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NONDESTRUCTIVE EVALUATION TECHNOLOGY INITIATIVES PROGRAM II (NTIP II)

Delivery Order 10, Task 010-015: In Search of Excellence - An Historical Review

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This report provides a brief historical account of the organization evolution, the research and development activities and the important technology contributions made by the Nondestructive Evaluation Branch of the Air Force Research Laboratory's (AFRL) Materials and Manufacturing Directorate (ML) and predecessor organizations. Its purpose is to bring attention to and document a remarkable legacy of people, vision and accomplishment. It tells the story of the early beginnings in 1919 at McCook Field in Dayton, Ohio along with many of the subsequent advances in Nondestructive Evaluation (NDE) science and engineering made by the men and women of the ML NDE Research and Development Program spanning over 8 decades of service. This report covers the NDE organization evolution; timeline of the people who served; notable events that influenced the national awareness and the growth of the NDE Program; the more significant NDE developments that impacted the AF; key NDE Program partnerships; and other important NDE topics. This brief history is important to the understanding of the significance of past developments and the dedication of many inventive Air Force technologists who helped pave the way to today's innovations and their positive impact on the safety and reliability of both aeronautical and space assets.

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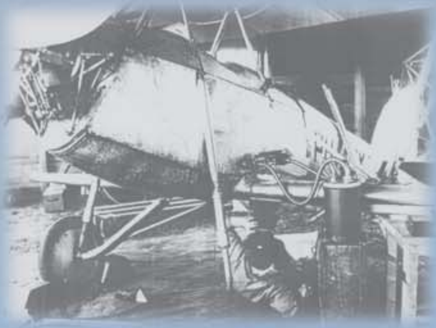
Table of Contents

Page #

In Search of Quality
A Historical Review

Air Force Research Laboratory
Nondestructive Evaluation Branch
Research & Development



Systems Health Monitoring

by
Donald M. Forney

Preface

This volume provides a brief historical account of the organization evolution, the research and development activities and the important technology contributions made by the Nondestructive Evaluation Branch of the Air Force Research Laboratory's (AFRL) Materials and Manufacturing Directorate (ML) and predecessor organizations. Its purpose is to bring attention to and document a remarkable legacy of people, vision and accomplishment. It tells the story of the early beginnings in 1919 at McCook Field in Dayton, Ohio along with many of the subsequent advances in Nondestructive Evaluation (NDE) science and engineering made by the men and women of the ML NDE Research and Development Program (hereafter NDE Program) spanning the following 8 and a half decades of service. This brief history is important to the understanding of the significance of past developments and the dedication of many inventive Air Force technologists who helped pave the way to today's innovations and their positive impact on the safety and reliability of both aeronautical and space assets. Retired General Ronald R. Fogleman, who served as the United States Air Force Chief of Staff during the period of 1994 – 1997, observed that "history is a resource that allows us to apply valuable lessons of the past to today's knowledge and decision making. Therefore," he said, "to ignore history is a mistake." [a]

This history is presented in topic sections, each chronologically organized, in order to provide the reader with the opportunity to review separately the NDE organization evolution; a timeline of the people who served; some of the more notable events that influenced the national awareness and the growth of the NDE Program; the more significant NDE developments that impacted the AF and others; key NDE Program partnerships; and other topics. Recounting this history has been a challenge in that there are a number of lapses in availability of some earlier information and historical records to draw from. Furthermore, most early participants prior to about 1960 with possible personal recollections are no longer available.

With the sheer quantity of ML NDE R&D programs, results, publications and information to work with, along with the fact that a plethora of individuals with some untapped knowledge of events were no longer available, a complete journal was beyond reach. Nevertheless, the author has attempted to incorporate all available information to the extent that resources and time permitted. Many individuals provided help with research, documents, photographs and discussions. My gratitude and acknowledgement goes to them for their time and knowledge shared and other information sources they provided. To the extent possible, these persons are listed in the Acknowledgement section.

The U.S. Air Force Research Laboratory, Materials and Manufacturing Directorate (AFRL/ML) and Universal Technology Corporation made resources available for me to write this book. Furthermore, I contributed significant additional personal time and effort, as well, in order to help assure that the optimum desired scope and detail were achieved.

Donald M. Forney

April 2006

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[a] Duffner, Robert W., Science and Technology: The Making of the Air Force Research Laboratory, Air University Press, Maxwell Air Force Base, Alabama, November 2000.

Introduction

From the outset of the developmental evolution of the airplane, it was evident that the constant and careful inspection and maintenance of this unique machine would be an essential ingredient for success throughout its expected useful life. Nondestructive testing and inspection of aircraft components actually may have been applied for the first time by the Wright brothers themselves as they designed, fabricated and assembled parts made in meticulous detail and put together with meticulous care. They carefully checked and verified measurements, quality of construction materials, the precision of fit, and strength of assemblies. In essence, they were searching for and verifying the quality they intended. Aviation historians have marveled at the genius of the Wright's original construction notes for their hand-built Kittyhawk craft, which revealed their focus on detail and quality. In fact, a modern day project to build a full-scale replica of the 1903 Wright Flyer using drawings carefully made from the Wright's original notes and specified materials, provided a vivid demonstration of the quality they intended to achieve through attention to detail coupled with nondestructive visual inspection. The all-volunteer project team led by Howard DuFour, a master model maker retired from Wright State University in Dayton, Ohio, completed the replica in August 2001, having used the same hand-building methods the Wrights used. It now hangs majestically suspended, as if in flight, from the ceiling of the Atrium of the Wright State University Paul Laurence Dunbar Library located adjacent to Wright-Patterson Air Force Base near Dayton.


Replica of the Original Wright Flyer.

This appreciation for the vital task of maintaining quality in the construction and operation of the airplane was carried over to the Material Section of the Army Air Service's Engineering Division and its early beginning in 1919 at McCook Field in Dayton, Ohio. The 1 October 1919 issue of the McCook Field publication "Slipstream" cited one of the Material Section missions as being to "test fabricated parts and to make routine inspection tests for the Procurement Section." Figuratively speaking, this general statement may have signaled a modest birth of a nondestructive quality testing, inspection and evaluation function that, in later decades, would become a critical-path tool to help assure and maintain the high performance and structural integrity of the modern Air Force fleet.

Dating from the time people first began acquiring and trading material goods or fashioning implements to perform their work, they have searched for the best quality they could get. Depending largely upon their intuition and senses, craftsmen and consumers alike have searched for methods and tools to verify quality without damaging or otherwise lowering the value of the objects in the process – in other words, to test nondestructively. At some time in antiquity master sword makers learned to strike a newly forged blade and listen to the clarity of its ring as a measure of its quality. Some 2200 years ago Archimedes' fortuitous discovery of the principle of specific gravity gave the Greek mathematician and scientist the means to prove for his friend King Hieron of Syracuse that a new gold crown was, in fact, not as pure as claimed by its makers. These are early illustrations generally of what now is variously termed nondestructive testing (NDT), nondestructive inspection (NDI), or more generally, nondestructive evaluation (NDE).[b]

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[b] Forney, Donald M. and Chimenti, Dale E., *"Nondestructive Evaluation – Coming of Age,"* 1986 Yearbook of Science and the Future, Encyclopaedia Britannica, Chicago 1985, pp 86-105.

Some three dozen or more nondestructive evaluation methods are presently in use or under study for industrial, medical or other uses. Nearly all of them have appeared since the 1920s, and most since 1940. Five NDE methods are still used industrially far more often than any others: radiography, ultrasonics, eddy current, magnetic particle, and fluorescent liquid penetrant. A number of newer methods are advanced variants of one of the established five.

Radiography was the first method of internal visualization adapted to NDE, based on the pioneering work of Horace Lester during the early 1920s at the U.S. Army Watertown Arsenal in Massachusetts. Early work by Sokolov (USSR) in 1929 and German scientists Trost, Mulhauser and Pohlman in the 1930s with ultrasonic waves for detecting defects in metals, paved the way for the invention by University of Michigan's Floyd Firestone of the ultrasonic "reflectoscope" in 1940, the forerunner of modern ultrasonic pulse-echo equipment. The eddy current method of testing was first investigated systematically in the early 1930s by Cecil Farrow at Republic Steel, but the in-depth analytical and experimental work of the 1940s by German scientist Friedrich Förster provided most of the scientific basis for the method.

Around 1928, Alfred V. de Forest at the Massachusetts Institute of Technology, began his pioneering work in developing magnetic methods for NDE by experimenting with circular magnetization that would cause fine iron powder to be attracted to surface defects such as cracks. Patents were issued in 1934 and 1935 for his advanced magnetic-particle methodologies. In 1934, in association with F. B. Doane, he founded the Magnaflux Corporation. In the mid- to late 1930s as World War II approached, the increased use of nonmagnetic structural materials, such as aluminum, magnesium and stainless steel (primarily for aircraft construction), sparked the need for better NDE for these materials. In 1942, following several years of experimentation, brothers Robert and Joseph Switzer introduced the fluorescent penetrant inspection (FPI) process that provided a critical additional method to inspect propellers, engine components, castings, bearings and other complex-shaped parts for surface-breaking defects.

For over eight decades, the methodologies of NDT, NDI and NDE have become essential tools in virtually all activities in society.[c] Today, the U. S. Air Force recognizes these methodologies as a critical path technology for many of its operations. The Air Force Research Laboratory (AFRL) Materials and Manufacturing Directorate (ML), and it predecessor organizations and people, have played, and continue to play, a significant leadership role, through its internationally recognized NDE R&D Program. This active leadership and its strong long-term dedicated program has been a vital force in the overall evolution and accelerated growth of NDE technology in general, and specifically in its applications in the aerospace community. In recent decades, the Program has increasingly featured strong efforts to expand the NDE state of the art as well as adapt NDE knowledge from other fields to help satisfy AF needs. Not only has the rapid transition of new technology to AF applications been a priority, but significant attention has been given also to potential technology transfer to civilian uses. Finally, active participation by NDE Program staff members in civilian technical activities, both nationally and internationally, has helped to facilitate increased attention toward AF needs and contributions.

The archiving of this historical experience not only serves to recognize and highlight appropriately the vision and leadership, hard work and outstanding accomplishments of the U.S. Air Force's "Materials Laboratory" NDE R&D community, but it also chronicles the significance of many contributions made to the international NDE state-of-the-art.

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[c] Three terms evolved over the years to describe this technical function. The initial term NDT traditionally referred to an initial validation of the intended quality and integrity of a material or component. The term NDI was introduced to describe recurring inspections using specific procedures to monitor the continued quality and integrity of a material or component. The more general term NDE evolved to describe computer-based advanced technology approaches to classify or quantitatively measure flaws and irregularities, materials condition, properties and dimensions of materials and components to assist in the determination of the degree of integrity, rate of any deterioration, and continued serviceability.

CHAPTER 1

Genesis of the ML NDE Organization

Early Beginnings

In 1909, the Army Signal Corps acquired its first airplane from the Wright brothers for evaluation by its newly formed Aeronautical Division. However, due to limited resources and other official support, little came of it. But with World War I looming, the government released in 1916 the first "Specification for Military Airplanes" defining the performance requirements and it launched an accelerated program in which some 17,000 aircraft were produced by U.S. companies between March 1917 and the Armistice, many of which were licensed British and French designs.[1.1]* This number was supplemented by others acquired from our Allies on the Western Front.

Following the decision by the War Department in 1917 to consolidate its aviation activities, the Signal Corps, along with its Airplane Engineering Department, received approval to relocate to McCook Field in Dayton, Ohio upon completion of construction there in December of that year.[1.2] By 1919, after several organizational changes from the original Army Signal Corps, the new Army Air Service emerged, along with its Engineering Division to which was attached the Material Section as illustrated in Figure 1.1 (also shown in Appendix A, Figure A.1, and subsequently in Figure A.2). It was observed later by historians that this Engineering Division was eventually considered the antecedent of the Air Force Systems Command and the Material Section the ancestor of the Air Force Materials Laboratory.[1.3] The 1 October 1919 issue of the McCook Field publication "Slipstream" cited that one of the Material Section's numerous functions was to "test fabricated parts and to make routine inspection tests for the Procurement Section." Another function, this in support of the Inspection Engineer, was to "outline the methods of calibrating and determining the accuracy of testing machines, the proportionate amount of material necessary for inspection tests in order to be reasonably sure of the uniformity of the lot from which the specimens are selected, and prepare instructions to guide inspectors in accepting or rejecting material."

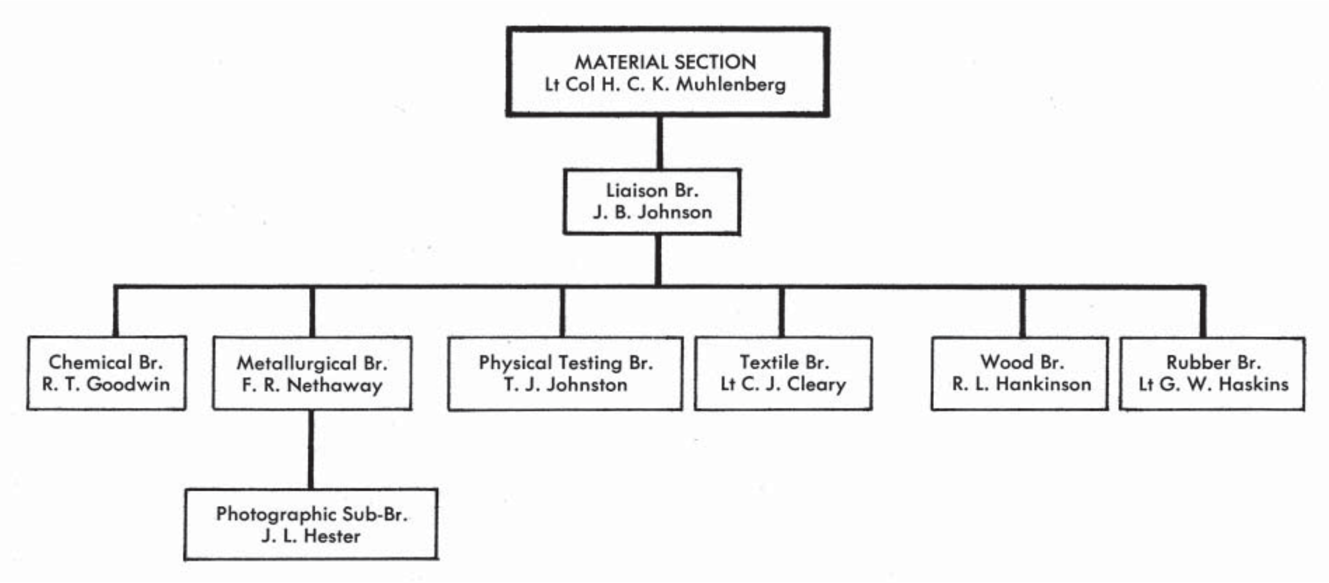


Figure 1.1. Material Section Organizational Structure, 1919.

After 1919, the Engineering Division experienced a period of retrenchment that extended into 1927, brought on by pressures from aeronautics private industry for a greater share of R&D dollars. The Army Air Service became the Army Air Corps in 1926. Then in October 1927, the McCook Field operations, including the Material Section, were moved to new quarters at Wright Field in what is now Area B to provide a larger flying field and to expand facilities. With a name change, the Materials Branch was housed in early 1927 in the northeast corner of Building 16 as shown outlined in Figure 1.2. The organizational structure of the Materials Branch pictured in Fig. A.3 remained nearly stable during this period with a staff of 30 plus people. By 1930, metal had superceded wood as the most important

** References located at the end of each chapter/appendix.*

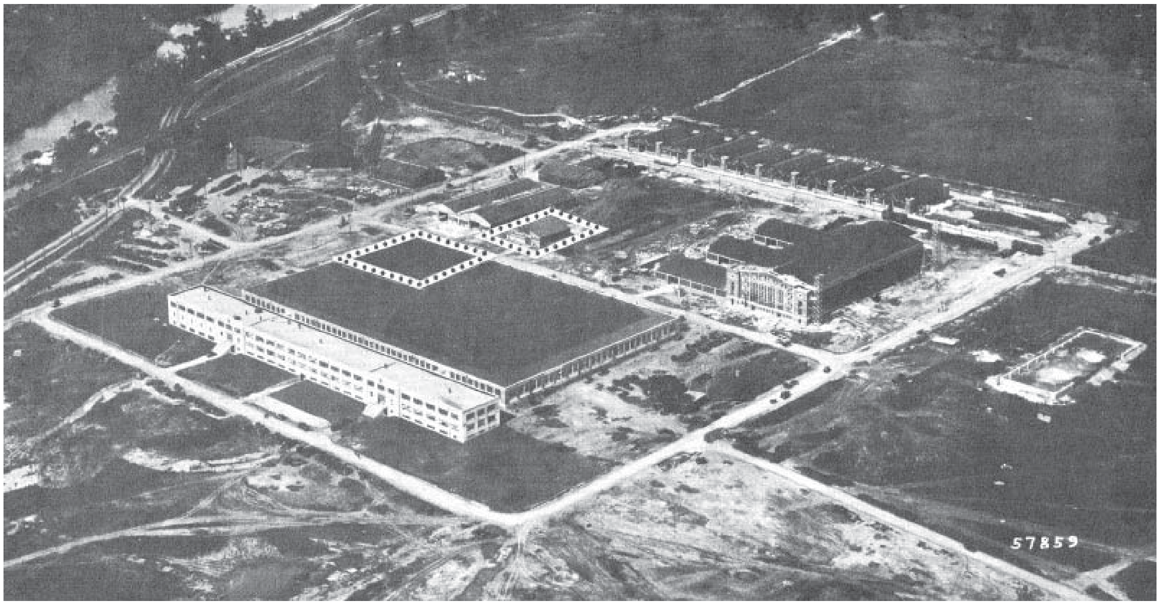


Figure 1.2. Wright Field 1927 - Materials Section, Location in Building 16. (Outlined)

structural material in aircraft design, which was reflected in the organizational structure shown in Figs. A.4 and A.5.

In 1939, the Materials Branch was renamed the Materials Laboratory, and with World War II imminent, significant expansion of the laboratory program and subsequent organization occurred in 1940 and 1941 (Figure A.6). This included the establishment of the first recognized stand alone NDT development program activity, focusing on Radiography, which was assigned to the Laboratory's Metallurgical Unit.

During WW II, ML specialists performed a large number of technical assistance tasks to industry, including inspection, to assure that processes met the necessary level of quality. In addition, many in-house investigations were conducted, including NDT, pertaining to Army Air Force (AAF) equipment malfunction or failure. In 1944, ML moved from Building 16 to larger quarters in nearly Building 32. Included in the many unique features in the Building 32 renovation were a series of x-ray rooms with 12-inch thick reinforced concrete walls and heavy lead-lined doors.

The early post-war years brought a number of changes in ML organization, staff size and program emphasis. The U.S. Air Force was formed as a separate branch of the military establishment in September 1947. As materials technology advancements and new capability needs emerged from the WW II experience, corresponding changes occurred by 1949 in the ML organization structure as illustrated in Figure A.7. The NDT function remained in the Metallurgical Unit.

In 1951, the USAF established the Air Research and Development Command (ARDC), which reflected its significant commitment to a stronger R&D focus. Furthermore, the Wright Air Development Center (WADD) was established at Wright Field in 1951, along with its Research Division under which the ML was placed. As the importance of materials technology grew, ML's mission responsibility was broadened and it attained a position of high technical stature within the AF and the scientific community. Together with the pressure of the Korean War, the increased R&D mission activity and staff led to an expanded organizational structure by the beginning of 1953 as shown in Figure A.8. The new Non-Destructive Test Section (WCRTL7) had been established in the Metals Branch in May 1952.[1.4] Another organizational structure change took placed in September 1956 shown in Figure A.9. The structure of the line portion of the organization shown is essentially that which emerged from the February 1954 internal reorganization. The staff structure of 1956 shown was a result of further alteration of that function due to subsequent changing management situations. The NDT Program remained in the Metals Branch Design Criteria Section.

In 1960, the Materials Laboratory was renamed Materials Central. Alignment of some programs to the new line organization structure occurred as illustrated in Fig. A.10. The NDT program was placed in the new Metals and Ceramics Laboratory's Strength & Dynamics Branch, Applied Mechanics Section as shown in Figure A.11. In 1962, with the elimination of formal Sections in a new internal realignment, the Applied Mechanics program, which included the NDT program activity, was re-designated as a formal Technical Area within the Strength & Dynamics Branch as displayed in Fig. A.12.

As pictured in Fig. A.13, the new Processing & NDT Branch was established in early 1966 as part of an internal Metals and Ceramics Division realignment of branches. This change emphasized the growing importance of NDT technology development.[1.5]

In 1972, a two-year study called "Project REorientation for the (19) Eighties," (coined PREE, or PRE^2 ["pre-square"]) was initiated by the Laboratory to determine new materials research and development requirements to meet Air Force needs of the 1980's. Subsequently, a reorganization and revitalization of the AFML program was announced. Taking effect in May 1972, this program, and associated organization realignment, included the replacement of the Processing & NDT Branch with the new NDT & Mechanics Branch, as shown in Fig. A.14. No changes in the NDT personnel were involved.

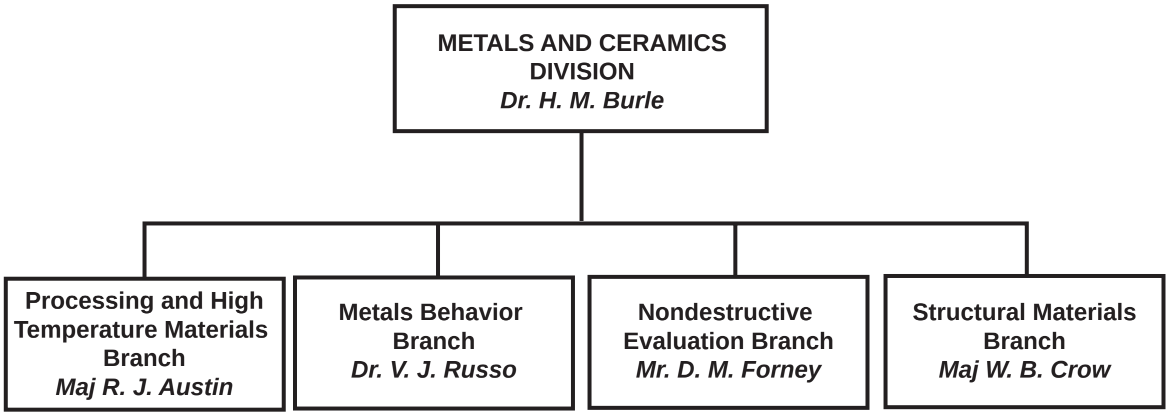


Figure 1.3. Metals and Ceramics Division Structure, July, 1974.

A New Beginning

One conclusion drawn from the 1972 PRE^2 requirements analyses was that a significant increase in research and development was needed in NDT/NDE to support current and future Air Force operations. The resulting plan called for strengthening the technology program in Fundamental Inspectability and the Engineering program to advance Applied NDT.[1.6] As an eventual consequence of this decision, together with a growing Air Force-wide concern about fleet structural integrity and safety, the NDT/NDE program was elevated to a Nondestructive Evaluation Branch level, which was established in February 1974, as seen in Fig. A.15. By July 1974, following some management personnel changes, the Division organization was as displayed in Fig. 1.3 (also Fig. A.16).

In late fall 1974, parts of ML began the phased process of relocating from Area B buildings 32, 51, 17, parts of Building 56 and two NDE Branch office trailers into its new five-building complex under phased-construction nearby. The NDE Branch facilities were, in the interim, relocated to Area B building 450 where it remained until completion of Building 655, the last to be completed in the new ML complex. The branch facilities were moved in the summer of 1987 to the location outlined in Figure 1.4.[1.7]

The Metals and Ceramics Division organization structure remained intact until 1996 at which time a reorganization/realignment of its functions was initiated to better represent its updated principal program priorities and objectives, as shown in Fig. 1.5 and Fig. A.17. This Division realignment and name change, decided by the ML Executive Group and Director Dr. Vincent Russo, reflected a further recognition of the vital role played by advanced NDE in the improvement and maintenance of reliable fleet operations. The organization structure has remained unchanged to this date.

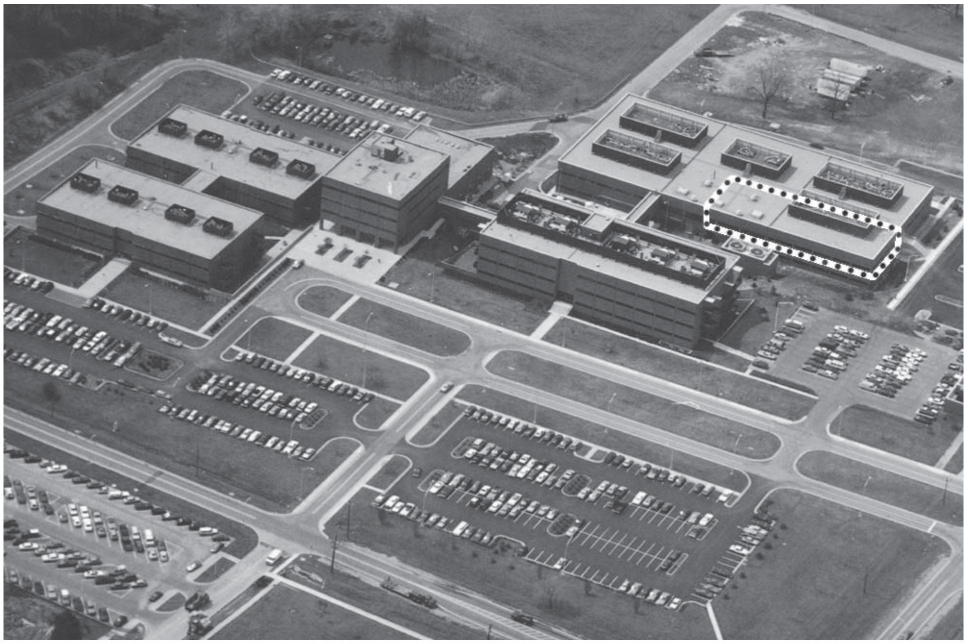


Figure 1.4. Aerial View of Current AFRL Materials and Manufacturing Directorate Building Complex Outlining Location of NDE Branch in Bldg. 655.

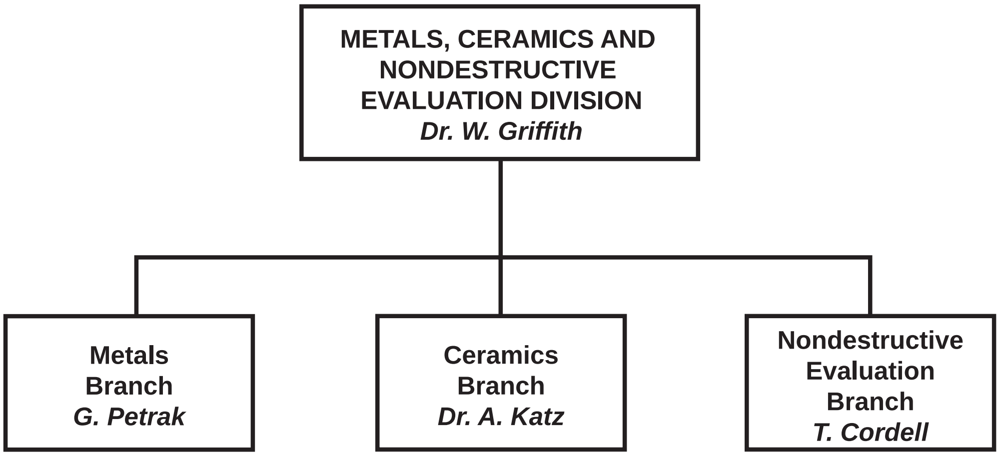


Figure 1.5. Metals, Ceramics and NDE Division, 1996.

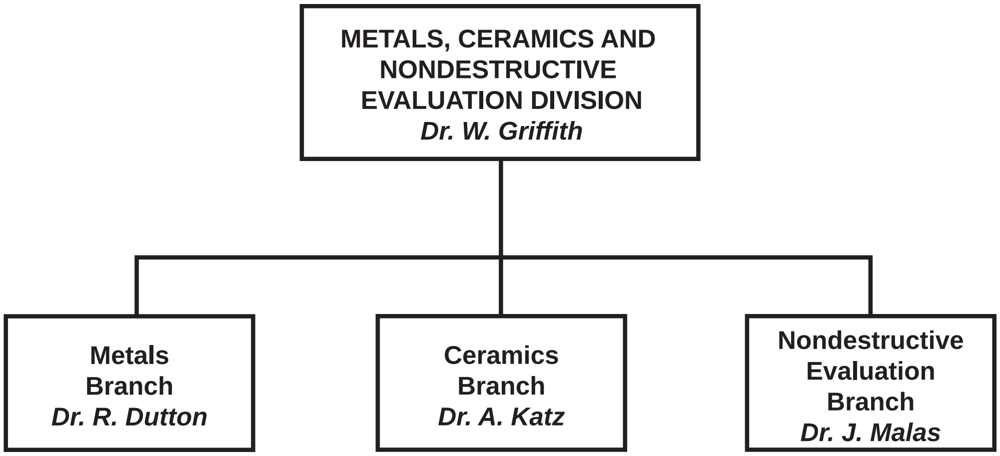


Figure 1.6. Metals, Ceramics and Nondestructive Evaluation Division Structure, 2006.

References

1.1 Hadcock, Richard N., *“Review of Aircraft Structures and Materials; 1920-1995,”* RNH Associates, Inc., Special Report to the Air Force Wright Laboratory, WL/MLLP under Universal Technology Corporation Subcontract No. S-401-01-27-C2, May 30, 1995.

1.2 Five Decades of Materials Progress, 1917 - 1967, James J. Niehaus, Air Force Materials Laboratory, Wright-Patterson Air Force Base, OH, 4 December 1967.

1.3 Ibid.

1.4 Materials Laboratory Historical Report, 1 January – 30 June 1952, AFRL/ML Data Base 1003, located at Universal Technology Corporation, Dayton, OH.

1.5 Authorization to Establish a New Branch in the AFML, Materials Laboratory History Document, 23 March 1966, AFRL/ML History Data Book File No. 3637, located at Universal Technology Corporation, Dayton, Ohio.

1.6 AF Materials Laboratory Historical Report Vol I Narrative, December 1971, AFRL/ML History Data Book File No. 1176, located at Universal Technology Corporation, Dayton, Ohio.

1.7 *“History of the Air Force Materials Laboratory,”* Vol II, Part I The Military Construction Program, Universal Technology Corporation, November 1992.

CHAPTER 2

A Heritage of Leadership

From a historical perspective, the continually growing field of nondestructive testing/inspection/evaluation (NDT/I/E) began to emerge even before the 1920s largely from intuitive and sometimes incidental observations or discovery. Both radiography and magnetic particle methods evolved later from such observations. In the fledgling years of aircraft design and construction, which was characterized by larger safety factors, such an unsophisticated approach to NDT/I was adequate. As aircraft design, manufacturing capabilities and materials technology improved, the inspection function remained an important element.

T.J. Johnston

R.R. Moore

D.M. Warner

The initial organization structure of the Material Section emerged in 1919 as illustrated in Fig. 1.1 (also listed in Appendix A as Fig. A.1). The Physical Testing Branch, first led by T. J. Johnson, was responsible for the nondestructive testing (NDT) and inspection (NDI) work described earlier. By 1922, R. R. Moore was appointed chief of the Branch. He became well known also for his development of the R. R. Moore rotating beam fatigue test machine widely used internationally for decades thereafter.

By 1927, D. M. Warner assumed the duties of chief of the Physical Testing unit of the Materials Branch (renamed from Material Section), where he remained until 1941. During this period, NDT of parts to determine if they were defect-free became an important part of aeronautical materials research. A 1926 report of Materials Branch developments indicated the use of x-ray testing also for the exploration of embedded defects in materials. In another study, Physical Test unit investigators developed a simple, effective method to reveal surface defects in aluminum alloy forgings, consisting of a light etch in an alkaline solution followed by an acid dip. This method was also adopted by the Navy, the Aluminum Company of America and many contractors as a standard method for inspecting aircraft propellers.

In the early 1930s, D. M. Warner again led an initiative to investigate another potential NDT tool – the magnetic particle inspection method (MPI), drawing upon the pioneering work by the National Bureau of Standards and Alfred V. de Forest of Massachusetts Institute of Technology.[2.1] By 1933, the dry powder method had been adapted and applied to inspections of steel propellers and springs, and adopted by propeller manufactures. By 1937, the improved method was in use also in the automotive, marine and railroad industries.[2.2]

In the period of a manpower buildup in 1940 and 1941, the Materials Laboratory (ML) (renamed from Materials Section in 1939) underwent an organization expansion. By May 1941, ML had grown from about 40 to approximately 100 personnel, to accommodate its growing responsibilities. D. M. Warner was assigned to head a new Special Test Unit of ML. At that time, a new radiography program led by x-ray technician Robert Katz was formed in the ML Metallurgical Unit, which was managed by Richard R. Kennedy.[2.3] (Fig. A.6). Due to the accelerated aircraft production buildup program as war loomed, and the laboratory's resulting significant increase in procurement support activities, a growth of ML's research and development efforts beyond current levels was curtailed. This provided for the continued growth in the areas of procurement support and service failure analyses. ML manpower grew from about 100 in December 1941 to 214 in August 1945, two days before VJ Day. Throughout World War II, ML provided NDT support, including radiography and magnetic particle inspections, to hundreds of laboratory investigations pertaining to malfunction or failure of Army Air Force equipment and components during service or while undergoing test. Other efforts were devoted to analyses of foreign materials used for aeronautical purposes and evaluations to compare them with AAF materials.

Work on NDT development lagged during the post-war years due to a lack of sufficient resources and urgency of need. During the Korean War, efforts again were required to adapt NDT methods to support a new generation of Air Force equipment. By 1953, ML established a new Non-Destructive Test Section in the Metals Branch (Fig. A.8). Development efforts focused on both new methods and improvement of existing techniques.

In 1954, a thorough internal restructuring of the ML line organization took place that reduced the number of branches from 10 to 6 in order to reduce span of control. The NDT program was placed in the new Design Criteria Section attached to the Metals Branch, with Donald A. Shinn named as Section Chief (Fig. A.9). Work continued to explore new and emerging NDT techniques and procedures. Following a reorganization of ML to the "Materials Central" in August 1959, the NDT program was assigned to the Applied Mechanics Section of the new Strength and Dynamics Branch (Fig. A.10). Edward Dugger served as Section Chief with Richard Rowand serving as the senior NDT physicist. With the reassignment of Ed Dugger to another ML management position in 1961, Dick Rowand became chief of the Section and of the NDT program (Fig. A.11). In 1964, an organizational change took place in ML resulting in a title change to Technical Manager for Nondestructive Testing in the Strength & Dynamics Branch, ML, with no change in responsibility (Fig. A.12).[2.4] During his tenure, Dick Rowand was instrumental in increasing the focus of both Air Force and industry planners on Air Force NDT development needs. He also played a significant role in organizing and managing the annual national Symposium of the Physics of NDT.

D.A. Shinn

E. Dugger

R.R. Rowand

In a branch realignment of the Metals and Ceramics Division in early 1966 to improve management control, the Processing & NDT Branch was established (Fig. A.13). Thomas D. Cooper, previously serving as Technical Manager of the Division's High Strength Metals group, was named branch chief on 17 June 1966. Figure 2.1 pictures members of the NDE Group of the branch in October 1970. In 1972, a realignment of the Division program occurred again, resulting in the formation of the NDT & Mechanics Branch, achieved without a change in the NDT program (Fig. A.14). During this time, Tom Cooper focused significant program attention on adaptation of NDT methodologies to characterize structural materials integrity properties. He remained as Branch Chief until December 1973 when he was appointed Chief, Materials Integrity Branch of the ML Systems Support Division, which included in-service NDT/E applications methodology development. During this period, he was named a Fellow of ASNT. Dr. Vincent Russo of ML was appointed as interim chief of the NDT & Mechanics Branch during a transition period of December 1973 through February 1974.

T.D. Cooper

Figure 2.1. NDT Personnel, NDT & Mechanics Branch, 1970. Top row, left to right: James Holloway, Richard Rowand, Doris Johnson. Bottom row: Capt. Jim Bohlen, William Shelton, Maj. Charles Hansult, Capt. Lee Gulley.

The reorganization of the ML Metals and Ceramics Division in January 1974 from five branches to four accomplished the objective of achieving an improved technical program alignment and management structure. The resulting establishment of the new Nondestructive Evaluation Branch reflected the decision to increase the level of attention being given to the development of advanced NDE capabilities for the Air Force (Fig. A.15). Dr. (Captain) Stephen A. Crist, who was serving as Chief of the Division's Mechanical Physics Branch, was appointed as the first

S.A. Crist

D.M. Forney

chief of the new branch. After serving for several months, Dr. Crist was forced to depart due to an illness from which he did not recover. Donald M. Forney, who was returning from a special assignment in the Materials Laboratory Plans Office as a materials behavior expert, was appointed Branch Chief in July 1974, holding that position until his retirement at the end of October 1990. During that period, his significant program growth advocacy efforts, along with recognition of new requirements, led to a greater than tenfold increase in ML NDE R&D funding. Many new developments continued to evolve as a result (see Chapter 4). Members of the NDE Branch in the 1988-89 time period are shown in Figure 2.2a and b.

Figure 2.2a. NDE Branch Team During Period of 1988 -1989. Starting from the top, left to right: Dr. K.P. (Chris) Bhaget, Mark Blodgett, Charles Buynak, Dr. Dale Chimenti, Dr. Robert Crane, Curtis Fiedler. Second row, left to right: Donald Forney, James Holloway, Marion Kaufman, Claudia Kropas, Nancy Lammers, Laura Mann. Third row, left to right: Dr. Thomas Moran, Dr. Joseph Moyzis, Cassandra Maloney and Kenneth Shimmin.

Figure 2.2b. UDRI On-Site Research Contract Support Team During Period of 1988 -1989. First row, left to right: Robert Andrews, Jeffrey Fox, Brian Frock, Edward Klosterman, Dr. Prasanna Karpur. Second row, left to right: Richard Martin, Mary Papp, Mark Ruddell, David Stubbs, Robert Yancy.

Tobey M. Cordell, who was performing research management duties in the Nonmetallic Materials Division of ML, was named chief of the Nondestructive Evaluation Branch in November 1990. During his term, he was noted for expanding significantly the NDE Program for space assets and low observable materials. He remained in that position until his retirement in early 1999. Members of the NDE Branch during the 1996-99 time period are shown in Figure 2.3.

Figure 2.3. NDE Branch Personnel During Period of 1996-1999. First row, left to right: Dr. Daniel Elon, Dr. Theo Matikas (UDRI), King Keiber (contr), Elaine Calloway, Edward Klosterman (UDRI), Tobey Cordell, Mark Ruddell (UDRI), Charles Buynak. Second row, left to right: Dr. Shamachary Satish (UDRI), Dr. Mark Blodgett, Laura Mann, Dr. Thomas Moran, Dr. James Snide (UDRI), Richard Martin (UDRI), Scott Monnin. Third row, left to right: Bill Mullins, Greg Tyler (UDRI), Dr. Robert Crane, Bryan DeHoff (contr), Lt. Nathan Diedrich, Jeff Fox (UDRI), Bryan Frock (UDRI), Dan Daniels (ARACOR). Fourth row, left to right: Dr. George Frantziskonis (visiting scientist), Bryan Foos.

T.M. Cordell

J.C. Malas

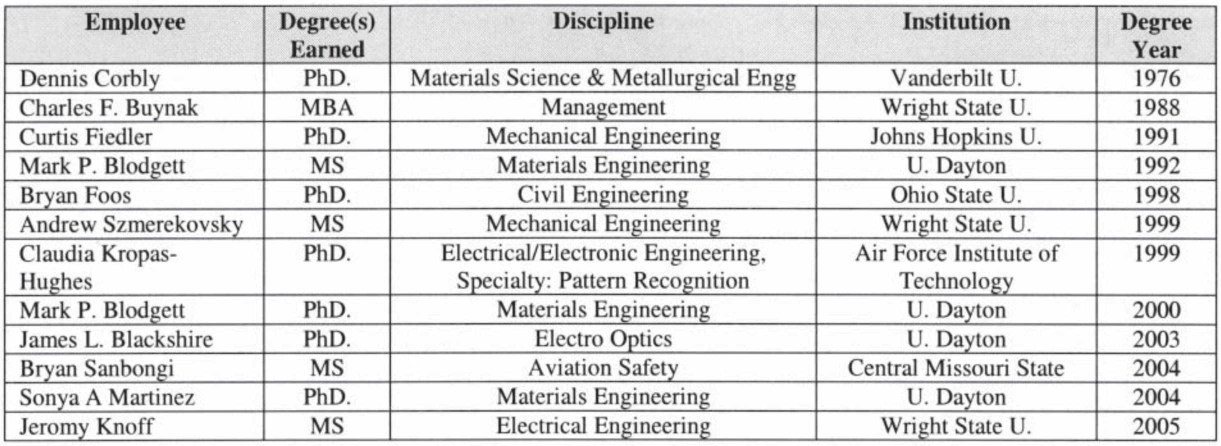
Dr. James C. Malas, who was serving as Research Leader of the ML Material Process Design Group, was named chief of the Nondestructive Evaluation Branch in February 1999 where he remains at this writing. To this point, he has overseen a significant increase in the NDE Program technical staff, an expanded in-house research program and a growing scope of the emerging systems health management initiative. Members of the NDE Branch as of September 2005 are shown in Figures 2.4a and 2.4b, respectively.

Figure 2.4a. NDE Branch Members During 2004-2005. First row, left to right: Dr. Jim Blackshire, Dr. Mark Blodgett, Charles Buynak, Juan Calzada. Second row, left to right: Larry Dukate, Lt William Freemantle, Dr. Kumar Jata, Jeremy Knopp. Third row, left to right: Dr. Jim Malas, Rob Marshall, Dr. Sonia Martinez, Dr. Tom Moran. Fourth row, left to right: Matt Cocuzzi (Coop Student), Adam Cooney (Coop Student), and Dr. Matt Golis (Visiting Consultant).

Figure 2.4b. ML On-Site Research Support Contractors During 2004-2005. Top row, left to right: Tim Campbell (UDRI), Jeff Fox (UDRI), Edward Klosterman (UDRI), Dr. Ray Ko (UDRI). Second row, left to right: Dick Martin (UDRI), Dan Daniels (ARACOR), Christopher Kacmar (Anteon), and Samuel Kuhr (Anteon).

Pursuit of Advanced Education. Over the Years, a Number of NDE Branch Members Pursued Advanced Education While Still Performing Their R&D Responsibilities. These New Capabilities and Skills Greatly Enhanced the Quality and Productivity of the NDE Program.

Table 2.1. Advanced Degrees Earned by NDE Branch Members.



Employee	Degree(s) Earned	Discipline	Institution	Degree Year
Dennis Corbly	PhD.	Materials Science & Metallurgical Engg	Vanderbilt U.	1976
Charles F. Buynak	MBA	Management	Wright State U.	1988
Curtis Fiedler	PhD.	Mechanical Engineering	Johns Hopkins U.	1991
Mark P. Blodgett	MS	Materials Engineering	U. Dayton	1992
Bryan Foos	PhD.	Civil Engineering	Ohio State U.	1998
Andrew Szmerekovsky	MS	Mechanical Engineering	Wright State U.	1999
Claudia Kropas-Hughes	PhD.	Electrical/Electronic Engineering, Specialty: Pattern Recognition	Air Force Institute of Technology	1999
Mark P. Blodgett	PhD.	Materials Engineering	U. Dayton	2000
James L. Blackshire	PhD.	Electro Optics	U. Dayton	2003
Bryan Sanbongi	MS	Aviation Safety	Central Missouri State	2004
Sonya A Martinez	PhD.	Materials Engineering	U. Dayton	2004
Jeromy Knoff	MS	Electrical Engineering	Wright State U.	2005

References

2.1. Thomas, Willys E., *“Magnaflux Corporation – A History” The first fifty years.* Magnaflux Corporation, Chicago, Ill. 1979.

