

USAF NDE PROGRAM - REQUIREMENTS FOR TECHNOLOGY  
TRANSITION

D. M. Forney, Jr.  
Air Force Materials Laboratory  
WPAFB, Ohio 45433

The final session of our meeting is intended to be a change of pace with the express purpose of better focusing on the realistic aspects of the application of NDE in the field; practical problems and limitations, the requirements, potential and opportunities. Actually, Gerry Posakony did a good job of kicking off this end of the meeting subject last night with a discussion of his problem with the rather complex looking structures for which he has to develop operational inspection techniques.

Assuring that the R and D community has a better understanding of the realities and range of field conditions, requirements and limitations, we feel is both helpful and important because it is this future market place into which new technology must be transitioned if the research is going to be profitable at all.

Technology transfer is not an automatic, self-sustaining process nor is it a process where responsibilities are obvious or even accepted for that matter. On the one hand the scientific R and D community is involved, rightly so, in advancing the state of the art, worrying about fundamentals, bridging the gap between phenomena and the understanding of the nature and physics of things. They are a rather conservative group whose scope is usually limited, necessarily, to fundamental aspects and details of the problem, and their understanding or concern for field application requirements may not be brought into the picture or may not exist.

On the other hand are the systems developers and users. They have schedules to keep, they have costs to keep down; they are not really interested in incurring risks that can go with the introduction of new technology. As a matter of fact, to hear them say it, new technology initially has a pretty poor track record. To sum it up they are suspicious, basically, of new technology and very conservative in its application.

The question is: who is in the middle with the job of making transition occur? Generally speaking, the systems people just don't have the time or the inclination to reach backward very far and draw new technology in. Therefore, like it or not, the R and D community carries the bulk of the job of technology transfer if it is to occur. Consequently, it is important that this group have a constantly updated view of the realities of field application; they must take the initiative to get the user interested in and supportive of the R and D program early, and eventually make plans to demonstrate new technology on real situation problems in order to interest the user market, which paradoxically, needs the new technology.

Current USAF NDI Program

Until about ten years ago, NDI\* activities in the USAF were still somewhat narrow in scope, being concerned mainly with remedial diagnostic inspection of parts as necessary during the maintenance of aircraft at the local base level. Many NDI shops were operating somewhat independently with periodic support coming from individual aircraft manufacturers, all of which resulted in considerable variation in practice, accuracy and effectiveness. Major inspection and overhaul programs on aircraft were conducted at several major depots in the U.S. only as necessitated by specific repair requirements. Thus, these programs were called Inspection and Repair as Necessary (IRAN). In 1964, as part of an effort to improve and standardize maintenance engineering procedures and significantly reduce cost, a major decision was made to place all USAF NDI activities under central management control and to incorporate the NDI function as a critical step in a new controlled maintenance process. This new role for NDI, and the details of its implementation, were formalized in 1966 in USAF Regulation 66-38 entitled, "Nondestruction Inspection Program," which established new NDI policies, including:

---

\*The terms "Nondestructive Testing" (NDT), "Nondestructive Inspection" (NDI) and "Nondestructive Evaluation" (NDE) are frequently used interchangeably and have sometimes been the cause of confusion. While no consensus has been reached, there is, in fact, increasing agreement that

NDT should refer to the development and application of the nondestructive test methods themselves ... ("tools").

NDI should refer to the performance of inspections to established specifications or procedures using the NDT methods to detect anomalies ... ("functions").

NDE should refer to the broad examination of materials, components, or assemblies to define, classify and make qualitative, and eventually, quantitative measurements of anomalies in terms of size, shape, type, orientation, and hopefully materials strength and stress levels. The term NDI was initially chosen to describe the USAF inspection task within the maintenance function as established by AFR 66-38. The term NDE as used by the USAF, and in this paper, encompasses the entire subject including the research and development activities.

a) NDI will be used as an integral part of all activities.

b) Accessibility of critical components for NDI will be a design consideration.

c) NDI skills and equipment required by new aircraft systems will be identified and made available before system delivery.

d) USAF - approved NDI techniques will be incorporated by manufacturers in qualification of first articles.

