For aircraft, in the area of structures, we are concerned with fatigue, fatigue-induced cracks and the growth of cracks, delamination of composites caused by minor impacts like dropping tools and wrenches on the wing of the craft which are basically undetected in maintenance operations, and also corrosion under the painted surfaces. There are a number of NDE techniques which are listed in Fig. 1 and which are commonly used for the detection of these flaws.

The major limitations that are shown can be applicable to one or more of the NDE techniques - they are not in a line-by-line relationship. For example, safety limitation really applies only to the x-ray restrictions that are imposed with the use of the equipment, while operator sensitivity limitation is applicable to eddy current and ultrasonics in terms of the skill of the operator who uses the equipment, and also for the interpretation of the results. I've used this same type of limitation throughout my discussion. Also, since we're dealing with built-up fabricated structure, accessibility with the use of NDE equipment is a very, very vital concern to us and a serious limiting factor.

In the conventional ship area, a major area of concern is the adequacy of steel welds during the construction repair phase. I've listed some of the problem areas that would be of concern in Figs. 2 and 3. The biggest problem that we have is that we are dealing with thousands of feet of welds and so a speedy NDE capability is vital. We have to have sufficient area coverage, if it is possible; and safety, as I mentioned before, is a problem of cost associated with safety requirements. We have to clear areas when we begin to do x-rays. That holds up on the actual construction work. In terms of the hull coating quality, this is a critical area for the Navy with conventional ships. For the large areas that we have to deal with, our best inspection technique is visual observation and a fingernail test - stick it under the paint and see how well it adheres. We have a large problem in this area in terms of scheduling. The last item usually on a ship-building schedule is the painting, and that's when everyone is pushing the ship out so you don't really have too much time to take a good look at it.

**Figure 1. U.S. Navy NDE requirements of operation and maintenance, aircraft.**

**Figure 2. U.S. Navy NDE requirements construction-repair, conventional ships.**
In the area of propulsion we are looking for subsurface cracks and voids in the propeller blades and waterjet impellers. I'd say we have the NDE capability and techniques for this particular application. It's just that some of them are troublesome in terms of the limitations I've shown.

I've listed other limitations where applicable. In terms of the propulsion machinery area, we have no way of monitoring in-situ the material condition of valves and bearings - there is some effort using fiber optics for examining the condition of the bearings. We are looking at various parameters now, but it's still not a fully implemented system in the field. Right now we rely more on the ear of an experienced crewman. If the valve doesn't sound right, something's wrong and that is the first level of detection. Accessibility, of course, is a problem here.

High performance ships are fabricated from a thin gauged material, 3/8" to 1" thick. It has thousands of feet of welds and is typical of some of the construction that we have. Conventional NDE techniques are used and we have problems. For the thin gauge aluminum alloys, x-rays provide poor quality radiographs. We have problems due to the lack of standards in this area and the possibility of using composite structure for some of the high performance ships adds to our problems. With composite structures, I think we have the same problems that everybody else has been pointing out except we will use them in a marine environment which will aggravate it to some extent.

In the area of propulsion, we have the same kind of problems with the gas turbines that we had on the aircraft except now we are working at higher temperatures and closer to the highly corrosive, marine environment. We have subsurface cracks and voids in the valves and piping systems and in bearings that are difficult to detect.

For high performance craft, in terms of operation and maintenance, we are concerned with fatigue cracks or grout crack growth in some of the structures. We have some of the capability in terms of NDE. However it is not adequate enough for us. Accessibility and the lack of an NDE underwater capability are problem areas. Detection of delamination, disbonds and composite-metal interfaces integrity where we're joining composites to metal interfaces in the structures are major items of concern. We do have a good sensitivity for small defects in this area. Accessibility is a critical problem. The quality of coatings I have already discussed.

For air-cushioned vehicle skirt systems, assessment of the integrity of the adhesive bond between the rubber and the reinforcing fabric is vital. We have problems in finding out just how good a bond we have and how it performs in service or in test. We have no really good handle on this right now. We ran some x-rays and basically, all we could see was where the gross failure is and that's all. We know no more than that. We couldn't find out anything from it and yet we know there is damage taking place in other parts of the test specimen as indicated by changes in the physical properties. In the area of propulsion per-

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### Figure 3. U.S. Navy NDE requirements operation-maintenance, conventional ships.

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### Table: Conventional Ships

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<th>Limitations</th>
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<td>Quality of Adhesive Bond between Fabric and Reinforcing Cloth</td>
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<td>NDE Underwater</td>
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### Table: High Performance Ships

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### Figure 4. U.S. Navy NDE requirements construction-repair, high performance ships.

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### Table: High Performance Ships

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### Figure 5. U.S. Navy NDE requirements operation-maintenance, high performance ships.

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formance, we are concerned with cracks in gas turbine blades - we are looking for NDT capabilities there and for detection of internal cracks and corrosion in the piping systems. This is the same problem as found in conventional ships. For submarines there are a number of problems which I will not discuss at this unclassified meeting. I'll just say that some of the problems are similar to what I've shown for some of the other areas. For example NDE requirements for submarine hull coating and those of conventional ships are not very much different.

In the area of missiles, these are some of the problems - which I think Frank Kelly addressed earlier. Our particular problem is that we are looking at a number of different type nose tips for these missiles, and in the case of the graphite composite we know that we do not want a defect any larger than .006 inch crack. That's one criteria we have. For the carbon-carbon composite we do not have a defect level established yet. Basically, there's no real problem with the NDT capabilities that are available right now except for the obvious one. We just haven't been able to relate the defect size to the performance that we get except in that one case. For missile structure, I'm not going to go into that really too much - it's self-explanatory. For the motor case and liner and interface voids, I think Dr. Kelley addressed that before.

Figure 6. U. S. Navy NDE requirements construction-repair, missiles.

In this summary chart the covered area relates to thickness range which we are interested in. I have basically summarized what the requirements are we have been looking at.

In terms of NDE needs, I would think that our first requirement would be reliability of the equipment, followed by safety. I don't think you have any idea of the cost for doing NDE inspection in the field or a shipyard. We don't do 100% inspection, only the critical areas and it still drives costs up. The other need is the reduction in required skill level. We need NDE equipment for field use where we do not have to rely on a highly skilled operator. For example, we have used electronic technicians, who are fairly well educated in the Navy systems, with eddy currents and evaluations. The results were erratic. They found fatigue induced cracks in ship structure that would indicate near term failure. When an experienced radio eddy current inspector performed the same evaluation, he didn't find the same flaws and those that he did find were not that large. Because of the problem of accessibility, there is a need for more compact equipment.

Figure 7. U. S. Navy NDE requirements.

MATERIALS:
- Aluminium, Titanium, Steels, Composites, Ceramics, Elastomers.

REQUIREMENTS:
- Residual Stresses, Cracks, Voids, Delaminations, Coating Integrity.
- Fatigue Cracks and Growth, Stress Corrosion Cracking, Weld Quality.

NDE NEEDS:
- Accuracy: Detect flaw, detect size with location and orientation.
- Reliability: Reproducible results under the same conditions.
- Safety: No hazard to the operator.
- Size: Small enough for field use by a single operator.
- Documentation: Permanent record of flaw.
- Sensitivity: Established by application requirements.

Figure 345. U. S. Navy NDE requirements.