2.2. <u>Five Decades of Materials Progress, 1917 - 1967</u>, James J. Niehaus, Air Force Materials Laboratory, Wright-Patterson Air Force Base, OH, 4 December 1967.

2.3. Ibid.

2.4. Ibid.

CHAPTER 3

Notable Events That Influenced Significant Developments

Many notable events, circumstances and requirements over time have had a major influence on the growth of the ML NDE organization and program. A representative number of these are discussed briefly here to illustrate their impact. As described earlier, the use of x-rays was explored in 1926 by the Materials Branch as a means of detecting defects in materials (Fig. 3.1). Although the potential of the method was recognized at that time, it could not provide the desired reliability. If the straight line beam of the x-ray were not correctly oriented with the path of the crack, the defect would not be detectable. However, at some time later, attention was given to the challenging task of exploring possible means to apply this process to assembled parts (Fig. 3.2). By 1931, government specifications were published.[3.1] The Branch also investigated a new potential tool – a magnetic particle inspection (MPI) method, drawing upon the pioneering work beginning in 1928 by Alfred V. de Forest of the Massachusetts Institute of Technology with the use of circular magnetization to detect longitudinal defects.[3.2] Following a demonstration by de Forest at Wright Field, the Branch purchased some de Forest magnets and small magnetizing equipment and tried the method in routine overhaul inspections under the leadership of D.M. Warner. The result was the discovery of many fatigue cracks which would otherwise have gone unnoticed. A specification to require the use of this method by its contractors in purchase orders for aircraft, engines and parts became official in the late 1930s.[3.3] By 1933, the dry powder method had been perfected and applied to inspections of steel propellers and springs, and adopted by propeller manufactures. By 1935, complete specifications for a magnetic particle inspection apparatus had been prepared. In 1937, the magnetic particle inspection method was also adopted in the automotive, marine and railroad industries.

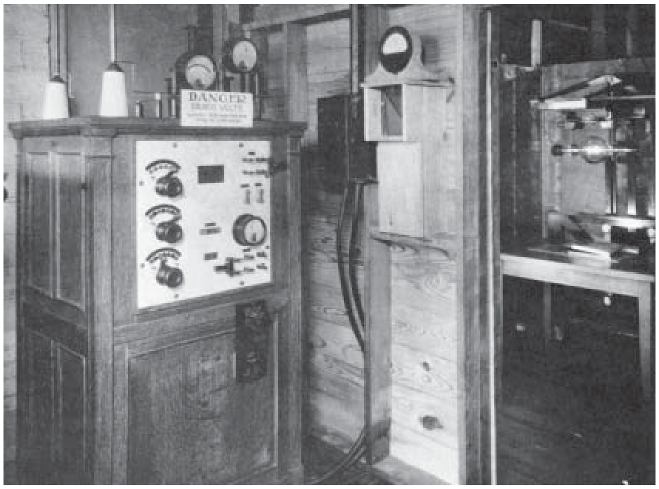


Figure 3.1. Original Materials Section – X-Ray Equipment.

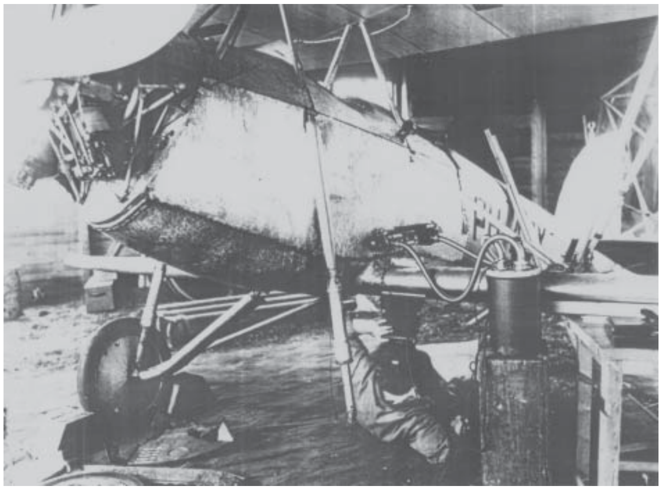


Figure 3.2. Example of Early X-Ray Imaging of Aircraft Component.

World War II Years

The unprecedented build-up and operations during World War II of the Army Air Corps aircraft fleet derived significant benefit from the technical developments by the Materials Laboratory. Included was the identification of substitute materials choices for those categories in limited or critical supply, and in the solution of numerous service failure problems with aircraft materials and equipment. Available nondestructive magnetic particle and radiographic inspection procedures were used to support these activities as appropriate. During this time, a newly developed fluorescent penetrant method was introduced by licensee Magnaflux Corporation, finding numerous applications. These included aircraft propellers and aluminum and magnesium castings, as well as aircraft engine components, such as hard-faced exhaust valves, cylinder heads, crank cases and stainless steel supercharger impeller wheels.[3.4]

During the war years, the ML strength grew from 100 in December 1941 to 217 at war's end in August 1945. The remaining 1940's brought a reduction in ML personnel to 120 by 1949. With this drop came a rapid expansion in the use of R&D contract programs with civilian laboratories and industries to carry out many of the expanding R&D efforts.[3.5] Meanwhile, Gen. "Hap" Arnold, the commander of the Army Air Forces of World War II and a strong advocate of a future high-tech Air Force, asked the eminent scientist Dr. Theodore von Kármán to lead the Scientific Advisory Group in identifying potential advanced technologies to create a new generation of high performance aircraft. The resulting publication of *Toward New Horizons* in December 1945 represented a key step for the Air Force in eventually gaining the reputation as the "technically oriented" service.[3.6]

Numerous other notable events have taken place in the intervening years that have, in one form or another, significantly affected the growth and direction of the NDT/I/E technology development and implementation program activities in the USAF. Some of the more important of these are given in this chapter.

1950 – 1960

The subsequent introduction of jet aircraft resulted in an expanding role for NDT/I. However, 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 airbase level. During the early to mid-1950s, increasing numbers of aircraft component failures/incidents due to fatigue gained significant attention. Finally in 1958, as a result of a series of B-47 bomber wing failures, General Curtis LeMay, Commander of the Strategic Air Command, approved the creation of the initial version of the Aircraft Structural Integrity Program (ASIP).[3.7] The program evolved as described in several early documents, including ARDC-AMC Program Requirements for the Structural Integrity Program for High Performance Aircraft (1959) and ASD-TN 61-141 (1961).[3.8] However, it would not be until the 1970s, with the introduction of damage tolerance requirements into ASIP and use of durability and damage tolerance assessments (DADTA) of older aircraft, that the problem of unacceptably high aircraft losses due to structural fatigue failures was finally brought under control.

1960 - 1970

- **Establishment of ASIP Process.** The Aircraft Structural Integrity Program (ASIP) was established initially at the beginning of the 1960s to assure that USAF aircraft have adequate integrity and service life, based on a safe-life concept and a full-scale verification fatigue test.[3.9] The rate of growth of any damage had to be slow enough such that no reduction in strength should occur before a scheduled next inspection.

- **Establishment of ASD Division Advisory Group (DAG) on ASIP Implementation.** The Aeronautical Systems Division Commander authorized the formation in the early 1960s of a standing advisory group of Air Force and Aircraft Industry structural design and performance experts (ASD DAG) to provide technical support to the ASD Engineering Division in the implementation of the required strong ASIP program and processes. Membership included selected structures and materials experts from both aircraft industry and the ASD engineering and Laboratory communities. ML members were materials fatigue and fracture experts Walter J. Trapp and Donald M. Forney.

- **Issuance of Air Force Regulation 66-38, Nondestructive Inspection Program.** In 1964, the Air Force made a major decision 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, was formalized in 1966 in USAF Regulation 66-38, entitled "Nondestructive Inspection (NDI) Program," which established and defined new policies and responsibilities. These included incorporation of NDI as an integral part of all maintenance activities, and the authority to perform research and development on new and improved NDI techniques and equipment.[3.10]

On March 14, 1980, a revision of Air Force regulation AFR 66-38 was issued, changing and expanding the AF NDI program. Included was a revision of Air Force System Command (AFSC) responsibilities that stressed NDI development efforts and coordination with the Major Commands. Influenced by the advocacy of the ML NDE Program, the term Nondestructive Evaluation (NDE) was introduced in the regulation, defining the use of "advanced technology approaches to classify or quantitatively measure flaws or irregularities, material condition, properties and dimensions of materials and components to determine the degree of integrity and serviceability." See Appendix F-3. One year later, Supplement 1 to AFR 66-38 was issued, strengthening the coordination between AFLC and AFSC regarding NDI/NDE R&D, equipment improvements and field applications. This resulted in the formation of an NDI team of technical development (AFSC) and maintenance management (AFLC) focal points meeting semi-annually to optimize technical development objectives and facilitate transition to in-service applications.

- **Partnership with ARPA on NDT.** In 1968, the

Processing and NDT Branch began assisting the DoD Advanced Research Projects Agency (ARPA) with its new three-year NDE research program initiative with selected industries and universities, including the establishment of program details and technical monitoring of the efforts. Efforts included acoustic emission, exoelectron emission, and early detection of fatigue damage in materials. This initiative was a forerunner of a larger joint effort that developed in 1974, as described below (also see Appendix C-2 for more details).

- **Introduction of New ML Focal Point System.** The new ML Focal Point system was adopted in the autumn of 1969 to provide a program planning and monitoring tool beginning with the FY71 program planning cycle. In order to plan cohesive program areas, a further management decision was made to establish the program plan in five-year increments, thereby illustrating individual project interactions. Each of the major ML program areas was divided into a series of Application Areas, some of which also included supporting Technology Areas as appropriate. Nondestructive Testing was identified as an important thrust area and was included as Application Area 20 (A-20). Processing and NDT Branch Chief, Thomas Cooper, served as the first NDT Focal Point from 1969 to mid-1975.

1970 - 1980

- **Catastrophic In-Flight Failure of F-111 Fighter Bomber Wing Pivot Fitting.** In December 1969, a low flight time F 111 crashed after losing its left wing during a low-level practice bombing run, killing both crew members (Fig. 3.3a). The resulting investigation during 1970 revealed the cause to be the catastrophic fracture of the D6ac high strength steel outer wing pivot fitting due to the presence of a manufacturing-introduced one inch surface crack that had been missed repeatedly by NDI during fabrication (Fig. 3.3b).[3.11] At that point in time, no in service NDI had yet been required or performed. The Air Force convened a special ad hoc committee of the Scientific Advisory Board (SAB) to investigate the failure causes. Ultimately, the committee recommended that every aircraft in the fleet be subjected to a fracture-mechanics-based low-temperature proof load test (minus 40 F) with equivalent loading range of +7.33g to –2g (Fig. 3.4). These tests were repeated indefinitely at periodic intervals, which were determined for each aircraft from the predicted rate of crack growth in that aircraft based on its actual measured use. During the subsequent 25 years until fleet retirement, there were 11 proof test failures.[3.12]

Figure 3.3a. Nearly Intact Left Wing Separated During Low Level Bombing Maneuver.

Figure 3.3b. Undiscovered Elusive Manufacturing-Induced Flaw (Dark Half Ellipse) Extended by Fatigue Growth (Narrow Lighter Band) Causing Failure.

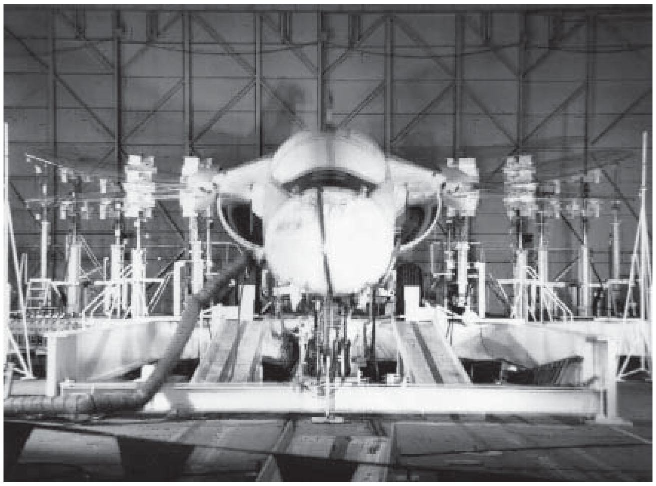


Figure 3.4. Cold Temperature Proof Testing of F-111 Aircraft Double Exposure Photo Illustrates Wing Deflection at +7.33 g Loading.

The national impact of this incident led Air Force Secretary Robert Seamans to order landmark changes in fundamental Air Force aircraft structural design procedures. Additionally, since this event exposed serious deficiencies in NDI/E practices within the aerospace industry generally, he challenged them to increase their capabilities and their vigilance during weapon system manufacture (see Appendix C-1 for more detailed discussion of this topic). Moreover, he called for a significant increase in the Air Force's NDI/E R&D level of effort to expedite the development/availability of the needed major improvements in flaw detection capabilities. At that time, the ML NDI/E R&D budget consisted of approximately $550K (combined 6.1 and 6.2 funds) annually (see Fig. 3.5).

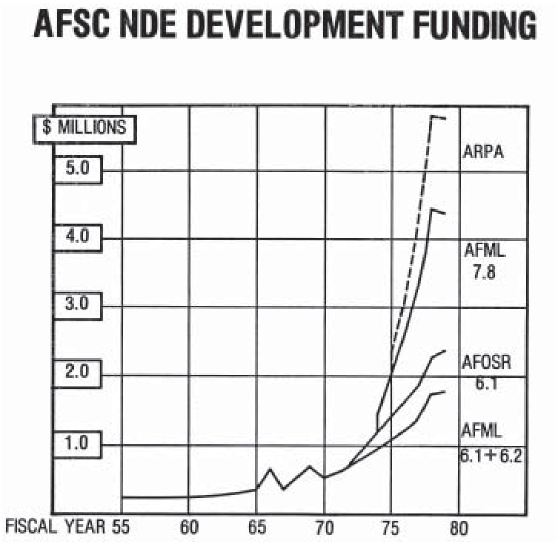


Figure 3.5. AFSC NDE Development Funding.

- **Adoption of Damage Tolerance Design Philosophy.** The F-111 wing pivot fitting failure provided much of the impetus for the Air Force to abandon the safe-life approach and adopt damage tolerance requirements on all of its aircraft. To strengthen its engineering efforts, ASD engaged a team of three internationally recognized industry senior structural engineering experts on three-year appointments to advise on the incorporation of fracture mechanics and damage tolerance philosophies in appropriate governing military specifications and standards. The experts included Walter J. Crichlow, a well-known fracture and damage tolerant design expert, Lockheed Aircraft Corporation, Dr. John W. Lincoln, Chief of Structural Integrity, LTV Aerospace Company, and Charles F. Tiffany, a senior airframe and propulsion structures staff engineer, and ultimately Executive Vice President, Boeing Military Airplane Company. By 1974, the new damage tolerance design philosophy was in place and governed by MIL STD 1530 "Aircraft Structural Integrity Program (ASIP)." A year later, MIL A 83444 "Airplane Damage Tolerance Requirements" was published. Contained therein were specific "fail-safe" flaw sizes the designer had to assume were present in critical components, designed from that point forward, if there was an absence of experimentally demonstrated capabilities to detect with NDI/E any smaller sizes, with 90% probability at a confidence limit of 95%. A damage tolerance assessment of all previously designed weapon systems commenced shortly thereafter. [3.13]

- **Establishment of the AFML-ARPA NDE Science Center Program.** By 1974, the collaborative effort with ARPA on quantitative NDE/I started in 1968 was redefined and expanded. The NDE Branch's Dr. Michael Buckley chaired a meeting of the new program's Executive Advisory Board, including members representing the Army, Navy, Air Force, ARPA and Nuclear Regulatory Commission, to establish program goals and initial research efforts. The initiative became a nationally recognized jointly-funded AFML/ARPA program on Advanced Nondestructive Evaluation, managed by the AFML NDE Branch and performed by the Science Center of Rockwell International, together with a number of subcontracted researchers. As an adjunct effort, a short course was designed and presented to introduce advanced NDE methods to the designers and engineers working on the B-1 bomber program before a redesign that was scheduled to begin in June 1975. In 1980, the program was relocated to Iowa State University after the program principals (Drs. Donald Thompson and Bruce Thompson [not related]) accepted joint positions there with the University and the Department of Energy's (DOE) Ames Laboratory. There it became the core program of the new Center for Nondestructive Evaluation (CNDE). This was an important step, for it opened the door to extensive student involvement in the emerging quantitative NDE technology, provided for the formation of the first accredited NDE minor program in the U.S, and linked together high technology users of QNDE (DOD, DOE, and industry at large). The program set research directions that have become standards in today's technology (see Appendix C-2 for additional detail).

- **Significant Increase of ML NDE Technology Development R&D Program Budget.** As influenced both directly and indirectly by the implications of the F-111 crash in December 1969, the changes that took place in the design philosophy of all future USAF aircraft, and the recognition of a more important role of NDT/E, the annual funding available for NDT/E development efforts increased more than 2-fold, from about $450,000 in the early 1970s to $1.2 million in 1974 (Fig. 3.5).

Also of major consequence was a critical decision made in 1973-74 by the Air Force and ML, to apply manufacturing technology funding to help facilitate the advanced development, production and transition of selected promising new NDE capabilities into production/field level inspection operations. Spearheaded by the ML Manufacturing Technology Division Chief James Mattice, promising technologies demonstrated in exploratory development efforts were identified as candidates for transition through ManTech programs (see Appendix C-3 for more detailed discussion of this decision).

NDE Branch Chief, Donald Forney, was named NDE Focal Point in early 1975, serving to the end of 1990.

Together with a substantial funding increment from the DoD Advanced Research Projects Agency (ARPA) for focused research on new quantitative NDE technologies, the total annual funding available reached $5,800,000 by 1979. This funding decision added significantly to the expanding scope and productivity needed for the NDE program plan.

Richard R. Rowand, an accomplished senior engineer and NDT/I/E expert in the NDE Branch, was designated to serve as the program manager of the new ManTech-funded programs and was co-located in the ManTech Division for a period of time to provide NDE expertise not yet available there.

- **Key NDE Advocacy Briefings to Higher Headquarters and Air Staff Offices.** A number of important high level NDE program information and advocacy briefings were requested by higher headquarters and presented, particularly since the mid-1970s. This interest was motivated by the relatively rapid recognition of the importance of the NDE function to aircraft flight safety and integrity, brought on by a number of structural problems in the fleet. A critical, high profile short-notice briefing was presented by the NDE Focal Point to the Air Force Vice Chief of Staff, together with numerous other General Officer attendees in early 1977, describing the state of NDE technology relative to the serious impending C-5A wing safety problem of cracks under installed fasteners (CUFS). This was an important demonstration of the growing energy in the revitalized NDE program, even though the NDE Program remained funding-limited. In a unique advocacy opportunity, another keystone informational briefing on 30 August 1977 by the NDE Focal Point was requested specifically by AFSC/CC. Following a brief overview of the NDT/I/E methods and state of development, a summary of the expanding NDE program relative to major USAF needs at that time was presented (see Appendix F-1 for briefing text). Subsequent briefings over a period of time included those to several successive AFSC and AFLC commanders and "two-letter" headquarters offices, several Air Logistics Center commanders, the Joint Logistics Commanders (JLC), Ballistic Missile Office (BMO)/CC Maj Gen A.G. Casey, several Department of Defense Research and Engineering staff offices, and others). These and subsequent briefings raised the awareness of NDE capabilities and the need for significant improvements through R&D.

- **Unique Air Force Program to Measure In-Service NDI Capabilities.** In 1978, the Air Force Logistics Command published results of a major two year study to measure field inspection capabilities typical across the operational Air Force (5 Air Logistics Centers and 15 air bases were sampled). This unique assessment, the first of its kind around the world, and popularly known as the "Have Cracks Will Travel" program, revealed a significant and serious in service NDI/E capability shortfall in inspecting airframe components using ultrasonics, eddy current, penetrant and radiographic NDI.[3.14] Figure 3.6 illustrates one type of structural test specimen used and associated NDI data plots obtained. It was revealed that the smallest flaws detectable with even modest reliability (50% probability for example) were generally up to an order of magnitude too large. The scheme of using Probability of Detection (POD) as a mode for characterizing NDE effectiveness was publicized and made a key ingredient in future performance demonstrations. The need for swift correction action

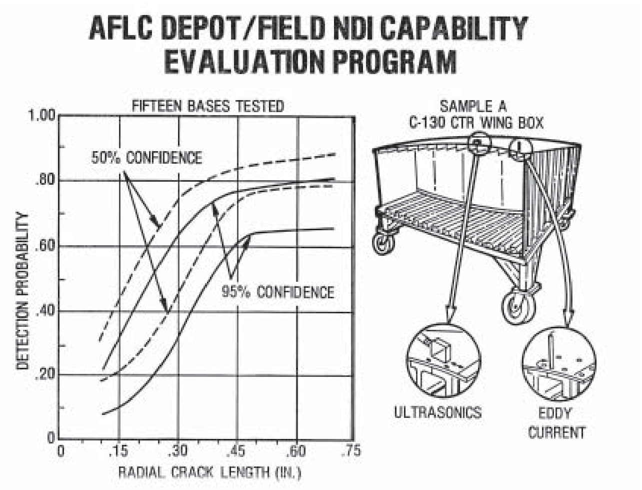


Figure 3.6. AFLC Depot/Field NDI Capability Evaluation Program.

was documented by AF and AFLC Inspector General inspections, AF Studies Board reports, Joint Logistics Commanders (JLC) Joint Technical Coordinating Group on NDI (JTCG NDI), Air Staff tasking through PMD L Y1038(1) and other sources.

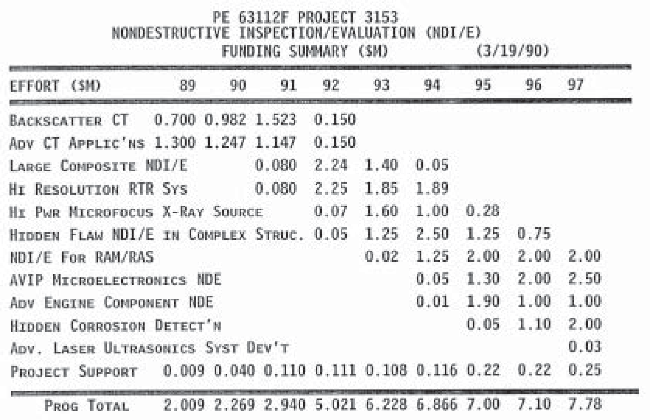
- **Pioneering Feasibility Experiments on X-ray Computed Tomography.** In a search in 1978 for a more effective means to inspect and nondestructively evaluate carbon-carbon composite materials intended for aerospace applications for which conventional inspection methods were inadequate, NDE Branch scientists Drs. Robert Crane and Thomas Moran investigated the newly developed X-Ray Computed Tomography (CT) methodology just coming into use in the medical field. Employing the General Electric Model 7800 Medical X-Ray Computed Tomography instrument at the Wright-Patterson Medical Center for the research, they demonstrated that CT could produce quantitative measurements related to density of a space-grade carbon-carbon composite material and detect almost closed delaminations.[3.15] Additional work was performed to validate the findings, including detection of manufacturing anomalies in thermal protection tiles for the NASA Space Shuttle. The results of these visionary experiments were so striking that a major program decision was made by the AFML to fund the development of an industrial-class X-Ray CT system capability, with an initial concentration on space hardware applications ranging from small engine and missile components to Peacekeeper ICBM motors.

- **DC-10 Airliner Crash at Chicago's O'Hare Airport in 1979.** An American Airlines DC-10 stalled, rolled and crashed on May 25, 1979 immediately after takeoff from Chicago's O'Hare Airport when the left pylon and engine tore loose from the wing, passed over it, and fell to the runway (Figure 3.7). Lost were the 272 people on board and two persons on the ground. The National Transportation Safety Board investigation concluded ultimately that the pylon separation "resulted from damage by improper maintenance procedures which led to failure of the pylon structure." Examination revealed there had been a pre-existing 10-inch crack in the pylon aft bulkhead resulting from improper pylon installation or removal from the wing some weeks earlier, not by the crash. The Board held that "its residual strength had been critically reduced by a maintenance-induced crack which was lengthened by service loads." [3.16]

Figure 3.7. A DC-10 Airliner Spins Out of Control Second Before Crashing Near Chicago's O-Hare Airport on May 25, 1979.

1980 - 1990

- **New NDE Advanced Development Program Approved.** Two key briefings by the NDE Focal Point to the Joint Logistics Commanders (JLC), first at Eglin Air Force Base, Florida in 1981, then at Hill Air Force Base, Utah (Ogden Air Logistics Center) in 1983, drew significant attention to the inadequacy of funding to improve the state-of-the-art and produce meaningful technology transition. As a result of the subsequent findings of the JLC's Joint Technical Coordinating Group on NDI (JLC JTCG NDI) study of USAF NDI/E deficiencies, and of the concerns of the two Air Force commanders (AFSC Gen Marsh and AFLC Gen Mullins), Headquarters AFSC requested in September 1983 that an out of cycle PE 6.3 NDI/E program be inserted by AFWAL/ML in the AFSC FY86 POM to establish a strong, appropriately funded advanced technology demonstration and transfer path that was missing up to that point. The program "Nondestructive Inspection and Evaluation (NDI/E)" was incorporated in the AF FY86 POM as PE 63454F PDP 220 but did not achieve congressional approval as a new PE. The program was resubmitted successfully in the FY87 POM



PE 63112F PROJECT 3153
NONDESTRUCTIVE INSPECTION/EVALUATION (NDI/E)
FUNDING SUMMARY ($M) (3/19/90)

EFFORT ($M)	89	90	91	92	93	94	95	96	97
Backscatter CT	0.700	0.982	1.523	0.150					
Adv CT Applic'ns	1.300	1.247	1.147	0.150					
Large Composite NDI/E			0.080	2.24	1.40	0.05			
Hi Resolution RTR Sys			0.080	2.25	1.85	1.89			
Hi Pwr Microfocus X-Ray Source				0.07	1.60	1.00	0.28		
Hidden Flaw NDI/E in Complex Struc.				0.05	1.25	2.50	1.25	0.75	
NDI/E For RAM/RAS					0.02	1.25	2.00	2.00	2.00
AVIP Microelectronics NDE						0.05	1.30	2.00	2.50
Adv Engine Component NDE						0.01	1.90	1.00	1.00
Hidden Corrosion Detect'n							0.05	1.10	2.00
Adv. Laser Ultrasonics Syst Dev't									0.03
Project Support	0.009	0.040	0.110	0.111	0.108	0.116	0.22	0.22	0.25
Prog Total	2.009	2.269	2.940	5.021	6.228	6.866	7.00	7.10	7.78

Figure 3.8. NDE Advanced Development Program Funding Summary in March 1990.

as Project 3153 within the established PE 63211F PDP 046 with a budget plan very similar to that shown in Fig. 3.8. Each of the next two AFLC Commanders following Gen Mullins (Generals O'Laughlin and Hansen) sent strong support letters to AFSC/CC. However, following additional reviews at the Air Staff level and Congress, the program recovered only about 20% of the funding level approved originally by Headquarters AFSC and USAF Air Staff for PE 63454F. The initial funding plan for the new Project Commencing in FY90, Project 3153 was contained in the newly established PE 63112F, pending congressional approval.

- **Establishment of ENSIP Process.** Motivated by numerous instances of inadequate turbine engine structural integrity and several engine failure-caused aircraft losses, the concept of an Engine Structural Integrity Program (ENSIP) utilizing a damage tolerance analysis (DTA) was first introduced in 1978. The first ENSIP was performed on the Pratt & Whitney F100 engine in 1979 and on the General Electric TF34 and F101 in 1980. In 1983, the Air Force defined the ENSIP requirements in MIL-SPEC 1783, which extended structural integrity requirements to turbine engine critical components, similar to those applied earlier to airframes, and tied directly to the available NDI/E capabilities. Finally, MIL-STD-1783 (USAF) "Engine Structural Integrity Program (ENSIP)" was published on 30 November 1984, with ENSIP concepts required for new engine designs as well as for managing fielded systems. There have been several updates to the program based on evolving technologies, and further engine failures in the area of High Cycle Fatigue (HCF).

- **Have Cracks Will Travel Survey for Engine Components.** By 1984, the results of a study by AFLC at two engine maintenance depots on turbine engine components, similar in purpose and approach to the "Have Cracks Will Travel" program discussed earlier, also indicated a capability shortfall, although not as severe as that for airframes, due principally to the relatively more controlled inspection environment for engine components. The largest discrepancy was in the assumed detectable flaw size for fluorescent penetrant inspections (FPI). However, the use of ENSIP dictated that the majority of damage tolerant inspections would be accomplished using enhanced inspection techniques such as eddy current or ultrasonics. The impetus for the survey was the Retirement-for-Cause program. It was imperative to be able to accurately characterize the POD of cracks in discrete locations and materials within the engine disks in order to accommodate a life extension of these high energy parts. Otherwise, these disks were being condemned based on their -3σ low cycle fatigue life (LCF) (Fig. 3.9).

Figure 3.9. Turbine Engine Disks "Retired" from Service after Reaching an Analytically Prescribed Conservative Usage Life.

A group of industry experts were gathered to establish a new methodology for calculating POD due to the nature of the turbine engine's small flaw criteria. The group included individuals from GE, P&W, P&W Canada, Rolls-Royce, Garrett, Teledyne, Allison and Williams International. Under the direction of the ASC propulsion SPO, they developed a new methodology to determine POD for turbine engines. The group also formed the foundation for the Engine NDI Advisory Board, which was established in 1984 to discuss NDI issues and offer solutions concerning NDI and POD. In 1989, a draft Military Standard was completed. The draft also formed the basis for a NATO AGARD Lecture Series in 1993. This lecture series was presented in Turkey, Portugal, Greece and Canada. The draft Military Standard eventually became Mil-Hdbk-1823 published in 1999. In addition the AFLC depot survey, POD demonstrations were instituted in production on the F100-PW-229 and F110-GE-129 engine programs to establish true reliable flaw size capabilities. This necessitated the manufacture of new realistic crack specimens for all geometric concerns.[3.17]

- **Catastrophic Post-Launch Failure of Titan IV 34D-9 SLV.** Following the explosive failure of a Titan IV 34D-9 Space Launch Vehicle (SLV) shortly after launch in April 1986, the Air Force convened a special AF Mishap Board to investigate the cause and to make fleet recovery action recommendations. Prior to this failure, 146 solid rocket boosters (SRB) had been launched successfully without incident.[3.18] This investigation, and associated Titan 34D Recovery Program, focused on a preliminary assumption that a burn through in a casing segment assembly occurred for unknown reasons.

Four possible failure mode scenarios were studied: (1) Forward Insulation Unbond from Case; (2) Restrictor Unbond and Separation; (3) Potting Defect Allows Propellant Ignition; and (4) Autoignition of Void. It was determined that from the beginning of the Titan IV program, confidence had been placed on well-established design and process control methods; thus, no NDT/I procedures were in place and applied to assess these possible conditions except visual and TAP tests.[3.19] During the Recovery Program, two ML NDT/I experts, NDE Branch Chief Donald Forney (Metals and Ceramics Division) and Materials Integrity Branch Chief Thomas Cooper (Systems Support Division), were added to the team to serve as Air Force ad hoc NDT/I technical resources. The Recovery Program team developed detailed NDT/I procedures for each possible flaw condition associated with each candidate failure mode and implemented them as part of the recovery effort.[3.20] In its June 1986 initial report, the Mishap Board identified the failure mode (1) above as the cause of the Titan 34D-9 launch failure.[3.21] The Recovery Program subsequently led to the implementation of an aggressive NDT/I process extended to all features of loaded components: ultrasonics for case/insulator and insulation bondlines and restrictor/propellant bondlines; radiography of aft closure inserts as well as tangent and thru-body radiography of bondline areas and propellant; compression face load tests; and other measurements. No subsequent failures occurred due to the aforementioned failure modes.[3.22] This experience added to the increased awareness of the importance of advanced NDT/I to help assure weapon systems integrity and safety. On October 19, 2004, the 368th and last launch of the Titan SLV took place at Vandenberg Air Force Base, California, having experience no further failures and signaling the end of an era that began in 1959.[3.23]

- **Aloha Airlines Fuselage Failure in Flight.** The incident of the Aloha Airlines fuselage failure in flight on April 28, 1988, shown in Figure 3.10, galvanized the NDE community into seeking improved approaches to detection and characterization of distributed fatigue cracking in aircraft structures. A commercial Boeing 737 lost part of the upper fuselage in the front passenger section due to cracking found along the line of fasteners used to attach the skin to the internal superstructure of the plane. The solution to the effective detection of such cracking was made a central theme of NDE personnel involved with both commercial and military aircraft safety. This dramatic failure added significant energy around the world to expansion of NDE development efforts focused on the growing age of both military and commercial aircraft fleets.[3.24]

- **United Airline DC-10 Crash at the Sioux City Airport in 1989.** A United Airlines DC-10 crashed on July 19, 1989 as it attempted an emergency landing at the Sioux City, Iowa airport with the loss of 112 of the 296 people on board. The cause was traced to a metallurgical anomaly in a titanium alloy fan disk, known as hard alpha, within which cracks are apt to initiate. The crack that was believed to have caused the engine disk to rupture was about 4 inches long, emanating from a hard alpha discontinuity, and had reportedly been overlooked in inspections during two prior overhauls, although penetrant residue was reportedly found in the crack later. The disintegration of the engine disk produced flying metal fragments which severed several hydraulic lines that powered the aircraft's control system. This resulted in the flight crew's inability to control the aircraft during the attempted emergency landing.[3.25]

Figure 3.10. Near Catastrophic Failure of Upper Fuselage Structure of Aloha Airlines Boeing 737 in 1988.

1990 – 2000

- **Dedication of New Materials Laboratory In-House CT Research Facility.** In the spring of 1987, the NDE Branch conducted a design study for a new

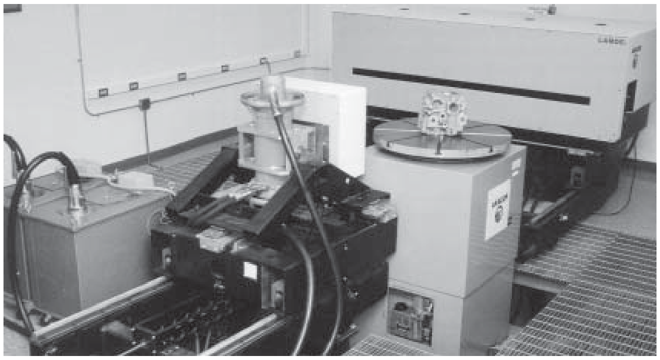


Figure 3.11. 420 keV Laminography/Dual Energy (LAMDE) Computed Tomography System in NDE Branch.

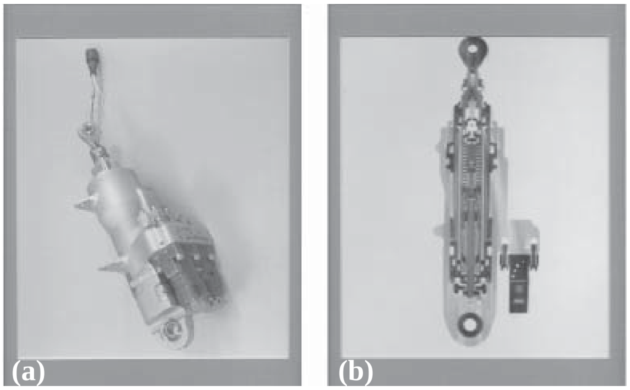


Figure 3.12. (a) Photographic Image of Aircraft Hydraulic Slat Actuator. (b) CT Image of Transverse Slice through Actuator.

in-house state-of-the-art x-ray computed tomography (CT) research facility to explore advances in technology, methodology, and equipment. The study developed a plan for the refurbishment of a former turbine test cell in Building 71 in Area B, to accommodate two shielded laboratory rooms on the ground floor, a control room on the second floor and a ground floor storage area. Construction was completed in the spring of 1990. Installed in one shielded laboratory was a 420 keV laminography/dual energy (LAM/DE) medium resolution CT system designed by ARACOR, pictured in Figure 3.11, capable of imaging objects within an envelope of 20 in. diameter and 34 in. high, weighing up to 220 pounds. The spatial resolution of the system is 0.02 inch with typical scan times ranging from 15 to 25 minutes per slice. Shown in Figures 3.12a and 3.12b, respectively, are an aircraft hydraulic slat actuator and longitudinal laminographic (LAM) CT image of its interior.

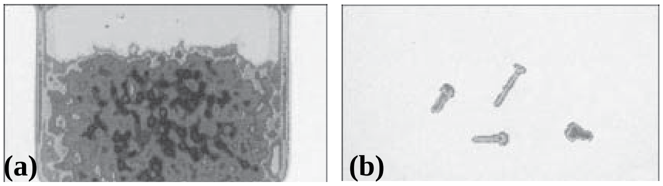


Figure 3.13. Chemical Separation Using Dual Energy CT Capability. (a) Digital Radiograph of a Beaker of Steel and Aluminum Screws. (b) Image Data Selectively Processed to Reveal Only the Four Steel Screws.

The dual energy (DE) capability of the system can accomplish selected imaging as a function of chemical composition of the scanned object, as illustrated in (Figure 3.13a and 3.13b).

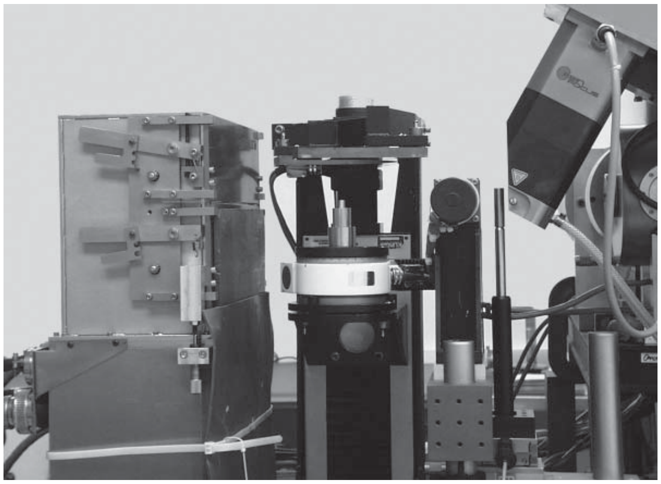


Figure 3.14a. Microfocus X-Ray CT Tomoscope System.

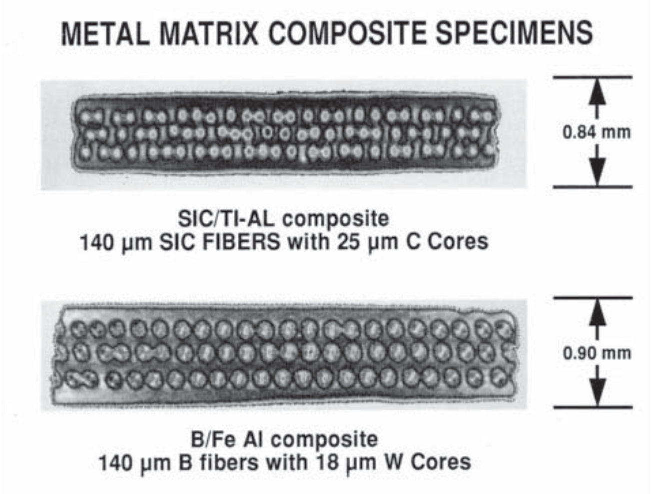


Figure 3.14b. Microfocus X-Ray CT Image of Flawed Metal Matrix Composite.

Installed in the second shielded room was an ARACOR-designed and built 250-keV microfocus Tomoscope high-resolution x-ray CT system, with an object scan envelope of a 4-inch diameter and 8-inch height, and weight limit of 12 pounds (Figure 3.14a). The initial model demonstrated an imaging capability as seen in Figure 3.14b.

A formal facility dedication ceremony was held on 1 June 1990 with many distinguished guests, along with many ML employees and families, and business associates attending. Among the official guests of honor (Figure 3.15) were Brig. General Stuart Cranston, ASD Vice Commander and Brig. General Ronald Spivey and AFLC Deputy Chief of Staff (Plans and Programs), both of whom spoke of the importance of state-of-the-art NDE to the safety and mission readiness of the Air Force combat fleet. Colonel Richard Paul, Wright Research and Development Center commander and Dr. Vincent

Figure 3.15. Honored Guests at Dedication of New NDE Program X-Ray Computed Tomography Laboratory, 1 June 1990. Left to right: Brig Gen Stuart Cranston, Brig Gen Ronald Spivy, Col Richard Paul, Col James Gerber, Dr. Harris Burte.

Russo, ML Director (Figure 3.16) hosted the dedication and official ribbon cutting ceremony. They pointed to the need to conduct cutting-edge NDE R&D, citing the new CT R&D facility as another important tool to help achieve that goal.

The initial objectives of the CT Facility program were established to include:

INVESTIGATION OF MATERIALS CHARACERIZATION METHODOLOGIES
- MICROSTRUCTURAL UNIFORMITY
- CHEMICAL CHARACTERIZATION
- INTERNAL DAMAGE STATE

EXPLORATION/OPTIMIZATION OF ADVANCED PROCEDURES
- DUAL ENERGY METHODOLOGY
- LAMINOGRAPHY FOR NON-UNIFORM STRUCTURES
- BOUNDARY RESOLUTION ENHANCEMENT METHODOLOGY

COLLABORATIVE STUDIES OF APPLICATIONS
- FAILURE ANALYSIS
- ADVANCED MATERIALS DEVELOPMENT
- FIELD APPLICATIONS

Figure 3.16. Dr. Vincent Russo, ML Director, Speaking at ML CT Facility Dedication Ceremony 1 June 1990.

With the retirement of Don Forney at the end of October 1990, Tobey M. Cordell was named NDE Branch Chief and NDE Focal Point in April 1991. Among the numerous evolutionary changes and increases in the program during his tenure were several examples cited here:

Increased emphasis on NDE for space systems applications. The formation of the Air Force Space Command in 1982, and the broader use of space assets during the 1991 Iraq Desert Storm conflict, helped focus greater management attention, both Air Force and ML, on increasing funding support for NDE R&D efforts. The continued expansion of the Space Command mission resulted in the elevation in 2002 of the commander's rank to four-star general.

Increased emphasis on LO materials NDE program. With the increased use of LO materials and structures in the design of advanced Air Force aircraft, a new emphasis was placed on the development of appropriate NDE methods. This new focus included creation of specialized sensors and instrumentation as well as support software. A significant increase in specialized ML LO NDE efforts was begun, facilitated by the approval of an NDE Program scientist for membership on the tri-service LO NDE Working Group.

Significant Increase in Aging Aircraft ML NDE Program. The Air Force has had an aggressive NDI/E program in place for many years to help monitor the structural integrity and flightworthiness of the USAF fleet. However, with the decisions to extend the usage life of a significant number of aircraft beyond original design lives, it became critical to substantially improve the NDI/E methods, procedures and equipment being employed and expand and accelerate the NDE R&D efforts.

Some Notable Events Included:

- **MAB Study of Aging of U.S. Air Force Aircraft.** In 1996, the U.S. Air Force requested the National Research Council and its National Materials Advisory Board (NMAB) to identify research and development needs and opportunities to support the continued operation of its aging aircraft, focusing specifically on their associated structures and materials. The objectives of this major study included the recognition and prioritization of specific technology opportunities in the areas of fatigue, corrosion prevention, nondestructive inspection, maintenance and repair, and failure analysis and life prediction methodologies.[3.26] The study committee included senior structures expert Charles Tiffany (Chair), retired Executive Vice President of Boeing Military Airplanes; internationally recognized NDE experts Drs. Donald Thompson and Boro Djordjevic; and several structures experts having membership in the National Academy of Engineering (NAE).