This official document also established the authority and assigned responsibilities to specific commands to:

a) Maintain NDI field laboratories at most major air bases worldwide to conduct field NDI using standardized procedures, equipment and specifications.

b) Develop and implement NDI procedures which will reduce life cycle costs.

c) Identify aircraft systems and components requiring NDI.

d) Establish aircraft inspection intervals.

e) Verify and approve new NDI methods and equipment for field use.

f) Develop standards and specifications for NDI procedures.

g) Conduct NDI technician training and certification programs.

h) Perform research and development on new and improved NDI techniques and equipment.

In the nine years since implementation, the NDI program has moved rapidly toward procedural maturity and is now an integral part of the overall task of maintaining operational readiness of USAF equipment. Today the USAF aircraft maintenance program is supported by NDI field laboratories at over 190 air bases worldwide and at five major USAF maintenance depots (Air Logistics Centers or ALC's). The Air Force Logistics Command (AFLC) is responsible for program implementation. The present USAF inventory includes 58 different aircraft, missile and engine systems, and their associated ancillary supporting equipment, and each is monitored through its own periodic maintenance cycle geared to specific design features, operational environments and usage rates, and feedback from service experience.

The current inspection and maintenance program in the USAF is designed to emphasize field maintenance procedures which cause a minimum disruption of flight-ready status of aircraft (termed "on-condition" maintenance) and to anticipate and avoid problems before they occur. A particular version of this program is established for each aircraft system in which all critical locations or possible failure points which must be monitored are identified during system designs and full scale tests. Additional information is derived from initial service experience, and past engineering experi-

ence in general. In addition, specific NDI procedures for each inspection point are worked out and verified on the full-scale test article as well as on other experimental set-ups. Finally, the frequency of the field inspections is chosen, as illustrated in Table 1, so as to be consistent with those found to be necessary during the system design, development and full scale test programs, and occasionally modified by service experience (see Ref. 1 for additional discussion).

TABLE 1  
PROGRAMMED INSPECTION AND MAINTENANCE PROCESS

INSPECTION TASK	INTERVAL
1. ORGANIZATIONAL AND INTERMEDIATE (BASE LEVEL) MAINTENANCE (O&I)  PREFLIGHT BASIC POSTFLIGHT SPECIAL INSPECTION PERIODIC INSPECTION ● AIRFRAME ● ENGINE ● FUNCTIONAL SUBSYSTEMS ● CORROSION	BEFORE FIRST FLIGHT OF THE DAY AFTER EACH FLIGHT AS NECESSARY  FLIGHT HOUR BLOCKS FLIGHT HOUR BLOCKS FLIGHT HOUR BLOCKS CALENDAR TIME BLOCKS
2. PHASED/ISOSYNCHRONAL INSPECTION	AFTER SEVERAL PERIODIC INSP.
3. PROGRAMMED DEPOT MAINTENANCE (PDM)	TYPICALLY 20 TO 40 MONTHS
4. ANALYTICAL CONDITION INSPECTION (ACI)	AS APPROPRIATE
5. LEAD THE FORCE (LTF) AIRCRAFT INSPECTION	AS APPROPRIATE

An official NDI technical application manual entitled "Nondestructive Inspection Procedures" is prepared for each system detailing all of the NDI procedures required by the maintenance schedule. These manuals are published as Technical Orders (TO's) with designations such as TO-1F-111A-36 for the F-111A aircraft, TO-1C-5A-36 for the C-5A transport, TO-1J-57-9 for the J-57 turbojet engine, and so on. The manual for each aircraft system is referred to as its "dash 36" manual; for each engine system, its "dash 9" manual; and for each missile system, its "dash 26" manual. A TO entitled "Periodic Inspection Requirements" and referred to as the "dash 6" manual, is also issued for each system to establish the specific timing of each inspection action. The manuals for each system are distributed to all base and depot NDI laboratories where the system is expected to be located. A comprehensively prepared general manual, T033B, which documents uniform procedures for conducting the five basic NDI methods, as well as certain specialized procedures, is also available at every laboratory as a technician level manual and NDI technicians are required to have full knowledge of the skills involved.