In the course of the study, the MAB committee recognized NDE as a pivotal technology in the management of the aging fleet. Specific needs identified included the development of new, more robust techniques to detect (1) fatigue cracks under fasteners, (2) small cracks associated with widespread fatigue damage (WFD), (3) hidden corrosion, (4) cracks and corrosion in multilayer structures, and (5) stress corrosion cracking in thick sections. The committee recommended in general that the Air Force pursue several recommended development areas, some near term, some longer term, to produce advanced, more capable inspection technology for aging aircraft:

Priority 1 – (a) methods for early corrosion detection; (b) accelerated evaluation, validation and implementation of currently available/emerging NDE equipment and methods; (c) integrated quantitative NDE capability based on life-cycle management principles; (d) automation of inspection methods and for wide area inspection.

Priority 2 – (a) automation and data processing/analysis for rapid, wide-area NDE; (b) development of candidates for hybrid inspection technologies; (c) development of NDE candidates to measure integrity of composite repairs of metallic structures.

Priority 3 – (a) development of signal/image processing techniques and data base methods to track damage and maintenance trends; (b) development of NDE for early corrosion detection.

The MAB committee recommended that development efforts should explore and apply new engineering approaches to develop quantitative NDE techniques that are much faster, less costly, and that result in a technology base that is more flexible and easily adapted to the diversity of aging aircraft problems. Furthermore, the program focus should include optimized NDE capabilities that will support the inspection requirements resulting from new durability and damage tolerance analysis (DADTA) updates. The MAB recommendations represented a highly significant endorsement of a stronger NDE R&D program in support of the aging fleet.

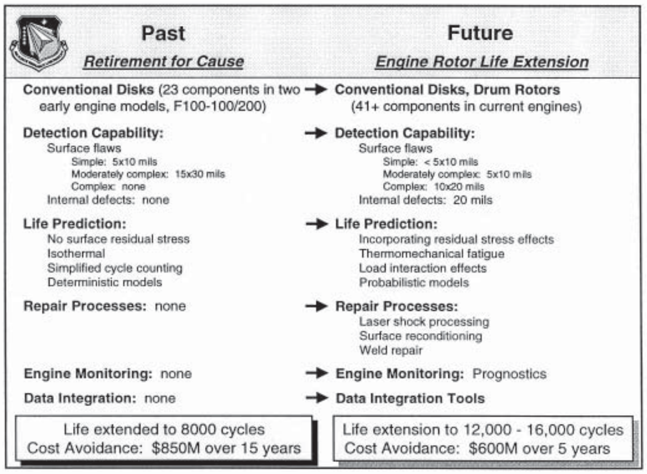
- **Emergence of New Advanced Technology Development (ATD) Programs by AFMC and ASC.** In the mid-1990s, AFMC and ASC examined ways to expedite the maturation and transition of identified key technologies to the warfighter in the shortest possible time. The Advanced Technology Council (ATC) was founded at ASC to link the technology provider (AFRL) to the technology transition agent (ASC) to the technology implementer (Depot/Field). Led by the AFMC Vice Commander, this worked to bridge the gap between the development laboratory and the Depot/Field with formal agreements between these parties to expedite the refinement, transition and implementation of these technologies.

In 1997, the ASC Aeronautical Enterprise Program Office (AEPO) facilitated an ATD to address major operational NDE deficiencies entitled "Advanced NDE for Aging Structures" with 5 key milestones. This enveloped a large majority of the efforts under way within the 6.3 Advanced Development Program Elements to transition maturing technologies to a Depot/Field user. The major programs included:

- Detection of Corrosion Thinning - (TCORR)
- Pulsed Eddy Current (Methodology) Transition – PECTRAN)
- Digital Radiography Transition/Insertion Program (DRIP)
- Magnetoresistive (MR) Sensors for Crack Detection
- Data Fusion/Data Mining Applications

(These five programs are discussed in Chapter 4 in the time period between late 1990s and 2006).

• **Establishment of Engine Rotor Life Extension (ERLE) initiative.** To reduce the growing sustainment burden for fielded gas turbine engines, the Air Force embarked on a science and technology initiative in 1999, in collaboration with the Turbine Engine Industry, to extend the operational lifetime of fracture-critical turbine-engine-rotor components. Known as the Engine Rotor Life Extension (ERLE) program, its approach was established to develop, and incrementally implement, improved life management methods, compared to existing Retirement for Cause (RFC) inspection systems, that integrate state-of-the-art fracture mechanics, NDE, engine-usage and health monitoring, data fusion, and repair technologies into a future comprehensive life-management system. The initial focus of the program is the F100 and F110 engines. The eventual payoff sought was defined as a doubling of the operational life of fracture-critical components, a 50% reduction in disk replacement costs, increased depot throughput, and reduced maintenance cost per component.[3.27] The incremental NDE improvement goals for the ERLE initiative, compared to the existing RFC capabilities, are depicted in Figure 3.17. Numerous NDE advances and improvements have been achieved to date in sensors and probes, scanning procedures, material condition assessments/measurement, signal and data analysis, and others as influenced by the ERLE program objectives. In addition, mature embedded defect detection technologies are required to extend the lives of some components. Program goals have included qualification of the capability of the inspection technology systems by generating probability of detection curves.



Past ***Retirement for Cause***		**Future** ***Engine Rotor Life Extension***
Conventional Disks (23 components in two early engine models, F100-100/200)	→	**Conventional Disks, Drum Rotors** (41+ components in current engines)
Detection Capability: Surface flaws Simple: 5x10 mils Moderately complex: 15x30 mils Complex: none Internal defects: none	→	**Detection Capability:** Surface flaws Simple: < 5x10 mils Moderately complex: 5x10 mils Complex: 10x20 mils Internal defects: 20 mils
Life Prediction: No surface residual stress Isothermal Simplified cycle counting Deterministic models	→	**Life Prediction:** Incorporating residual stress effects Thermomechanical fatigue Load interaction effects Probabilistic models
Repair Processes: none	→	**Repair Processes:** Laser shock processing Surface reconditioning Weld repair
Engine Monitoring: none	→	**Engine Monitoring:** Prognostics
Data Integration: none	→	**Data Integration Tools**
Life extended to 8000 cycles Cost Avoidance: $850M over 15 years		Life extension to 12,000 - 16,000 cycles Cost Avoidance: $600M over 5 years

Figure 3.17. RFC Life Extension Achievements & ERLE Planned Activities.

Following Tobey Cordell's retirement in early 1999, Dr. James Malas was named NDE Branch Chief and NDE Focal Point in February 1999. Among the numerous evolutionary changes and increases in the program during his tenure were several examples cited here:

<u>Implementation of New Core Technology Area (CTA) Program Planning Framework</u>. A new Core Technology Area (CTA) technical program planning and administrative management system was introduced by ML in April 1999 and applied to the Fiscal Year 2000 technology program planning process. The CTA process replaced the Focal Point planning system originally introduced in 1969. The former Focal Point FA-4 for NDE was subsequently renamed CTA-4 NDE Leader. The NDE program mission remained unchanged. Reducing the ML technical program management areas from 14 to 12, through some technical program consolidation and planning process simplification, improved interactions with AF technology customers, streamlined implementation interactions and communications with transition partners, and reduced program administrative costs.

A key feature of the new CTA structure was the creation of Technology Development Leaders (TDL) for each CTA. The TDL responsibilities included assisting in the planning and execution of the specific technology program. Dr. Thomas Moran was appointed the first TDL for CTA-4 NDE. Figure 3.18 thru 3.20 illustrates the evolving CTA-4 configuration.

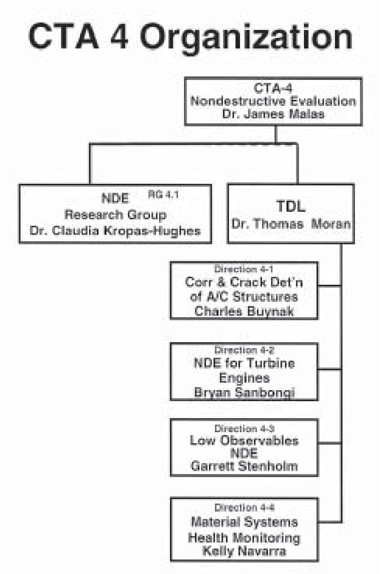


Figure 3.18. CTA-4.

<u>New leadership role for NDE Program in Vehicle Health Monitoring (VHM)</u>. Based on his vision in 1999 that the NDE Program would provide a vital path toward achieving VHM capabilities, and in the far term be eclipsed by VHM technology, the ML Director assigned ML VHM program leadership responsibilities to the NDE Branch and Program. The ML VHM team collaborates currently with other Air Force entities engaged in this technology area.

2000 – 2006

<u>ML NDE Program Integrated Product Team (IPT) formed</u>. An ML NDE IPT was added to the CTA-4 planning structure in 2000 for the purpose of assuring optimum coordination of the overall NDE research, NDE manufacturing technology, NDE applications for system support, and logistics activities. As illustrated in Figure 3.xxx, the IPT addition assures simplified liaisons with key ML program technology transition targets, including the AF-identified Integration Application Areas (IAA) Air Vehicles, Space Vehicles, Sustainment, Weapons (Directed Energy, Munitions) and Agile Combat Support. This action was taken in response to the AF Scientific Advisory Board Review feedback that ML's overall NDE R&D activities would be improved accordingly.

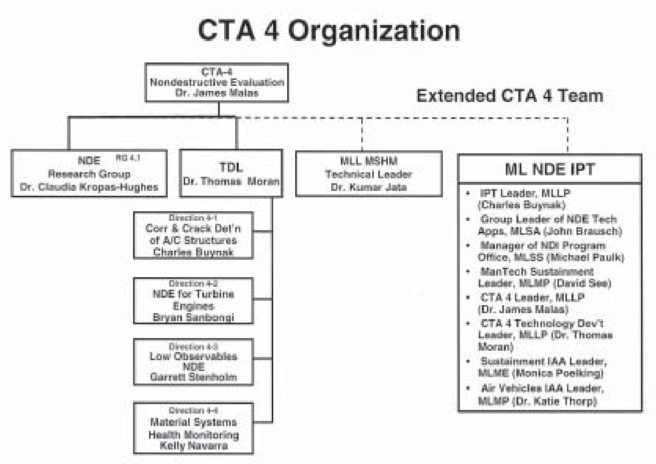


Figure 3.19. CTA-IPT.

<u>Increase in NDE Branch R&D staff members</u>. In 2001, the AF launched an advanced technology initiative to increase the assignment of new officers trained in the technical disciplines to a number of laboratory R&D program growth positions. As the need for broader in-service NDI/E capabilities in the AF continued to grow, several engineer-trained junior officers were added to the NDE Branch roster. Following the appropriate duty tours and departures, personnel policies allowed the refilling of the vacated military positions with additional permanent civilian R&D personnel. As a result of this important initiative, the Branch technical staff size was increased nearly 75 percent between the beginning of 2000 and the end of 2005.

<u>New leadership role for NDE Program in Homeland Defense and Force Protection</u>. Following the terrorist attack on the World Trade Center towers on September 11, 2001, the ML Director Dr. Charles Browning led an assessment of ML's core competencies and capabilities from the perspective of how they

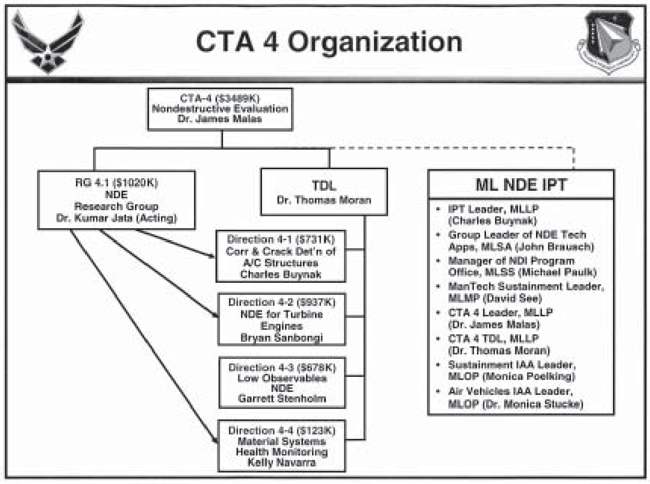


Figure 3.20. CTA-IPT.

could support prevention of, or response to a future attack in four principal areas: (1) Force Protection, (2) Contingency Operations, (3) Homeland Defense, and (4) Emergency Response. NDE was clearly recognized as a key competency that could contribute expertise and technologies for finding "hidden terrorist weapons or bombs" or other contraband, and supporting search and rescue activities such as locating attack victims buried under rubble. As a result, the NDE Program sponsored an FY03 Small Business Innovative Research (SBIR) topic on that subject. The program attracted the interest of the Air Force Chief Scientist, DARPA and others. A follow-on FY06 SBIR topic is aimed at exploiting NDE capabilities, emerging sensor materials, and novel interrogation approaches to develop enhanced capabilities to detect current and potential weapons and contraband items. These projects became a center of attention, whereby the ML Director assigned the NDE Branch to lead subsequent ML development program efforts.

References

3.1. "Nondestructive Testing – A Survey," Southwest Research Institute, NASA, Washington D.C., 1973.

3.2. Thomas, Willys E., *"Magnaflux Corporation: A History" The first fifty years.* Magnaflux Corporation, Chicago, Ill, 1979.

3.3 Betz, Carl E., *"Principals of Penetrants,"* Magnaflux Corporation, Second Edition, Chicago, IL, 1969.

3.4. Five Decades of Materials Progress, 1917 - 1967, James J. Niehaus, Air Force Materials Laboratory, Wright-Patterson Air Force Base, OH, 4 December 1967.

3.5. Duffner, Robert W., Science and Technology: The Making of the Air Force Research Laboratory, Air University Press, Maxwell Air Force Base, Alabama, November 2000.

3.6. Ibid.

3.7. King, Troy T., *"Some Developments in the Air Force Aircraft Structural Integrity Program (ASIP),"* Proceedings of the Air Force Conference on Fatigue and Fracture of Aircraft Structures and Materials, Eds. Wood, H.A., Bader, R.M., Trapp, W.J., Hoener, R.F. and Donat, R.C., AFFDL TR 70-144, Wright-Patterson Air Force Base, Ohio 45433, September 1970, pp. 701-716.

3.8 ASD-TN 61-141 (1961)

3.9. Forney, D. M., Jr., *"NDI in The United States Air Force,"* British Journal of NDT, May 1976.

3.10. Forney, D.M. and Lowndes, H. B., *"Application of F-111 NDI and Cold Proof Test Concepts to Future Weapon Systems,"* Special Report, Air Force Systems Command, Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio, 1 December 1970.

3.11. Richey, G. Keith, *"F-111 Systems Engineering Case Study for the Air Force Institute of Technology (AFIT) Center for Systems Engineering,"* January 2005.

3.12. Forney, D.M. and Lowndes, H. B., *"Application of F-111 NDI and Cold Proof Test Concepts to Future Weapon Systems,"* Special Report, Air Force Systems Command, Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio, 1 December 1970.

3.13. *"Aging of U.S. Air Force Aircraft,"* – Final Report, National Materials Advisory Board, National Research Council Publication NMAB-488-2, 1997.

3.14. Lewis, W.H., Sproat, W.H., Dodd, B. D. and Hamilton, J. M., *"Reliability of Nondestructive Inspections,"* Lockheed-Georgia Company, Marietta, Georgia, San Antonio Air Logistics Center Report SA-ALC/MME 76-6-38-1, December 1978.

3.15. Crane R.L., Moran, T.J. and Patterson, T.M., *"X-Ray Computed Tomography of Carbon/Carbon Composites,"* Proceedings, DARPA/Air Force Review of Quantitative NDE, La Jolla, California, July 1979.

3.16. *"NTSB: DC-10 Crash End Result of Maintenance Damage,"* Aviation – Engineering and Maintenance, Volume 4 No. 2, February 1980.

3.17. Discussion by Susan Vukelich.

3.18 Air Force Mishap Board Report – Titan IV 34D-9 Space Launch Vehicle Failure, June 1986.

3.19 Ibid.

3.20 Discussion with Ward Rummel, Martin Marietta Astronautics, retired; WD Enterprises, Inc.

3.21 Air Force Mishap Board Report – Titan IV 34D-9 Space Launch Vehicle Failure, June 1986.

3.22 Discussion with Ward Rummel.

3.23 *"Last Titan Rocket Blasts Off; an Era Ends,"* Associated Press, October 19, 2005, Copyright 2005.

3.24 *"737 Fuselage Separation Spurs Review of Safeguards"*, Aviation Week & Space Technology, May 9, 1988, pp. 92-94.

3.25 *"$15 million, Admission from Jet-Cash Accord,"* Chicago Tribune, September 13, 1996.

3.26. *"Aging of U.S. Air Force Aircraft,"* –Final Report, National Materials Advisory Board, National Research Council Publication NMAB-488-2, 1997.

3.27 Larsen, J.M., Rasmussen, Bruce, Russ, S.M., Sanbongi, Bryan, Morgan, Jim, Jira, Jay, Blodgett, Mark, Moran, Tom, Johnson, David, LeClair, Steve, Shaw, Debbie, Strange, Bill, Meininger, Matt, and Fecke, Ted, *"The Engine Rotor Life Extension (ERLE) Initiative and Its Contributions to Increased Life and Reduced Maintenance Cost,"* Proceedings of the 6th International Turbine Engine High Cycle Fatigue (HCF) Conference, Jacksonville, FL, 5-8 March 2001.

CHAPTER 4
Summary of Significant Developments

While it is unrealistic to include all of the research and development (R&D) projects and activities that have been performed by the Nondestructive Evaluation Branch and all of its predecessor organizations, a number of the more significant development efforts are summarized here to demonstrate the magnitude of their contributions toward establishing a strong NDE technology and applications base for the U.S. Air Force.

Historically, the ML NDT development efforts leading up to the 1960s focused principally on technique improvements and adaptations to meet Air Force systems inspection needs during both manufacturing and in-service maintenance at operational bases.

1960 - 1970

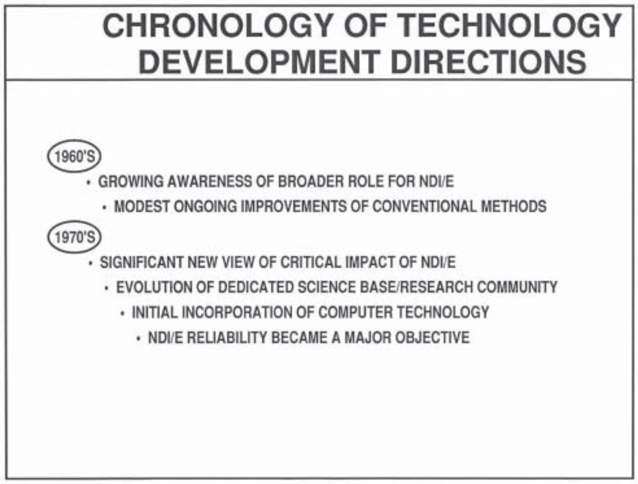
With the 1960s came a growing awareness of a broader role for NDI/E beyond the continuing modest improvements of conventional methods. Many factors came into play with this shift, such as the arrival of the jet and space ages and the emergence of more sophisticated weapon systems. Another key influence, which emerged in the early to mid 1960s, was the introduction of new fleet safety and service life management requirements such as the Aircraft Structural Integrity Program (ASIP) and other major guidelines. These established safe-life design criteria and integrity monitoring with NDI.[4.1] A number of initiatives to explore new, and often risky, ideas were begun in this time period:

- **Annual Symposium on Physics and Nondestructive Testing.** The NDE Program, under the leadership of Richard Rowand, recognized that advancements in NDT technology would depend on a better understanding of the fundamental physics of the measurements of interest. This premise had brought about the organization in 1960 of a successful annual national Symposium series on Physics and Nondestructive Testing by the Illinois Institute of Technology Research Institute (IITRI), providing a forum for exchange of new NDT-relevant research data. In 1964, the NDT Program took over the leadership and subsequent sponsorship of the symposium, with Richard Rowand serving as symposium director, with the aim of stimulating creative applications of new and useful methods and techniques.[4.2] Southwest Research Institute served as the symposium support contractor. The emphasis of the symposium series, which ran annually from 1960 through 1969, was focused on the basic principles underlying nondestructive methods for the evaluation of materials and materials properties. This symposium resulted in a greatly expanded national focus on advancing NDT technology.

- **Increased Emphasis on New NDT Methods.** Among the new NDT Program initiatives was the development of a radiation gaging technique to determine the density of discrete volumes of graphite to within ± 1% as a means to help select graphite nozzles for the Air Force Blue Scout rocket vehicle. Also demonstrated was the feasibility of neutron radiography for inspecting boron fiber reinforced alloys of aluminum, nickel and titanium, thus offering an increased resolution over conventional radiography for multi-layers.[4.3] In other work, the feasibility of magnetoabsorption to measure residual and applied stress was demonstrated.[4.4, 4.5, 4.6] The thermoelectric probe was developed under contract by AVCO for inspecting coated refractory metals, such as monitoring thickness of a coating during processing of a part.[4.7] As a result, Pratt & Whitney adopted the technique, with modifications for automation within its production lines for control of coating thickness on turbine blades. A Lamb wave mode of ultrasonic inspection was developed and successfully demonstrated for inspecting thin sheet materials.[4.8] The acoustic emission technique was investigated for possible application to integrity monitoring of pressure vessels such as rocket motor cases.[4.9] An exploratory effort was conducted to develop nondestructive testing techniques for composites.[4.10] In-house R&D efforts were pursued to develop NDT techniques for evaluating this and ultra thin sheet materials.[4.11(a), (b)]

1970 - 1980

During the 1970s, the significant role of NDI/E came into focus with new development directions (Figure 4.1). This was influenced by the occurrence of some disastrous failures, as well as instances of fleet safety degradation, that were caused by undetected critical flaws. A dedicated science base and research community began to evolve, accelerated by the growing development and use of computer technology. Improved NDT/I reliability became a major objective. [4.12] Specific directions for the evolving program emerged.[4.13] Included as emphasis areas were Advanced Materials Inspection, Field & Development Applications, Engine Component Inspection, NDE Methods Improvement and NDE of Fastened Joints. In the early 1970s, studies included evaluation of an acoustic impact technique to detect bolt-hole cracks, a Delta Scan technique round



CHRONOLOGY OF TECHNOLOGY DEVELOPMENT DIRECTIONS

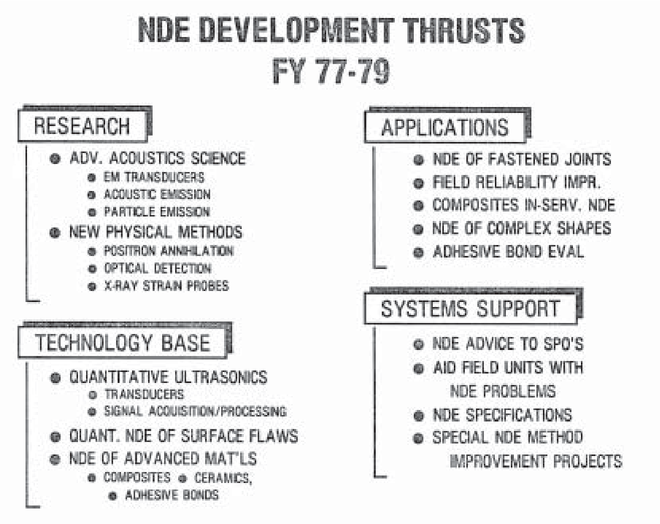
1960'S
- GROWING AWARENESS OF BROADER ROLE FOR NDI/E
  - MODEST ONGOING IMPROVEMENTS OF CONVENTIONAL METHODS

1970'S
- SIGNIFICANT NEW VIEW OF CRITICAL IMPACT OF NDI/E
  - EVOLUTION OF DEDICATED SCIENCE BASE/RESEARCH COMMUNITY
    - INITIAL INCORPORATION OF COMPUTER TECHNOLOGY
      - NDI/E RELIABILITY BECAME A MAJOR OBJECTIVE

Figure 4.1. Chronology of Technology Development Directions.

robin to evaluate that technique, eddy current techniques for leading/trailing edges of turbine blades, an acoustic emission technique to detect low cycle/high cycle fatigue, and exoelectron emission for fatigue detection.

By 1975, the program plan included a series of research, advanced technology and applications development thrust areas extending into FY77 – 79 (Figure 4.2).



NDE DEVELOPMENT THRUSTS FY 77-79

RESEARCH
- ADV. ACOUSTICS SCIENCE
  - EM TRANSDUCERS
  - ACOUSTIC EMISSION
  - PARTICLE EMISSION
- NEW PHYSICAL METHODS
  - POSITRON ANNIHILATION
  - OPTICAL DETECTION
  - X-RAY STRAIN PROBES

TECHNOLOGY BASE
- QUANTITATIVE ULTRASONICS
  - TRANSDUCERS
  - SIGNAL ACQUISITION/PROCESSING
- QUANT. NDE OF SURFACE FLAWS
- NDE OF ADVANCED MAT'LS
  - COMPOSITES
  - CERAMICS,
  - ADHESIVE BONDS

APPLICATIONS
- NDE OF FASTENED JOINTS
- FIELD RELIABILITY IMPR.
- COMPOSITES IN-SERV. NDE
- NDE OF COMPLEX SHAPES
- ADHESIVE BOND EVAL

SYSTEMS SUPPORT
- NDE ADVICE TO SPO'S
- AID FIELD UNITS WITH NDE PROBLEMS
- NDE SPECIFICATIONS
- SPECIAL NDE METHOD IMPROVEMENT PROJECTS

Figure 4.2. NDE Development Thrusts FY 77-79.

The most significant development efforts among the numerous efforts in this period included the following:

- **Development of Capability to Detect Cracks Under Installed Fasteners.** By the early 1970s, the need became more imperative for reliable inspection methods to detect the growth of non-visible fatigue cracks at fastener holes without having to remove the fasteners (for example, estimated to cost $100 per fastener in a depot inspection of approximately 2100 holes per F-4 aircraft). [4.14] The need to detect cracks under fasteners (CUFS) stemmed from causes such as aircraft usage beyond design lives, usage changes, design deficiencies and improper hole manufacture and assembly. The NDE program began sponsoring R&D to produce a reliable ultrasonic system capable of detecting 0.030 inch radial length cracks, in a manner similar to that shown in Figure 4.3. Figure 4.4a shows a series of prototype scanners developed and evaluated, starting with the initial Boeing "Rotoscanner" produced in 1972 and an improvement in 1974, both with a demonstrated 0.030-inch detection capability.[4.15]

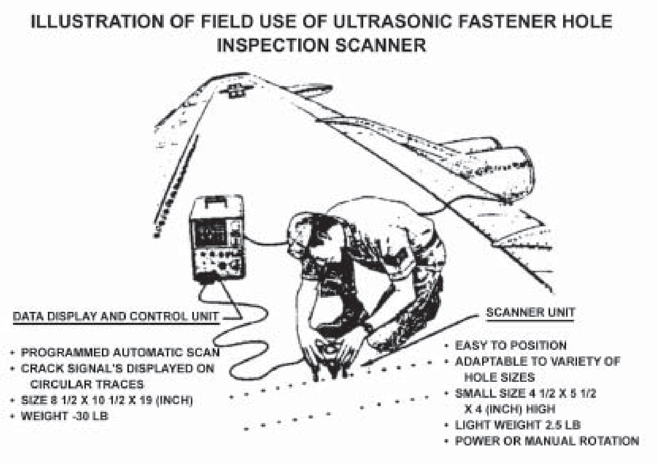


Figure 4.3. Illustration of Field Use of Ultrasonic Fastener Hole Inspection Scanner.

In 1977, an urgent requirement for a highly reliable first layer 0.01-inch CUFS detection capability and desired second layer 0.030 inch detection for the

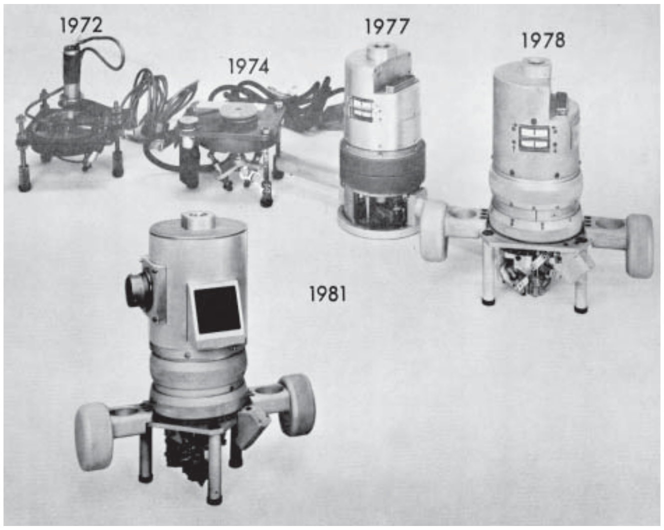


Figure 4.4a. Rotoscanner-Autoscan Scanner Series Developed to Detect Cracks Under Installed Fasteners (CUF).

Figure 4.4b. Autoscan System Evaluation on B-52 Wing at San Antonio ALC.

C-5A wing expedited the NDE program-sponsored development of the Systems Research Laboratories "Autoscan" ultrasonic system. Two prototype versions (Figure 4.4a 1977 and 1978) preceded the final model finished in 1981. Figure 4.4b illustrates the use of the final 1981 model on a B-52 upper wing. The system was successfully demonstrated on a wide verity of aircraft, including the F-4, KC-135, T-38, T-39, A-10, A-7, F-5, E-3, C-5A and B-52. Furthermore, it displayed a 90%/95% Probability of Detection/Confidence Level for the detection of a 0.030 inch notch on the back surface of a series of simulated C-5A aircraft skin fastened joint test samples. While field evaluations of the Autoscan systems validated that detection goals were met, assessments indicated that further improvements were still needed to simplify its use in the maintenance environment. Pending further improvements, the system was still considered essential for numerous E-3 ASIP inspections and was delivered to OC-ALC (see later 1990-2000 discussions).

- **In-Service Inspection Capability for Composite Components.** In the mid-1970s, large area composite aircraft components generally were inspected manually using hand-held ultrasonic transducers. In this process, the interpretation of response signals was necessarily instantaneous and subjective, being highly dependent on operator skills, and of questionable reliability/reproducible. Inspection times were excessive: F-15 vertical stabilizer approximately 6 manhours; F-16 horizontal stabilizer approximately 18 manhours; B-1B weapons bay door approximately 20 manhours. In 1977-78, the NDE Program provided funding to General Dynamics Ft. Worth (GDFW) to extend its investigation of a non-immersion ultrasonic pulse-echo method to image ply cracks and other defects in composite material. [4.16] This successful effort was the basis for a ManTech-funded follow-on program to develop an In-Service Inspection System (ISIS) prototype capable of scanning on-aircraft composite structures with a capability to map defects and delaminations (Figure 4.5). system concept utilized a microphone sensing bar to determine the ultrasonic transducer position, thus providing the means to produce C-scan images of internal defects in the composite component. Resulting from the ISIS evaluations at WR-ALC and OO-ALC in 1982-83, the prototype was judged worthy of further development with additional ManTech funding (Fiscal Year 83-84).

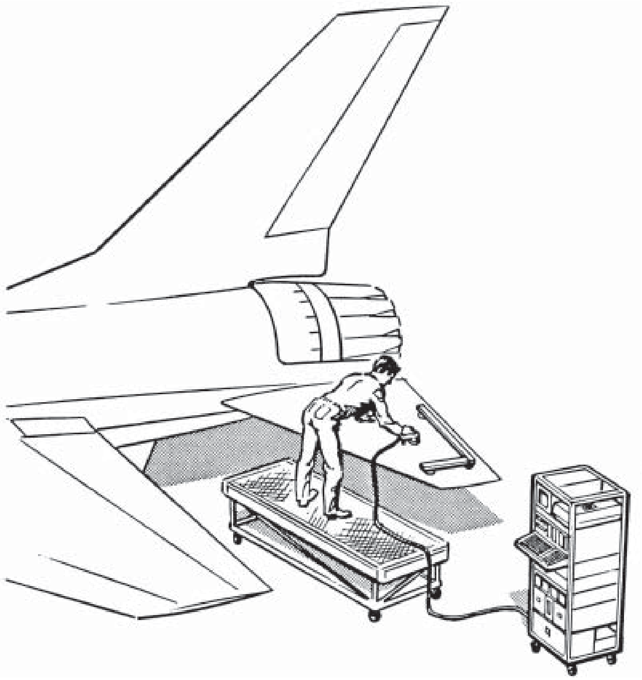


Figure 4.5. Concept of In-Service Inspection System (ISIS) in Operation.

- **Advanced Real-time Inspection System for Composites.** Since GDFW declined to pursue further development of the ISIS prototype for large area composites, the next evolutionary step was given to Southwest Research Institute in 1983 to produce an Advanced Real-time Inspection System (ARIS) prototype. Figure 4.6 illustrates the unit being used to inspect an F-16 composite empennage on the flight line. Added capabilities included a 4 ft x 4 ft scanning area without relocating the position receiver assembly, electronic templates to define the inspection area, advanced automated data recording, processing and analysis functions, real-time data displays, and a capability to perform through transmission using light-weight yoke fixture. Receiving significant guidance from Air Force major command users, extensive field

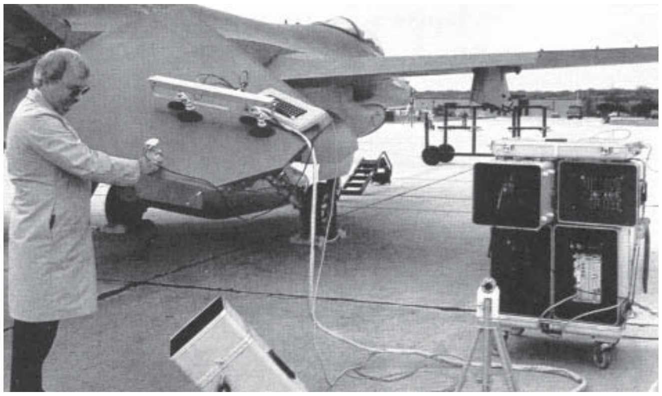


Figure 4.6. Evaluation of Advanced Real-Time Inspection System (ARIS) on F-16 Empennage.

evaluations were conducted successfully by USAF, Navy, Canadian Defence Forces and the UK Royal Air Force.

- **Computer-Automated Ultrasonic Inspection System (CAUIS).** With the occurrence of an economic move toward near-net shaped forgings for engine and aircraft component manufacturing, and away from easier-to-inspect intermediate sonic shapes, the need for improved NDE methodology was obvious. The NDE program funded General Dynamics Corporation Ft. Worth Division to continue its exploratory development effort to determine feasibility of a computerized UT immersion system for aircraft parts (see Appendix F-2, roadmap 10). The specially designed contour-following subsystem controls the orientation of the transducer, allowing it to automatically follow the contour of a complex forged shape. The basic system was demonstrated successfully in 1976.[4.17] The NDE program managed a follow-on ManTech-funded program to demonstrate the producibility of an engineered CAUIS version for application to F-16 parts (see Appendix F-2, Roadmap 10). The contour following and computer control and display portion of this system were incorporated later by Pratt & Whitney Aircraft under a ManTech-funded program.

- **Automated Eddy Current Inspection System for Engine Disks.** The increasing number of turbine engine component structural deficiencies and failures in the 1970s prompted the requirement for improved safety inspection capabilities to remove parts containing critical sized cracks. Based on its success in developing new crack detection eddy current technology, The General Electric Aircraft Engine Group (GE-AEG) was provided ML ManTech funding in 1978 to construct and prove out a prototype 6-axis computer-controlled, automated eddy current inspection system capable of detecting a 0.030 inch long by 0.005 inch deep surface crack with a signal to noise ratio of 2. Significant technical participation was given by NDE Branch engineers. The resulting prototype (Figure 4.7), designated EC-I, was set up at the San Antonio ALC for evaluation.

In 1980, a production upgrade of EC-I, with improved computer control and automated eddy current scanning system, was developed for engine depot inspection applications. This system, designated EC II (Figure 4.8), was intended to replace a number of manual NDI/E operations resulting in higher flaw detection accuracy and reliability and with a significant increase in throughput. This development was in response to Logistics Need AFALD AFWAL/ML 3008 79 02 “NDI Techniques for Engine Disks” issued by AFLC. Extensive field trials validated excellent performance of the resulting system. The prototype development contractor, GE-AEG, continued system improvement efforts independently. By 1985, GE had installed

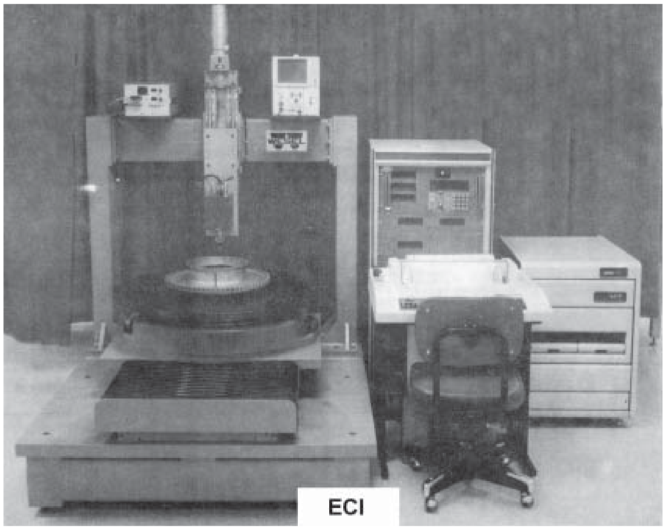


Figure 4.7. Automated Eddy Current System Prototype (EC-I) for Turbine Engine Disks (General Electric Aircraft Engine Group).

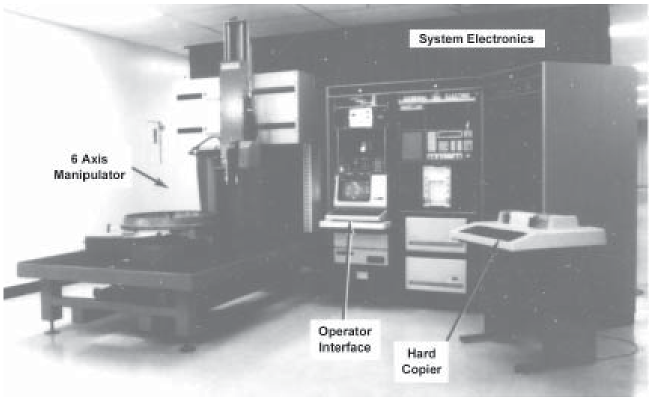


Figure 4.8. General Electric Aircraft Engine Group EC-II System Based on the Production Upgrade of the EC-I System.

23 units in U.S. and allied Air Force and commercial facilities.[4.18]

- **Near Net Shape Engine Disk Inspection System Development.** Development of an advanced automated ultrasonic inspection system for inspecting new near net engine disk forgings for small internal flaws was completed in 1979. The ManTech production prototype system, developed with NDE Program technical assistance, was completed by both Pratt & Whitney and General Electric, which established alternative approaches. Both Air Force Computerized Ultrasonic Evaluation (AFCUE) systems eliminated the prior need for sonic shapes, using either adaptive (GE) or pre-programmed (P&W) surface contour following by the transducer to maintain normal entry angle. Each system utilized some of the technical advancements developed in the ML-funded CAUIS near net shape inspection system program by General Dynamics, described above. Both featured 5-axis transducer motion control, computerized data acquisition, storage, analysis and reporting, flaw evaluation using reject criteria in file, automated calibration and graphics display. By 1980, each system entered in-plant operational use by its developers.[4.19]

- **Integrated Blade Inspection System (IBIS) X-Ray CT Module.** With NDE technical assistance by the NDE Branch, a manufacturing technology program to develop an Integrated Blade Inspection System (IBIS), designed to have inspection modules for visual inspection (VIM), fluorescent penetrant (FPIM), infrared (IRIM), and x-ray computed tomography (XIM). These modules were designed to function as part of a mechanical computer-controlled blade transfer and manipulation system. The program, which included Army and Navy funding contributions, was initiated with GE-AEG in 1978 and continued to the end of 1983. The first production-ready XIM unit, capable of producing both CT images and digital radiography (DR) images, such as shown in Figures 4.9.a and 4.9b, respectively, was installed in the GE Madisonville Kentucky Turbine Airfoils Plant with the capability of detecting 0.010 inch minimum internal flaws and measuring dimensions with an accuracy of 0.005 inch.[4.20] The San Antonio Air Logistics Center took delivery of the completed system and continued investigations of its application.

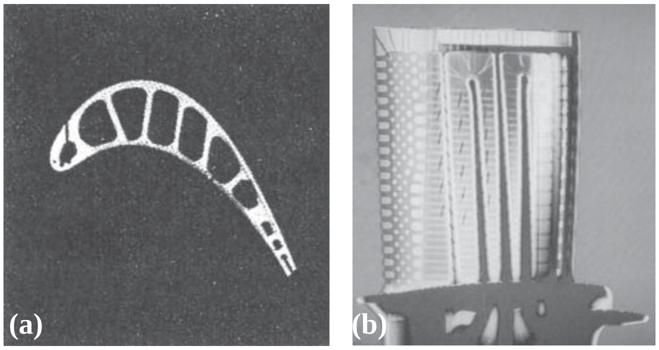


Figure 4.9. High Resolution Radiographic Images of Turbine Engine Hollow Turbine Blade Produced by the GE Aircraft Engine Group X-Ray Imaging Module (XIM). (a) Single CT Slice of Cross Section. Fine Resolution of Cooling Passages Allows Detection of Thinning Effects. (b) Digital Radiograph of Blade.

In-House Research Program 1970-1980

Early in this period, a series of important ML management decisions was made to begin building a strong in-house NDE research group within the Branch. Its charter was to study radically new fundamental approaches to material and structural inspectability and life prediction.[4.21] One important objective was to help influence general NDE R&D activities nationally to focus more on Air Force-specific needs and objectives. Another was to help educate Air Force research engineers and scientists to become “smart buyers” of contracted R&D efforts through an expansion of their own R&D experience. As opportunities arose, some new technologists educated in physics, physical chemistry, materials science, electronic instrumentation, and similar specialties germane to NDE, were sought and added as branch members. Also during this time, the organization began initiatives to add a few selected non-government “visiting scientists” and technologists for prescribed periods of service, in addition to the established on-site research contractors, to enhance the research staff and perform in-house NDE research efforts. Representative of these visiting researchers were Drs. Thomas Moran, Steve Gustafson, Joseph Moyzis and Josef Bar-Cohen.

Under the initial leadership of Dr. Michael Buckley, assisted by Dr. Rodney Panos, the group developed an initial in-house research plan and began exploration of new and unique approaches to flaw and feature detection/characterization. The plan included studies of various flaw-energy interactions, and of new, potentially more sensitive sensor/transducer devices. Communications with other research groups conducting NDE studies were initiated with the aim of sharing research results and helping establish a strong national NDE science base research community, which ultimately would benefit the Air Force. Supplemental support funding from the Air Force Office of Scientific Research (AFOSR) enhanced the growth process. Several key research efforts pursued during this period included the following:

- **Electromagnetic Acoustic Transducer (EMAT) Studies.** Upon his joining the NDE Branch in 1976, Dr. Thomas Moran initiated research to continue the studies he was pursue at Wayne State University to advance the capacities of an electromagnetic acoustic transducer (EMAT) concept. The design and construction of small hand-held flexible PC board-based transducers utilizing Rare Earth magnets to get the high magnetic fields required were investigated. It was then shown how the surface wave devices could also be used to create electronically selected angle beam bulk waves. Finally, the research evolved to the point of adding addition of digital coding to improve the bandwidth of the surface waves to get short pulses for improved range resolution.[4.22, 4.23, 4.24, 4.25, 4.26] While the research was viewed as successful, a side effect of the modification was the generation of unwanted bulk waves at all angles, which acted as noise sources. However, this work led to the research described next.

- **Advanced Ultrasonic Signal Generation and Analysis.** The principal thrust of the developing effort was to study and exploit ultrasonic techniques, including quantitative flaw characterization capabilities, ultrasonic imaging and ultrasound scattering from flaws, and ultrasonic methods showing potential for detection/characterization of defects and anomalies in multi-layered structures (Figure 4.10). This focused on investigating (a) various ultrasonic signal generation and analysis methods having potential for enhanced signal-to-noise in situations where ultrasound energy losses are significant, and (b) continuous wave (CW) ultrasonic techniques for their applicability to the multi-layer inspection problem. In addressing objective (a), the in-house team led by Dr. Tom Moran developed and demonstrated a unique method employing a pseudo-random binary noise (PRBN) concept to code ultrasonic input signals such that the coded reflected signal containing the same predetermined code can be separated from truly random background noise through correlation methods. The approach provided a major advantage over other random signal approaches developed elsewhere which, due to many practical limitations, are not suitable for ultrasonic systems.[4.27] The technique succeeded in accelerating the signal correlation by several orders of magnitude. An invention disclosure on a method to extend this concept was filed by the inventor, Dr. Thomas J. Moran, on 13 June 1978, entitled “Phase Shift Keyed Pseudorandom Binary Noise Nondestructive Evaluation Ultrasonics System.” For this research, Dr. Moran was recognized as a Finalist for the 1979 ML Charles J. Cleary Award for Scientific Achievement.

Figure 4.10. Dr. Robert Crane (left) and Dr. Thomas Moran (right) in NDE Program Computer Laboratory.

- **Feasibility Experiments on X-Ray Computed Tomography.** In a search in 1978 for a more effective means to inspect and nondestructively evaluate carbon-carbon composite materials intended for aerospace applications, for which conventional inspection methods were inadequate, NDE Branch scientists Drs. Robert Crane and Thomas Moran investigated the newly developed X-Ray Computed Tomography (CT) methodology just coming into use in the medical field. Employing a General Electric Model 7800 Medical X-Ray Computed Tomography instrument at the Wright-Patterson Medical Center for the research, they demonstrated that CT could produce quantitative measurements related to density of a space-grade carbon-carbon composite material and detect almost closed delaminations.[4.28] They succeeded not only in easily imaging large delaminations, but several heretofore undetected tight delaminations and apparent density variations as well. Metallographic sectioning was performed and point-by-point densities were measured to validate the observations. Additional work was performed to validate the findings, including detection of manufacturing anomalies in thermal protection tiles for the NASA Space Shuttle. The results of these visionary experiments were so striking that a major program decision was made to fund the development of an industrial-class X-Ray CT system capability, with an initial concentration on space hardware. For their pioneering experimental research and analytical work, Drs. Crane and Moran were recognized as finalists for the ML 1980 Robert T. Schwartz Engineering Achievement Award.

- **New Concept for Sizing Second Layer Cracks.** The accurate radial length sizing of fastener-hole cracks, especially in the unobservable inner layer, would enhance the reliability of this inspection. However, little or no prior progress had been reported or observed. Thus, the NDE Program initiated in-house studies in 1979 to develop and validate a unique concept of sizing second layer cracks using a Doppler Shift effect technique. With the technique, a transducer is rotated (with a fixture) at a uniform rate around a hole under inspection, as illustrated in Figure 4.11. Due to the fact that the transducer travels past a crack, the backscattered reflection will be frequency-shifted, with the magnitude of this Doppler shift reaching a maximum value at the crack tip. Measurements of this frequency information are sufficient to calculate tip-to-hole center distances (Figure 4.11). Experimental results on second-layer fatigue cracks indicated that crack length can be calculated to within ± 20 percent accuracy, thus establishing feasibility.[4.29, 4.30] At that time, the additional work necessary to make the technique operational was not pursued. This technique was deemed limited to laboratory use by the requirement to maintain a constant angular rotation rate in order to measure the small change in frequency accompanying the Doppler shift in the reflected signal. Higher grade instrumentation to overcome this limitation was not available at the time.

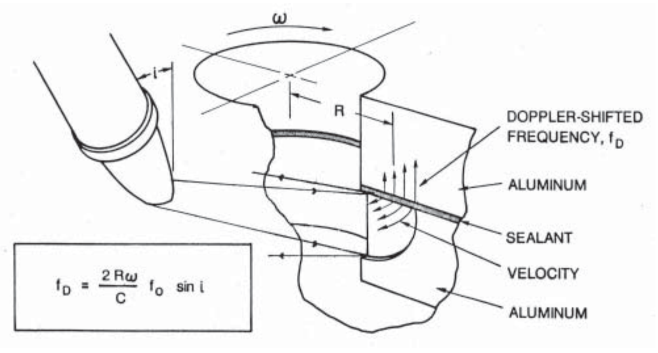
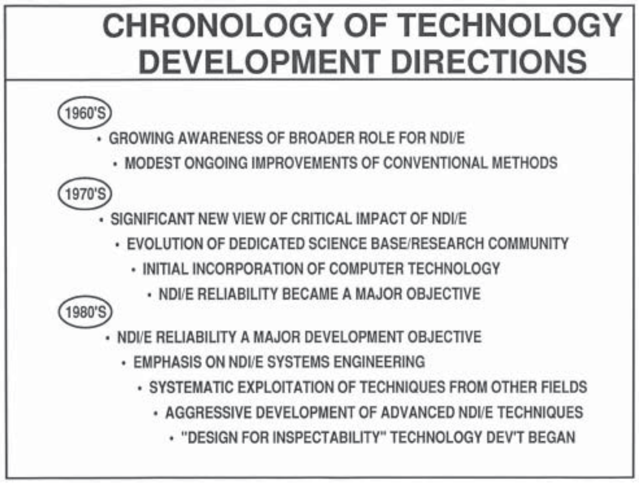


Figure 4.11. Doppler Shift Method for CUFS.

- **Direct Exposure X-Ray Sensitive Paper.** Improvement in currently used field NDE methods having significant economic impact has been an important continuing objective for the in-house program. In one case, the routine use of radiographic inspection throughout the USAF has involved an enormous annual expense, just in X-ray film alone. Thus, an experimental direct exposure X-ray sensitive paper concept introduced by Eastman Kodak in 1971 resulted in considerable interest. The paper system, consisting of a silver halide emulsion and development agent coating, could be developed right at the inspection site immediately after exposure in an inexpensive portable processor, in less than 15 seconds. The per-sheet cost at that time was approximately 21 cents compared to approximately $1.10 X-ray film cost. An in-house trade-off study demonstrated a potential reduction of 60% in man-hours involved by using the more readily processed paper. The NDE Program evaluation in 1975 [4.31] and subsequent field trials in 1977 [4.32] led to certification of the paper system. The overall savings potential in time and material costs were quite substantial considering the nearly 2000 radiographs that might be taken of one C-5A transport during a major inspection.

1980 – 1990



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1980'S
- NDI/E RELIABILITY A MAJOR DEVELOPMENT OBJECTIVE
- EMPHASIS ON NDI/E SYSTEMS ENGINEERING
- SYSTEMATIC EXPLOITATION OF TECHNIQUES FROM OTHER FIELDS
- AGGRESSIVE DEVELOPMENT OF ADVANCED NDI/E TECHNIQUES
- "DESIGN FOR INSPECTABILITY" TECHNOLOGY DEV'T BEGAN

Figure 4.12. Chronology of Technology Development Directions.

As illustrated in Figure 4.12, R&D efforts began to accelerate in the 1980s, not only with the continued attention given to improving reliability through advance techniques (including some from other technical fields), but also with a greater emphasis on developing well-engineered, computer-based integrated NDI/E systems. In addition, increased emphasis was directed toward including “inspectability” as a serious design goal.[4.33] The specific rank-ordered Logistics Needs (LN) for NDI issued by AFLC for Fiscal Year 1987 to emphasize its priority development needs were:

- Detection of Hidden and Inaccessible Corrosion
- Rapid Inspection of Composites
- Rapid NDI for Engines
- NDI of Second Layer Joint Cracks Under Installed Fasteners
- Inspection of Brazed Honeycomb Abradable Airseals.

A summary of significant R&D efforts include the following:

- **Low Frequency Eddy Current (LFEC) Probe**

for Second Layer Crack Detection. The quest for an eddy current-based second-layer cracks under fasteners detection CUFS capability began in 1977 with an in-house evaluation of several available ultrasonic and eddy current-based devices. In a substantial number of follow-on investigations, the NDE Program funded investigation or development of a multi-frequency (MFEC) prototype system by Battelle-Columbus Laboratories, an electric current perturbation (ECP) method by Southwest Research Institute, the application of electromagnetic acoustic transducer (EMAT) ultrasonics, and evaluations of Alcoprobe ALC-1, along with a Super Halec instrument manufactured by Hocking Electronics (located in the U.S. and England). Generally, decisions were made to not pursue further development of these options due principally to inadequate performance and/or excessive development costs. The exception was the favorable performance of the low frequency eddy current (LFEC) prototype by Northrop Corporation. [4.34]

A manufacturing technology program, managed by the NDE Program, was initiated subsequently with Northrop Corporation in 1981 to produce an operational prototype Low Frequency Eddy Current Array LFECA system. This system was based on the aforementioned Northrop exploratory development work in order to achieve a production prototype of its low frequency eddy current (LFEC) instrument to meet the reliable detection goal of 0.10 inch long crack below 0.24 inch aluminum around titanium fasteners.[4.35] The program demonstrated the practicability of a multi-segment or circular LFECA) probe operating at 400 Hz, along with a suitable driver, to sense second-layer cracks. However, the crack detection levels demonstrated were insufficient to meet the necessary development target. Thus, further work was suspended.

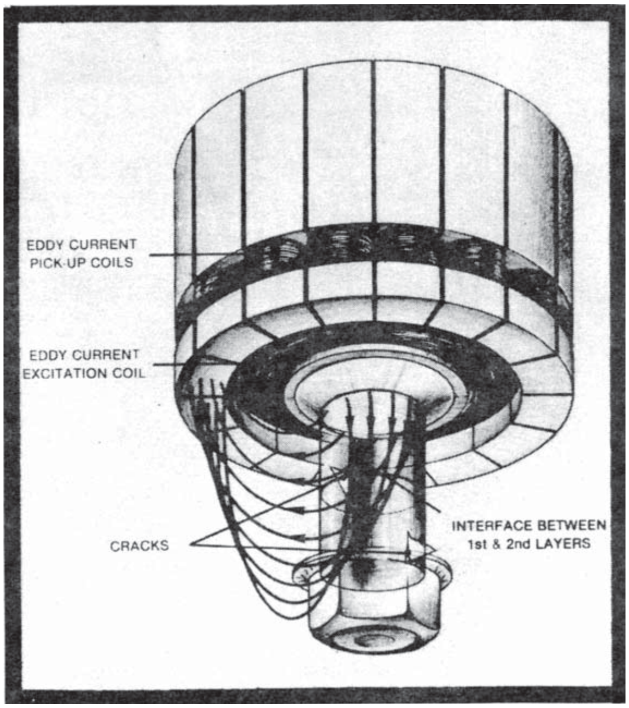
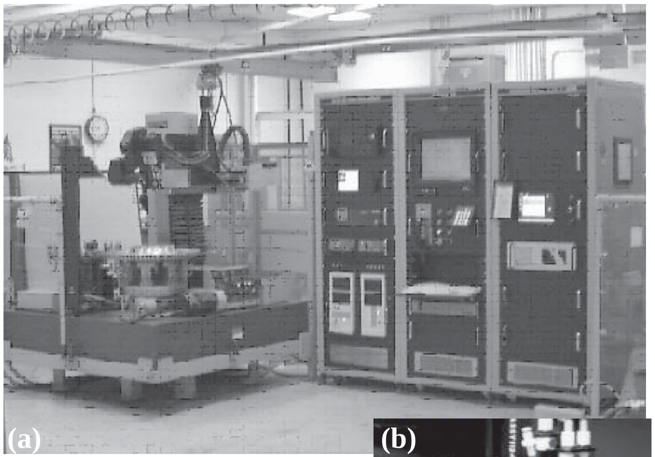


Figure 4.13. Low Frequency Eddy Current Array (LFECA) Probe Concept for Second Layer Crack Detection.

- **Turbine Engine Disk Retirement for Cause (RFC) Inspection System.** The introduction of the Engine Structural Integrity Program (ENSIP) in 1978, using a damage tolerance analysis (DTA), featured a very conservative approach to retiring components after they reached a given number of operating cycles. When 1 of 1,000 parts could potentially develop a crack, all 1,000 parts would be retired on the basis of usage time to eliminate the possibility of catastrophic failure in flight (Figure 4.14). With a spare parts crisis looming with this philosophy, the solution was to develop nondestructive inspection technology to reliably detect small cracks (as small as 0.005 inch deep) in used parts, prior to their reaching a critical "potential failure," length thus allowing continued use of those parts without cracks. Even though the Materials Laboratory had just completed funding General Electric to develop the very successful eddy current disk inspection system, EC II, capable of performing the inspections on the Pratt & Whitney F100 engine, it was not universally accepted because of the competitive nature of the aircraft engine industry.[4.36]

Figure 4.14. Turbine Engine Disks "Retired" from Service after Reaching an Analytically Prescribed Conservative Usage Life.

The Air Force made the deliberate decision to develop a common, generic inspection system to be used on engines without regard to specific engine manufacture. Several enabling technology studies were conducted by the ML in preparation for initiating a new generic disk inspection system development. The NDE Program funded the PE 6.2 program "Retirement for Cause Inspection System Design" in 1980 with Pratt & Whitney to develop potential design features and specifications for such a system of to meet the inspection goals set by disk design and performance experts. [4.37, 4.38] On October 1981, the Retirement for Cause/ Nondestructive Evaluation (RFC/NDE) contract was awarded to Systems Research Laboratories, Inc. with multiple integrated contractors which included Aircraft and Engine Manufacturers, NDE academia and industry, and Research Institutes.



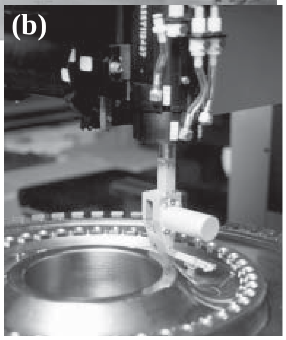


Figure 4.15. Air Force Eddy Current Inspection System (ECIS) for Turbine Disks Inspection During Engine Deport Maintenance. (a) Overall ECIS View. (b) Eddy Current Probe Positioned for Disk Scanning.

The development of higher resolution eddy current probes, together with robotic precision probe positioning and manipulation were essential to meeting the stringent detection requirements. The RFC system (Figure 4.15a and b) surpassed the original intended use by becoming the USAF standard fully automated Eddy Current Inspection Station (ECIS) for the ENSIP and RFC programs at the Oklahoma City Air logistics Center (OC-ALC). Today, the Air Force has 31 ECIS operational at OC-ALC inspecting the F-100 engines (F-15 and F-16 aircraft), F101 engines (B-1B aircraft), F110 engines (F-16 aircraft) and F-118 engines (B-2 aircraft). Benefits from the application of the RFC system has been a return on investment of 25:1, increased engine availability, decrease in engine failures, and projected $1 billion overhaul cost savings.

- **Development of Industrial Based CT System Capabilities.** Based on their feasibility experiments described in Chapter 3, NDE Branch researchers initiated and managed a ManTech program with an Aerojet General-ARACOR team in 1980 to develop a prototype of the first operational industrial x-ray CT system capability of its size specifically for NDI/E. The system shown in Figure 4.16a, which employed a 420 KV x-ray source, a multi-element solid state detector unit and a precision turntable to rotate inspection objects up to a 30-inch diameter reconstruction circle, became operational in 1982. Known as the Air Force Advanced CT System I (AFACTS I), it was the forerunner of several subsequent advanced systems in use today. A second prototype system AFACTS II, with a 15 MeV x-ray source and scaled to scan cross sections up to a 100-inch diameter reconstruction circle, such as the 96-

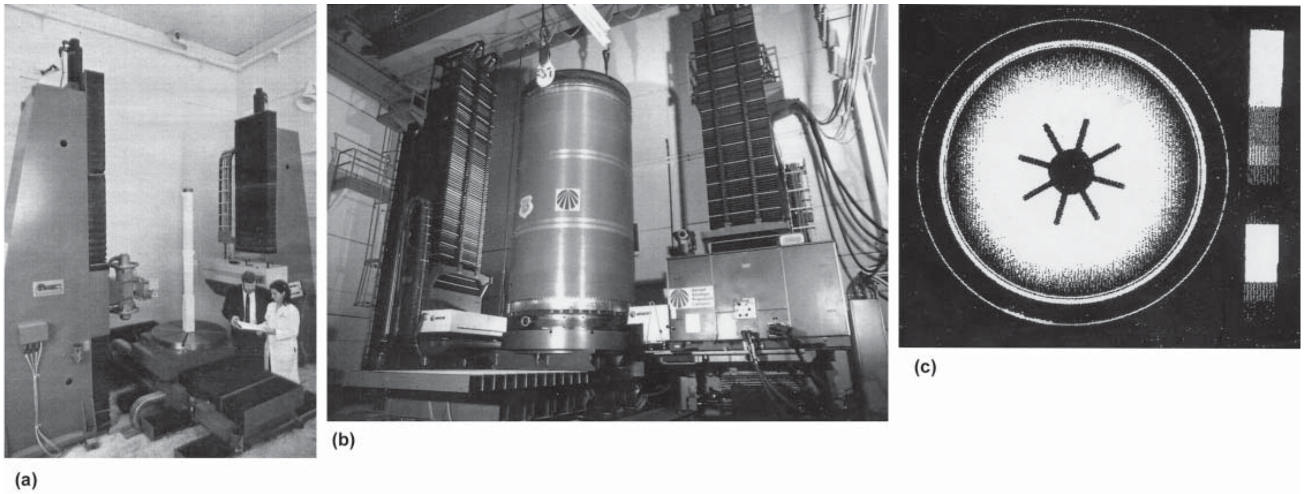


Figure 4.16. Air Force Advanced Computed Tomography Systems. (a) 420 KV Air Force Advanced Computed Tomography System I (AFACTS I), (b) 15 MeV Air Force Advanced Computed Tomography II (AFACTS II), and (c) AFACTS II Image of 96-inch Diameter Peacekeeper Missile Solid Motor.

inch diameter Peacekeeper missile solid motor, is shown in Figure 4.16b. The system demonstrated the capability to produce remarkable images of the Peacekeeper solid motor as shown in Figure 4.16c. During the course of the ML NDE Program efforts to develop advanced CT capabilities, along with numerous briefings to AFLC maintenance commanders, Headquarters AFLC authorized the installation of state of the art facilities at each of the 5 ALCs.

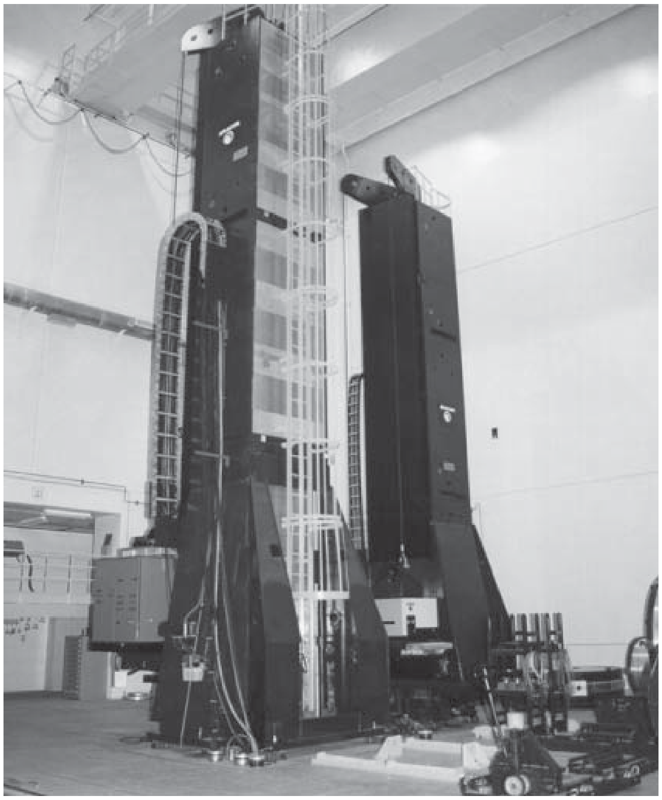


Figure 4.17. Operational 16 MeV X-Ray CT System Installed at Ogden Air Logistics Center for Inspection of Large Solid Motor Boosters. System was Built by ARACOR Based on its Earlier AFACTS II Prototype Developed for ML NDE Program.

An operational system, the largest CT system in use today, based on the AFACTS-II prototype, was built by ARACOR in 1990 for the USAF and is located and in operation at Ogden Air Logistics Center (OO-ALC), Hill Air Force Base, UT. Identified as the ICT 2500 CT System, its sole mission is to support the aging and integrity surveillance of the Air Forces Inter Continental Ballistic Missiles (ICBM) fleet. This system, pictured in Figure 4.17, is capable of handling and inspecting solid boosters ranging from Peacekeeper ICBM first stage down to a Minuteman ICBM 3rd stage. The system specifications/inspection envelope includes:

- 96” diameter
- 336” height
- 150,000 lb Max table load
- Linatron 6000 HRO 15 Million Electron Volt (MeV) radiation source.

A second operational CT facility at OO-ALC is the ICT 1500 CT System is utilized for a two fold mission, our primary mission is to support the war fighter by means of providing CT inspection capability for Minuteman 3rd stage rocket boosters and an assortment of Department of Defense (DOD) munitions (i.e. AMRAAM, Sidewinder). The second mission of the system is for private industry utilization (partnering), the CT system is available for use to the private sector. OO-ALC presently has three contracts/Memoranda of Agreements (MOA’s) with private companies, under which OO-ALC provides CT scanning services for these companies on an assortment of projects. The system specification/inspection envelope includes:

- 57” diameter
- 100” height
- 10,000 lb Max table load
- 1 to 25mm slice thickness range
- 4096 reconstruction under one minute
- Linatron 3000, variable 7/9/11 MeV radiation source.

- **Follow-On CT System Capability and Applications Evaluation Series.** Continuing studies were extended in the late 1980s through the mid-1990s with the Boeing Defense and Space Group’s CT development group to (1) identify and evaluate the technical and economic potential of CT for specific cost-effective applications and to (2) identify modifications of the CT techniques to expand their applicability.[4.39] Also included was the development of a CT Systems Design Specification Guide [4.40] and an on-going economic analysis. Through contract efforts, the following studies and assessment tasks were conducted:

  - CT for Electronics [4.41]
  - CT for Thermal Batteries & Other Closed Systems [4.42]
  - CT for Castings [4.43]
  - CT for Composites [4.44]
  - Guide to CT System Specifications [4.45]
  - CT for Geometry Acquisition [4.46]
  - CT Standards [4.47]
  - CT for Whole System Evaluation [4.48]

- CT for Adv. Materials and Processes [4.49]
- High Resolution CT [4.50]
- CT for Failure Analysis [4.51]
- CT for Casting Development [4.52]
- CT for Casting Demonstration [4.53]
- CT for Emerging Aerospace M&P Devt [4.54]
- CT for Full Scale Castings [4.55]

• **Laser Ultrasonics for Large Area Composite Inspection.** When work began by several research groups in the early 1980s on the potential of laser-generated ultrasonics, the technique appeared to have potential for scanning large area contoured composite components. By having the ability to generate ultrasound traveling normal from the surface into the part without requiring a normal laser beam incident angle or contact with the surface, contoured surface shapes should be easily scanned. The potential for fast scanning of large areas was also considered a major attribute. With this interest, the ML NDE Program provided ongoing exploratory development funding to General Dynamics – Ft. Worth Division beginning in 1982 to augment GDFWs continuing IRAD effort to develop a laser UT system capability for both its factory and potential Air Force depot applications. Early development scans illustrated significant potential capabilities (Figure 4.18).

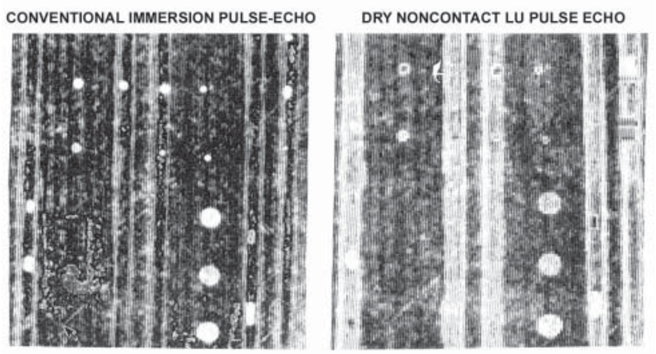


Figure 4.18. Comparison of Conventional Pulse Echo Ultrasonic Image (left) and Laser Generated Ultrasonic Image (right) in Joint Work by General Dynamics – FW and the ML NDE Program.

• **Mobile Automated Ultrasonic Scanner (MAUS) Systems Development.** As part of the Air Force's effort to develop NDE methods to scan large area composite components, the ML NDE Program funded a PE 6.2 exploratory development Program funded a P.E. 6.2 exploratory development program in 1985 with McDonnell Douglas Corporation (MDC) to augment MDCs continuing IRAD effort to develop a breadboard portable hand scan Mobile Automated Ultrasonic Scanner (MAUS). For this purpose, MDC utilized surface scanning methodologies taken from its highly successful Automated Ultrasonic Surface Scanning System (AUSS) developed for production inspection of composite wing structures. The jointly-funded prototype device, designated MAUS-I (Figure 4.19a), consisted of four ultrasonic sensors on a linear oscillating frame (Figure 4.19b) using a water squirt bottle to apply the required couplant.[4.56] MDC continued IRAD efforts centered around the miniturization of the scanning head and with the addition of small plastic tubes feeding water drops to couple sensors to the surface being inspected, thus leading to its second generation MAUS-II version by 1987. In 1988, additional MDC IRAD effort was initiated to integrate eddy current and rersonance scanning into MAUS-II system capabilities. Subsequently, the 3.5 lb MAUS II version was renamed Mobile AUtomated Scanner due to expansion of capabilities beyond ultrasonics. With four sensors, this system was capable of scanning an area of 100 ft2/hr and going into tighter areas when configured with fewer sensors.[4.57]

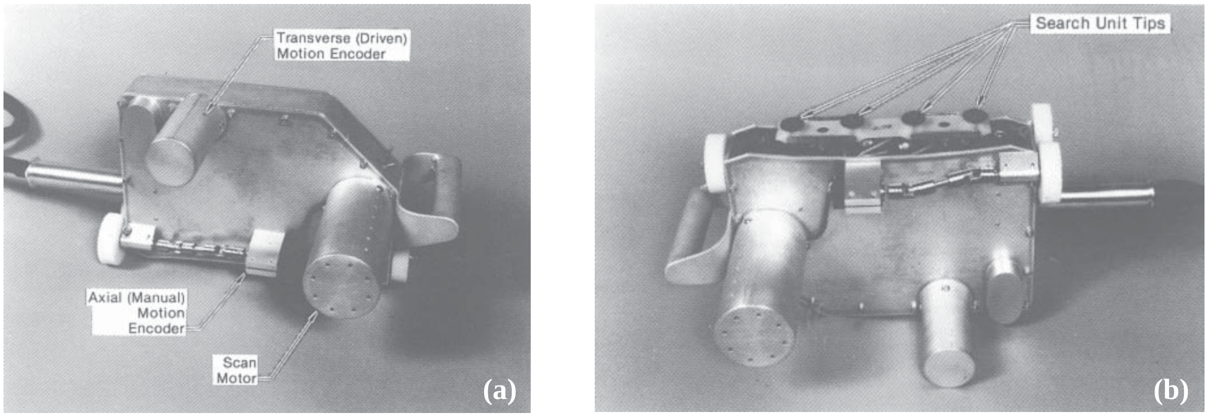


Figure 4.19. Original Prototype MAUS Scanner Head. Shown in (a) was the Unit in the Upright Position on a Surface to be Scanned. (b) Reveals the Transducer Positions.

In-House Research Program 1980-1990

The goals during this period for the in-house research program were to develop and exploit ultrasonic and electromagnetic techniques and instrumentation for the detection and characterization of defects in both thick and thin multilayer structures and engine components. Specific research areas included (a) signal processing methods such as signal-to-noise enhancement techniques; (b) adhesive bond quality characterization through studies of plate vibration modes; (c) improved eddy current detection and measurement techniques, and electrical characterization of cracks; (d) characterization of composite material condition and degradation. Some examples are included here:

- **Advances in Ultrasonic Wave Propagation Theory and Analysis.** Completed during this period was an original experimental and theoretical modeling study by Dr. Dale Chimenti of finite beam ultrasonic wave propagation in coated materials (Leaky Waves) with an experimental verification of the theory for the case of a loading layer coating.[4.58] A potential application cited for this methodology was the determination of coating thickness using the acoustic microscope. For his work, Dr. Chimenti was recognized as a finalist for the 1981 ML Charles J. Cleary Award for Scientific Achievement.

In subsequent research, Dr. Chimenti studied the dispersion characteristics of plate waves in composites, identifying anomalous behavior in the dispersion curve and developing a nondestructive scanning technique based on these leaky plate waves. The scheme devised by Dr. Chimenti permits easy discrimination between critical defects and unimportant plate features. In 1986, Dr. Chimenti was again recognized as a finalist for the 1985 ML Charles J. Cleary Award for Scientific Achievement.

- **Ultrasonic Backscatter Imaging Methodology for Composite Ply Cracks.** While studying how weathering in a graphite/epoxy composite affected the attenuation of normal-incidence through-transmission ultrasonic pulses, Drs. Yosif Bar-Cohen and Robert Crane observed only slight attenuation differences but data scatter larger than the effect itself. Next, using a back reflected or pulse-echo signal, they were unable to see the reflected signal because the surface reflection and those from the inner defects/crazing overlapped. Thus, they decided to examine the reflected signals from an off-normal direction. Using a quasi-isotropic (0, ± 45, 90)S fatigued specimen, they could see all of the ply cracks in each of the differently oriented plies by simply orienting the transducer in a direction perpendicular to the cracks in the different plies (see Figure 4.20).[4.59, 4.60] They could even resolve the cracks in similarly oriented plies located at different depths by time gating the signals. By comparison, these cracks were not visible using the accepted radiograph method in conjunction with exposure to tetrabromoethane (TBE) radiographic penetrant.

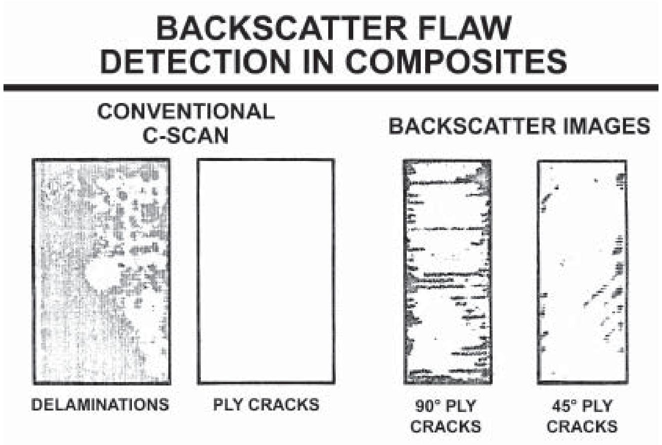


Figure 4.20. Composite Play Cracks.

- **Novel Acoustic Coupling Device for Ultrasonic Scanning.** It was recognized that current portable ultrasonic inspection systems generally required the use of cumbersome methods to couple the acoustic energy into a material or part. Although solid couplants, such as gels, or large amounts of water are used, each have significant operational disadvantages, e.g., inconsistent performance and post-inspection cleanup. Branch researchers Charles Buynak and Dr. Robert Crane studied a new concept in which a semi-permeable membrane was used to contain a water-column delay line, attached at the end to a transducer. This arrangement allowed the simultaneous leakage of very small amounts of water onto the inspection surface. The membrane proved to be virtually invisible to the acoustic beam. These types of commercially available membranes were commonly used for filtration of minute solid particulates from liquids or gases. Several design iterations of the coupling device were constructed and evaluated to optimize the concept. The first experimental design features included ease of changing the candidate membrane, transducer, and focal length of the water column, minimized size of water supply tube and angle of incidence fixed at 90 degrees. The second and third design iterations included flexibility to change the length and diameter of the water column tube to accommodate different diameter transducers, refined design of the couplants water supply tube and ability to perform angle beam or shear wave inspections. Figure 4.21a & b illustrates how the membrane was tightly held by an elastic band at the end opposite the transducer. In this study, membranes of several materials were examined (i.e., nitrocellulose, cellulose acetate, polytetrafluoroethylene [PTFE], and nylon-66).

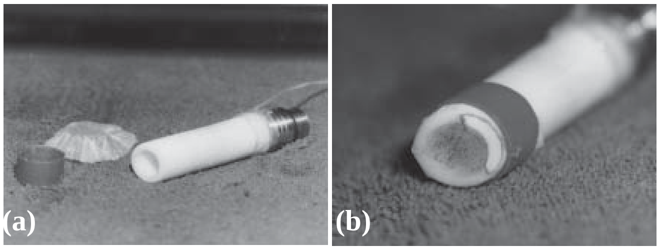


Figure 4.21. Ultrasonic Transducer with Water Delay Line and Permeable Membrane. (a) Components Disassembled. (b) Assembled Transducer.

In an impressive demonstration of membrane ruggedness, a rough surface graphite epoxy sample was mounted on a turntable and scanned with the membrane coupling device. After several days and an approximate distance of 25 miles travel, the membrane finally evidenced a puncture or hole worn section; yet, the acoustic properties appeared unaffected. The experimental characterization of the coupling device prototypes demonstrated their simplicity, accuracy, versatility, durability and low cost.[4.61]

• **Unique Ultrasonic Imaging of Ply-by-Ply Delaminations.** NDE Program in-house researchers developed a new method in 1987 to produce much higher resolution ultrasonic images of defects (delaminations) in composites and with less computation required. Using the new software-gated ultrasonic technique invented by Dr. Thomas Moran to image all major defects not shadowed by the other defects, high resolution delamination images such as those at the top of Figure 4.22 showing low-energy impact damage, became possible. The validity as well purity of the software-gated ultrasonic images was demonstrated by comparison with the actual delamination geometries shown at the bottom of Figure 4.22.[4.62] These damage sites were accurately documented using the comprehensive, meticulous experimental destructive analysis (deplying) and gold chloride staining techniques developed by Charles Buynak. This new software-gated methodology was integrated into the ARIS large area composites system discussed earlier. Dr. Moran and Mr. Buynak were presented with the 1987 ML Charles J. Cleary Award for Scientific Achievement for this development.

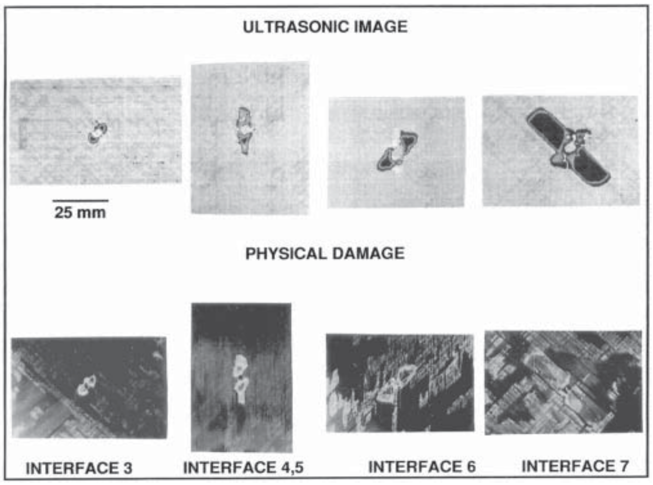
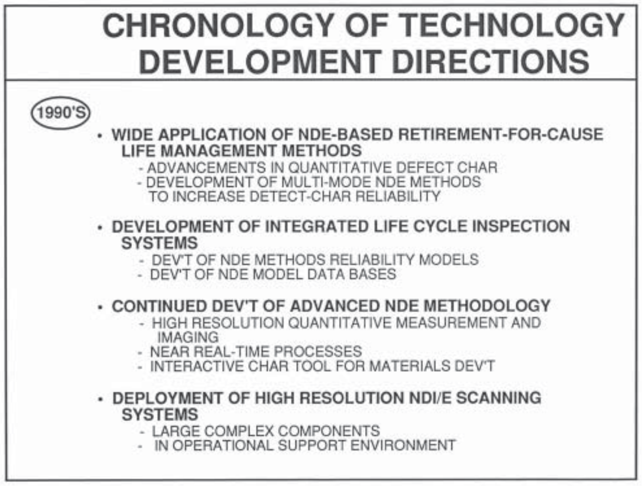


Figure 4.22. High Resolution Composite Delamination Images Generated Using Software - Gated Ultrasonic Technique.

1990 – 2000



CHRONOLOGY OF TECHNOLOGY DEVELOPMENT DIRECTIONS

1990'S

- WIDE APPLICATION OF NDE-BASED RETIREMENT-FOR-CAUSE LIFE MANAGEMENT METHODS
  - ADVANCEMENTS IN QUANTITATIVE DEFECT CHAR
  - DEVELOPMENT OF MULTI-MODE NDE METHODS TO INCREASE DETECT-CHAR RELIABILITY
- DEVELOPMENT OF INTEGRATED LIFE CYCLE INSPECTION SYSTEMS
  - DEV'T OF NDE METHODS RELIABILITY MODELS
  - DEV'T OF NDE MODEL DATA BASES
- CONTINUED DEV'T OF ADVANCED NDE METHODOLOGY
  - HIGH RESOLUTION QUANTITATIVE MEASUREMENT AND IMAGING
  - NEAR REAL-TIME PROCESSES
  - INTERACTIVE CHAR TOOL FOR MATERIALS DEV'T
- DEPLOYMENT OF HIGH RESOLUTION NDI/E SCANNING SYSTEMS
  - LARGE COMPLEX COMPONENTS
  - IN OPERATIONAL SUPPORT ENVIRONMENT

Figure 4.23. Chronology of Technology Development Directions.

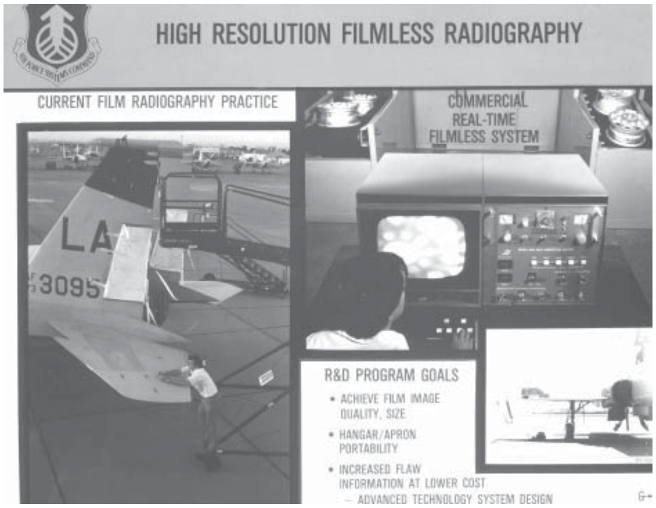
At the turn of the decade of the 1990s, attention was focused on such technology development directions as a wider application of NDE retirement-for-cause life management methods augmented by advances in reliable quantitative defect characterization; development of reliability models for NDE methods, and model data bases; continued development of advanced NDE methods, procedures and instrumentation, including high resolution quantitative measurement and imaging and near real-time processes; and deployment of high resolution NDE scanning systems for large complex components in the operational support environment.

The specific rank-ordered Logistics Needs (LN) for NDI issued by AFLC for Fiscal Year 1991 - 1992 to emphasize its priority development needs were:

- Detection of Hidden and Inaccessible Corrosion
- NDI of Aircraft Panels using Real Time Radiography

  - Rapid NDI for Advanced Composites with Complex Shapes, Variable Densities
  - Rapid Inspection of Composites
  - Rapid Inspection for Engines
  - Inspection of Brazed Abradable Airseals
  - NDI Techniques for Crack Detection in 2nd Layer Structures
  - Inspection of Stainless Steel
  - NDI Techniques to Reliably Detect 0.02 – 0.05 inch Fatigue Cracks

• **The Quest for High Resolution Filmless Radiography Capability.** As the cost and workload of utilizing film-based radiography NDI escalated in support of in-service and depot maintenance operations, the need for filmless methods became apparent. Conservative cost estimates for field-level radiography (as in Figure 4.24 [left]) exceeded 0.7 manhours and $8 for film and processing in the 1980s. As a frame of reference, almost 2,000 film radiographs would be taken of one C-5A transport during a major inspection.[4.63]



HIGH RESOLUTION FILMLESS RADIOGRAPHY

CURRENT FILM RADIOGRAPHY PRACTICE

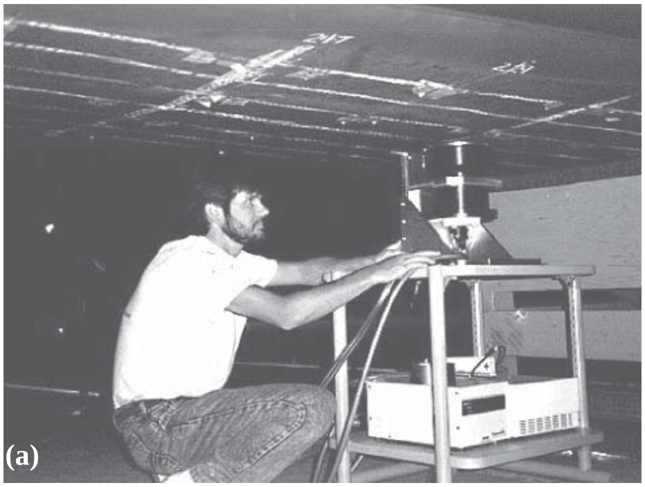
COMMERCIAL REAL-TIME FILMLESS SYSTEM

R&D PROGRAM GOALS

- ACHIEVE FILM IMAGE QUALITY, SIZE
- HANGAR/APRON PORTABILITY
- INCREASED FLAW INFORMATION AT LOWER COST
  — ADVANCED TECHNOLOGY SYSTEM DESIGN

Figure 4.24. High Resolution Filmless Radiography (Vugraph)

In 1989, the NDE Branch launched a study of several methods to produce a high resolution real-time radiography (HRRTR) capability for on-aircraft inspection, producing a digital output in place of conventional film images, such as depicted in the lower right part of Figure 4.24. These previous SBIR and exploratory development efforts identified several solid state imaging candidates. In 1991, the NDE Branch contracted with Lockheed Missiles and Space Company in 1991 for an advanced development and demonstration program to evaluate the most promising prototype system including X-ray source, solid state detector, advanced data processing and image analysis.[4.64] The resulting prototype featured a fiber-optic scintillating faceplate/screen x-ray to light converter and charge-coupled device (CCD) imaging line pairs per millimeter (lp/mm) were achieved with dynamic ranges of 50 times better than film technology.[4.65] Figure 4.25a shows the HRRTR imager positioned to inspect a sine wave spar in a B-1 bomber horizontal stabilizer. Shown in Figure 4.25b is the x-ray image.