To date, approximately \$30 million has been invested in the preparation and distribution of this series of manuals. In addition, the USAF has provided specialized NDI training for over 2,000 inspection personnel. Moreover, an inventory of over 8,500 NDI equipment and component items, along with over 10,000 ancillary items, has been established by AFLC to perform the NDI program at a cost in excess of \$24 million.

The Air Force has sponsored NDE research and development projects, although initially at relatively modest levels, since the early 1950's. Emphasis was placed on:

- methods and equipment improvement

- assistance in solving field problems
- development of new approaches.

Funding levels for NDE R&D efforts were about as shown in Fig. 1. Some funding increase resulted from the introduction of AFR 66-38 which brought new management attention to the area.

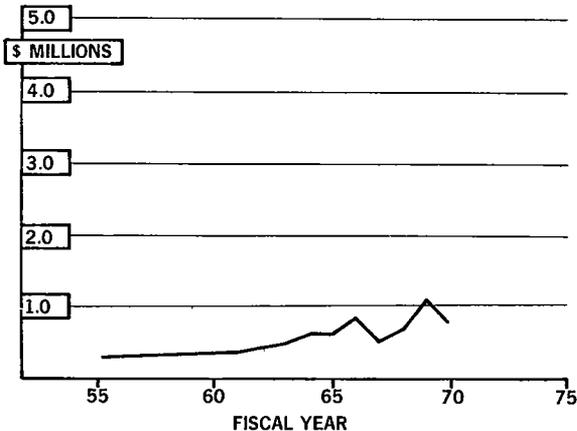


Figure 1. Air Force NDE R&D funding trend.

#### New Factors Expand Importance of NDE

The continuing program to increase the strength and effectiveness of the USAF at minimum cost is applying considerable pressure to improve supporting NDE capabilities. Behind this pressure are several significant new factors affecting aircraft systems which have increased in importance since 1970:

- Adoption of new airplane damage tolerant design requirements.
- Trend toward aircraft life extension rather than replacement.
- Efforts to reduce operational and support (O&S) costs (cost of ownership).
- Emergence of new structural concepts and materials.

#### A. New Design Requirements

Since 1961, USAF aircraft have been designed, manufactured and operated in accordance with the technical requirements of an Aircraft Structural Integrity Program (ASIP) established to assure that they have adequate integrity and service life<sup>2</sup> Flight critical structural elements also had to meet damage-tolerant design requirements such that if a fracture or crack initiated, the structure remaining or a portion of the same structure could sustain a percentage of its design load without catastrophic failure. The inadequacy of these ASIP requirements and guidelines was revealed in 1969 with the crash of a USAF F-111A fighter bomber when, even though operating well below design limits, a wing separated in flight during a practice run over a target area. An investigation revealed that the loss was caused by the failure of a wing pivot fitting and this failure emanated from a one-

inch flaw generated during the manufacturing process which remained undetected by all subsequent NDE.

The F-111 incident, together with various deficiencies experienced with other aircraft systems, led to the assurance of a new set of ASIP requirements in 1972, now contained in Military Standard MIL-STD-1530,<sup>3</sup> which set forth a new structural integrity and durability design philosophy for USAF aircraft. The designer must generate data required to manage fleet operations in terms of inspections, modifications and damage assessments. This in turn, led to the development of a new Military Specification MIL-A-83444 "Airplane Damage Tolerance Requirements", dated 2 July 1974. A critical feature of this philosophy is that a designer must now assume that aircraft structures unavoidably contain small flaws and defects at delivery whose assumed presence must be taken into consideration in the initial design and in setting up NDI intervals,<sup>4</sup> as well as technique selection, sensitivity levels and inspection zones in parts. MIL-A-83444 allows, under prescribed conditions, a choice between a fail-safe approach which prevents catastrophic failure by using multiple load paths or crack-stoppers, and a slow growth approach in which growth rates are kept too low for cracks to reach critical sizes within the inspection interval. In addition, the required initial flaw size assumptions and required levels of inspectability for both design approaches are prescribed. The introduction of these requirements focused considerable new attention on NDE capabilities, and limitations, and indirectly set new and stiff goals for achievement of improved detection sensitivity and reliability levels.

#### B. Trend Toward Life Extension

As a natural consequence of the rising costs of manufacturing replacement aircraft and the greater initial cost of new advanced designs of increased sophistication, management motivation exists to consider the alternative of extending the useful life of as much hardware already on hand as possible while still maintaining fleet strength. The useful service lives of several aircraft systems, such as the B-52 bomber and KC-135 tanker, have in fact been extended through engineering modifications, selected structural replacements, and increased inspection coverage. An important step was also taken, with the institution of MIL-STD-1530 in 1972, to establish significantly longer service lives for aircraft in the future as an initial design requirement. Since 1972, engineering evaluations conducted on several in-service aircraft have established structural changes necessary to meet the new life requirements, although existing aircraft were essentially exempt from the requirements. Many first line aircraft systems will eventually undergo this structural integrity and durability reassessment. It is anticipated that upgraded NDE procedures will play a vital role in assuring the required safety and economic levels.

#### C. Efforts to Reduce O&S Costs

The operation and support (O&S) of USAF airplanes is a major category of expenditure, and the time consumed in maintenance and NDE is an important limitation on the number of aircraft available

to meet mission requirements at any given time. Serious efforts are underway to improve and reduce the costs of these functions in two important ways:

- Streamline the maintenance cycle
- Make NDE more economical

The USAF is presently conducting an extensive Maintenance Posture Improvement Program to parameterize the total maintenance process, to develop alternative analytically-based scheduling models, and to present new options for a cheaper and more efficient inspection and maintenance program flexible enough to accommodate changing conditions, economics and fleet management schemes. The interface between NDE and corrosion control requirements is an example of the factors being considered.

There are, as can be imagined, many instances where the cost of NDE methods and procedures applied to aircraft inspection must be reduced, and many opportunities to do so are available. An important objective in many of the current USAF research and engineering development efforts is to learn more about so called "high cost centers" in the many NDE functions, and to devise alternative techniques, technique modifications, simpler procedures or cheaper inspection materials.

#### D. New Structural Concepts and Materials

An aggressive research and development program is conducted by the USAF to investigate and develop new airframe and engine structural concepts, construction materials, and fabrication processes. The achievement of significant weight and cost reductions as well as improvements in damage tolerance and performance are the principal motivating objectives. From a performance point of view, a few important opportunities are becoming realities; however, marginal NDE capabilities in some of the cases will be a limiting factor unless major improvements are brought about. Among the significant challenges to the NDE field are or will be:

- advanced composite structures
- primary adhesive bonded structures
- laminated components
- processed-to-net shapes
- special engine materials: ceramics, directionally solidified (DS) eutectics, single crystals, metal matrix composites.
- highly complex shapes (such as hollow air-cooled turbine blades).

The level of funding devoted to NDE research and development since the 1970 time period has been influenced upward significantly, as shown in Fig.2, by the factors just discussed. It is principally the trend of this chart that is important in illustrating the magnitude of the increased attention to NDE. The specific dollar amounts should be considered approximate since they are estimated by combining several NDE funding sources, including, for example, ARPA funding for the Science Center program being reviewed at this conference.

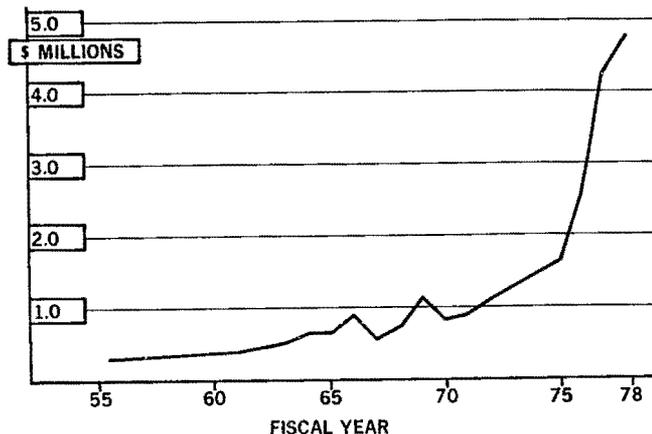


Figure 2. Air Force NDE funding trend.