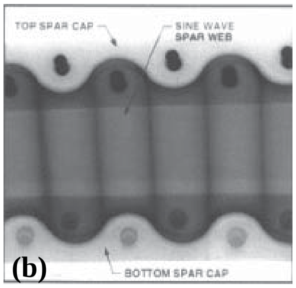


Figure 4.25. HRRTR Prototype Imaging System Undergoing Field Evaluation at Oklahoma City Air Logistics Center. (a) Fiber-Optic Scintillating Screen Charge-Coupled Device (CCD) Imaging System Being Positioned for Test; (b) High Resolution Digital Image of B-1 Horizontal Stabilizer Sine Wave Spar.

At this point, the competitive commercial market interest in industrial solid state digital imaging devices and equipment reached a level where additional Air Force development funding was no longer needed to meet its requirements.

• **NASP Government Work Package (GWP) on X-30 Aircraft NDE.** Within the National Aero-Space Plane (NASP) program, accurate and reliable NDE capabilities were considered critical. They were needed to meet manufacturing quality, structural integrity and flight safety requirements for the many unconventional materials and structural components for the planned X-30 vehicle. Numerous GWPs were created for various technical initiatives to be performed by Air Force, Navy and NASA laboratory organizations. The NDE Program was responsible for GWP 100 (NDE), initiated in 1990, in which NDE Branch retirees Donald Forney and Dr. Joseph Moyzis led a team of nationally recognized experts in a three-year study that (1) identified the principal NDE requirements, (2) evaluated the current or near term NDE capabilities available to the program, (3) recommended changes in practice where appropriate and (4) identified additional NDE development efforts where essential.[4.66] From sixteen development recommendations, four essential improvements were emphasized, including NDE for critical protective coatings, bondlines and two types of actively cooled structures (microchannel-based and thin wall tubing-based). Also emphasized was the need to perform test article NDE both before and after tests to help generate the data needed to maximize NDE accuracy and reliability. In the course of this study, several emerging NDE methodologies potentially valuable for detecting and characterizing manufacturing process defects and anomalies in NASP materials were evaluated. The upper picture in Figure 4.26 is a high resolution real-time filmless digital X-radiograph of a 4-ply titanium matrix composite laminate panel for NASP revealing fiber swimming defects, imaged by the high resolution 2048 X 2048 CCD prototype system being developed for the NDE Program by Lockheed Missiles and Space Company. The center and lower images in Figure 4.26 are, respectively, eddy current and ultrasonic scans, of the same areas as above, by McDonnell Douglas Corporation, using its mobile automated scanner (MAUS) prototype under development with joint MDC-NDE Program funding, to provide a direct comparison. Also included in the evaluations was the application of the laser-generated ultrasonics system being prototyped by General Dynamics Corporation-Ft. Worth. At the top in Figure 4.27a is illustrated the detection of eight delaminations inserted in a nine-ply carbon-carbon composite specimen, with the shallowest delamination at the upper left and increasing one ply in depth each image clockwise to the deepest at the lower left. In the bottom part of Figure 4.27b is shown the successful detection of density variations in a C-C specimen.

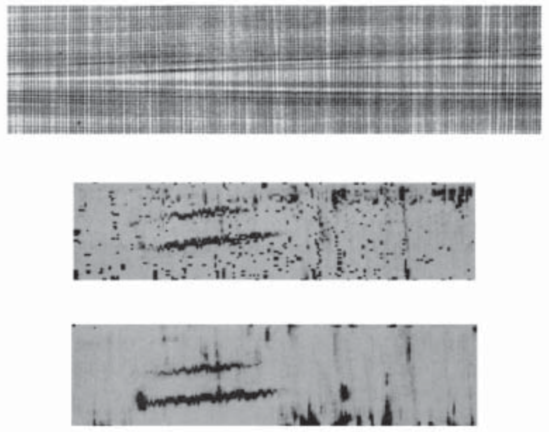


Figure 4.26. (top) High Resolution Real-Time Digital Radiograph of TMC Laminate "Fiber Swimming" Defects; (center) MAUS Prototype Eddy Current Scan of Same Area, (bottom) MAUS Prototype Ultrasonic Scan of Same Area

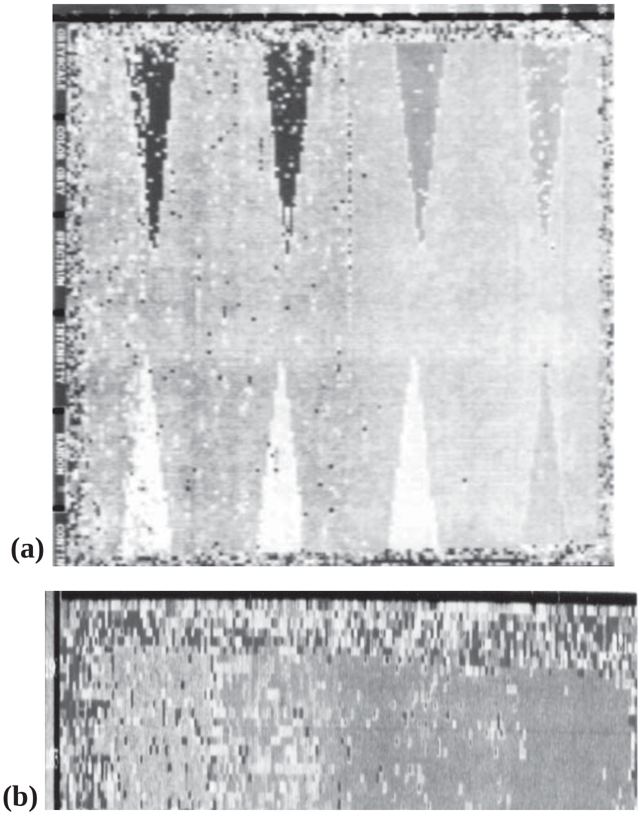


Figure 4.27. Laser-Generated Ultrasonic Imaging. (a) Delaminations in 8-Ply Carbon-Carbon Composite Specimen (upper left shallow, lower right deepest). (b) Detection of Density Variations.

- **Large Area Component Inspection Systems (LACIS).** As the need grew for faster, more efficient methods for inspecting large area components, such as composites, attention was directed toward new and unique processes. Not only had there been an increased volume of composite production, there had also been a dramatic increase in part complexity. Several promising approaches, some of which were explored during the mid to late 1980s, were initiated in the newly established NDE Advanced Development Program (ADP) described in Chapter 3, starting in 1989 (see Appendix F-. Chief among these efforts were (a) laser generated ultrasonics (LGU), (b) Mobile Automated Scanner (MAUS), (c) Diffracto D-Site, (d) high resolution real time radiography (HRRTR), and (e) High Resolution 3-dimensional Computed Tomography (HR3DCT).

(a). Laser Ultrasonics for Large Area Composite Inspection. The GDFW laboratory breadboard laser ultrasonic system discussed above was demonstrated successfully to the ML NDE Program in 1990. A follow-on funded multi-year effort, called an Air Force Reliability and Maintainability Technology Insertion Program (RAMTIP), was secured by the NDE Program and conducted at the AFLC Sacramento Air Logistics Center (SM-ALC), under the technical guidance of NDE Program scientist Dr. Curt Fiedler, to further demonstrate and improve the system. In that program, the prototype, pictured in Figure 4.28, was called LUIS (Laser Ultrasonics Inspection System). In 1993, advanced development funding was applied to the development work by the ML NDE Program as part of its continuing effort to evaluate and help improve the GDFW laser UT prototype.

Figure 4.28. Early Laser Ultrasonics Inspection System (LUIS).

Since that time, the successor company, Lockheed Martin Aeronautics in Fort Worth and its predecessors capped 16 years of research and prototyping to develop the current system, known as LaserUT™. The system is able to handle components up to 54 feet long, 27 feet wide and 21 feet high. The inspection rate averaged approximately 64 ft^2 per hour. Future laser improvements should increase the rate to over 160 ft^2 per hour The “Alpha” facility went on line in January 1999, and the “Beta” facility was approved for production use in June 2000.[4.67, 4.68] With a demonstrated 90% reduction in inspection time for equivalent components and requiring no expensive fixturing, manufacturing span times are shortened significantly with cost savings expected over the course of F-22 and F-35 Joint Strike Fighter production. Projections at the time suggested that LaserUT™ might save several hundred million dollars over the service lives of next generation fighter aircraft through similar inspection time reductions.[4.69]

(b). Mobile Automated Scanner (MAUS) Systems Development. In 1992, PE 6.3 advanced development funding was provided to MDA to expand and improve on the design and functional capabilities of the MAUS-II prototype, including advanced scanner design, signal conditioning and data management, as part of the ML NDE Program’s initiative to develop a Large Area Composites Inspection System (LACIS). This program resulted in the development of the third generation MAUS-III system capable of 200 square feet per hour data acquisition, lightweight (less than 20 lbs), and rapid setup in less than 10 minutes. Furthermore, the system was capable of configuration changes in less than five minutes, and multiple inspection modes – UT pulse echo, UT resonance, and eddy current. This allowed damage detection in composite laminates, co-cured complex composites, bonded assemblies and metallic structures. MAUS III was evaluated by Boeing in 1993 on C-17 structures and by Northrop on B-2 structures. It is shown in Figure 4.29 being evaluated on a KC-135 wing at the Oklahoma City ALC. It was deployed to the five Air Force Air Logistics Centers for field trials and evaluation.

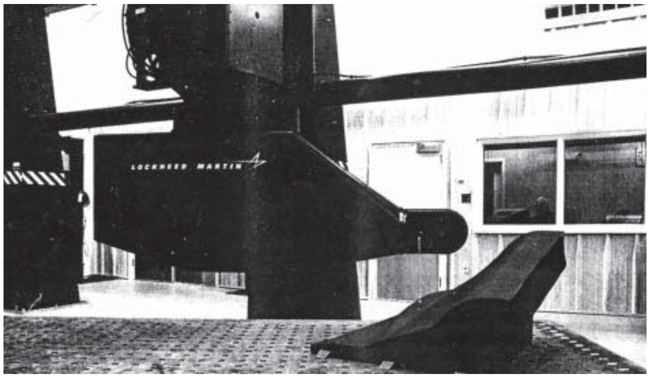


Figure 4.29. Lockheed Martin LaserUT™ System Scanning a Complex Composite Duct.

In 1998, a P.E. 7.8 manufacturing technology effort was initiated, with the assistance of the NDE Program, to increase the manufacturability of the system, focusing on inspection of disbonds and delaminations. This resulted in the MAUS IV version, featuring improved equipment portability, easier setup, greater versatility and very fast inspection rates (100 sq ft/hr @ 0.04 inch pixel size. Over fifty MAUS IV systems entered service throughout the world.

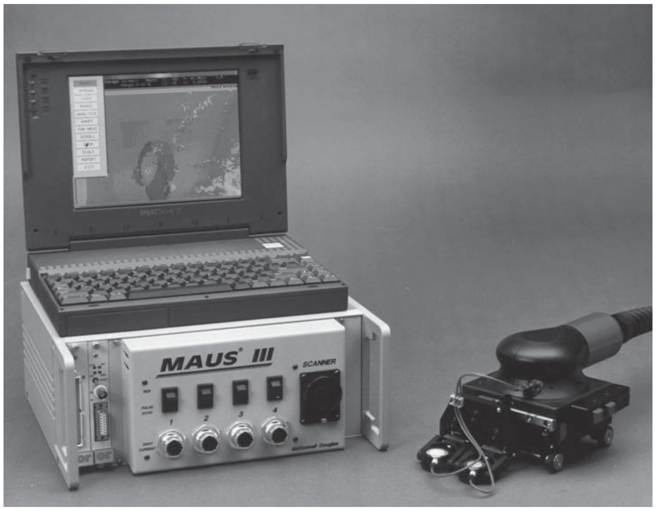


Figure 4.30. Mobile Automated System (MAUS) III.

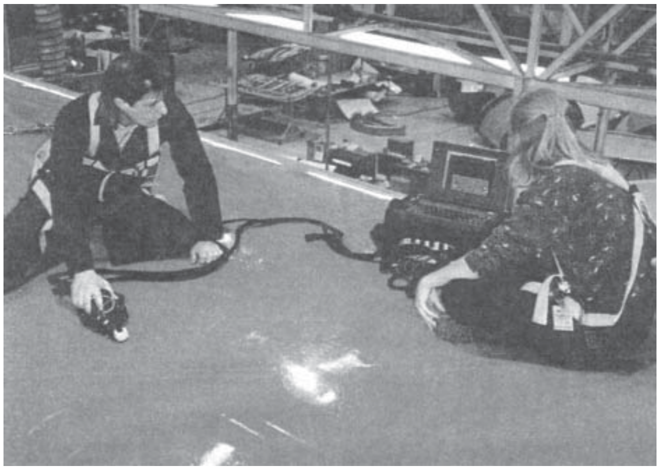


Figure 4.31. Mobile Automated Scanner (MAUS) III Inspecting KC135 at Oklahoma City ALC.

The Aeronautical Systems Center (ASC) Aging Aircraft Program Office (AAA) launched an Advanced Technology Demonstration (ATD) P.E. 6.5 program in 1999-2000, with the assistance of NDE Program engineers, to facilitate and hasten the transition of selected newly developed and enhanced NDE technologies with immediate applications to aging aircraft inspection and characterization requirements. One of these efforts focused on the incorporation of newly developed, more accurate capabilities to detect and measure corrosion thinning (coined TCORR). The effort incorported results from parallel ML NDE advanced development programs, and enhanced with advanced automation features. Included with this upgraded version were improved software features such as data filter algorithms to highlight corrosion, and a new software database system to reduce inspection setup times. In addition, the enhanced architecture provided a platform to support many other capabilities that require faster rates of data processing, such as linear and phased ultrasonic arrays and multi-frequency/pulsed eddy current. One application of the new capability has been to KC-135 tapered lap joint inspection.

Other advanced development work was completed also to adapt new Transient/Pulsed Eddy Current technology into the MAUS IV platform in order to facilitate more accurate inspection into thicker structures than possible with previous traditional eddy current methods. The results of this 2005-06 transition program (coined PECTRAN - Pulsed Eddy

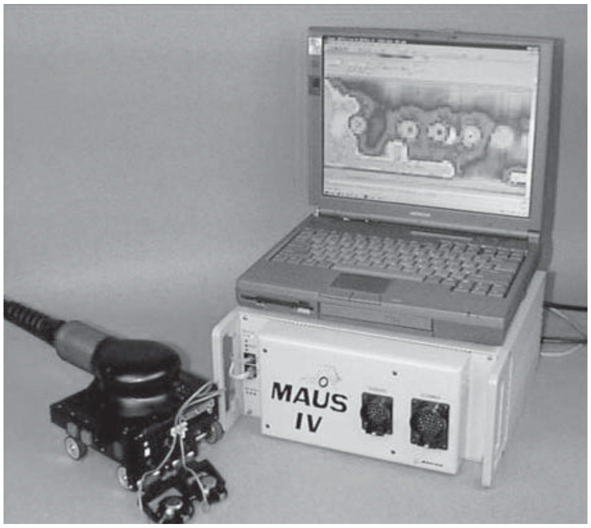


Figure 4.32. Mobile Automated System (MAUS) IV.

Figure 4.33. Mobile Automated System (MAUS) IV Scanning On-Aircraft Airframe Component.

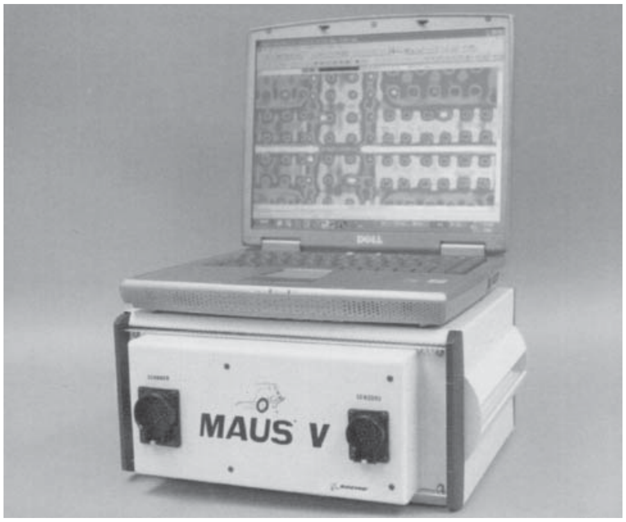


Figure 4.34. Mobile Automated System (MAUS) V.

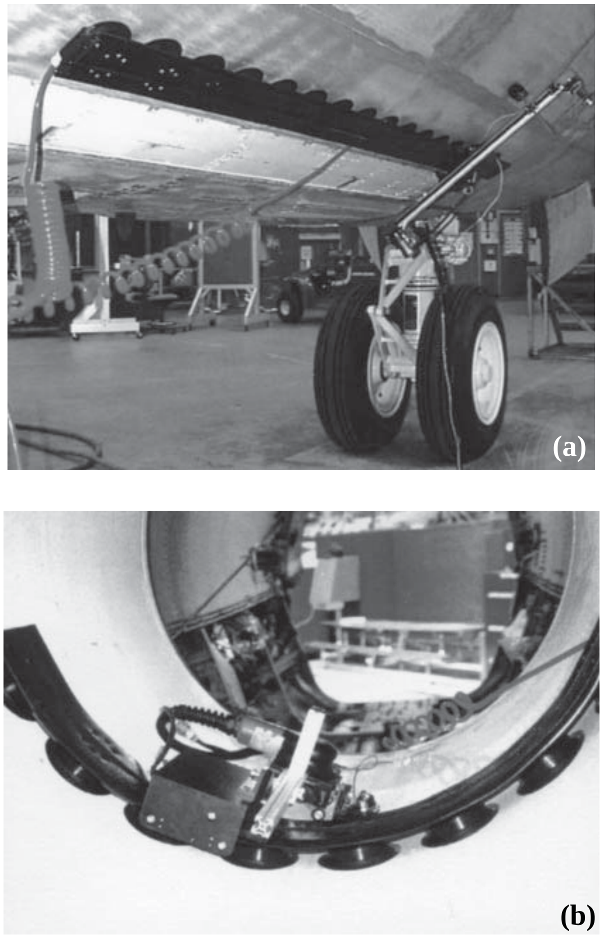


Figure 4.35. MAUS V Scans Guided by Flexible Tracks can Produce Fast, Accurate Inspection Results. (a) - Guided Scan Along an Aircraft Fuselage Lap Joint. (b) - Controlled Scan of a Confined Interior Complex Curvature.

Current Transition), which is funded by ASC/AASS, is demonstrating the application of this technology for B-52 BL55 inspections.

Under the guidance of engineers from the NDE Program and the sponsor Aeronautical Enterprise Program of ASC (ASC/AAA), the fifth generation model of the Boeing Mobile Automated Scanner (MAUS-V) was transitioned in October 2003 to the Oklahoma City Air Logistics Centers use on the E-3 aircraft, then later on the KC-135 and B-52 aircraft. In comparison to MAUS-IV, MAUS-V provides greater depth resolution, higher data processing speeds, improved software features that better highlight corrosion, provides reduced inspection setup times, and more. The faster data processing capability will, for example, reduce some KC-135 inspection times by 50 percent.

The MAUS flexible track, which is attached to the part surface using vacuum pressure created from a shop air source, provides fully automated, hands free scanning capability. Two track sections mounted end-to-end are provided to allow the operator to "leap frog" the sections for long continuous inspections, e.g., on an aircraft lap joints, as illustrated in Figure 4.35a. The track also conforms to complex curvatures as the aircraft air intake duct illustrated in 4.35b. Upgrading of available MAUS IV units at the ALCs to MAUS V was initiated to capitalize on the new features.

(c). D-Site™ Aircraft Inspection System (DAIS). During the late 1980s, Diffracto Ltd. of Windsor, Ontario, Canada experimented with and developed a prototype light-reflection-based surface inspection devise for detecting the presence of hidden corrosion in aluminum aircraft skin structures. In simplified terms, the prototype devise, which is enclosed in a light-tight box (Figure 4.36) illuminates a surface being inspected with a white light source. The aircraft surface must

Figure 4.36. D-Site™ System Positioned on an EC-135 Aircraft Radome for Inspection.

be reflective, or be made reflective with a thin film of highlighter. Any local curvature variations on the surface will act to focus or disperse the light onto a retroreflective screen as a unique pattern of bright and dark gray-scale variations related to the surface distortions. The light returned by the retroreflector is detected by the D-Site™ sensor which uses a CCD camera. Figure 4.37 shows a D-Site image of "pillowing" around fasteners due to the higher volume of corrosion product than the aluminum it replaced. The D-Site system, which is lightweight, portable, lightight and self-contained, demonstrated considerable sensitivity to corrosion in lap splices.

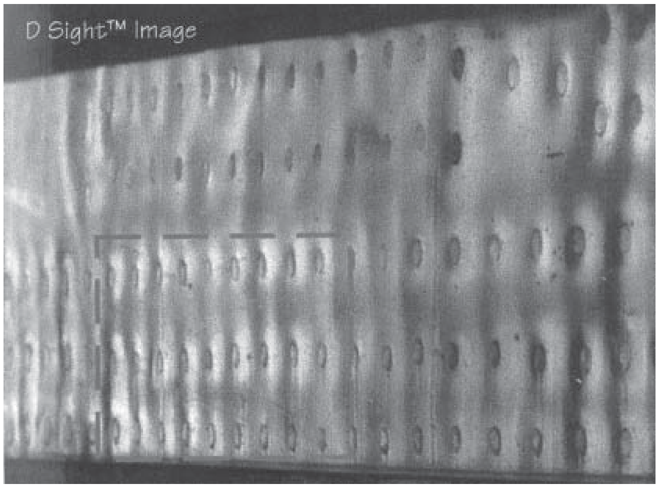


Figure 4.37. D-Site™ Image Revealing Evidence of Subsurface Corrosion Beneath Component Surface. The "Pillowing" and Consequent Bright Haloing Around the Rivet Fasteners is Due to the Greater Volume of Corrosion Product than the Aluminum it Replaced. The Greater the Surface Deflection, the Greater the Amount of Corrosion.

(d). High Resolution Digital Radiography System for On-Aircraft Component NDE. In partnership with the ASC Aeronautical Enterprise Program Office (AEPO) within the ATD program, the NDE Program initiated the Digital Radiography Insertion Program (DRIP) in 2002. This significant engineering development effort accomplished the design, building and integration of Digital Radiography (DR) systems into production NDI facilities at Warner Robins ALC (WR-ALC), Robins AFB, GA and Oklahoma City ALC (OC-ALC), Tinker AFB, OK (See also Chapter 6). The system advanced designs incorporate the optimal industrial DR system components currently available for real time radiography at inspection speeds comparable to or exceeding contemporary film procedures. Included are (1) a General Electric DXR-250RT flat panel detector system and the GE Radworks 5.1 imaging software and (2) a Siefert 160 kV MicroFocus X-ray source. A key component of the 10-axis x-ray (MAX) system is the programmable manipulation of the x-ray source and detector about the aircraft in a safe, programmable, and repeatable manner that utilizes the existing F-15 x-ray hangar facility (Fig.4.38). The system, which became operational in 2004, is shown performing an automated NDE scan of the right vertical tail of an F-15 fighter.

Figure 4.38. Automated High Resolution Real-time Multi-Axis Radiography (MAX) System for On-Aircraft Nondestructive Inspection. The System is Shown Scanning an F-15 Vertical Tail.

The inspection head containing the aligned x-ray source and digital detector package is programmed to scan virtually all critical areas of a component and transmit digital x-ray data for computer analysis.

(e). High Resolution 3-Dimensional Computed Tomography (HR3DCT). Solid rocket motors (SRMs) are typically built with an outer casing, internal insulation and solid propellant, all of which are separated by bondlines with adhesives and barrier coatings. These must be accurately applied to assure correct operation and prevent flaws or gas paths to bondlines which can lead rapidly to catastrophic failure of the SRM during vehicle launch. A major challenge is to correctly and precisely detect and quantify such flaws. While NDE with both radiography and computed tomography (CT) is used, the former produces inadequate bondline resolution and the latter insufficient spatial resolution to recognize bondline separations as small as 10 mils (0.010 inch).

From 1993 to 1995, NDE Program engineers worked with a contract team of experts to develop a novel solution: high resolution 3-dimensional computed tomography. The team, headed by Perceptics, Inc., included Skiametrics, Inc., Alliant Telesystems, Inc., Lockheed Martin Missile Systems, and Tufts University.

Since the bondline defect detection required good through-the-thickness spatial resolution of the bondlines in the radial direction only, this was achievable by continuously scanning slowly along the length of an SRM while it is rotated in a tangential radiography fixture (pictured in Figure 4.39). The reconstructed data exhibited sensitivity comparable to conventional CT. The x-ray source mounted on an extension arm is shown positioned near the top side of the SRM with the detector aligned diagonally across on the lower stand. The reconstructed data exhibited sensitivity comparable to conventional CT.[4.70]

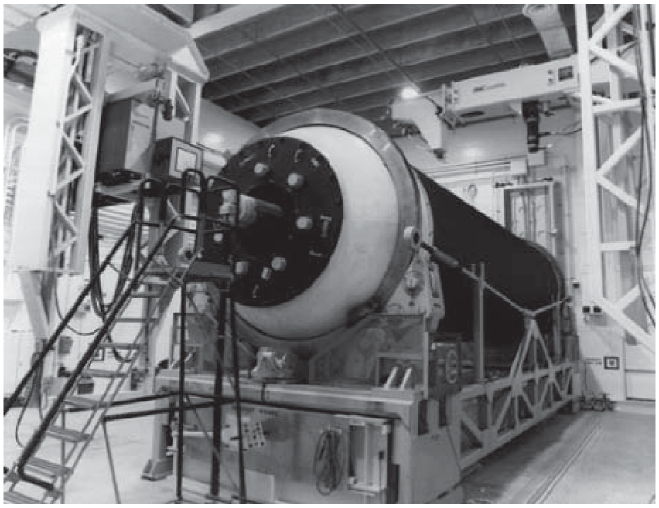


Figure 4.39. Solid Rocket Motor Mounted on the HR3DCT Rotary Stand for Bondline Inspection.

- **Advanced Technology Upgrade of RFC/ENSIP Inspection System.** The objective of this advanced development program was to enhance the inspection methods and equipment being used in the RFC and the ENSIPs at SA-ALC and OC-ALC since the late 1980s to inspect the Air Force's advanced supersonic gas turbine engines. The result of this upgrade effort was expected to bring about a further reduction in the operation and maintenance costs associated with turbine engine sustainment efforts. This program directly addressed stated needs relating to upgrading key elements of the eddy current inspection systems (ECIS), such as enhancing eddy current probes and eddy current instrumentation, incorporating PC technology, creating an automated scan plan generation tool, providing more precise calibration of eddy current probes, improving the robotic signal controller system and providing probability of detection (POD) reliability analysis studies.[4.71] ECIS systems have been in production for more than 15 years, inspection almost $1 billion in engine components.

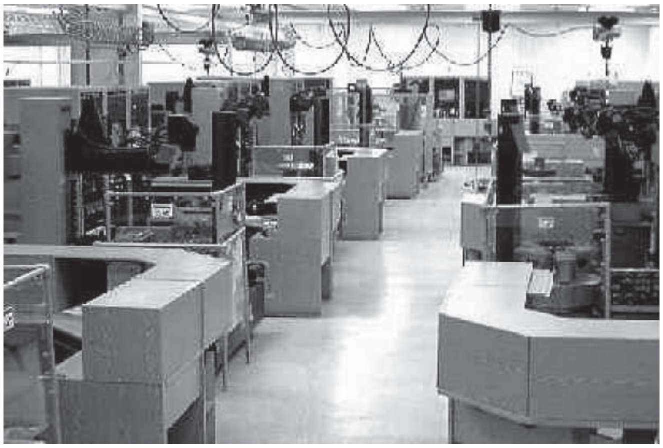


Figure 4.40. State of the Art Turbine Disk ECIS Facility at Oklahoma City Air Logistics Center.

- **Nondestructive Evaluation for Low Observables.** Research investment in the area of NDE for low observable (LO) materials began in earnest in 1997 following the identification of several LO material maintainability issues by Air Combat Command (ACC). It was determined that maintenance of LO material systems was driving maintenance on LO platforms and impacting aircraft availability. In order to decrease this impact, new development effort in several technical areas for LO materials maintainability were initiated as a priority and coordinated between ASC, the AFRL NDE Program and ACC. Developments began on several improved methods of NDE of LO materials and components being used on advanced stealth weapon systems. One such initiative, an initial multi-functional point inspection tool, pictured in Figure 4.41, was developed by the Lockheed Martin "Skunk Works" and dubbed the MM-

Figure 4.41. Evaluation of LO Component on F-117 Stealth Aircraft with a Point Inspection Tool Developed Under Contract by Lockheed Martin Skunk Works.

704A. It proved to be capable of measuring the LO signature integrity of operational aircraft, marking it as an important milestone in the continuing development of fieldable advanced capabilities.[4.72]

In order to formalize this investment, an Advanced Technology Demonstration (ATD) program was commissioned in 2001 to ensure the development and transition of LO maintainability technologies from AFRL to ACC. Furthermore, it identified areas of responsibility for the technology developer, AFRL, and ACC, the technology user in developing and transitioning the technology. These roles and responsibilities were documented in the governing Technology Transition Plan (TTP). One of the technology areas identified, prior to and as part of the ATD, nondestructive evaluation for low observables (designated LONDE), was subdivided into four development sub-thrusts: 1) RF LONDE - handheld inspection tools to measure the material properties of LO materials and determine the effect of material defects at radio frequencies; 2) IR LONDE - handheld inspection tools to measure the LO material performance at infrared frequencies; 3) RF Imaging - portable imaging systems to inspect the performance of LO materials following material repairs; 4) Signature Management LONDE - technology to determine the impact of material defects on signature using data measured by tools developed in the other three sub-thrusts.

In subsequent years, insight has been gained into several of the LO material inspection techniques and the focus of investment narrowed from four to two sub-thrusts. Current development efforts focus on the RF LONDE and Signature Management LONDE sub-thrusts. The goal of LONDE is to provide to LO platform maintainers easy-to-use LO material inspection systems and to use the data collected to determine the impact of materials defects on signature. In addition, it will provide input into larger signature management systems to better help users plan for maintenance and improve the rates of aircraft availability.

- **Next Generation Cracks Under Fasteners (CUFS) Detection System Developments.** In 1998, the Air Force began considering options for an Autoscan replacement. A trade study indicated that a phased array ultrasonic approach to have the greatest promise. In 1999, the ASD Aging Aircraft Program Office (AEPO) initiated a new “Autoscan Redesign” project, in coordination with the E-3 aircraft program office, with a new design approach (dubbed FastFocus) based on the use of a phased-ultrasonic-array developed by RDTech. As the FastFocus program was reaching completion, the E-3 system program office determined that its particular inspection requirement could be eliminated. Subsequently, the T-38 weapon system program initiated a similar follow-on T-38 Rotoscan Replacement effort, in conjunction with the OO-ALC NDI Office, to replace aging T-38 Rotoscan system, in operation for many years. This program, started in late 2005 with Olympus NDT, will use the new Omniscan system design with the updated phased-ultrasonic-array technology and focus on the rapid inspection of more than 18 different T-38 CUFS on each aircraft. The inspection capability will include detection of first-layer fastener hole cracks 0.05 inch deep by 0.06 inch long cracks along the hole shank beyond the countersink. Inspections sites will include fastener-filled holes from 3/16 inch to 5/16 inch in diameter.

In-House Research Program 1990-2000

The initial vision for this period was to explore, modify and extend physical measurement principals (and potential NDE methods) for application to the quantitative nondestructive evaluation of advanced materials and structural geometries. A major goal was to improve the detection reliability and quantitative characterization of flaws in layered media and multiphase materials and apply them to critical Air Force problems. Specific emphasis was placed on (a) signal and imaging methodology to efficiently extract and fuse defect and material property information from multiple NDE measurements and (b) development of models, measurements and signal processing with potential field applicability.

By 1996, the research plan was modified to include studies of nondestructive characterization of advanced materials, advanced signal processing methods, and of potential NDE methods for precise in-situ process control and characterization of materials such as metal and ceramic matrix composites. Target capabilities included direct interrogation of fiber-matrix interfaces, shear stress transfer at fiber matrix interfaces, and detection of fiber breaks during loading. Project examples included:

- **High Resolution Micro-NDE Tools and Methods.** The NDE Branch in-house research program included the development and improvement of several more approaches to characterize materials:

High Precision Scanning Acoustic Microscope (HiPSAM). Developed in 1992 and shown in Figure 4.42, this tool uses high frequency ultrasonic waves (up to 200 MHz) and high positional scanning resolution of 1 micron on all three axes to perform materials characterization studies and detection of minute defects, such as titanium hard alpha, high cycle fatigue and defects in microelectronic components. The HiPSAM was utilized in support of the joint DOD – NASA X-30 National Aero-Space Plane (NASP) development program to study interlayer oxidation and deterioration in titanium matrix composite laminates found to occur in the vicinity of cracks at high temperatures, as seen in Figure 4.43. This ultrasonic C-scan generated at 50 MHz revealed subsurface oxidation damage along fiber-matrix interfaces extending away from cracks propagating from a notch in a titanium matrix composite during high temperature crack propagation tests. Image accuracy was verified by a post-test matrix removal (etching) technique.[4.73]

Figure 4.42. Fine-Tuning a Material Characterization Test in the High Precision Scanning Acoustic Microscope.

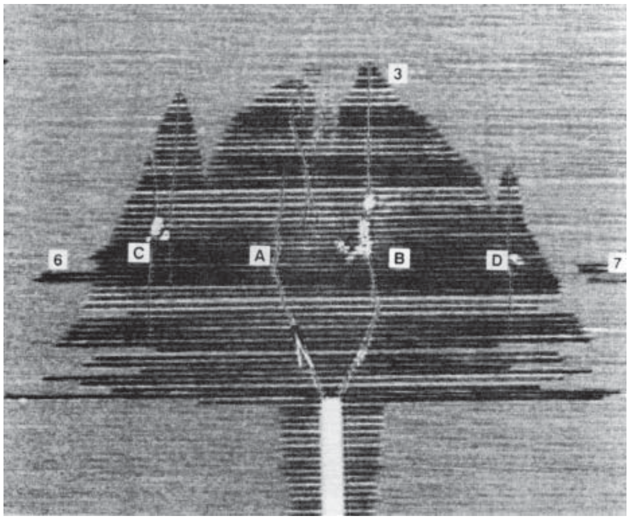


Figure 4.43. High Frequency Ultrasonic C-Scan Revealing Subsurface Oxidation Damage Adjacent to Cracks in TMC Laminate.

<u>Thin Layer Ultrasonics</u>. Under the direction of Dr. Curt Fiedler, the use of high frequency laser ultrasonics was explored as a method to perform the highly accurate interferometric characterization of properties of very thin films. Given the name Picosecond Laser Ultrasonic System (PLUS), the experimental system can inspect materials which are not piezoreflective, such as materials used in semiconductors. The interferometer used in the system has the same sensitivity, but a frequency range that is four orders of magnitude larger than, conventional interferometers. The precision experimental system developed by Dr. Fiedler is shown in Figure 4.44. A delay line in the initial beam path is used to increase the frequency response of the interferometer to allow the detection of ultrasonic echoes in thin films. Figure 4.45 shows the beam splitter cube in a novel orientation that results in improved noise rejection qualities. Examples of applications include quality and integrity characterizations of non-transparent ultra thin protective coatings and films, in the range from 100 nm to 1mm, on microelectronic devices and turbine engine blades and other thin coatings used by the Air Force.

Figure 4.44. Fiedler Operating PLUS Experimental System.

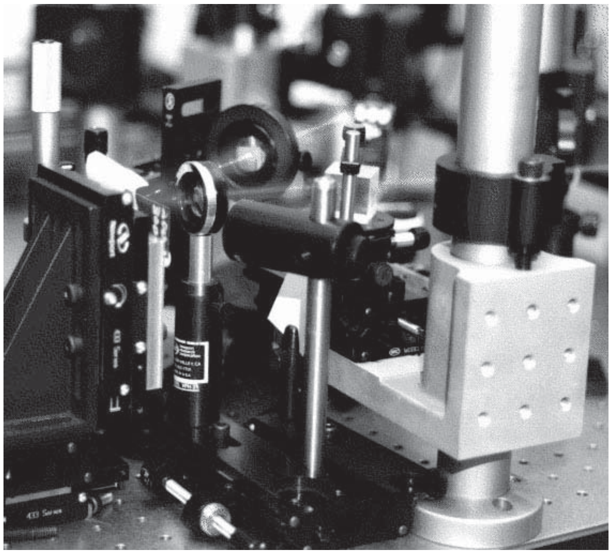


Figure 4.45. PLUS Beam Splitter.

- **New NDE Method to Detect Wing Structure “Weep” Hole Cracks.** The in-house research team developed a novel creeping wave technique for the purpose of detecting small, virtually inaccessible cracks in any of the 1860 fuel transfer holes or “weep” holes through internal risers in wet-wing structures (used as fuel tanks) of each Air Force C-141 transport. The purpose of the 0.25-inch-diameter holes is to permit the even distribution of remnant fuel during flight.[4.74] These holes became sites where fatigue cracks that are difficult to detect tend to originate, primarily growing upward over time to weaken the stiffener and diminish wing integrity. Downward cracks could also occur and are more easily detected. The Air Force grounded 45 C-141s and limited 116 of the of the transport aircraft from any in-flight refueling because of mounting evidence of excessive weep hole cracking.[4.75, 4.76] Since the conventional creeping wave technique experiences a strong specular reflection from the near surface of the hole that masks the creeping wave arriving later in time, an advanced split aperture (two element) transducer was used that resulted in both specular and creeping wave echoes of approximately equal magnitude. Using the two transducers alternately between pitch-catch and pulse-echo modes, as illustrated in Figure 4.46, provided the return of a distinct crack detection signal with a crack length sensitivity threshold of 0.003 inch to 0.020 inch (the latter due to system saturation).

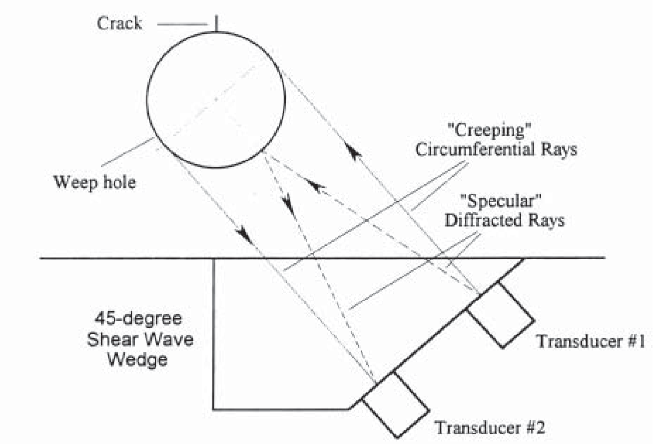


Figure 4.46. Schematic Diagram of the New Split-Aperture Creeping Wave Technique with a 45° Shear Ware Wedge.

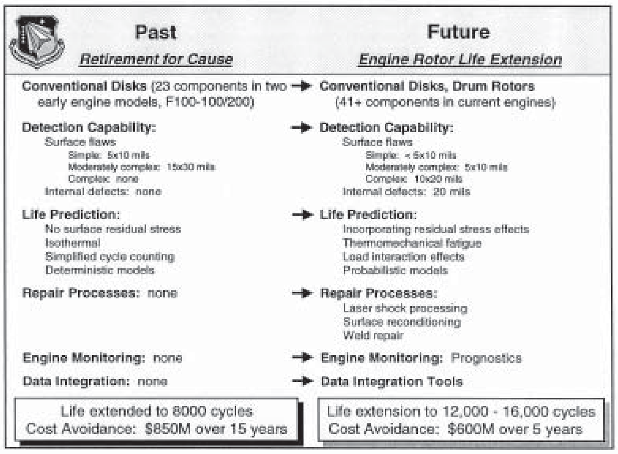
While the inspection technique developed for the C-141 Weep Hole was not deployed, the methodology was adapted to suit another structure in a different aircraft that had a similar geometry - the lower forward spar cap structure of the C-130 Hercules. The transition of the inspection process from the C-141 configuration to the C-130 configuration was funded by the C-130 SPO at Warner Robins Air Logistics Center (see Chapter 6 for additional details).[4.77]]The inspection technique had to be modified to address the differences in the two structures being inspected. The C-130 structure had a different geometry, plus two parallel rows of fasteners that needed to inspected. In addition, these fastener holes were filled with wet-installed fasteners.

- **A Computational Means of Fusing Image Data.** In considering the means to fuse image data, Dr. Claudia Kropas-Hughes studied concepts from the human biological neural system. Accomplishing this automatic image processing requires features be extracted from each image data set, and the information content fused. Dr. Kropas-Hughes determined a feature set through the use of human-visual-system models, and developed a new neural network architecture – the Autoassociative-Heteroassociative Neural Network to accomplish the desired data fusion.[4.78] For her work, she was honored as a finalist for the 1999 ML Charles J. Cleary Award for Scientific Achievement.

2000-2006

As the new millennium arrived, significantly increased emphasis was being placed on new science in both analytical modeling and experimental processes to gather and interpret complex quantitative NDE measurements. The focus on better NDE tools to inspect and monitor the structural integrity and safety of the aging fleet, and space systems assets, has continued into this decade. The major increase in the use of new aerospace vehicle materials, notably high performance composites, LO materials and high temperature propulsion materials, has raised the bar for higher performance NDE methodologies.

- **Establishment of Engine Rotor Life Extension (ERLE) Initiative.** To reduce the growing sustainment burden for fielded gas turbine engines, the Air Force embarked on a science and technology initiative in 1999, in collaboration with the Turbine Engine Industry, to extend the operational lifetime of fracture-critical turbine-engine-rotor components. Known as the Engine Rotor Life Extension (ERLE) program, its approach was established to develop, and incrementally implement, improved life management methods, compared to existing Retirement for Cause (RFC) inspection systems, as illustrated in Figure 4.47, that integrate state-of-the-art fracture mechanics, NDE, engine-usage and health monitoring, data fusion, and repair technologies into a future comprehensive life-management system. While initially targeting inspections for the F117 engines that power the C-17 transport aircraft, ML's existing Engine Rotor Life Extension Program (ERLE) embraced this new inspection capability for legacy turbine engine component life extension, specifically for F100 and F110 engines used to power F-15 and F-16 fighter aircraft. The goal of the $15 million, multi-year program was to improve the capability, efficiency, accuracy, maintainability, and throughput of NDI systems used in Air Force depots. These improvements include speeding up inspections, gathering and organizing depot inspection data, documenting the theory of operation of the RFC-ECIS systems at OC-ALC, and creating engine component ultrasonic NDI capability in the depot. Results from this work were: the insertion of more reliable eddy current probes into the OC-ALC depot process; an archived database containing 15 years of eddy current probability of detection (POD) results; and a complete, computerized reference guide for RFC-ECIS inspection algorithms containing 50+ technical papers describing the algorithms.



Past *Retirement for Cause*		**Future** *Engine Rotor Life Extension*
Conventional Disks (23 components in two early engine models, F100-100/200)	→	**Conventional Disks, Drum Rotors** (41+ components in current engines)
Detection Capability: Surface flaws Simple: 5x10 mils Moderately complex: 15x30 mils Complex: none Internal defects: none	→	**Detection Capability:** Surface flaws Simple: < 5x10 mils Moderately complex: 5x10 mils Complex: 10x20 mils Internal defects: 20 mils
Life Prediction: No surface residual stress Isothermal Simplified cycle counting Deterministic models	→	**Life Prediction:** Incorporating residual stress effects Thermomechanical fatigue Load interaction effects Probabilistic models
Repair Processes: none	→	**Repair Processes:** Laser shock processing Surface reconditioning Weld repair
Engine Monitoring: none	→	**Engine Monitoring:** Prognostics
Data Integration: none	→	**Data Integration Tools**
Life extended to 8000 cycles Cost Avoidance: $850M over 15 years		Life extension to 12,000 - 16,000 cycles Cost Avoidance: $600M over 5 years

Figure 4.47. RFC Life Extension Achievements & ERLE Planned Activities.