#### User's Requirements for Improvement

NDE user requirements for improved capabilities and practice provide the basis of the Air Force NDE R&D program plan. The success of technology transfer, no matter how sensational the technology, depends ultimately on its utility in meeting some of these requirements and within the limitations of the user's application environment. Thus, an appreciation of these becomes quite important to the researcher. Some of the more important needs and requirements are to:

- Improve sensitivity and resolution under field conditions
- Reduce operator dependency of NDE techniques
- Lower cost of NDE
  - Production
  - Maintenance
- Reduce inspection technique variables without sacrificing equipment versatility
- Develop simple quantitative readouts.
- Establish new, simple capabilities where absent
- Solve specific field inspection problems

One can conclude from this list that the emphasis is on increasing accuracy with reduced variability while lowering cost. A point must also be made that the cost-effectiveness and cost reduction opportunities related to production NDE and maintenance NDE functions are usually quite different and may involve different approaches.

Another standing user need is reflected in the fact that the "old, standard" techniques still require improvements. For example, despite the fact that x-ray radiography was initially introduced in 1934 and has seen wide, routine application, numerous use variables are still not resolved:

- Optimum kilovoltage
- Beam to crack alignment range
- Non-uniform developing solution characteristics  
(Time-Temp. - Density - Thickness Relations)

- Radiography viewing techniques
- Deterioration criteria/rates for unexposed film
- Penetrants - Hole vs Wire vs Mesh vs? (not useful in maintenance - what is?)

The fact that approximately 2,000 radiographs are made in the course of the periodic inspection of the USAF C-5A transport exemplifies the importance of and cost reduction potential in technique improvement and optimization. Other "classical" techniques - ultrasonics, eddy current, fluorescent liquid penetrant and magnetic particle - need similar improvement.

The Air Force field NDE program, performed as an integral part of the maintenance function, has numerous limiting characteristics, due in great part to its large scope. Some of these are intrinsic in nature while others can offer opportunity for R&D improvement efforts. Either way, they are important to recognize and take into consideration when deciding on the potential for development and transition of new technology. They include the following:

- Air Force inventory involves multitude of dissimilar items to inspect
- Reference standards are generally inadequate, ill-defined
- Commercial equipment designs/capabilities are frequently outdated
- Sensitivity/reliability factors are hard to pinpoint, control
- No certification-recertification (MIL-STD-410D) required for AF personnel
- Resistance to change or adopt new technology at field level
- Pressure to keep costs down

It would be fair to summarize this list as follows with respect to the Air Force NDE field environment:

- 1) techniques and equipment must be versatile-can't afford many specialized, limited application items.
- 2) large variable scope of inspection requirements makes standardization, generalization difficult.
- 3) techniques and new technology must be easy to apply by routinely trained technicians.
- 4) Field technicians are reluctant to change, are suspicious of new concepts, equipment or procedures.

#### NDE Research and Development Planning

The responsibility for planning and conduct of the USAF NDE R&D program, authorized in Air Force Regulation 66-38 described above, is assigned to the Air Force Systems Command (AFSC) and further delegated to the Air Force Materials Laboratory (AFML) as depicted in Figure 3.

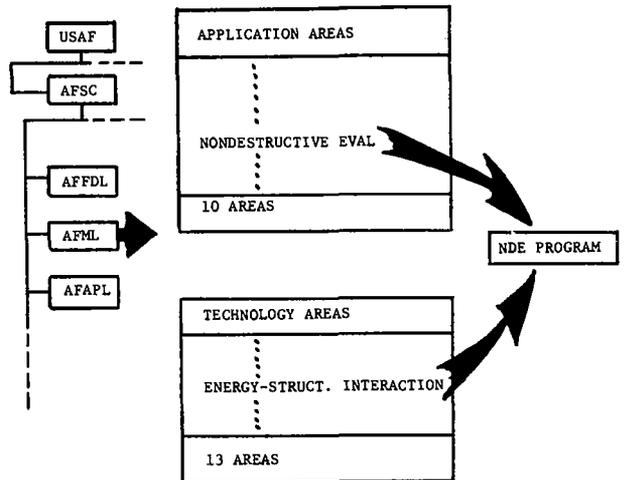


Figure 3. NDE R&D program evolution.