The eventual payoff sought was defined as a doubling of the operational life of fracture-critical components, a 50% reduction in disk replacement costs, increased depot throughput, and reduced maintenance cost per component.[4.79]

- **Sonic IR Turbine Engine Disk Inspection System.** The objective of this program is to establish the requirements and methodology for a Sonic Infrared turbine engine NDE capability which will meet engine rotor life extension needs for whole field crack detection in complex geometries. The whole field inspection of certain critical turbine engine components remains an important requirement and element of the Air Force's Engine Structural Integrity program (ENSIP), as well as meets a need of the Engine Rotor Life Extension (ERLE) program initiative.

In prior work for the NDE Program during 2001 and earlier, Wayne State University (WSU) researchers demonstrated the feasibility of its new "Thermosonics" technique to image very small corner cracks in titanium and other engine materials.[4.80] This method used a pulsed low frequency sonic/ultrasonic source to infuse the materia1 with directed high intensity sound, thus causing frictional heating between crack faces. In follow-on research for the NDE Program, scientists at SAIC extended the experimental studies to include turbine disks containing fatigue cracks in critical locations. Fatigue Technology, Inc. (FTI) was tasked with placing accurate fatigue cracks in anti-rotation windows in several F100 1st stage high-pressure turbine disks. This required that FTI use its unique fixture to fatigue the anti-rotation feature in the turbine disk to generate the desired fatigue cracks. Shown in Figure 4.48a pictures the laser vibrometer sound source in near-contact with a turbine disk containing test cracks. A Thermal Wave Imaging IR video camera has imaged the thermal radiation from an excited crack, thus producing and recording a crack image (Figure 4.48b). Investigations were expanded to measure the ability of the sonic IR system to detect cracks in turbine engine blades. Several cracked blades from OC-ALC at Tinker AFB, each containing at least one crack in the leading edge, trailing edge or tip of the airfoil, were tested in the test setup shown in Figure 4.49a. Figure 4.49b illustrates a successful infrared image of an edge crack without need for magnification.

A cracked and painted F-16 wheel was inspected and all of the cracks detected prior to painting were found again after the part was painted. The Sonic IR images for the painted wheel were obtained at lower energy settings than those used for the unpainted wheel. The input energy was minimized to help protect the painted surface from the ultrasonic horn. Research and

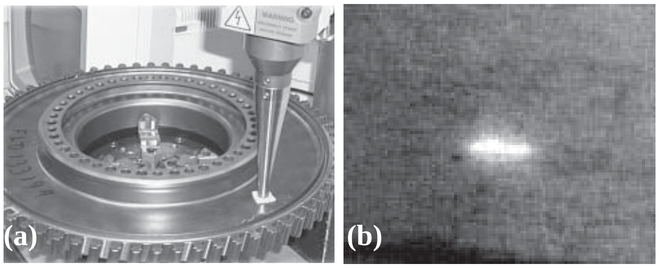


Figure 4.48. (a) Prototype Sonic Infrared Flaw Detection System with Excitation Sound Source in Position to Excite Turbine Disk. (b) IR Image of Small Crack in the Disk.

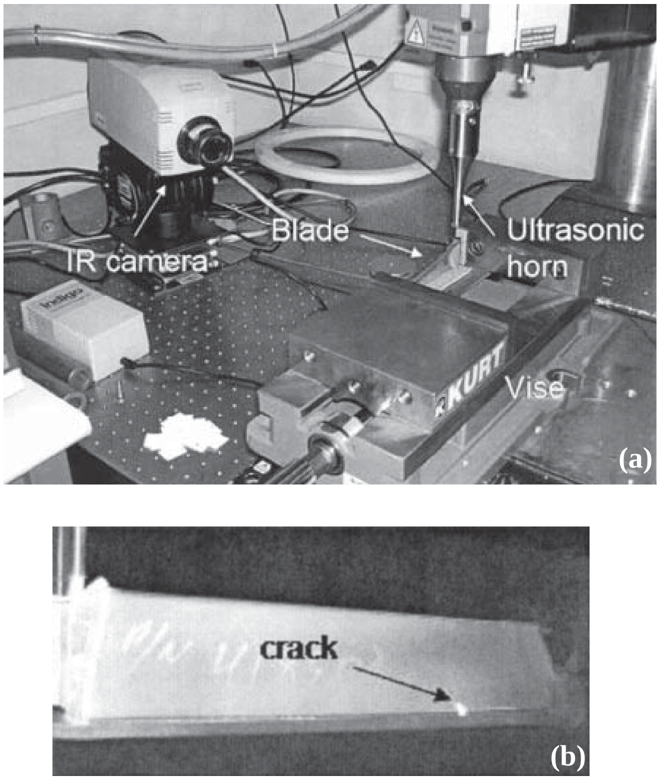


Figure 4.49. (a) Sonic IR Test Setup with Ultrasonic Horn Positioned to Excite Turbine Blade. (b) IR Image of Edge Crack.

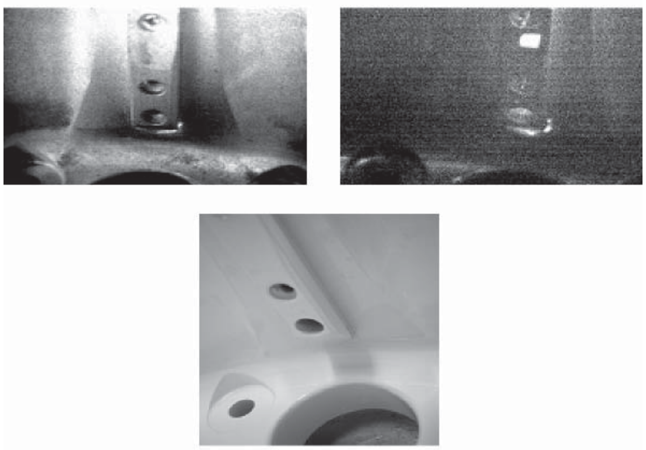


Figure 4.50. Sonic IR Images of F-16 Brake Mount #4m Unpainted (top left), Painted (top middle) and Optical Image (btm right).

development of this system concept is continuing with (1) refinement of the instrumentation/system design requirements and features, (2) exploration of broadened specific systems application issues, requirements and approaches, and (3) the evaluation and improvement of the detection capability of the methodology.[4.81]

- **Turbine Engine Sustainment Initiative (TESI) Advanced Disk NDE.** In July 2001, the NDE Branch, in conjunction with the University of Dayton Research Institute (UDRI), began a five-year Congressionally funded program entitled Turbine Engine Sustainment Initiative (TESI) with the goal of enhancing the Air Force's NDI/E capability to accurately locate certain critical, difficult-to-detect flaws in rotating gas turbine engine components. This capability is designed to complement the operational improvements of the current RFC-ECIS system by ERLE, as discussed earlier. This major TESI development now provides, for the first time at an Air Force depot, a fully automated capability to detect illusive embedded defects within in-service engine rotor components using the advanced robotic, phased array ultrasonic inspection system, pictured in Figure 4.51. It features an industrial 6-axis robot system with a probe tip positional accuracy of 0.002 inch per foot, positioning repeatability of 0.002 inch, probe speed of 80 inches per second and a test object weight of 66 lbs. The TESI UT System was designed and built to have the same level of automation as the ECIS units installed at OC-ALC. The system was implemented in 2005 as a totally compatible element of the OC-ALC engine rotor component inspection system for both surface breaking and embedded flaws.[4.82]

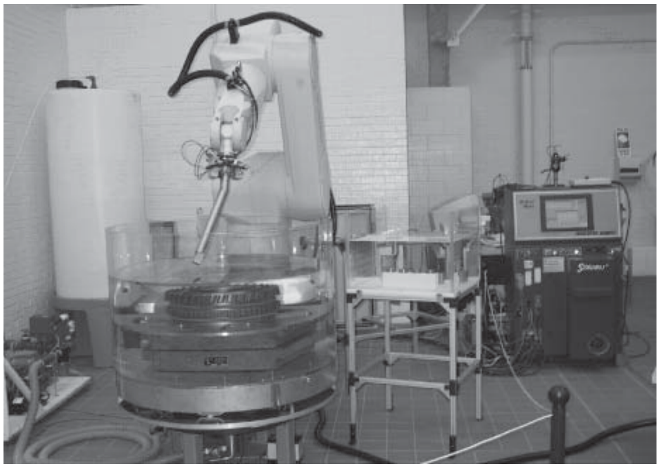


Figure 4.51. TESI Program Automated Ultrasonic Inspection System Inspecting a Compressor Disk Using a Phased Array Ultrasonic Probe.

- **Increased Emphasis on Development of Advanced Sensors/Detectors.** A significant and challenging need has existed for the accurate, reliable detection and characterization of some small, difficult-to-reach or sense cracks and other flaws in aging aircraft structures. Several advanced sensor studies begun in the 1990s are identified for that period in this chapter. Since 2001, an Advanced Technology Demonstration (ATD) Program on NDE for Aging Structures has been underway to produce capabilities to inspect for cracks in

2- and 3-layer wing structures of large transport aircraft. In one effort, the NDE Program engaged The Boeing Company to continue its work on magnetoresistive (MR) sensor technology for eddy current imaging. During 2001, Boeing successfully demonstrated that an array of anisotropic MR sensors (in this case, miniature magnetometers ~ 0.1 inch x 0.1 inch) could be used to rapidly image small cracks (up to about 0.5 inch deep) in a metallic aircraft structure, such as a lap splice. This was accomplished with an 8-element array as an initial trial for the array concept utilizing MR sensors. A 64-element array configuration with electronics and associated cabling was investigated as well. Studies to determine the optimum configuration of such arrays in terms of sensor type and sensor density led to the point where a 32-element linear array covering a one-inch wide swath was designed, built and demonstrated successfully for several specimen types with deeply lying cracks. Because of the chosen geometry, dependence on circular symmetry is obviated; thus, rapid scanning along a row of fasteners is possible, with real time imaging. The array was engineered for scanning with the MAUS platform, and demonstrated at the OC-ALC, Tinker AFB, Oklahoma on October 2005, and on 6-8 February 2006 at the Navy North Island NADEP, San Diego, California (Figure 4.52).

Figure 4.52. Prototype MR Sensor Array Contained in a Head Being Translated Over a Specimen by a MAUS Platform to Produce Real-Time Images.

- **Materials Systems Health Monitoring (MSHM) Initiative.** An important long term challenge for the Air Force emerging in this period of time has been the establishment of an Integrated System Health Management (ISHM) capability that connects system health information of an individual vehicle, and subsequently the fleet, with field operations, and the appropriate depots and manufacturers. This ISHM capability is aimed at ensuring fleet safety, reliability, readiness, and affordable maintenance methods through continuous monitoring of systems integrity and serviceability. The NDE Program has a critical ongoing role in the development of the material "state awareness" measurement tools and data capture capabilities that support and enable systems health diagnosis and prognosis. This, in turn, will have a major impact on maximizing mission capabilities and increasing asset availability, and minimizing operations and support (O&S) costs to the extent possible.

Since 2004, the NDE Program has been researching some of the fundamental building block technologies to achieve the above goals. These include advanced sensor system developments, such as those which utilize self-contained, low cost information storage devices that can be easily interrogated, for modeling and measuring material damage states. Developed within the next several years will be active, self-powered NDE "health" sensors that use piezo fibers to both sense and power the devices. Currently under development is a prototype crack detection system using embedded piezoelectric wafer active sensors (PWAS). The goal is to construct a rugged, durable sensor network capable of determining the location, size and growth rates of cracks in structures, in real time. Also included will be a system engineering approach to analyze large areas and optimal sensor placement for maximum effectiveness and efficiency. Studies are also beginning for the development of new data analysis and fusion/mining algorithms capable of merging multifrequency eddy current, ultrasonic, and radiographic data optimized for specific health management NDE applications.

Program emphasis is also being directed toward developing and demonstrating in-situ health monitoring of material damage in leading edge and acreage structure thermal protection system (TPS) materials, subjected to harsh environments.

In-House Research Program 2000-2006

The initial in-house research program plan (prepared in 2001) for this period focused on two primary technical areas: (1) material integrity characterization through NDE and (2) computational methods for NDE.

Area (1) consisted primarily of effort to:

- Define processes and tools that can perform material property identification and measurement from the microstructure level to the macrostructure.

- Detect defects and damage using existing NDE methods on new problems while determining the limits and restriction of these methods, and testing of new techniques in combination with materials characterization tools to unambiguously separate damage indications from benign structural and material variations.

Area (2) computational methods for NDE (CM-NDE)

A program plan for computational methods for nondestructive evaluation (CM-NDE) was prepared in 2000 by Dr. Jim Malas and Dr. Claudia Kropas-Hughes for the NDE branch. As a result of a recommendation by a USAF SAB review for the need for in-house basic research in NDE; the AF Office of Scientific Research allotted basic research funding for the computational modeling portion of the effort. The following features were included:

- Signal processing applied to individual NDE modalities. Specific modalities may be noise reduction, contrast improvements, measure enhancements, and feature or information extraction.

- Modeling and optimization techniques. Included in this effort is the fusion of information from multiple NDE techniques through extension use of modeling. The effort included approaches to bring the information from each of the single NDE methods together for improved evaluation of structural integrity.

Dr. John Aldrin joined the NDE Program team in 2001 as a visiting scientist tasked to lead this technical initiative, building upon the successful earlier effort to develop models and automated signal classification algorithms to improve the inspection procedure for C-141 weephole inspection.

Successful research examples from the in-house research program include:

- **NDE Methods for Microstructure Characterization.** In a search for accurate nondestructive methods to quantitatively measure various microstructure-related elastic and electrical properties of structural metals, Dr. Mark Blodgett studied a range of experimental procedures with various forged titanium alloys. The experiments with ultrasonics revealed some unusual properties in terms of the ultrasonic velocity, attenuation, and scattering. He also developed an eddy current materials characterization technique to map electrical property variations in various titanium microstructures. In addition, a laser interferometric ultrasonic detection experiment was developed to map microstructure-related spatial variations in the amplitude and phase of propagating acoustic waves. These experimental procedures provide new and potentially powerful NDE tools to aid in the development and structural monitoring of a number of high performance aerospace metallic materials.[4.83] Dr. Blodgett was awarded the 2000 ML Charles. J. Cleary Award for Scientific Achievements for this work.

- **Non-Linear Laser Ultrasonics.** An in-house research team led by Dr. Curt Fiedler succeeded in developing a prototype non-linear laser ultrasonic NDE laboratory system capable of measuring localized accumulated fatigue damage in a material with high sensitivity and resolution. Other researchers previously reported the discovery that changes in non-linear ultrasonic parameters occur in some materials (aluminum, titanium and nickel superalloys) by the time they undergo 30 to 40 percent of their total fatigue life. Dr. Fiedler demonstrated that by visualizing the fundamental and harmonic displacement fields propagating as surface and bulk acoustic waves, the unique system held promise for monitoring the fatigue state of key air vehicle materials.[4.84] It was also shown that detection of sub-picometer ultrasonic motions with laser ultrasound was feasible with high signal-to-noise (SRN) levels and microscopic resolutions.

- **New Method for Detection and Imaging of Microcracks.** In his research on advanced ultrasonics methods, Dr. James Blackshire discovered a novel near-field ultrasonic scattering process for detecting and imaging structural microcracks. He developed a near-field scanning interferometry system and a real-time holographic system to detect surface-breaking microcracks in aluminum and titanium. The systems induce scattering in the ultrasonic waves around the crack. By imaging the scattering, the technique effectively makes otherwise invisible cracks visible, rendering a detection capability that is substantially better than existing, state-of-the-art NDE techniques. Furthermore, Dr. Blackshire's research showed a direct correlation between the observed ultrasonic displacement level and the local crack depth, which provides a potentially revolutionary NDE measurement capability for imaging surface-breaking cracks in full 3-dimensional form.[4.85] For his discovery and work, Dr. Blackshire was awarded the 2003 ML Charles. J. Cleary Award for Scientific Achievements and the 2003 AFRL Corporate Scientific/Technical Achievement (Individual) Award.

By 2003, the near term Area 1 objectives focused on: (a) nondestructive methodologies to determine the gradient of near-surface residual stresses in turbine engine materials; (b) development of laser based methodologies for application to area detection for corrosion and cracking; (c) investigation of NDE methods for low observable materials; and (d) development of NDE methods to provide integrated vehicle health monitoring on both aged and new systems.

Area 2 near term objectives focused on development of: (a) algorithms for processing each of the selected NDE modalities and provide an output more easily analyzed; (b) classification algorithms for detecting “flaws” and other characterization aspects of interest; and (c) models to assist in analysis of material interactions with NDE sensors thereby providing simulation routines to predict results of flaw vs. non-flawed materials. Current research examples include:

- **Computational Model Development for Increased-Accuracy NDE.** Continuing research is focused on model-based methods to improve the extraction of features sensitive to a flaw, such as fatigue crack, while insensitive to other noise features. Although an asymmetry observed for a hole feature in an eddy current image is traditionally used to distinguish crack and no crack conditions, three non-flaw conditions have been identified that also produce asymmetric EC responses. These can include asymmetric gaps between the fastener and hole, variation in probe liftoff and inherent asymmetry in probe response (often related to the irregularities in the windings.) A series of parametric studies were thus designed to investigate potential features in the EC signal with sensitivity to fatigue cracking and invariance to these three noise features.[4.86]

In another study, NDE Program researchers teamed with other specialists to study analysis methods to distinguish signals from a crack and a geometric feature that are either closely spaced or superimposed in time. An example problem chosen was the ultrasonic inspection of aircraft holes in vertical riser structures with limited accessibility for a transducer from an external wing surface. A local correlation method was developed to detect the relative shift of signals in time for adjacent transducer locations due to the varying echo dynamics from crack and part geometries.[4.87]

- **In-House CT Research Facility Contributed to Critical Component Development.** The development by the AFRL Air Vehicles Directorate (VA) of a new higher efficiency, rugged, lightweight, high temperature carbon-carbon composite heat exchanger prototype for existing and next generation combat aircraft required a unique method of process control and integrity verification. The fabrication process involves co-processing C-C plates and fins, then the critical brazing of all joints to form the core and enclosed structure.[4.88] By utilizing ML’s CT research facility to nondestructively evaluate the quality control of the prototype manufacturing process successfully, the destructive evaluation of the heat exchanger internal structure integrity was avoided.

Figure 4.54 illustrates another application of CT examination to detect and image subtle internal flaws, in this case, an unbond between the outer case of a small igniter and the propellant, as seen between the 7 and 8 o’clock positions.

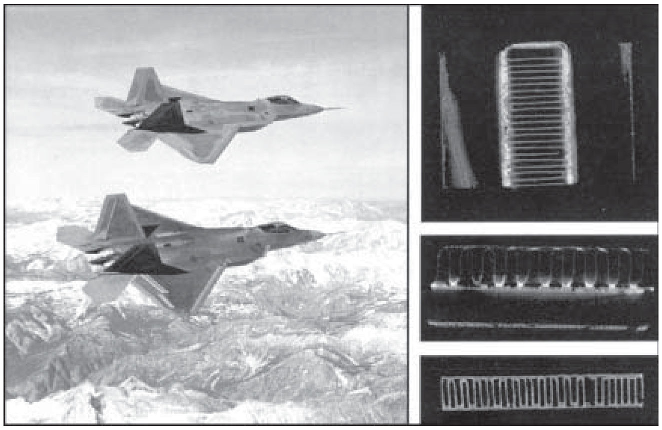


Figure 4.53. CT Images of Carbon-Carbon Composites Heat Exchanger Prototype.

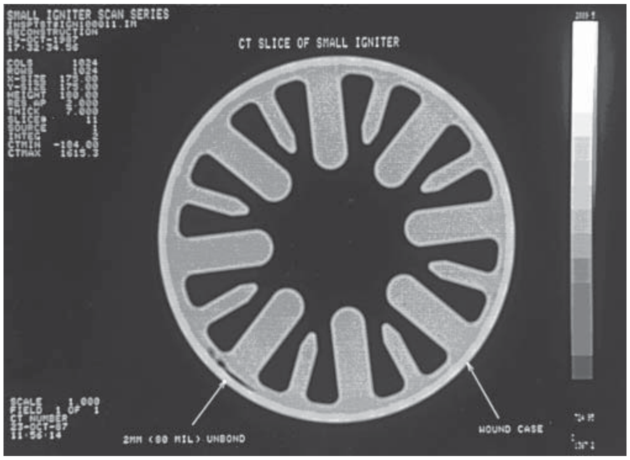


Figure 4.54. CT Image of Igniter Propellant-Case Unbond.

- **Realignment of Research Group Focus Areas.** In 2006, the in-house NDE research efforts, with Dr. Kumar serving as Research Group Leader, were regrouped into the major thrust areas shown below:

1. NDE/ISHM of Hidden Damage in Aerospace Structures, under the leadership of Dr. Eric Lindgren. Develop, evaluate and establish next-generation NDE and ISHM sensor methodologies for detecting and quantifying hidden cracks and corrosion in aircraft structures.

2. Residual Stress Gradient Measurement (RSGM):, under the leadership of Dr. Mark Blodgett. Develop and evaluate nondestructive techniques to measure near-surface residual stress profiles in surface treated (e.g., shot peened, laser peened, low-plasticity burnished) materials and components consistent with gas-turbine engine alloys.

3. Integrated Structural Health Management (ISHM), under the leadership of Dr. Jim Blackshire. Task includes Develop, evaluate and establish integrated sensing methodologies for space and hypersonic vehicles, thermal protection structures, cryogenic tank structures and hot structures such as the B-2 aft deck.

References

4.1. *"Air Force Structural Integrity Program Requirements,"* ASD-TR 66-57, ASD, Wright-Patterson AFB, OH (1968).

4.2. Proceedings of the Symposium on Physics and Nondestructive Testing, September 29 – October 1, 1964, Dayton, Ohio, Gordon and Breach, Science Publishers, New York 1967.

4.3. Feasibility of neutron radiography for inspecting boron fiber reinforced alloys of aluminum, nickel and titanium, Materials Laboratory Historical Report, 1 January – 30 June 1966, AFRL/ML Data Base 1103, located at Universal Technology Corporation, Dayton, OH.

4.4. Rollwitz, William L., *"Magnetoabsorption in Nickel and Iron Wire,"* Proc. Symposium on Physics and Nondestructive Testing, Southwest Research Institute, October 1964, pp 405-438.

4.5. Rollwitz, William L. and Claassen, John P., *Magnetoabsorption Techniques for Measuring Material Properties,"* Southwest Research Institute, AFML-TR-66-76, June 1968; Part II.

4.6. Rollwitz, *Magnetoabsorption Techniques for Measuring Material Properties: Part II,"* Southwest Research Institute, AFML-TR-66-101, July 1966.

4.7. Thermoelectric probe developed under contract by AVCO for inspecting coated refractory metals, AFRL/ML Historical Report, 1 January – 30 June 1969, Data Base 1156, located at Universal Technology Corporation, Dayton, OH.

4.8. Ibid.

4.9. Schofield, B.H., *"Acoustic Emission under Applied Stress,"* ASD-TR-63-509, Part I, April 1963, and Part II, May 1964.

4.10. Martin, George and Moore, J.F., *"Research and Development of Nondestructive Testing Techniques for Composites,"* North American Aviation, Los Angeles Division, AFML-TR-66-270, February 1967.

4.11a. Schmitz, G., Wieczorek, A. and Levine, M., *"Development of Nondestructive Testing Methods for the Evaluation of Thin and Ultrathin Materials,"* ML-TDR-64-278, September 1964.

4.11b. Kubiak, E. and Lichodziejewski, W., *"Development of Nondestructive Testing Methods for the Evaluation of Thin and Ultrathin Sheet Materials,"* General American Transportation Corporation, AFML-TR-66-304, February 1967.

4.12. Moyzis, J.A. and Forney, D.M., *"Increased Reliability – A Critical NDE Research Goal,"* Review of Progress in Quantitative Nondestructive Evaluation, Eds. D.O. Thompson and D.E. Chimenti, Vol 1, pp. 7-11, 1982.

4.13. Forney, Donald M., *“Evolving Partnership for NDE in Materials Engineering and Extended Life Cycle Performance,”* Review of Progress in Quantitative Nondestructive Evaluation, Eds. D.O. Thompson and D.E. Chimenti, 10A, pp. 13-33, 1991.

4.14. Cooper, T.D. and Forney, D.M., *“Detection of Cracks Under Installed Fasteners in Aircraft Structures,”* Materials Evaluation, Vol 10, No. 1, September 1983.

4.15. Raatz, C.F., Senske, R.A., Woodmansee, W.E., et.al, *“Detection of Cracks Under Installed Fasteners,”* AFML-TR-74-80, April 1974.

4.16. Chang, F.H., *“In Service Inspection of Advanced Composite Airframe Structure,”* AFWAL-TR-79-4087, 1979.

4.17. Yee, B.G.W. *“Computer Automated Ultrasonic Inspection System for Aircraft Forgings,”* AFML-TR-75-82, May 1975.

4.18. Cooper, T. D. and Forney, D. M., *“Increased Inspection Requirements for Critical Air Force Engine Components,”* Presented at the 1981 Air Transport Association Nondestructive Testing Forum, Phoenix, AZ, 1-3 September 1981.

4.19. Ibid.

4.20. Personal communication with Dr. Cyril Pierce, Plant Manager, General Electric Madisonville Turbine Airfoils, Madisonville, Kentucky.

4.21. History of the Air Force Materials Laboratory, Vol II, Part I, The Military Construction Program,, Universal Technology Corporation, November 1992.

4.22. Materials Laboratory Historical Report, 1 January – 30 June 1952, AFRL/ML Data Base 1003, located at Universal Technology Corporation, Dayton, OH.

4.23. T.J. Moran and R.M. Panos, *“Electromagnetic Generation of Electronically Steered Ultrasonic Bulk Waves,”* Appl. Phys., 47, 2225 (1976).

4.24. T.J. Moran, *“Use of Pulse Compression Techniques to Improve the Range Resolution of Electromagnetic Surface Wave Transducers,”* 1976 Ultrasonics Symp. Proc., IEEE Cat #76 CH1120-5SU, (1976), p.26.

4.25. T.J. Moran, *“Electromagnetic Ultrasonic Transducers,”* Proc. of 23rd Sagamore Army Materials Research Conf., August 24 27, 1976, Raquette Lake, NY.

4.26. T.J. Moran, *“Characteristics and Applications of Electromagnetic Surface Wave Transducers,”* Proc. of 1976 ARPA/AFML Rev. of Quant. NDE, AFML-TR-77-44, p.136 (1977).

4.27. Moran, Thomas J., *“A Pseudorandom Binary Noise NDE Ultrasonic Correlation System,”* Proceedings, IEEE Ultrasonics Symposium, 1978; also AFML-TR-78-205, January 1979.

4.28. Crane, R.L., Moran, T.J. and Patterson, T.M., *“X-Ray Computed Tomography of Carbon/Carbon Composites,”* Proceedings, DARPA/Air Force Review of Quantitative NDE, La Jolla, California, July 1979.

4.29. Crane, R.L. and Batra, N.K., *“Detection and Size Estimation of Radial Bolt Hole Cracks in Layered Structures,”* ASNT Spring Meeting, San Diego, CA, April 1979.

4.30. Batra, N.K. and Crane, R.L., *“Measurement of Radial Bolt Hole Crack Size Using the Doppler-Shift Technique.”* IEEE Trans. Sonics and Ultrasonics, Vol SU-27, No. 2, March 1980.

4.31. Holloway, J.A. *“Evaluation of Radiographic Paper System Using Ultraviolet Fluorescent Screens,”* AFML-TR-72-165, Part I, September 1972, Part II March 1973.

4.32. Holloway, J.A. and Bohlen, J.W., *“Air Force Evaluation of Industrex Instant 600 Radiographic Paper Systems,”* Materials Evaluation, Vol 35, Nr. 5, pp39-45, April 1977.

4.33. Forney, Donald M., *“Evolving Partnership for NDE in Materials Engineering and Extended Life Cycle Performance,”* Review of Progress in Quantitative Nondestructive Evaluation, Eds. D.O. Thompson and D.E. Chimenti, 10A, pp. 13-33, 1991.

4.34. Mih, D.T, *"Improved Low Frequency Eddy Current Inspection for Cracks Under Installed Fasteners,"* AFWAL-TR-80-4150, October 1980. Air Force Wright Aeronautical Laboratories, Wright-Patterson AFB, OH.

4.35. Cooper, T.D. and Forney, D.M., *"Detection of Cracks Under Installed Fasteners in Aircraft Structures,"* Materials Evaluation, Vol 10, No. 1, September 1983.

4.36. Keller, Sara, Pairazaman, Carlos, Berens, Al, Buynak, Charles and Garcia, Robert, *"Performance Experience and Reliability of Retirement for Cause (RFC) Inspection Systems,"* NATO RTO Workshop 2, Airframe Inspection Reliability under Field / Depot Conditions, May 11–15, 1998, Brussels, Belgium.

4.37. Cargill, J.S., LaGrotta, J.M., Harris, R.V., et al, Pratt & Whitney, *"Retirement for Cause Inspection System Design,"* AFWAL-TR-81-4111, October 1981.

4.38. Cargill, J.S., LaGrotta, J.M., Harris, R.V., et al, Pratt & Whitney, *"Retirement for Cause Inspection System Design,"* Review of Progress in Quantitative Nondestructive Evaluation, Eds. D.O. Thompson and D.E. Chimenti, Vol 1, pp. 83-96, 1982.

4.39. *"Exploitation of Advanced X-Ray Computed Tomography Technology,"* Boeing, AFWAL-TR-88-4018, May 1988.

4.40. *"CT Systems Design Specification Guide,"* Boeing, Unfinished.

4.41. Bossi, Richard H., Kruse, Robert J. and Knutson, Benjamin *"Computed Tomography for Electronics,"* Boeing, WRDC-TR-89-4112, December 1989.

4.42. Bossi, Richard H., *"Computed Tomography of Thermal Batteries and Other Closed Systems,"* Boeing, WRDC-TR-89-4113, December 1989.

4.43. Bossi, Richard H., Cline, John L., Costello, Edward G. and Knutson, Benjamin W., *"X-Ray Computed Tomography of Castings,"* Boeing, WRDC-TR-89-4138, March 1990.

4.44. Bossi, Richard H., Cooprider, Karen K. and Georgeson, Gary E., *"X-Ray Computed Tomography of Composites,"* Boeing, WRDC-TR-90-4014, July 1990.

4.45. Burstein, Paul and Bossi, Richard H., *"A Guide to CT System Specifications,"* WRDC-TR-90-4026, August 1990.

4.46. Crews, Alan R., Georgeson, Gary E. and Bossi, Richard H., *"X-Ray Computed Tomography for Geometry Acquisition,"* WL-TR-93-4036, March 1993.

4.47. Bossi, Richard H. and Nelson, James M., *"X-Ray Computed Tomography Standards,"* WL-TR-94-4021, February 1994.

4.48. Crews, Alan R. and Bossi, Richard H.,*"X-Ray Computed Tomography for Whole System Evaluation Small Jet Engines,"* WL-TR-91-4109, May 1992.

4.49. Georgeson, Gary E. and Bossi, Richard H., *"X-Ray Computed Tomography for Advanced Materials and Processes,"* WL-TR-91-4101, June 1992.

4.50. Bossi, Richard H., Cline, John L. and Georgeson, Gary E., *"High Resolution Computed Tomography,"* WL-TR-91-4102, July 1992.

4.51. Bossi, Richard H. and Shepherd, William, *"X-Ray Computed Tomography for Failure Analysis Investigations,"* WL-TR-93-4047, May 1993.

4.52. Georgeson, Gary E., Crews, Alan R. and Bossi, Richard H., *"X-Ray Computed Tomography for Casting Development,"* WL-TR-92-4032, September 1992.

4.53. Georgeson, Gary E. and Bossi, Richard H., *"X-Ray Computed Tomography of Full-Scale Castings,"* WL-TR-91-4049, October 1991.

4.54. Bossi, Richard H., Georgeson, Gary E. and Rempt, Raymond D., *"X-Ray Computed Tomography for Emerging Aerospace Materials and Processes Development,"* WL-TR-93-4054, May 1993.

4.55. Georgeson, Gary E., Bossi, Richard H. and Rempt, Raymond D., *"X-Ray Computed Tomography for Casting Demonstration,"* WL-TR-93-4048, May 1993.

4.56. King, D.C., Lawson, R.D. and Romine, B.J., “*Nondestructive Evaluation of Large Scale Composite Components,*” McDonnell Aircraft Company, MDA, AFWAL-TR-87-4116, January 1988.

4.57. “*Mighty MAUS,*” Aerospace America, November 1991.

4.58. Chimenti, D.E., “*Energy Leakage from Rayleigh Waves on a Fluid-Loaded, Layered Half-Space,*” Phys. Letter., 43, 46 (1983).

4.59. Bar-Cohen, Y. and Crane, R.L., “*Nondestructive Evaluation of Composite Materials with Backscattering Measurements,*” 6th ASTM Conference on Composite Materials: Testing and Design, Phoenix, AZ, May 1981, STP 787.

4.60. Bar-Cohen, Y. and Crane, R. .L., “*Acoustic-Backscattering Imaging of Subcritical Flaws in Composites*” Materials Evaluation, Vol 40, No. 9, September 1982, pp. 970 – 975.

4.61. Buynak, C.F. and Crane, R.L., “*A Novel Acoustic Coupling Device using Permeable Membrane,*” Presented at the 15th Symposium on NDE, Sponsored by Nondestructive Testing Information Analysis Center (NTIAC) and South Texas Section, ASNT, pp 109-117, April 23-25 1985. Published in Materials Evaluation, pp 743-746, June 1987.

4.62. Buynak, C.F. and Moran, T.J., “*Characterization of Impact Damage in Composites,*” Review of Progress in Quantitative Nondestructive Evaluation, Eds. D.O. Thompson and D.E. Chimenti, Vol. 6, pp. 1203-1211, 1986.

4.63. Forney, D. M. and Cooper, T.D., “*The Economic Implications of NDE: Opportunities and Payoff,*” Proc, NATO AGARD Conference, AGARD-CP-234, March 1978, Voss, Norway.

4.64. Bueno, C., Barker, M.D., Condon, P.E. and Betz, R.A., “*Solid State X-Ray Imaging Methodology,*” WL-TR-92-4003, March 1992, Wright-Patterson AFB, OH.

4.65. Ibid.

4.66. “*X-30 Nondestructive Evaluation Technology Development Recommendations,*” Forney, Donald M. and Moyzis, Joseph A., NASP Contractor Report 1170, Reference GWP-100, September 1994.

4.67. “*Laser Inspection for Composite Parts,*” Aerospace America, January 2001.

4.68. “*A Look at Laser Ultrasonics and Lockheed Martin’s LaserUT™ System,*” Nondestructive Testing Information Analysis Center (NTIAC) Newsletter, Vol 27, No. 3, September 2002.

4.69. Ibid.

4.70. “*High Resolution Three-Dimensional Computed Tomography,*” Perceptics Corporation, October 1996.

4.71. Keller, Sara, Pairazaman, Carlos, Berens, Al, Buynak, Charles and Garcia, Robert, “*Performance Experience and Reliability of Retirement for Cause (RFC) Inspection Systems,*” NATO RTO Workshop 2, Airframe Inspection Reliability under Field / Depot Conditions, May 11–15, 1998, Brussels, Belgium.

4.72. “*NDE Point Inspection Tool,*” Aerospace Engineering, June 2000, p. 14.

4.73. “*X-30 Nondestructive Evaluation Technology Development Recommendations,*” Forney, Donald M. and Moyzis, Joseph A., NASP Contractor Report 1170, Reference GWP-100, September 1994.

4.74. Nagy, Peter B., Blodgett, Mark and Golis, Matthew, “*Weep Hole Inspection by Circumstantial Creeping Waves,*” NDT&E International, Vol 27 No. 3, 1994.

4.75. Ibid.

4.76. “*New Technique Improves Fuel Tank Inspections,*” Aerospace Engineering, p. 14, October 1998.

4.77. Lingren, Eric, Abel, James, Concordia, Michael, Macinnis, Tim and Manderville, John, SAIC Ultra Imge; Aldrin, John, Computational Tools; Christiansen, Fritz, Darren and Mullins, Tommy, Warner Robins Air Logistics Center; Spencer, Floyd, Sandia National Laboratories and Waldbusser, Ray, C-130 Fst, A, Air-4.3.3. “*PoD Results and Deployment of the Inspection of the Vertical Leg of the C-130 Center Wing Beam/Spar Cap,*” 2005 Aging Aircraft Conference, Palm Springs, CA, January 31 – February 3, 2005.

4.78. Kropas-Hughes, C.V., *“Autoassociative-Heteroassociative Neural Network (A-HNN),”* Engineering Applications for Artificial Intelligence, 2000.13: pp 603-609.

4.79. Larsen, J.M., Rasmussen, Bruce, Russ, S.M., Sanbongi, Bryan, Morgan, Jim, Jira, Jay, Blodgett, Mark, Moran, Tom, Johnson, David, LeClair, Steve, Shaw, Debbie, Strange, Bill, Meininger, Matt, and Fecke, Ted, *“The Engine Rotor Life Extension (ERLE) Initiative and Its Contributions to Increased Life and Reduced Maintenance Cost,”* Proceedings of the 6th International Turbine Engine High Cycle Fatigue (HCF) Conference, Jacksonville, FL, 5-8 March 2001.

4.80. Mayton, Donna and Lindgren, Eric, *“Advanced Thermosonic Methods (Sonic IR) Sonic IR.”* SAIC/Ultra Image International, AFRL-ML-TR-2003-, July 2003.

4.81. *“Whole Field Turbine Disk Inspection,”* Monthly Status Report March 2006, SAIC, USAF AFRL Contract F33615-03-D-5204, NTIP II Delivery Order 002

4.82. Stubbs, D., et al., *“An Automated Ultrasonic System for Inspection of Aircraft Turbine Engine Components,”* Insight, Vol. 47, No. 3, March 2005.

4.83. Blodgett, Mark, *“Theoretical and Experimental Investigations of the Lateral Resolution of Eddy Current Imaging,”* Materials Evaluation, May 2000.

4.84. *“USAF Develops Nonlinear Laser UT System,”* USAF Materials Technology Highlights Periodical, Winter 2005.

4.85. Blackshire, James L. and Sathish, Shamachary, *“Near-field Ultrasonic Scattering from Surface-breaking Cracks,”* Applied Physics Letters, Vol. 80, No. 18, May 6, 2002, pp. 3442-3444.

4.86. Aldrin, J.C., *“Computational Methods in Nondestructive Evaluation (CM-NDE),”* Contract: F33615-03-D-5204, ICA 04-S508-006-C1, Monthly Report, March 17, 2006.

4.87. Aldrin, J.C., Kropas-Hughes, C.V., Knopp, J., Manderville, J., Judd, D. and Lindgren, E., *“Advanced echo-dynamic measures for the characterization of multiple ultrasonic signals in aircraft structures,”* Insight, Vol 48 No 3, March 2006.

4.88. *“CT Support to Development of Advanced Carbon-Carbon Composite Heat Exchanger Prototype for Combat Aircraft,”* Air Force Research laboratory (AFRL) TECH CONNECT Success Story, 00-ML-03.

CHAPTER 5

Impact Through Partnerships - Interagency, National and International

A major strength of the ML NDE Program historically has been its vigorous pursuit of technical communication and exchange, cooperation, leveraging, and partnering at many levels of interaction. A strong leadership role for the NDE Program came to pass on many occasions. Without exception, the breadth and strength of the ongoing NDE Program continuously drew much interest and discussion.

Summarized here are a number of the more notable interaction activities that have exemplified such contributions:

- **AFMC NDI Managers/Monitors Coordinating Meetings.** Following the issuance of USAF Regulation 66-38 in 1964 establishing the Nondestructive Inspection Program, a semi-annual program meeting has been held to coordinate the activities of the NDI Managers and Monitors at each of the AFMC Air Logistics Centers (ALC), and to share technical and management information. This provision also included the participation of delegates from the ML NDE/I Program to report on technical developments from both the R&D and Systems Support programs. These meetings, held at rotating locations, have provided critical information transfer opportunities to highlight both in-service/field NDE/I needs and new R&D technology opportunities.

- **The Technical Cooperation Program (TTCP) Panel 5 on NDE.** On 25 October 1957, the President of the United States and the Prime Minister of Great Britain formed a partnership to share information on each other's defense R&D programs for their common good. Canada joined the agreement soon after. Australia joined in 1965, and New Zealand joined in 1969 to complete the current membership. TTCP functions in a three-level structure – national TTCP Principals to select broad Defense S&T collaboration areas, ten Groups to define discipline-level areas for collaboration, and six to ten specific-subject Technical Panels per Group, each made up of scientific and technical specialists from the participating countries, to undertake nearly all of the S&T cooperative activities within each Group. Collaborative research, sharing of data and facilities, joint trials and exercises, etc. are all included in the cooperation. Generally, the U.S. has assigned three delegate members to each panel, one each from the Army, Navy and Air Force. Panel meetings of approximately two-week duration characteristically have occurred bi-annually in a rotating host country. Initially, Panel P-4 on Methods of Testing and Evaluation was formed in the Group responsible for Structural Materials, with Thomas Cooper serving as the Air Force participant during 1972 – 1973. In 1974, a new Panel 5 was formed for Nondestructive Evaluation for which the NDE Program has since provided the Air Force participant. Serving as the Air Force Panel 5 members have been Thomas Cooper (1974 – 75), Donald Forney (1975 – 85), Dale Chimenti (1985 – 89), Thomas Moran (1989 – 99), James Malas (1999 – 03), Claudia Kropas-Hughes (2003 – 05) and Thomas Moran (2005 -). Numerous data and information exchanges, collaborative testing and development efforts, round-robin test and evaluation projects, and tours of both government and commercial R&D and test facilities have been accomplished in and by the member countries.

- **North Atlantic Treaty Organization (NATO) Advisory Group for Aerospace Research and Development (AGARD).** The mission of AGARD is to bring together experts from NATO member nations in the fields of science and technology relating to aerospace in order to: improve co-ordination in aerospace research and development (ARD); provide scientific and technical advice to the Military Committee, and member nations, in the field of ARD and render technical assistance with R&D problems; provide assistance to member nations for the purpose of increasing their scientific and technical potential; recommend effective ways for member nations to use their R&D capabilities for the common benefit of the NATO community; and other mission elements.

The AGARD mission is carried out through Panels which are composed of subject experts appointed by the National Delegates and others officials. The results of AGARD work are made available through AGARD technical conferences and resulting series of publications for wide dissemination. Several examples of ML NDE Program-related papers presented at AGARD conferences are listed below:

Forney, D. M. and Cooper, T.D., *"The Economic Implications of NDE: Opportunities and Payoff,"* Proc, NATO AGARD Conference, AGARD-CP-234, March 1978, Voss, Norway.

Moran, Thomas J., *"Development and Application of Computed Tomography (CT) for Inspection of Aerospace Structures,"* AGARD Conference Proceedings AGARD-C P-462, 6 October 1989.

Tracy, N.A., Hardy, G.L. and Fechek, F.J., *"In-service Inspection of Composite Components on Aircraft at Depot and Field Levels,"* AGARD Conference Proceedings No. 462, 6 October 1989.