The AFML conducts a full spectrum materials technology program consisting of basic research, exploratory development, advanced development and manufacturing technology. The program is organized for planning, implementation and management purposes into the 13 "technology" base subjects or areas and 10 technology "application" areas shown in Fig. 4. The total AFML NDE program consists of a technology base program (entitled "Energy-Structure Interaction") incorporating all basic and some exploratory development and manufacturing technology work. The planning process is a broadbase team effort involving participation of or input from:

- AFML and other AFSC laboratories
- Aeronautical systems division (ASD) engineering
- AFMC NDI program office
- AF major commands, other DoD and Government agencies
- Aerospace and related industries

The total R&D program is organized as long range "roadmaps" which provide

- coordinated elements: R&D to transition
- consistent funding commitment
- specific application or customer "windows"

Through this method of program planning, it is possible to assure that all essential R&D projects or subelements of an overall development thrust are brought along at the required time. Consistent funding of all subelements is assured as a single decision. Finally, the integrated thrusts are designed to meet identified end requirements, generally a systems requirement. The program thrusts, established as of the Fiscal Year 1977 planning cycle, are prioritized as shown:

#### Applications Area

1. Fastened Joint NDE
2. NDE Method, Process and Equipment Optimization
3. Advanced Composite NDE
4. Adhesive Bond Evaluation
5. NDE of Complex (Engine and Airframe) Shapes
6. In-flight Structural Monitoring

Technology Area

1. Quantitative Flaw Characterization
2. Measurement of Adhesive Bond Strength
3. Characterization of Failure Related Materials Properties

A roadmap (current in FY77) from thrust No. 5 is illustrated in Figure 4. (It is beyond the scope of this paper to discuss the content of specific roadmaps).

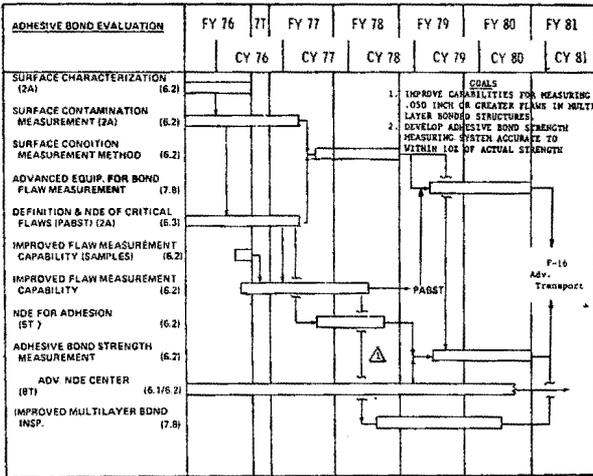


Figure 4. Typical program roadmap

Factors Controlling Technology Transition

While much can be said about the difficulties that can be encountered in the introduction of new or improved technology into use, one major obstacle worth noting is the significant length of time required for the R&D - Implementation cycle itself. Figure 5 illustrates the time needed for a typical R&D project on an inspection device (using a recent case history).

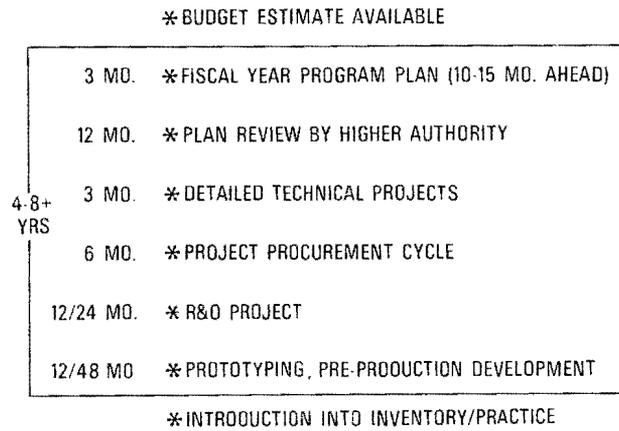


Figure 5. Typical R&D/implementation cycle

Following pre-production development and a successful field demonstration, and a requirement for inventorying has been established, a procure-

ment cycle, such as shown in Fig. 6, may follow:

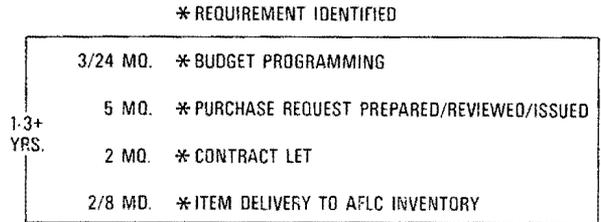


Figure 6. Typical procurement cycle AFLC NDI equipment

Thus, as this illustrates, it can take ten or more years to transition a new device to inventory (and that is if all goes well).

With few exceptions, new technology must transition into a conservative user's market where change usually raises concerns about increased risk, cost additions, lost time, new training requirements and general uncertainty as to benefits. The best chance to overcome these concerns is to show that benefits outweigh the other factors. In the Air Force NDE application environment, the essential questions which govern acceptability of new NDE procedures, methods or equipments include:

- Does it directly solve a current inspection problem?
- Is it faster?
- Is it more reliable?
- Is it more cost-effective?
- Does it provide more essential information?
- Is it usable in the inspection environment?

To generate enough justification or motivation to successfully introduce new technology usually requires at least several of these benefits in combination. The first and last features are usually required. To make new methods, instruments, or equipments functional and marketable, even though technologically acceptable, it then becomes essential to produce designs to

- Optimize simplicity
- Maximize versatility
- Optimize compatibility with existing equipment
- Minimize ownership cost
  - Acquisition
  - Operation
  - Maintenance
- Make rugged as possible
- Maximize operational stability (reproducibility)
- Minimize operator dependency
- Minimize required operator training

The criticality of the user environment factors such as outlined in this section cannot be over-emphasized. Outstanding technical innovations have been known to die because of failure to satisfy such requirements.

## References

1. Forney, D. M., "NDI in the United States Air Force," British Journal of NDT, pp 72-81, May 1976.
2. Wells, H. M., Jr., and King, T. T., "Air Force Aircraft Structural Integrity Program: Airplane Requirements," ASD-TR-66-57, May 1970.
3. Military Standard MIL-STD-1530 (USAF), "Aircraft Structural Integrity Program, Airplane Requirements," 1 September 1972.
4. Haviland, G. P. and Tiffany, C., "Understanding the USAF Structural Integrity Program," Astronautics, pp. 67-70, July 1973.

## DISCUSSION

DR. C. C. MOW (Rand Corporation): We have time for one or two questions.

COMDR. JIM ANDERSON (ONR): The question of certification and recertification, once your military people go to a school or learn the NDI inspection techniques, do they then acquire some sort of a designator that identifies them as skilled NDI operators?

MR. FORNEY: Yes, they are assigned an Air Force Specialty Code, or AFSC. All Air Force career fields are identified by AFSC as described in Air Force Manual (AFM 39-1). The AFSC assigned to military NDI inspectors is 531X5 where 531 is the Metal Working career field, X represents skill level and 5 identifies the NDI specialty. The entry skill level value of X (just out of NDI school) is 3, 5 represents six or more months on the job training plus a written proficiency test. Finally, 7 is the fully qualified senior level obtained after extensive experience (usually the senior non-commissioned officer level). Civilian NDI personnel are not included in the AFSC system and are governed by Civil Service regulations. The point to be made is that there is no automatic scheme and authority to require certification/recertification of these NDI personnel periodically as in the commercial sector. Opportunity for promotion/advancement must provide the motivation and retraining opportunity provides the means.