Keller, Sara, Pairazaman, Carlos, Berens, Al, Buynak, Charles and Garcia, Robert, *"Performance Experience and Reliability of Retirement for Cause (RFC) Inspection Systems,"* NATO RTO Workshop 2, Airframe Inspection Reliability under Field / Depot Conditions, May 11–15, 1998, Brussels, Belgium.

- **Joint Technical Coordinating Group (JTCG).** The JTCG functions as a staff level organization to support and coordinate specified needs of the DOD Joint Logistic Commanders (JLC) between Army, Air Force, Navy and Marine members. The technical representatives from each DOD branch are organized to coordinate R&D programs and activities in support of the Joint Logistic Commanders. The JTCG forms subgroups to address specific technical activities and compile specific technical information. Working with the NDE Branch, a JTCG-NDI group provided critical interfacing for several briefings of NDE developments and the NDE Program to AFSC, AFLC and AFMC commanders.

- **Tri-Service Working Group on NDE.** The Tri-Service Working Group on NDE was established in the early 1980s by the DOD Research & Engineering (DDR&E) leadership to help coordinate technical plans and progress emanating from the Army, Navy and Air Force NDE programs. Chaired by Jerome Persh, DDR&E, and meeting quarterly in the Washington area (usually the Pentagon), the service representatives reviewed individual program status and plans, evaluated opportunities to collaborate, and assisted in the preparation of selected DDR&E progress reports and briefings. Periodically, quarterly meetings were hosted at a member's home laboratory. The group also provided advice and recommendations on a verity of other technical and programmatic topics of mutual interest and concern, such as program content and management of the DOD-funded Nondestructive Testing Information Analysis Center (NTIAC).

- **The Four Power Long Term Technology Program (LTTP).** On June 8, 1988, a Memorandum of Understanding was signed by representatives of four allied nations to cooperate in several technology development areas of mutual interest – the French Republic, the Federal Republic of Germany, the United Kingdom of Great Britain and Northern Ireland, and the United States of America. One area of technical cooperation was established as Nondestructive Evaluation (NDE). The scope of the current NDE LTTP continues to be the exchange of information and to develop NDE techniques, procedures and methodologies that will enhance NDE capabilities where there is common need and interest. Cooperative efforts are organized to address such needs where this is possible within national programs. Being considered are problems arising both in the production and operation of fixed-wing aircraft and helicopters (structures, engines, equipment), including associated NDE. Periodic technical coordination meetings of the NDE Technical Group (TG), consisting of the Project Officers from each member nation, are convened at rotating country locations to exchange information and conduct other organized technical activity. NDE Branch members who have served as U.S. Project Officers have included Tobey Cordell (1991 – 1999), and Charles Buynak (1999 - current).

- **MatTec Communication Group on Non-destructive Evaluation (NDE).** This Communication Group, chaired by Dr. Lewis Sloter, ODUSD(S&T), falls under the Materials Technology (MatTec) Subcommittee of the Committee on Technology under the National Science and Technology Council (NSTC). Since 1988, there have been a series of meetings organized by the Nondestructive Testing Information Analysis Center (NTIAC) held annually.

The MatTec NDE Communication Group has provided an especially effective and useful forum for sharing information about NDE programs and plans,

Figure 5.1. LTTP NDE Technical Group Members at Dinner in Carcasonne, France During March 2005 Meeting in Toulouse. Left to right: Windy DeBroust, Alain Deom, Gilles Raimondi, Sylvain Gransart (France); Brian Morgan (UK); Gilles Lotis (FR); Charles Buynak (US - AFRL); David Bruce (UK).

and discussion about mutual areas of interest among Government departments and agencies. Although the NDE Communication Group focuses on Federally sponsored NDE research activities, it is anticipated that the group will interact with other communication groups and working groups under MatTec and will provide technical coordination, and support technical needs as appropriate. Participants include leaders from Department of Transportation (FAA and FHWA), National Aeronautics and Space Administration, Department of Commerce (NIST), Department of Defense (AFRL, ARO, NRO, NRL), Department of Energy (Office of Basic Energy Sciences), and the National Science Foundation. Dr. James Malas, ML NDE Branch Chief, represents the Air Force on this Group.

The purposes of the NDE Communication Group meetings are to:

(1) Provide an update on NDE programs and plans,

(2) Discuss special topics of general interest,

(3) Discuss any special issues involving inter-agency coordination, and

(4) Discuss interaction with other MatTec groups.

To help meet the objectives of the NDE Communication Group, representatives from participating federal agencies provide management/technical briefings on NDE programs underway and contemplated in their agencies. Narrative summaries of the meeting presentation are provided. An overall funding summary chart is included based on individual inputs provided by the presenters.

- **OSTP Interagency Council on Materials NDE.** As requested by the DOD, the NDE Branch developed a proposal for a broad inter-government-agency working group to exchange NDE R&D program information and discuss potential cooperative efforts among participant organizations. An advocacy briefing on the proposed action was presented by Branch Chief Donald Forney to the Under Secretary of Defense for Research and Acquisition Technology in late 1988. Based on this advocacy and the Under Secretary's subsequent recommendation, the White House Office of Science and Technology Policy (OSTP) chartered the Interagency Council on Materials NDE in 1989. As a result, thirteen federal departments with a common interest in NDE methods of imaging, testing, evaluating, scanning, measuring, and related technologies, joined to participate in semi-annual NDE technical and programmatic information exchange meetings. Included were elements of the Departments of Defense, Transportation, Energy, Health, Commerce, along with NASA and several other federal agency groups. These meetings were used to review briefings by representatives of each department describing NDE and similar program efforts and accomplishments, and to promote crosstalk and technical information exchange activities. Numerous interagency cooperation efforts and information exchanges developed from this activity during the several year life of the ad hoc initiative.

- **Defense S&T Reliance Plan Documentation.** Functioning under the leadership of the DOD Research & Engineering Deputy (DDR&E), the military departments and defense agencies work together to enhance the Department's Science and Technology (S&T) investment through the use of inter-service/agency collaboration. Guided by established DOD strategic development goals, the Reliance process coordinates the combined S&T plans through a number of Defense Technology Area Plan (DTAP) panels, one of which is for Materials and Processes (M&P) including NDE R&D programs. Panel delegates selected by each of the services/agencies collaborate to produce and annually update the DTAPs. Since the initiation of the Reliance planning process, the ML NDE Program has provided the Air Force NDE R&D planning delegate, including Tobey Cordell (1990 – 1999), Dr. James Malas (2000 - 2002) John Barnes (2003 - 2004) and Rob Marshall (2005 – present).

- **Aging Aircraft Steering Group (AASG).** To help coordinate aging aircraft activities and programs between technology developers and the users, the AF Office of Scientific Research (AFOSR) and the AFMC Engineering and Technical Management Division (AFMC/EN) jointly sponsored an Aging Aircraft Conference in April 1993 at Wright-Patterson Air Force Base, Ohio. This conference ultimately grew into the heavily attended jointly sponsored annual DOD/FAA/NASA Aging Aircraft Conference with annually rotating chairmanship. As a result of the initial conference, an Air Force Aging Aircraft Steering Group (AASG) was established by AFMC in October 1993 for Air Force aging aircraft activities, under the guidance of Dr. Jim Chang (AFOSR/Aerospace & Materials Science Directorate), Les Smithers (Wright Laboratory) and Otha Davenport (Headquarters AFMC). Ongoing Working Groups were formed for Nondestructive Evaluation (performed by the ML NDE Branch); Structural Integrity Assessment and Life Extension Methodology Development; Material Damage Behavior; and Corrosion and Fatigue. Experts from each of the five Air Logistics Centers also participated in program planning and implementation activities.

- **Joint Aging Aircraft Program Plan.** After much deliberation regarding the feasibility and potential value of joint planning, a USAF/FAA/NASA Science and Technology R&D management directive was issued in 1997 for the creation of a Joint Aging Aircraft Plan. The objective was to facilitate increased cooperation among the three agencies to make more effective use of limited resources and which would support fiscal year 2000 planning. The plan was intended to provide a broader benefit to the national aircraft sustainment community by exploiting R&D solutions to aging problems that are common across the military and commercial fleets. This plan outlined an Inter-Agency Program which would build on existing agency strengths and requirements, and define how coordination and collaborations would be executed. Participating for the Air Force were the appropriate AFRL Directorates and the ASC Aging Aircraft System Program Office, for the FAA the Hughes Technology Center Airworthiness Division, and for NASA, the Langley Research Center. US Navy and Coast Guard representatives participated as well as adjunct members.

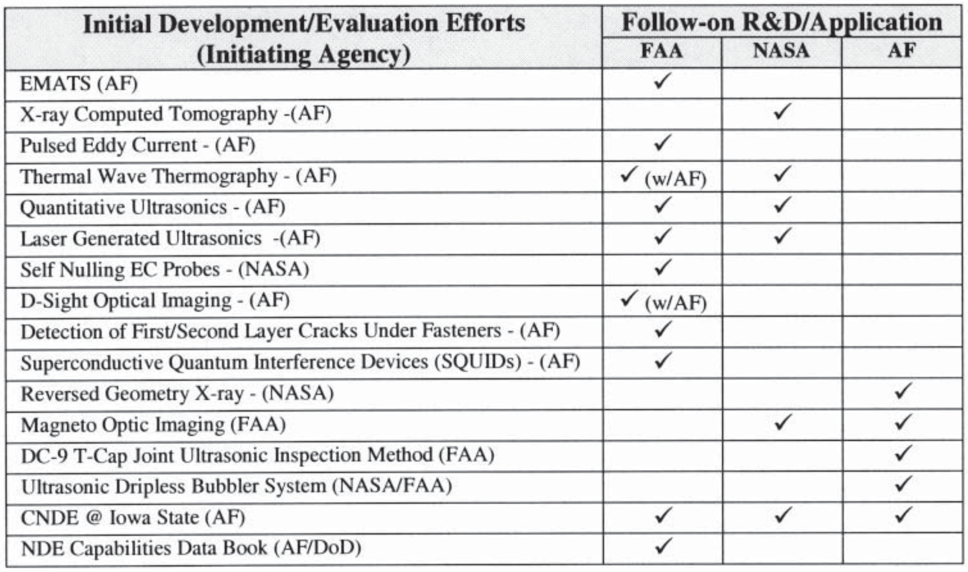
To support the development of the overall aging aircraft plan, the various aging aircraft programs were viewed as organized into eight (8) application areas, as shown below, featuring established common interests/objectives along with the identification of team leaders for each Agency and for each of the eight areas.

- Airworthiness Assurance/Fleet Management
- Aircraft Engines
- Avionics
- Advanced Structural Integrity Methodology
- Improved Corrosion Prevention and Control
- Advanced Nondestructive Inspection Systems
- Repair Methodologies
- Subsystems

The initial focus of the Joint Plan development was placed on Aging Aircraft Structures-related program areas. ML NDE Branch Chief Tobey Cordell was named to represent the Air Force in planning the Advanced NDI Systems area. Dr. Christopher Smith served as FAA Lead and Dr. William Winfree as the NASA Lead. Appropriate Memoranda of Understanding (MOU) between the three Agencies were signed on October 20, 1996.

Several periodic program review and coordination meetings of various area subgroups occurred with a focus on producing elements of the joint plan. Specific joint programs generally did not develop, due primarily to major systemic differences in agency-specific program priority setting, development objectives, and sustained funding availability. However, significant informal cooperation, coordination and exchange of NDE/I technical information historically has been occurring successfully for a number of years. Table 5.1 illustrates several examples of such actions. As noted, each agency historically has been a source of selected technology transfer opportunities for the others. These interactions also provided assistance in an unrelated initiative to create the Combined Roadmaps shown next.

Table 5.1. Partners in Technology Development/Transfer.



Initial Development/Evaluation Efforts (Initiating Agency)	Follow-on R&D/Application		
	FAA	NASA	AF
EMATS (AF)	✓		
X-ray Computed Tomography -(AF)		✓	
Pulsed Eddy Current - (AF)	✓		
Thermal Wave Thermography - (AF)	✓ (w/AF)	✓	
Quantitative Ultrasonics - (AF)	✓	✓	
Laser Generated Ultrasonics -(AF)	✓	✓	
Self Nulling EC Probes - (NASA)	✓		
D-Sight Optical Imaging - (AF)	✓ (w/AF)		
Detection of First/Second Layer Cracks Under Fasteners - (AF)	✓		
Superconductive Quantum Interference Devices (SQUIDs) - (AF)	✓		
Reversed Geometry X-ray - (NASA)			✓
Magneto Optic Imaging (FAA)		✓	✓
DC-9 T-Cap Joint Ultrasonic Inspection Method (FAA)			✓
Ultrasonic Dripless Bubbler System (NASA/FAA)			✓
CNDE @ Iowa State (AF)	✓	✓	✓
NDE Capabilities Data Book (AF/DoD)	✓		

- **NDE Combined Roadmaps.** In 1997, the NDE Program (under Tobey Cordell) initiated the development of a unique set of NDE program roadmaps, and accompanying short program narratives, displaying a consolidated view of the principal R&D related efforts of four DOD departments, (Army, Navy, Air Force, Defense Advanced Research Projects Agency), the FAA and NASA. The purpose of the project was to facilitate an assessment of areas of potential joint program interactions and data transfer and those areas requiring increased development activity and strengthening. Designated CRM 97-1 and dated 5 June 1997, the initial Combined Roadmaps effort was intended to be updated semi-annually (CRM 97-2, 98-1, etc.). However, time and effort for updating was not available. Meanwhile, this project helped draw further attention to the value of exchanging R&D program information and collaborative planning. A sample roadmap and narrative page are illustrated in Appendix F-7.

CHAPTER 6

Major Technology Transitions to the Air Force Customer and Transfer Beyond

In general, most cases of successful transition have satisfied or adequately accommodated the bulk of important customer acceptance factors, among them being a well established customer requirement, development completion in time to impact requirement, relative ease of application, reasonableness of implementation cost, reliability and durability of solution, and others (see Appendix C-5 for an expanded discussion of Air Force technology transition). Following are several representative technology transition/transfer examples:

- **X-Ray Sensitive Paper.** A detailed in-house evaluation of an experimental direct exposure X-ray sensitive paper concept introduced by Eastman Kodak in 1971 revealed that the paper system could provide significant benefits. The paper system, consisting of a silver halide emulsion and development agent coating and costing only 20 percent of that for an X-ray film, could be developed at the inspection site immediately after exposure in an inexpensive portable processor, in less than 15 seconds. The field trial demonstrated a potential reduction of 60% in man-hours involved by using the more readily processed paper. These evaluation results led to the Air Force certification of the paper system. AFLC issued more than 100 process orders to use the UV sensitive paper based on the ML evaluation.

- **Autoscan CUFS Inspection System.** While field evaluations of the Autoscan systems validated that detection goals were met (see Chapter 4), assessments indicated that further improvements were still needed to simplify its use and handling in the maintenance environment. Pending further improvements in the future, the system was still considered essential for numerous E-3 aircraft ASIP inspections and was delivered to OC-ALC in the early 1980s for that purpose.

- **Advanced Real-time Inspection System (ARIS) for Composites.** Extensive field trials were performed at twelve (12) Air Force operational bases (coordinated with Headquarters AFLC, including Edwards AFB [B-1B, F-l5, F-16, F-18, X-29, Randolph AFB [T-38], Hill AFB [F-16], Charleston AFB [C-141]). Tests were also conducted by the Navy at the Cherry Point Naval Air Station. In addition, ARIS was evaluated successfully by the Canadian Defence Forces, the UK Royal Air Force, and was used to perform a special inspection of the SR 71 fleet radomes. Many field inspection personnel operated ARIS without difficulty, indicating its operational reliable and ease of use in the field environment.

- **GD Computer-Automated Ultrasonic Inspection System (CAUIS).** The contour following and computer control and display portion of this system were incorporated later by Pratt & Whitney Aircraft under a ManTech-funded program.

- **Automated Eddy Current Inspection System for Engine Disks (EC II).** The prototype development contractor, GE-AEG, continued system improvement efforts independently. By 1985, GE had installed 23 units in U.S. and allied Air Force and commercial facilities. [6.1]

- **Near Net Shape Engine Disk Inspection System Development (AFCUE).** The two Air Force Computerized Ultrasonic Evaluation (AFCUE) systems, one using adaptive (GE) and the other using preprogrammed (P&W) surface contour following by the transducer to maintain normal entry angle, entered in-plant operational use by its developers by 1980.

- **Integrated Blade Inspection System (IBIS) X-Ray CT Module (XIM).** The first production-ready XIM unit, capable of producing CT images was installed in the GE Madisonville Kentucky Turbine Airfoils Plant with the capability of detecting 0.010 inch minimum internal flaws and measuring dimensions with an accuracy of 0.005 inch. The San Antonio Air Logistics Center (SA-ALC) took delivery of the completed system and continued investigations of its application.

- **Turbine Engine Disk Retirement for Cause (RFC) Inspection System.** The initial RFC system consisted of an Eddy Current Inspection Station (ECIS), and an ultrasonic inspection station that was not implemented in production at the time. The ECIS module became the USAF standard fully automated disk inspection system for the ENSIP and RFC programs at the Oklahoma City Air logistics Center (OC-ALC). Today, the Air Force has 41 ECIS operational at OC-ALC inspecting the F-100 engines (F-15 and F-16 aircraft), F101 engines (B-1B aircraft), F110 engines (F-16 aircraft) and F-118 engines (B-2 aircraft). Benefits from the application of the RFC system has been a return on investment of 25:1, increased engine availability, decrease in engine failures, and projected $1 billion overhaul cost savings.

- **X-Ray Computed Tomography (CT).** The Air Force Advanced CT System I (AFACTS I), served as the forerunner of several subsequent advanced systems in use today by both the Air Force and industry. The largest operational CT system in use today, the ICT 2500 CT System based on the AFACTS-II prototype, was built for the Air Force by ARACOR in 1990-92 and is located and in operation currently at Ogden Air Logistics Center (OO-ALC), Hill Air Force Base, UT. It utilizes a 15 MeV radiation source and an inspection envelope of 96” diameter, 336” height and a 150,000 lb. maximum table load capable of handling and inspecting solid boosters ranging from the Peacekeeper ICBM first stage down to a Minuteman ICBM 3rd stage.

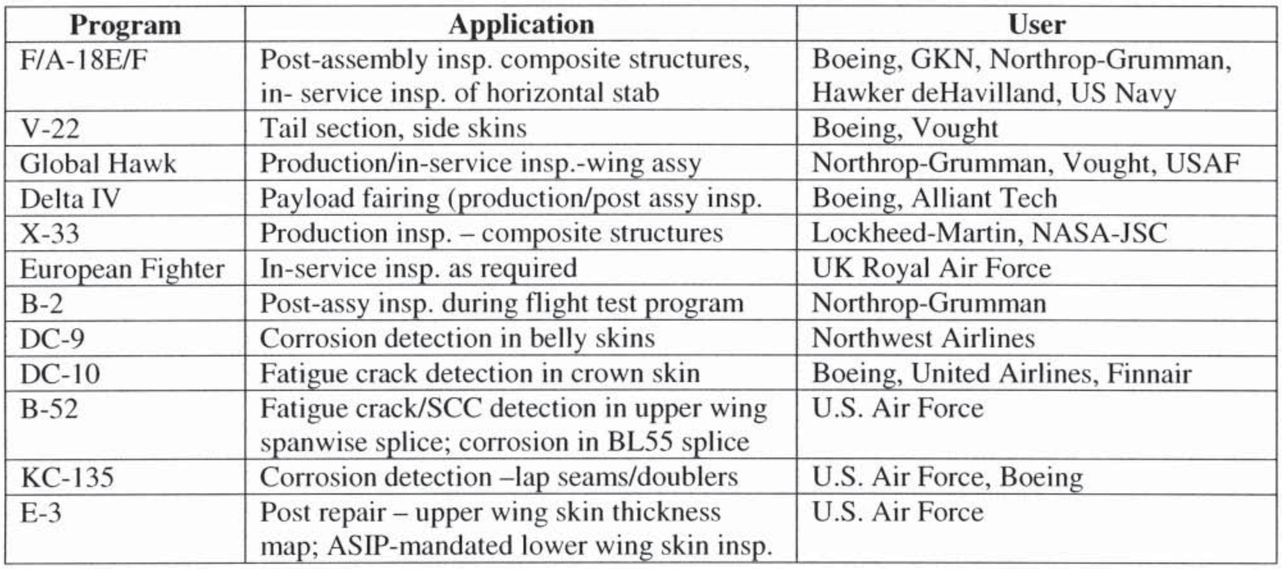
- **Mobile AUtomated Scanner (MAUS).** Following development of earlier versions, the third generation of the MAUS (MAUS III) was deployed to the five Air Force Air Logistics Centers for field trials and evaluation. Further evolutionary development produced MAUS IV. Subsequently over fifty MAUS IV systems entered service throughout the world. Table 6.1 summarizes the extent of system trials and applications to February 2003.

Following the incorporation of new system architecture, providing greater depth resolution and higher data processing speeds, the resulting in the current generation system, designated MAUS V, was deployed to the Oklahoma City and Ogden ALCs in 2003 for use on the E-3 aircraft. With new depth resolution abilities, the new system capabilities include skin thickness mapping (to detect thinning due to corrosion) throughout wing and fuselage surface structures and distinguishing material anomolies from adjacent near and back surfaces on complex composite and metallic structures. Since then, the MAUS-V has been used in PDM cycles on the KC-135 and B-52 aircraft. Upgrading of available MAUS IV units at the ALCs to MAUS V capabilities was initiated to capitalize on the new features.

- **Laser Ultrasonics for Large Area Composite Inspection.** After 16 years of research and development funding and technical assistance by the ML NDE Program, AF RAMTIP team, and Lockheed Martin Aeronautics (LMA) in Ft. Worth and its predecessors, the “Alpha” facility went on line in January 1999 at LMA. The “Beta” facility was approved for production use in June 2000 to provide support to F-22 and F-35 Joint Strike Fighter production (see Chapter 4). In addition, the laser ultrasonic NDI system developed by the AF RAMTIP effort referenced above for the Sacramento Air Logistics Center (SM-ALC), McClellan AFB, California was transferred (upon closure of SM-ALC) to the National Center for Aging Aircraft Research in Sacramento, CA for continuing civilian R&D in support of condition-based maintenance (CBM) methodologies.

- **High Resolution Real Time (Digital) Radiography (HRRTR).** Following more than 15 years of R&D efforts by the NDE Program in partnership with ASC and AFMC Warner Robins and Oklahoma City Air Logistics Centers, HRRTR systems were installed via the Digital Radiography Insertion Program (DRIP) in 2004. The new production multi-axis x-ray (MAX) system is located in the NDI facilities at Warner Robins ALC (WR-ALC), Robins AFB, GA for on-aircraft inspection of control surfaces. The new DR NDI facilities at Oklahoma City ALC (OC-ALC), Tinker AFB, OK are designed for off-aircraft component inspection.

Table 6.1. MAUS IV Applications as of February 2003



Program	Application	User
F/A-18E/F	Post-assembly insp. composite structures, in- service insp. of horizontal stab	Boeing, GKN, Northrop-Grumman, Hawker deHavilland, US Navy
V-22	Tail section, side skins	Boeing, Vought
Global Hawk	Production/in-service insp.-wing assy	Northrop-Grumman, Vought, USAF
Delta IV	Payload fairing (production/post assy insp.	Boeing, Alliant Tech
X-33	Production insp. – composite structures	Lockheed-Martin, NASA-JSC
European Fighter	In-service insp. as required	UK Royal Air Force
B-2	Post-assy insp. during flight test program	Northrop-Grumman
DC-9	Corrosion detection in belly skins	Northwest Airlines
DC-10	Fatigue crack detection in crown skin	Boeing, United Airlines, Finnair
B-52	Fatigue crack/SCC detection in upper wing spanwise splice; corrosion in BL55 splice	U.S. Air Force
KC-135	Corrosion detection –lap seams/doublers	U.S. Air Force, Boeing
E-3	Post repair – upper wing skin thickness map; ASIP-mandated lower wing skin insp.	U.S. Air Force

- **Point Inspection Tool for Low Observable Materials.** In 2000, the newly developed LO Point Inspection Tool produced by Lockheed Martin Skunk Works, through the NDE Program (see Chapter 4), was delivered to and evaluated by the 49th Fighter Wing at Holloman Air Force Base, New Mexico. Designated the MM-704A, the tool was found to be quite good by the Fighter Wing inspectors, as well as user-friendly, portable, and useful on multiple platforms. In an evaluation exercise, the tool was able to complete a quick readiness evaluation of 15 aircraft in a period of 1.5 days using only one tool.

Following are representative examples of technology transfer events:

- **MAUS Large Area Inspection System Demonstrated at Indy Racing League (IRL) Venues.** In view of the high performance composite material requirements of the automotive racing industry, AFRL, together with the NDE Program, contacted the IRL to market the MAUS inspection technology. After preliminary discussions and trial inspections on representative specimens, the AFRL NDE team participated by invitation in service inspection demonstrations at several IRL races at Orlando, Las Vegas, and Indianapolis in 1997. In 1998, the AFRL NDE team had a dedicated garage in the Indianapolis 500 for showcasing the MAUS inspection technology. The component of primary interest was the Racing Chassis (Tub) which is an integral, high value, primary component of the car that protects the driver (in the event of a crash) and provides the foundation structure for the car to which all other components (engine, fuel tank, suspension, etc) are attached. The Tub consists of two primary pieces (upper and lower halves) which are bonded together; inspection was conducted to ascertain the quality of this bonded joint (before (virgin tubs) or after (crashed tubs)). Several IRL racing teams and sponsors were able to examine this technology and its usefulness in maintaining quality in their racing programs. Material performance is a key component in the racing world. Slight relaxation of properties extrapolated into a reduction in performance of the car's handling and racing potential.

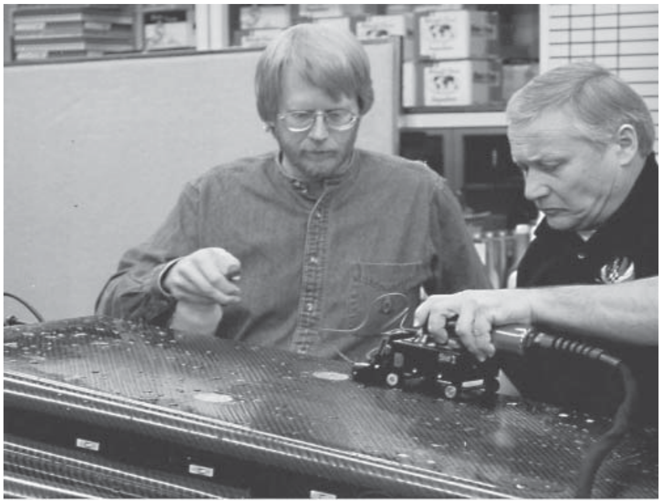


Figure 6.1. Demonstration of MAUS Scanning Performance on Indy Race Car Composite Tub Structure by NDE Program Members Mark Ruddell and Ed Klosterman (UDRI).

- **MAUS Demonstrated at American Power Boating Association (APBA) Racing Venues.** Building on the positive response with the IRL, the AFRL NDE team contacted the American Power Boating Association (APBA) to discuss and demonstrate the application of MAUS for these high performance material applications. Demonstrations were conducted on "Tunnel Boats" in Pittsburgh, PA in June 1996 and off-shore racing in Mission Bay, San Diego, CA. in September 1996. As with the IRL application, these sportsmen were most interested in the integrity of their structures but with the APBA, integrity of the structures after repairs was a bigger issue. APBA officials and sponsors were very interested in the portability and imaging capability for the MAUS technology. Tight budgets and/or material constraints limited the practicality of this technology for marine applications.

Figure 6.2. Demonstration of MAUS Performance on a Grand Prix Racing Boat Hull by NDE Program Member Brian Frock (UDRI).

- **DOD Technology Developments Display - Paris International Air Show, Le Bourget, France.** The NDE Program participated in the AFRL booth of the DoD (Navy, Air Force, Army) display at the Paris International Airshow, Le Bourget, France in June 1999 to demonstrate many new advancements in NDE

Figure 6.3. Air Show MAUS Demonstration Booth Managed by Chalres Buynak.

Figure 6.4. Charles Buynak Discussing MAUS Performance with U.S. Ambassador.

technologies. Display materials included graphics of the MAUS system in use at USAF depot facilities and additional technology transfer successes (racing car and boating applications discussed earlier). Live demonstrations of the MAUS III hand scanner unit were conducted by the NDE Program's Charles Buynak throughout the entire week on a simulated composite panel with embedded structural defects. Representatives of many European countries, including United Kingdom, France, Russia, Poland, and Canada, visited the booth to examine this and other emerging technologies. The impact of this technology was easily recognized as the live demonstration facilitated an inspection scenario with eye-catching results immediately observed by the visitors.

- **DOD Technology Developments Display - Moscow Air Show, Zhukovsky, Russia.** The USAF International Affairs office was able to secure a booth at this airshow, held in the MAKS Intentional Aviation and Space Salon in Zhukovsky, Russia in August 2001 with the US Department of Defense. The DoD sponsored the booth with military and civilian representatives of the USAF, USA, and USN. The AFRL NDE Program-developed (MAUS) was the only technical equipment and demonstration in the display. This afforded an opportunity to showcase this technology to the world and discuss other technology advances that the USAF was making in aircraft safety and sustainment. As the first ever DoD sponsored display at MAKS, this was a very unique opportunity. The excitement of the MAUS technology and the demonstration afforded the opportunity for visitors to visit the booth, learn about this USAF technology, and, in turn, learn about the other technology poster displays. Russian aircraft designers, developers, and maintainers were free to interact with the NDE technology and the NDE Program's Charles Buynak to learn more about the technology and its breadth of applications for composite and metallic structures. DoD sponsored multiple interpreters to aid in the transfer of this technology. This also afforded the opportunity for participation in the companion "6th Annual International Scientific Technical Symposium" to learn more about new worldwide advancements in aeronautical structures and advanced materials.

Figure 6.5. Chief Engineer Dr. Kashafutdinov Listening to Discussion by Charles Buynak with Russian Interpreter on Right.

- **Adaptation of Weep Hole Ultrasonic Inspection Technique.** While the inspection technique developed for the C-141 Weep Hole was not deployed, the methodology was adapted to suit another structure in a different aircraft that had a similar geometry - the lower forward spar cap structure of the C-130 Hercules.

The transition of the inspection process to the C-130 configuration was funded by the C-130 SPO at Warner Robins Air Logistics Center. The inspection technique had to be modified to address the differences in the two structures being inspected. The C-130 structure had a different geometry, as well as two parallel rows of fasteners, that needed to be inspected. In addition, these fastener holes were filled with wet-installed fasteners. These changes made it more difficult for the creeping wave to propagate around the hole, which required modifications to the automated software to analyze the ultrasonic signals, plus the transducers and related inspection hardware. Using this approach, the inspection was validated by a comprehensive Probability of Detection study. The inspection is now deployed at Warner Robins ALC and by contractor field teams. A summary of this development, validation and deployment process was given at the 2005 Aging Aircraft Conference in Palm Springs, CA. [6.2]

- **High Resolution Real-Time Digital Radiography System for On-Aircraft Component NDE.** In partnership with the ASC Aeronautical Enterprise Program Office (AEPO), the NDE Program helped accomplish the transition of newly developed digital radiography inspection systems, as part of the Digital Radiography Insertion Program (DRIP), into the production Engine Oil Tank and Cooler Inspection facility (November 2002) and the Advanced Composite Repair Center (March 2003), respectively, at the Oklahoma City Air Logistics Center (OC-ALC). An additional development, the Multi-Axis X-Ray (MAX) system, was transitioned to the Warner Robins Air Logistics Center (WR-ALC), becoming operational in July 2004. It is shown in Figure 4.38, Chapter 4 performing an automated NDE scan of the right vertical tail of an F-15 fighter.

References

6.1. Cooper, T. D. and Forney, D. M., *“Increased Inspection Requirements for Critical Air Force Engine Components,”* Presented at the 1981 Air Transport Association Nondestructive Testing Forum, Phoenix, AZ, 1-3 September 1981.

6.2. Lingren, Eric, Abel, James, Concordia, Michael, Macinnis, Tim and Manderville, John, SAIC Ultra Imge; Aldrin, John, Computational Tools; Christiansen, Fritz, Darren and Mullins, Tommy, Warner Robins Air Logistics Center; Spencer, Floyd, Sandia National Laboratories and Waldbusser, Ray, C-130 Fst, A, Air-4.3.3. *“PoD Results and Deployment of the Inspection of the Vertical Leg of the C-130 Center Wing Beam/Spar Cap,”* 2005 Aging Aircraft Conference, Palm Springs, CA, January 31 – February 3, 2005.

CHAPTER 7

Vision for the Future

In the formative days of the Air Service's applications of materials and parts inspection, projections of what nondestructive inspection capabilities would be needed to verify quality were generally limited to the visual and physical measurement experience at hand. However, with the newly gained fabrication challenges, operational experience and maintenance lessons learned with vast quantities of aircraft used in World War I, more attention was given to cracking and other forms of deterioration, and potential methods of their detection prior to failure.

In the decades since then, remarkable advances have been made in the development of numerous effective NDT/I/E methods and procedures. These have greatly expanded our abilities to detect and characterize many types of material and component flaws, anomalies, properties, and in many cases, to project an estimate of remaining serviceability of a material or part. The current Air Force fleet management strategy includes the extension of service lives of a number of legacy weapon systems with the aid of advanced usage tracking, appropriate life-extending component replacement, and targeted inspection-based safety management. Newer weapon systems are now placed under appropriate parts of the same general life management philosophy as well. A linchpin of this strategy is the application of a strong, constantly improving state-of-the-art NDT/I/E capability.

With the rapid pace of new science and technology development, characteristic of the past decade or so, the time-proven adage that – "the more we learn, the more there is to learn" - rings true for this robust NDE technology area. The current NDE Branch Chief Dr. Jim Malas, joined by the prior three NDE Branch Chiefs (Tobey Cordell (1991-1999), Donald Forney (1974-1990) and Tom Cooper (1962-1974), put forth a consensus view of future development needs, goals and opportunities for the next 10 to 15 years. The result presents a challenging but exciting view of critical future research and development requirements, framed somewhat for convenience within the current general program directions:

- **NDE for Aging Aircraft.** Future NDE capabilities must address growing aircraft structural integrity problems, e.g., corrosion and crack detection, that impact fleet reliability, readiness, and associated maintenance costs. This is important because (i) the equivalent aircraft age of the fleet exceeds full scale fatigue test data which has greatly increased the probability of significant cracks, and (ii) maintainers have experienced increased NDI misses in the field. Continuing to operate the aging fleet safely will require improved NDI/E methods reliability and quantitative measurement of flaw size, coupled with a new maintenance strategy involving Probabilistic Risk Assessment and Integrated Systems Health Management (ISHM). The technical capability requirements to reaching these goals will include:

  -- Much better understanding of signal/flaw interactions, especially for complex conditions such as closed cracks under compressive loading,

  -- Greatly improved inspection accuracy by extracting flaw information in a cluttered data environment,

  -- More accurate detection of small flaws in large areas and with improved inspection speed,

  -- Capabilities to inspect through external coating systems, including advanced paint and low observable systems, and

  -- Capabilities to evaluate the strength of structural adhesive bonds

- **NDE for Turbine Engines.** Future NDE capabilities must assure turbine engine safety, durability and readiness at an affordable cost. This is important because (i) legacy engines will continue to be operated beyond original design lives, and (ii) emerging engines operate at higher temperatures and stresses. This will require many new capabilities to accurately perform:

  -- In-situ, on-wing material NDI/E to detect any damage,

  -- Inspection of repaired integral blade and rotor components,

  -- Nonlinear ultrasonics for precursor damage detection, and

  -- Subsurface residual stress measurement for titanium-based engine alloys.

The technical capability requirements to reaching such goals will include:

-- Use of condition based monitoring for assessing and predicting remaining life of components,

-- Use of embedded sensor systems for detecting and characterizing defects in complex geometry components with limited access,

-- Achievement of improved accuracy and more reliable NDI/E for component life extension, and

-- Use of alternatives to some NDE approaches (such as fluorescent penetrant inspection processes) that are insufficiently quantitative for some applications and/or produce hazardous by-products.

- **NDE for Low Observable Materials.** Future NDE capabilities must enable field-level LO signature verification in order to impact fleet readiness and survivability, and reduces maintenance costs. This is important because (i) this goal is one of the Air Combat Command's top 10 maintenance priorities, (ii) high maintenance burden lowers mission capability rates, (iii) LO signature uncertainty is a major concern for pilots, and (iv) high demand exists for verifiable field repairs. The technical capability challenges to reaching these goals will include:

-- Direct effect on radar cross section from changes to complex electromagnetic material properties, and

-- Embedded sensing for LO materials.

This will require near term capabilities to provide:

-- Portable, multifunction, intelligent LO NDE systems using physics-based material analyses, and

-- Improved sensors and analysis methods for complex material data analysis of multilayered LO systems

- **Material Systems Health Monitoring.** Future NDE capabilities must establish on-board, real time damage state awareness that impacts fleet reliability, readiness and maintenance costs. This is important because (i) embedded monitoring is essential to determine during the mission that the system is able to complete the mission and (ii) self initiated reporting is essential to produce automated maintenance action requests and autonomic logistics. This will require the capability to perform with accuracy:

-- Global monitoring of damage initiation,

-- Damage tracking of critical, inaccessible structures, and

-- Use of new smart, self aware materials

The technical capability requirements to reaching these goals include:

-- Sensor incorporation without compromising material performance,

-- Sensor output correlation to material damage states and life prediction, and

-- Robust, reliable sensing capability beyond 1000 degrees Centigrade.

Systems Engineering methods for designing integrated health monitoring systems must assure the use of effective and robust sensor system configurations for structures, engines, and subsystem applications will be important. Systematic approaches will be essential for determining what to sense, where to sense, and how to effectively configure and integrate a network of multi-modal sensors. A representative sample of future sensor-related development challenges and opportunities are recognized here:

-- Nanotechnology for self sensing and healing materials. Researchers are exploring a number of areas:

  - Organic matrix composites with carbon nanotube sensors dispersed throughout (this is important because current embedded sensing technologies have limited life expectancy and potentially significant calibration and maintenance requirements),
  - Nanocomposites used to create flexible, transparent electromagnetically active sensors with electromagnetic superposition of results directly within the conforming sheet, allowing truly direct correlation of information with location, and
  - Nanocomposite structures that function both as external emitting and receiving sensors and as self-contained internal degradation detectors, allowing, for example, interrogation of UAV structures at very low cost,

-- Wireless data communications for sensor networks and integrated systems health monitoring,

-- Imaging technologies for evaluating and visualizing 3D flaw characteristics,

-- In-situ sensing,

-- Quantitative diagnostics for determining direct impact of flaws on the behavior of structures. This would include computational model developments.

In the developing area of **NDE for Global War on Terrorism**, some technical capability challenges are similar to those for aerospace applications while others present some new variations. Challenges of particular importance will be:

-- Inspection accuracy, reliability and speed,

-- Accurate NDE signal extraction from noise,

-- Automated inspection system development, and

-- Accurate, safe energy-material interactions.

APPENDIX A

NDE Branch Organization Chart Chronology

Presented in this Appendix are the available organization charts that illustrate the evolution of the current Nondestructive Evaluation Branch of the AFRL Materials and Manufacturing Directorate. The original Material Section shown below is recognized by historians as the ancestor of the Materials and Manufacturing Directorate.

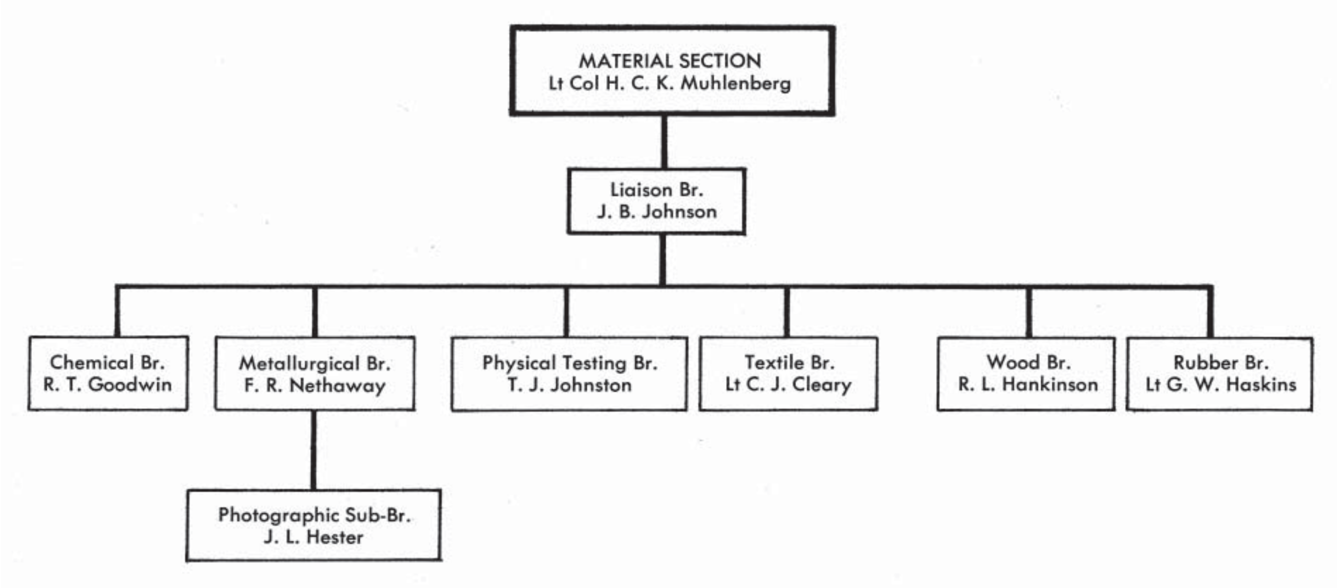


Figure A.1. Material Section Organizational Structure, 1919.

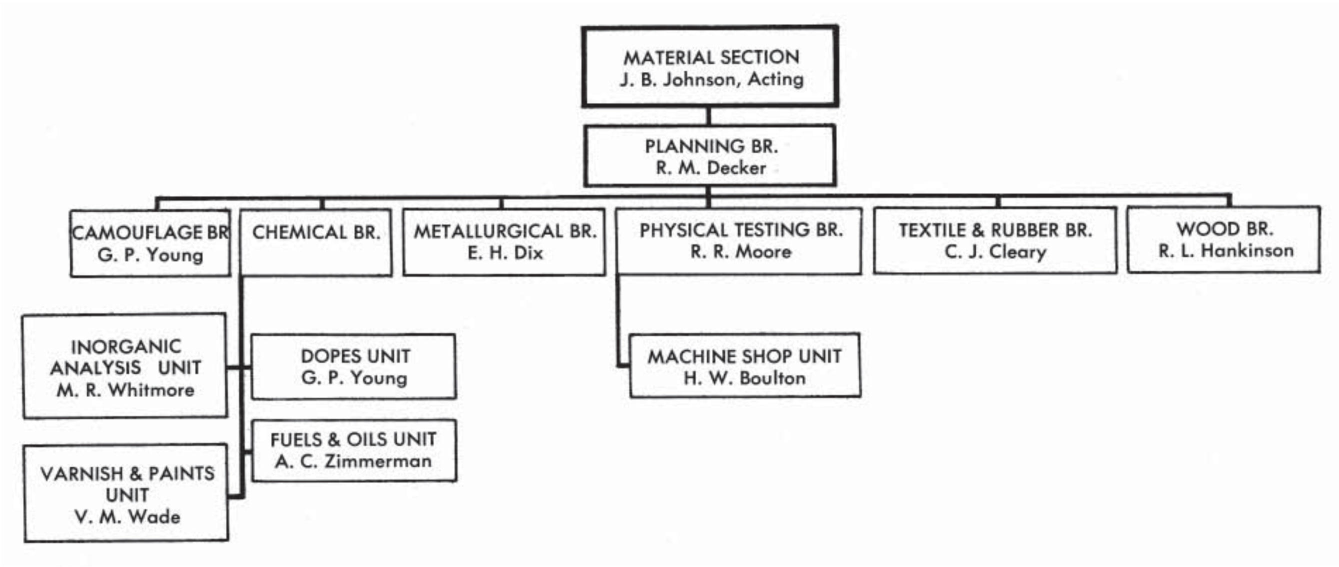


Figure A.2. Material Section Organizational Structure, 1922.

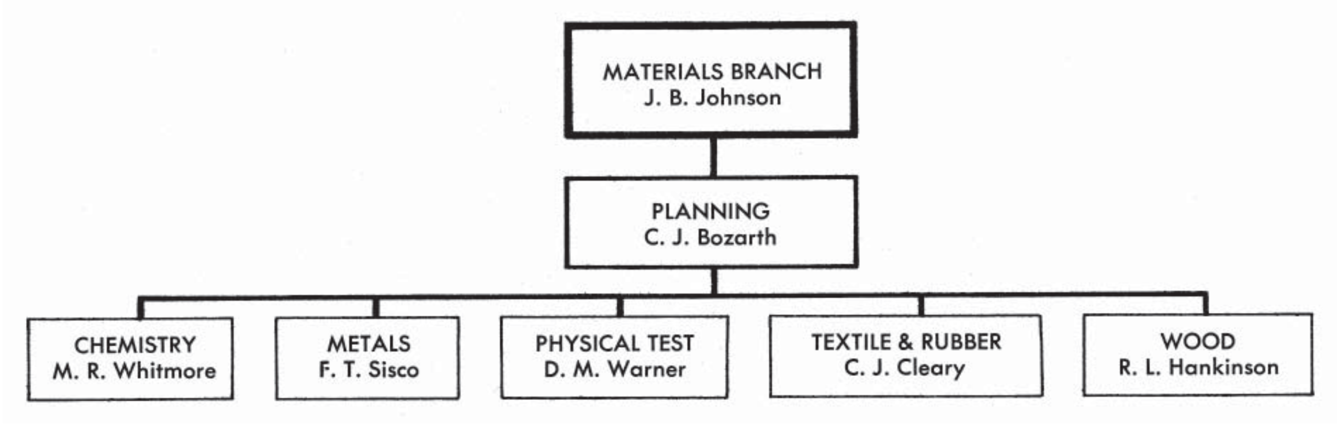


Figure A.3. Material Section Organizational Structure, Dec. 1927.

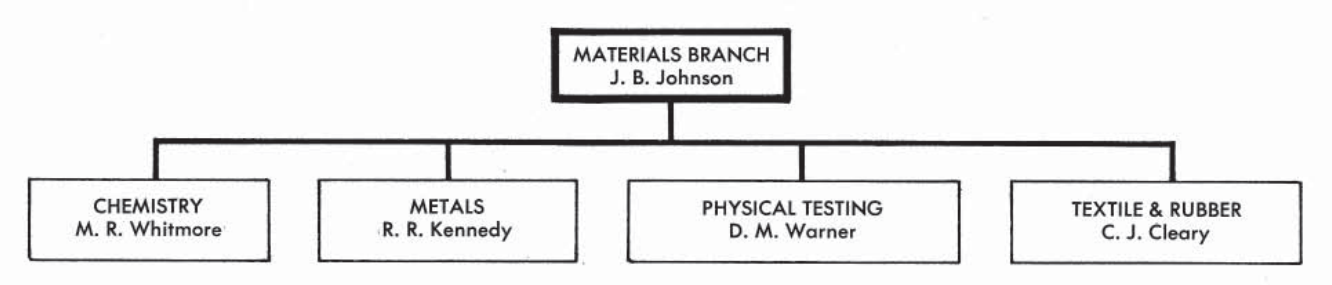


Figure A.4. Materials Branch, June 1930.

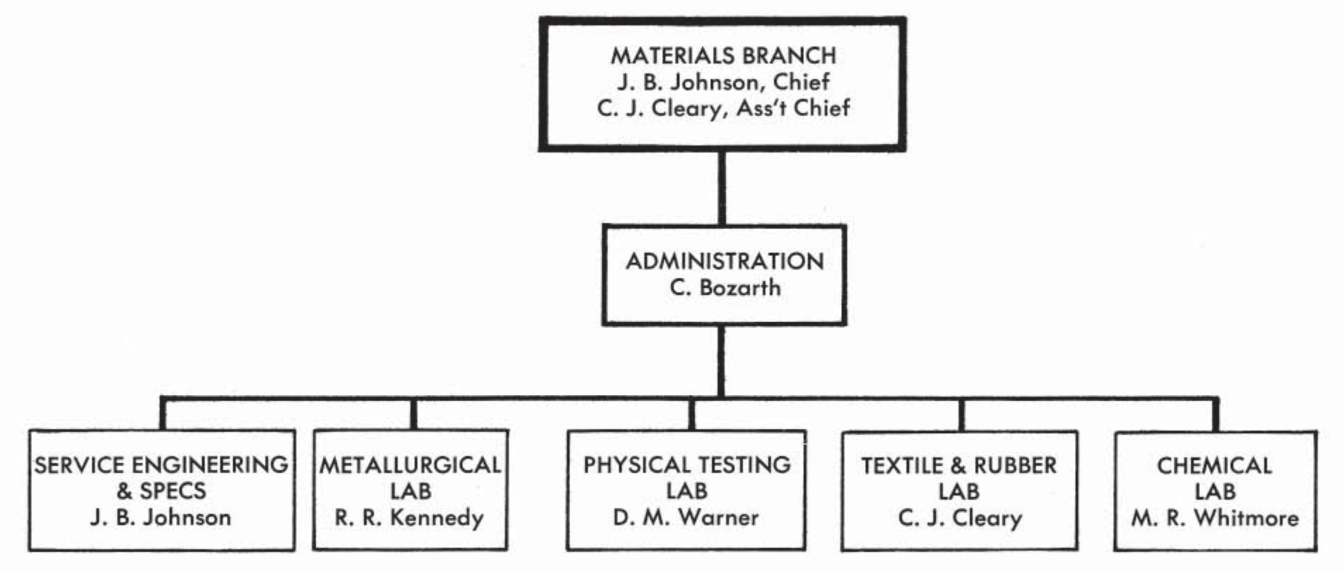


Figure A.5. Materials Branch, 1937.

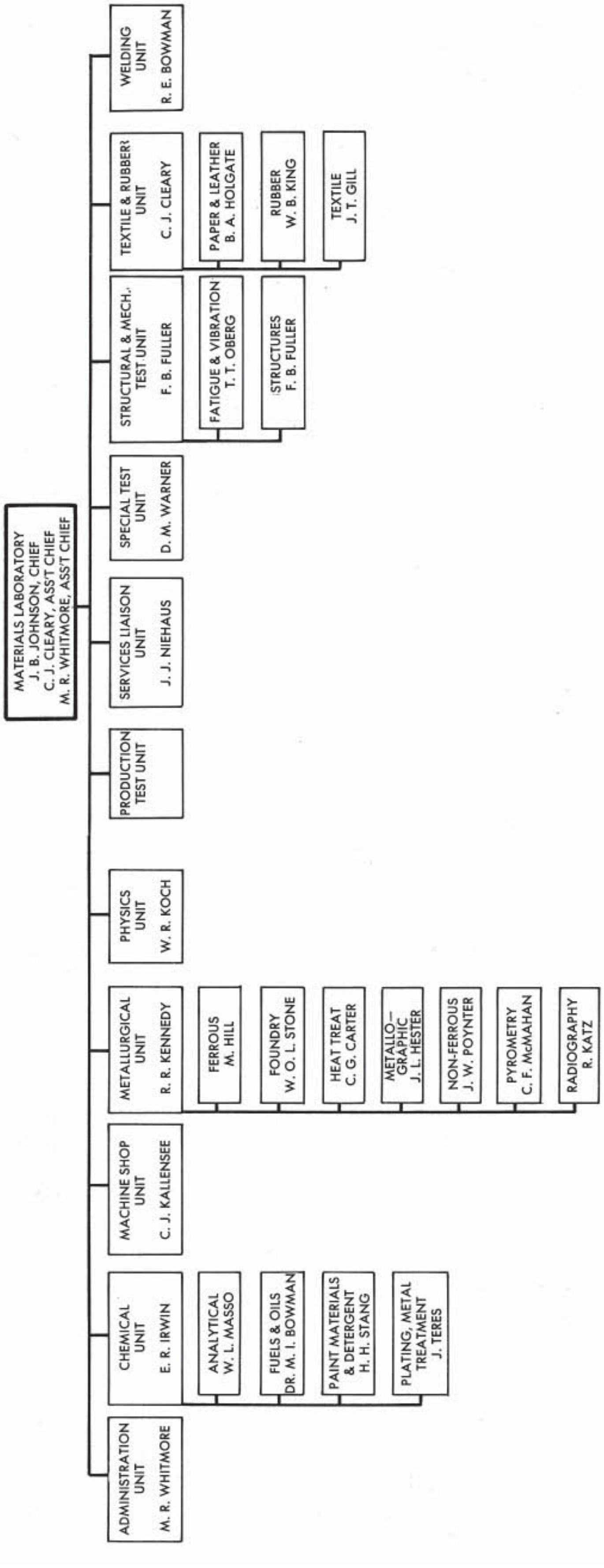


Figure A.6. Materials Laboratory, May 1941.

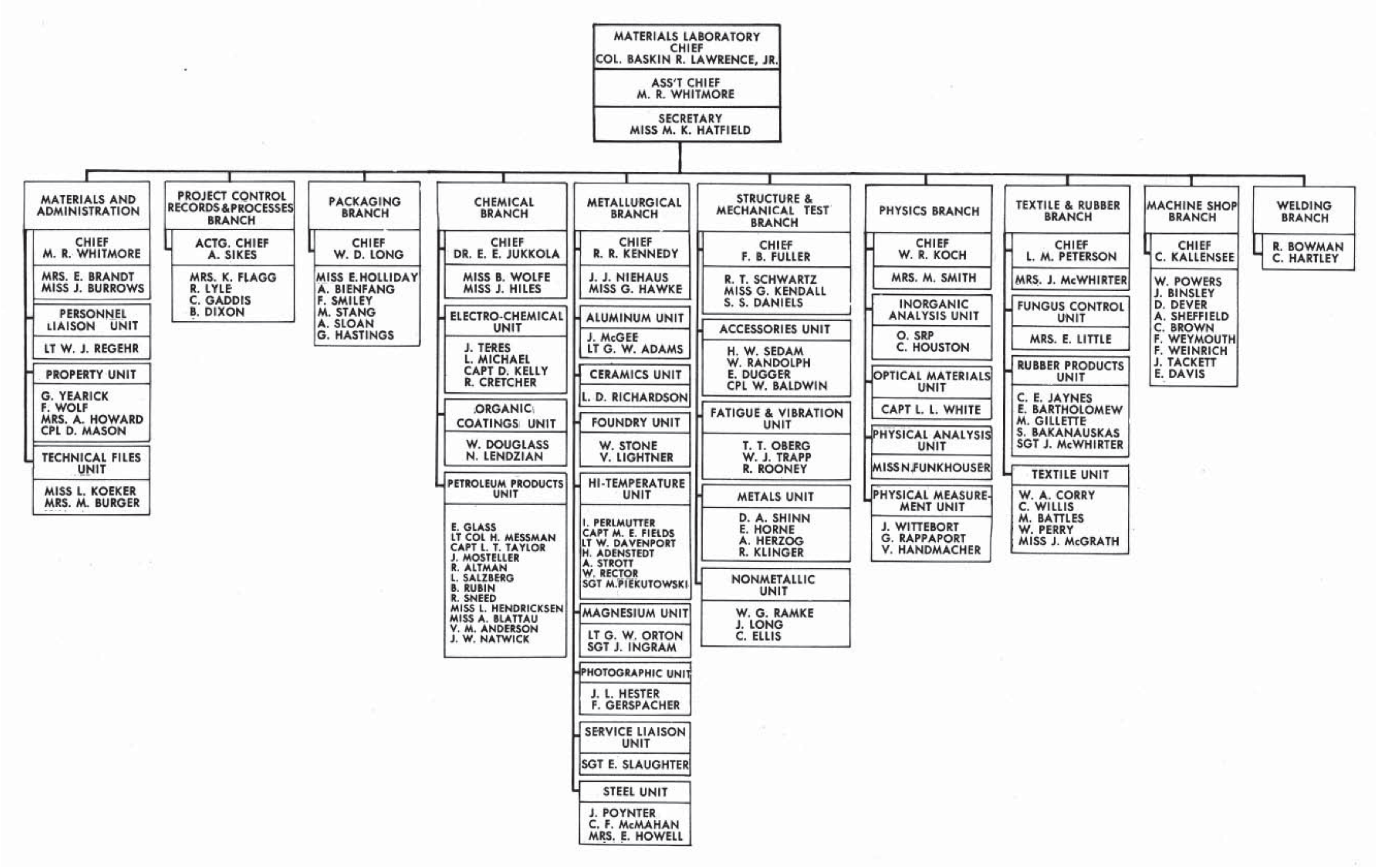


Figure A.7. Materials Laboratory, Dec. 1949.

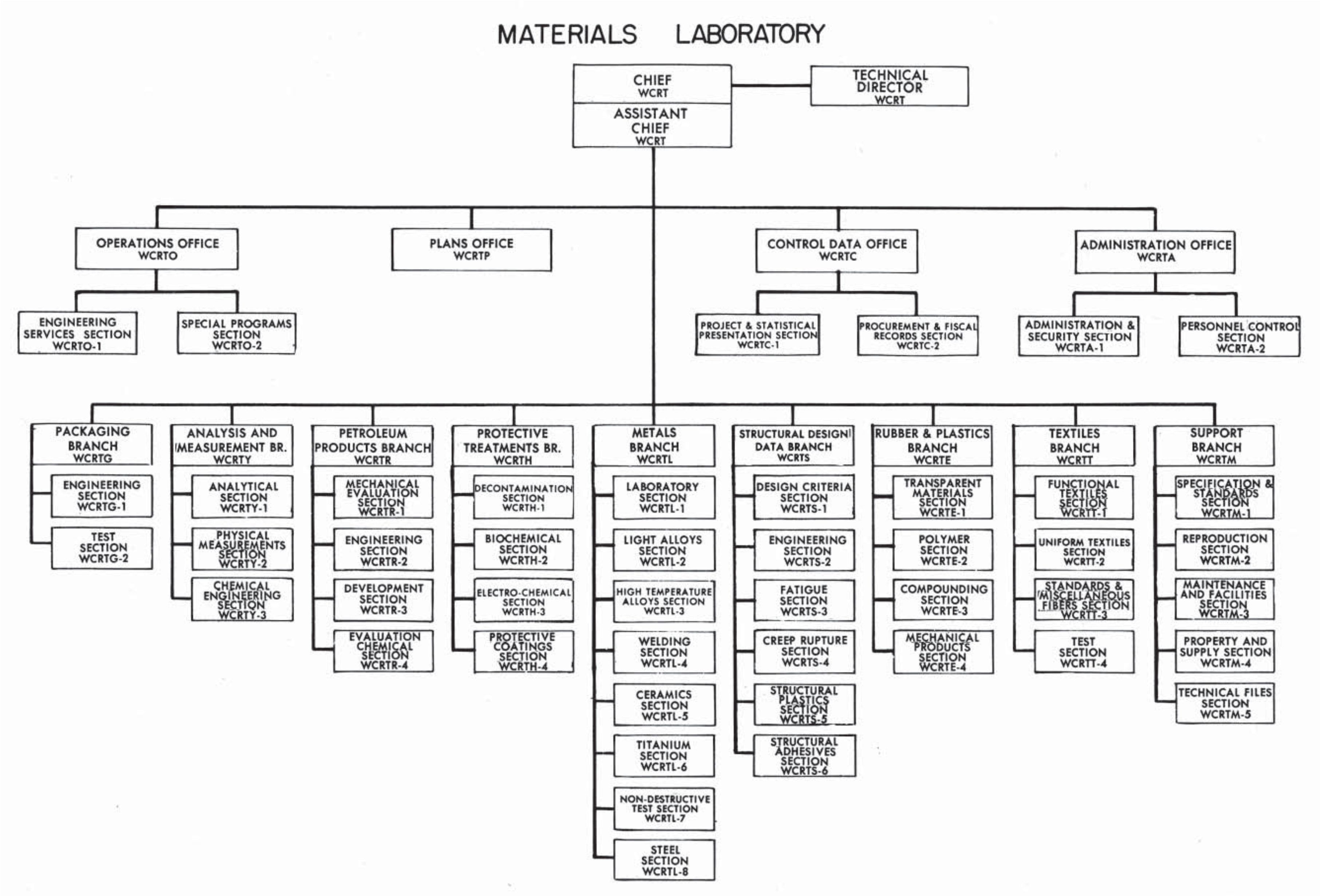


Figure A.8. Materials Laboratory Organizational Structure, 2 Jan. 1953.

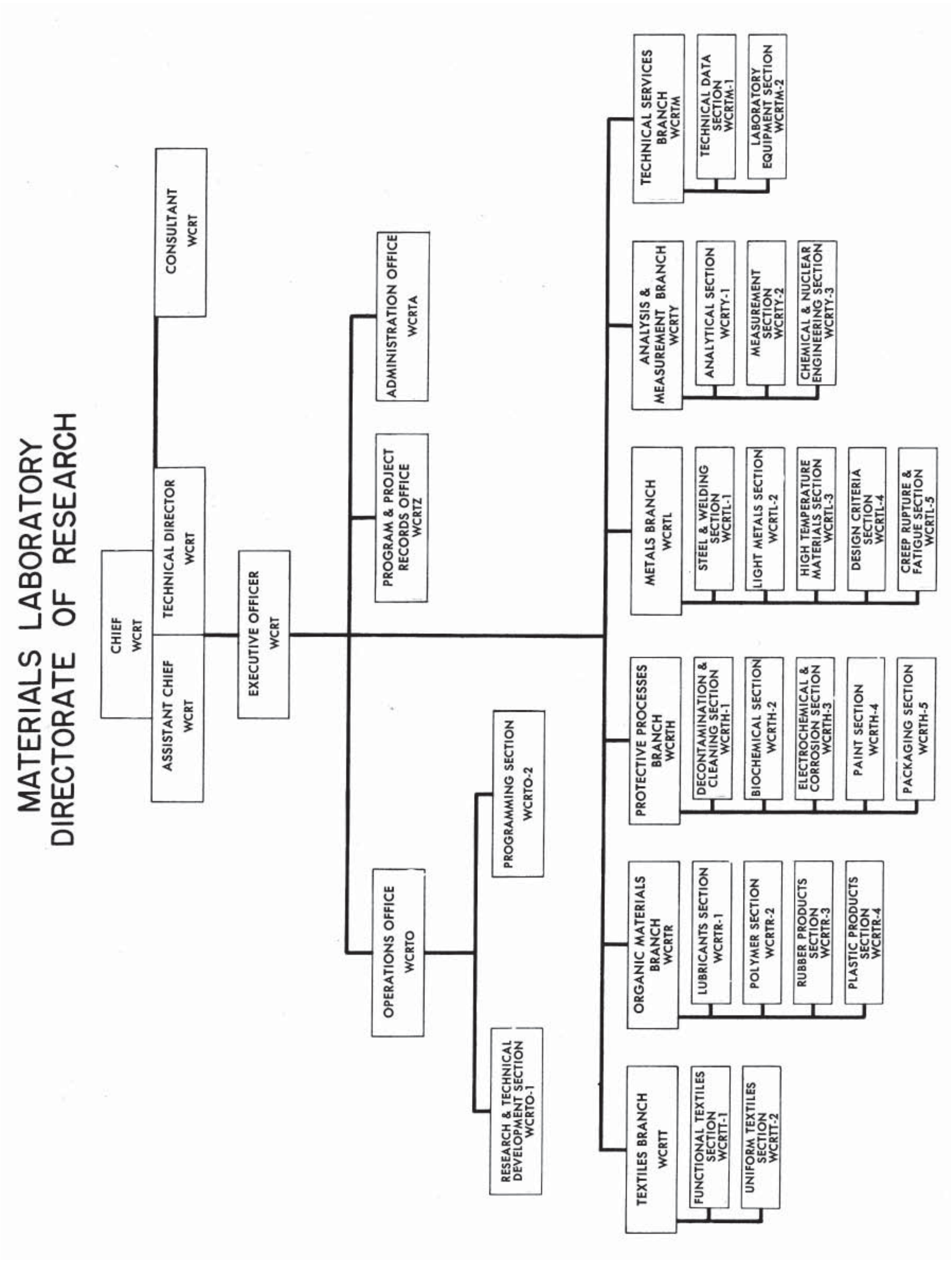


Figure A.9. Materials Laboratory Organizational Structure, 15 Sep. 1956.

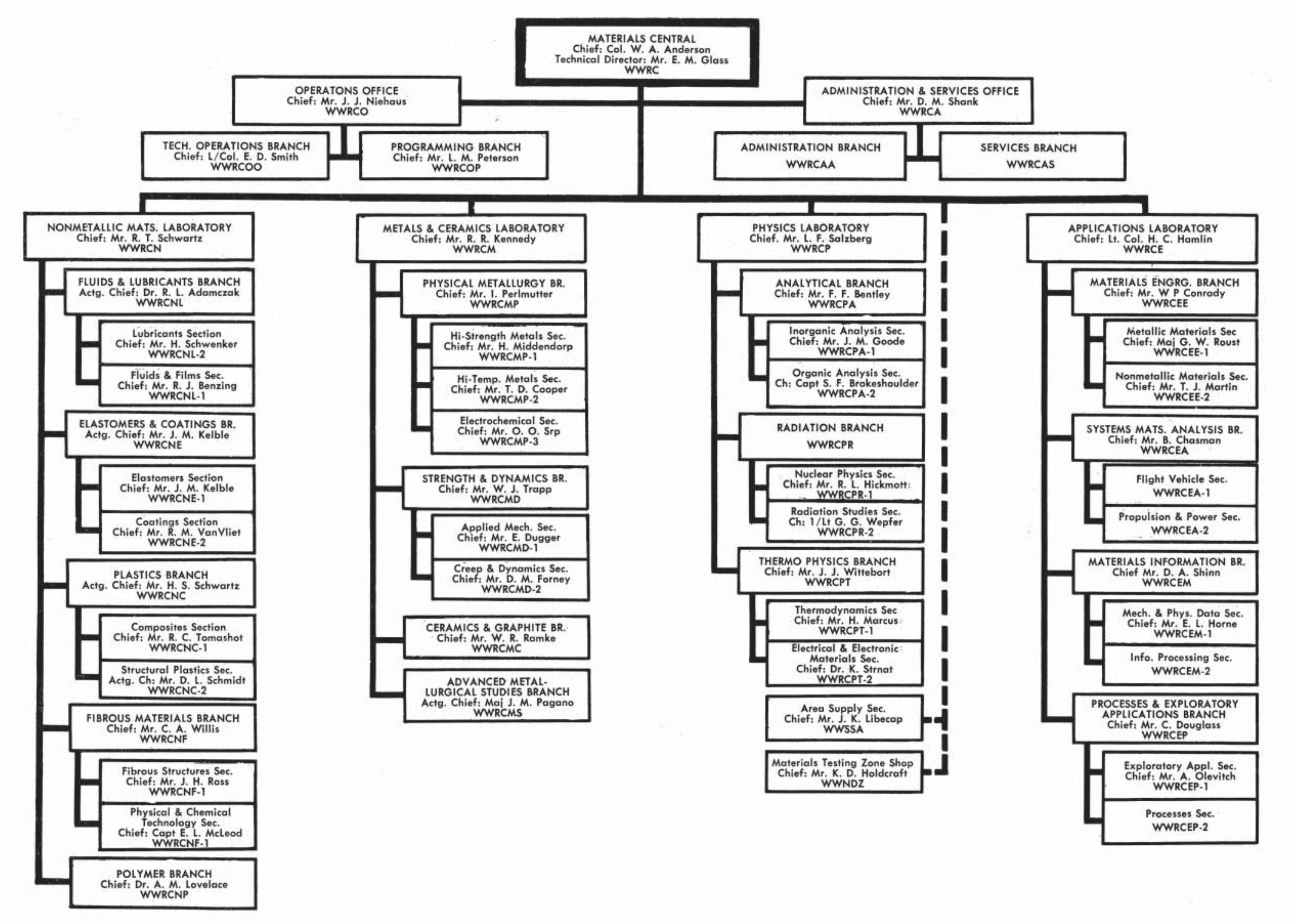


Figure A.10. Materials Central Organizational Structure, Aug. 1960.

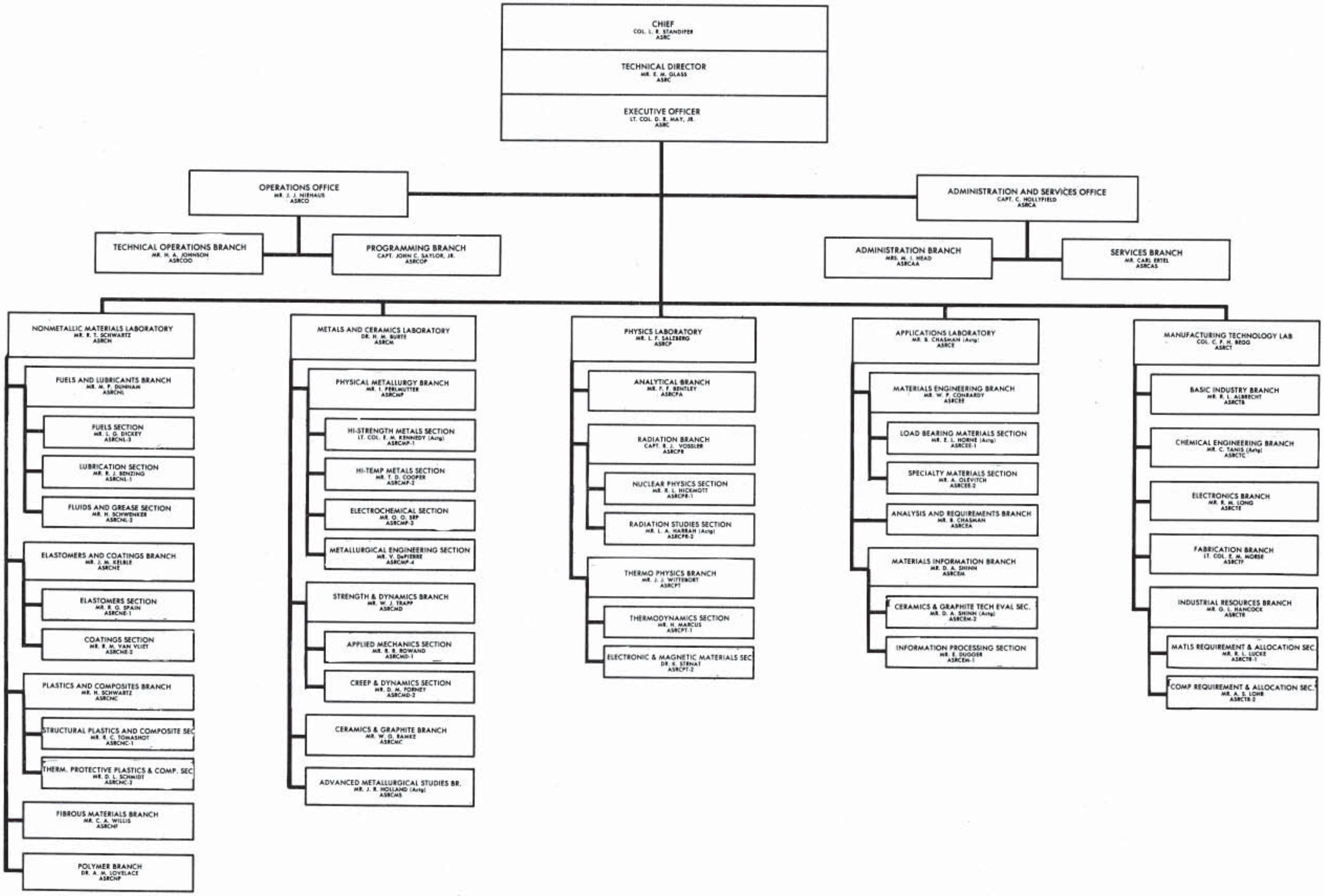


Figure A.11. Materials Central Organizational Structure, August 1961.

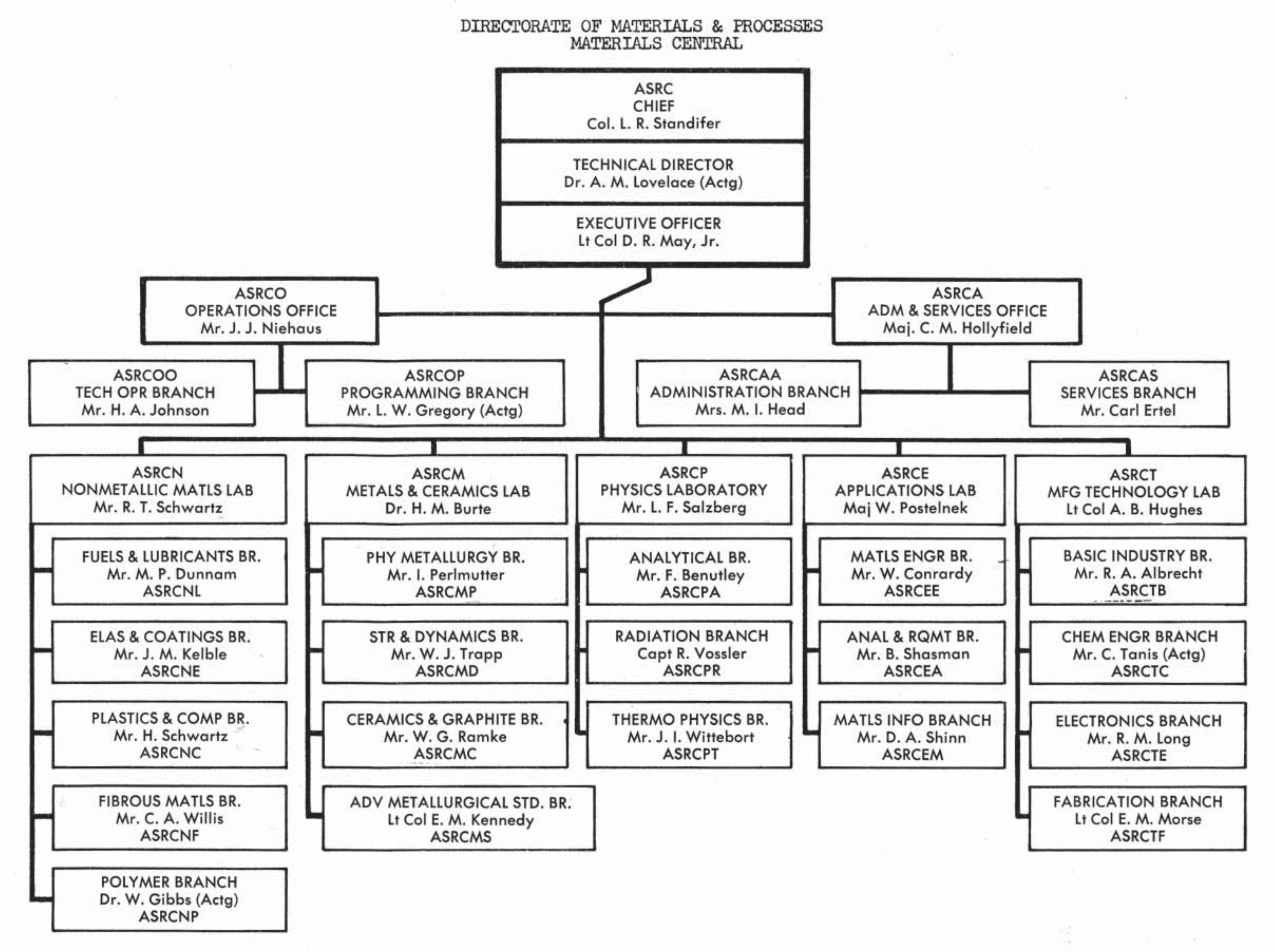


Figure A.12. Materials Central Organizational Structure, 1962.

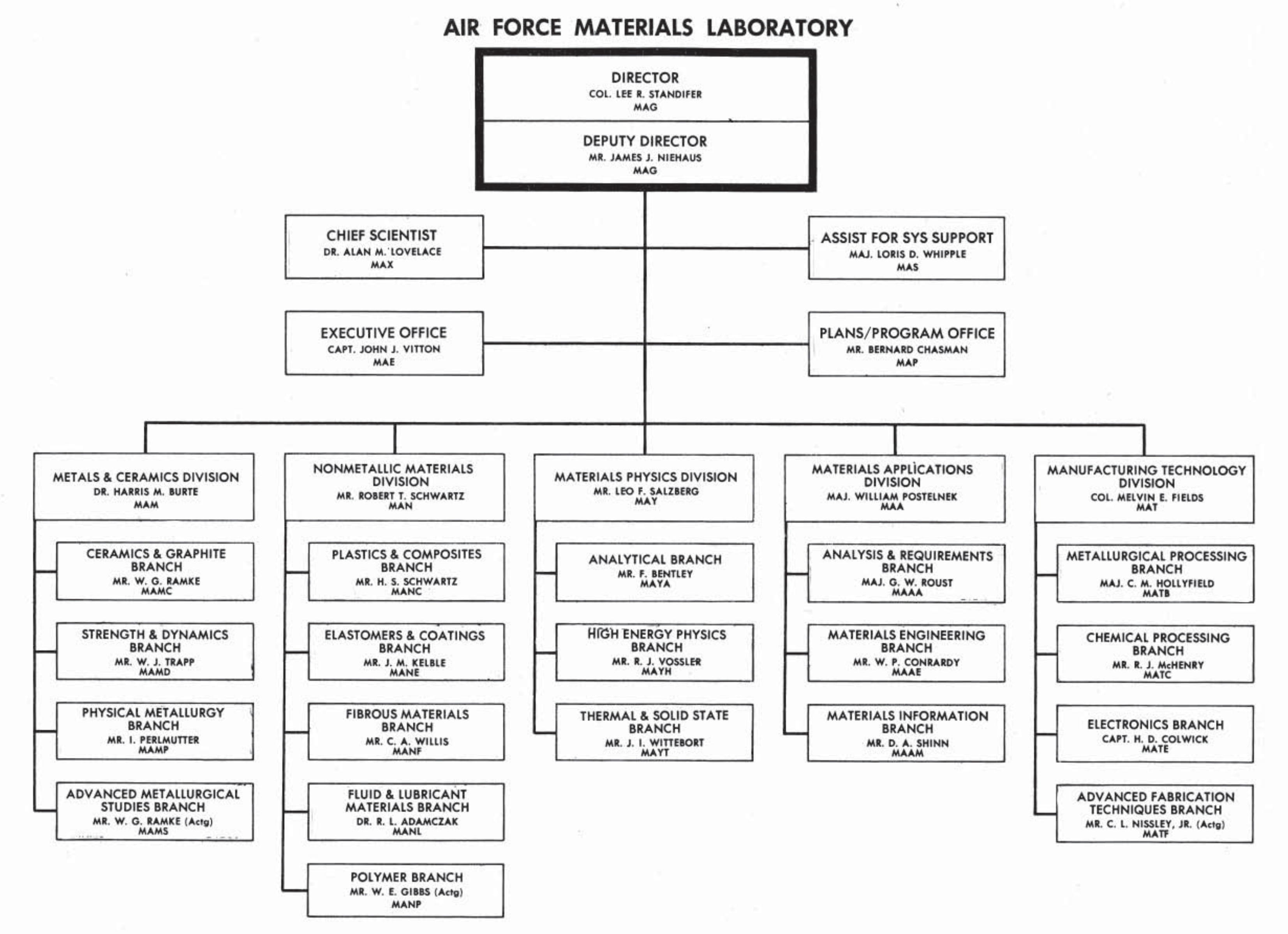


Figure A.13. 1963 Organizational Structure.

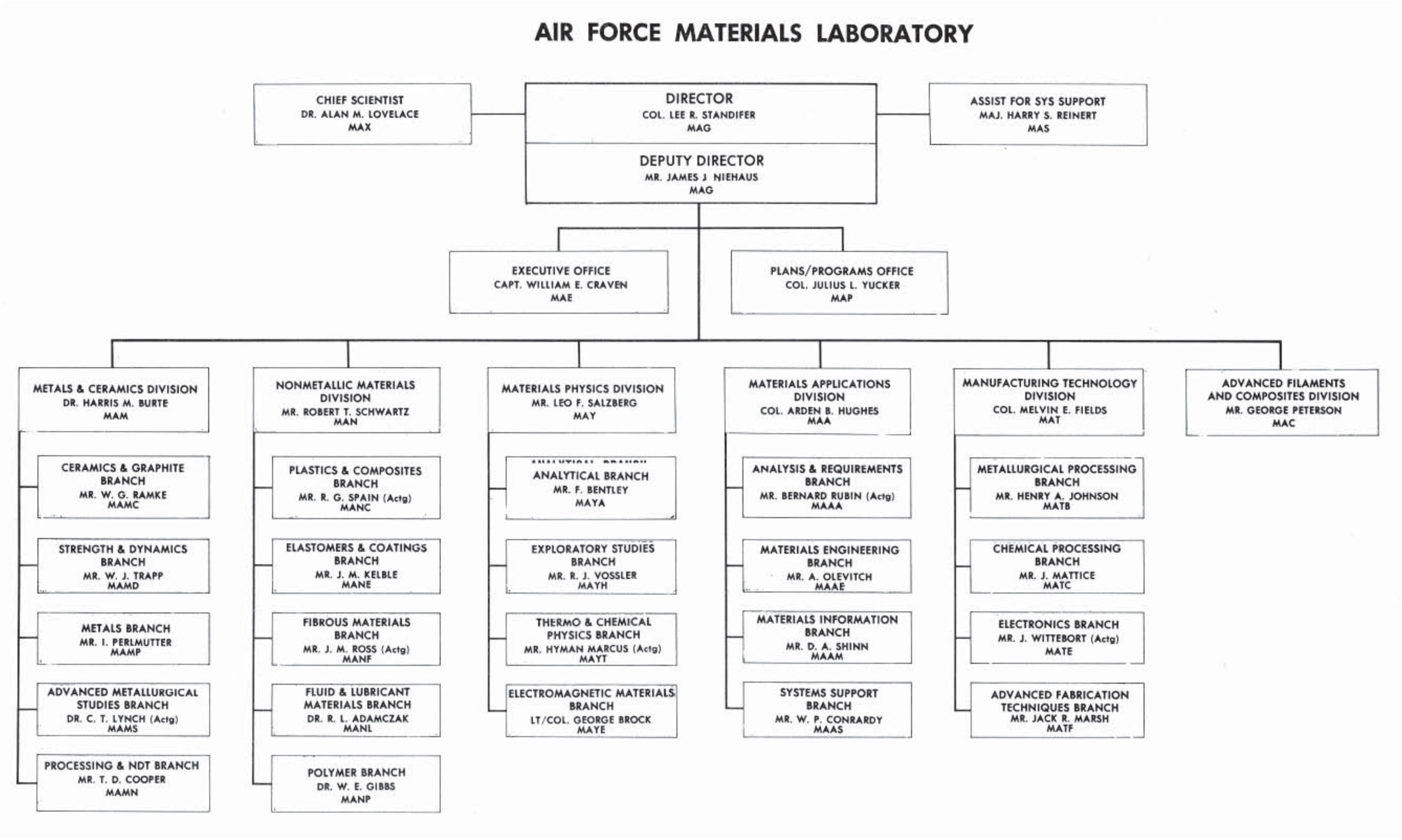


Figure A.14. Organizational Structure, 1966.

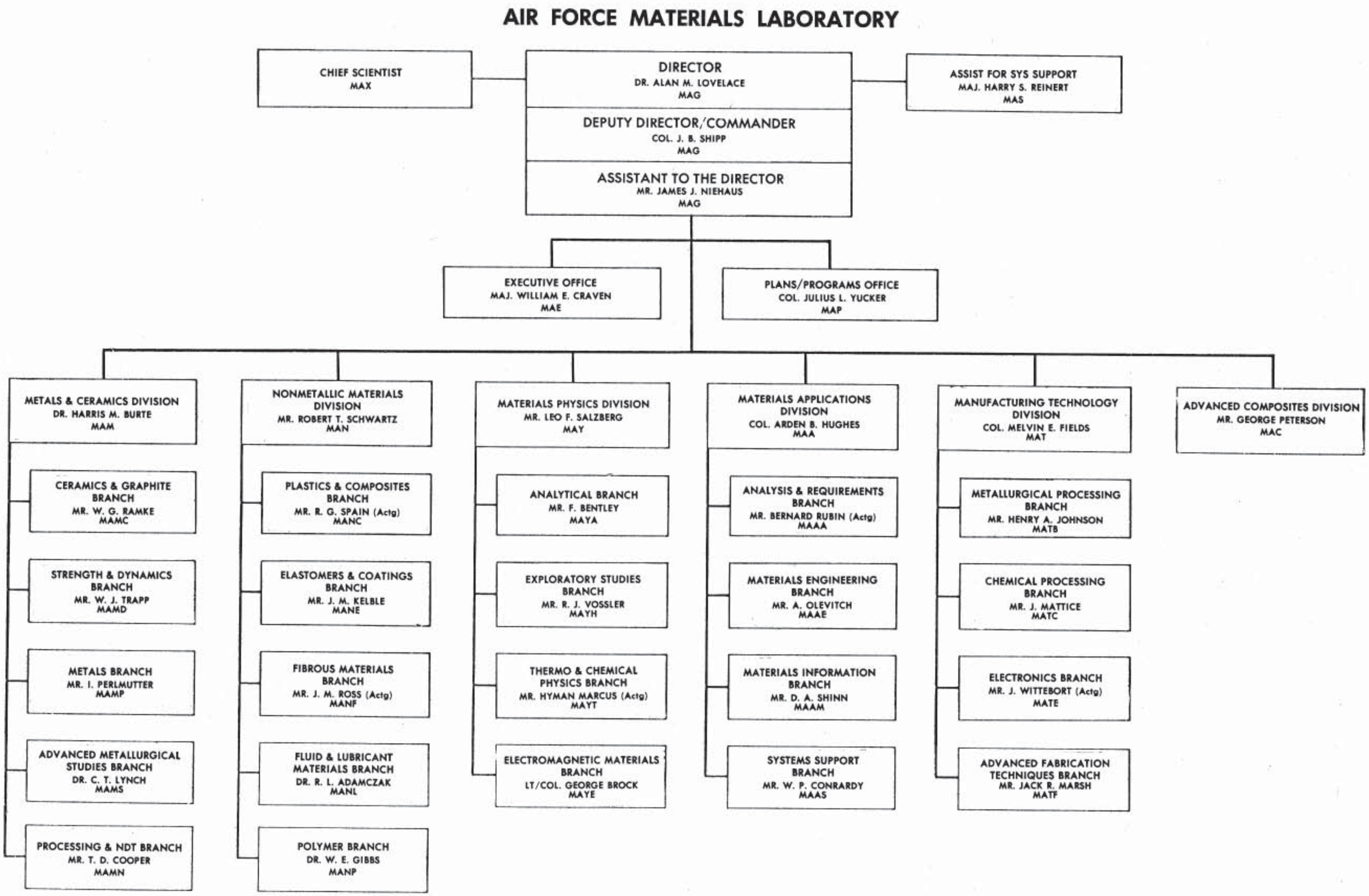


Figure A.15. Organizational Structure, 1967.

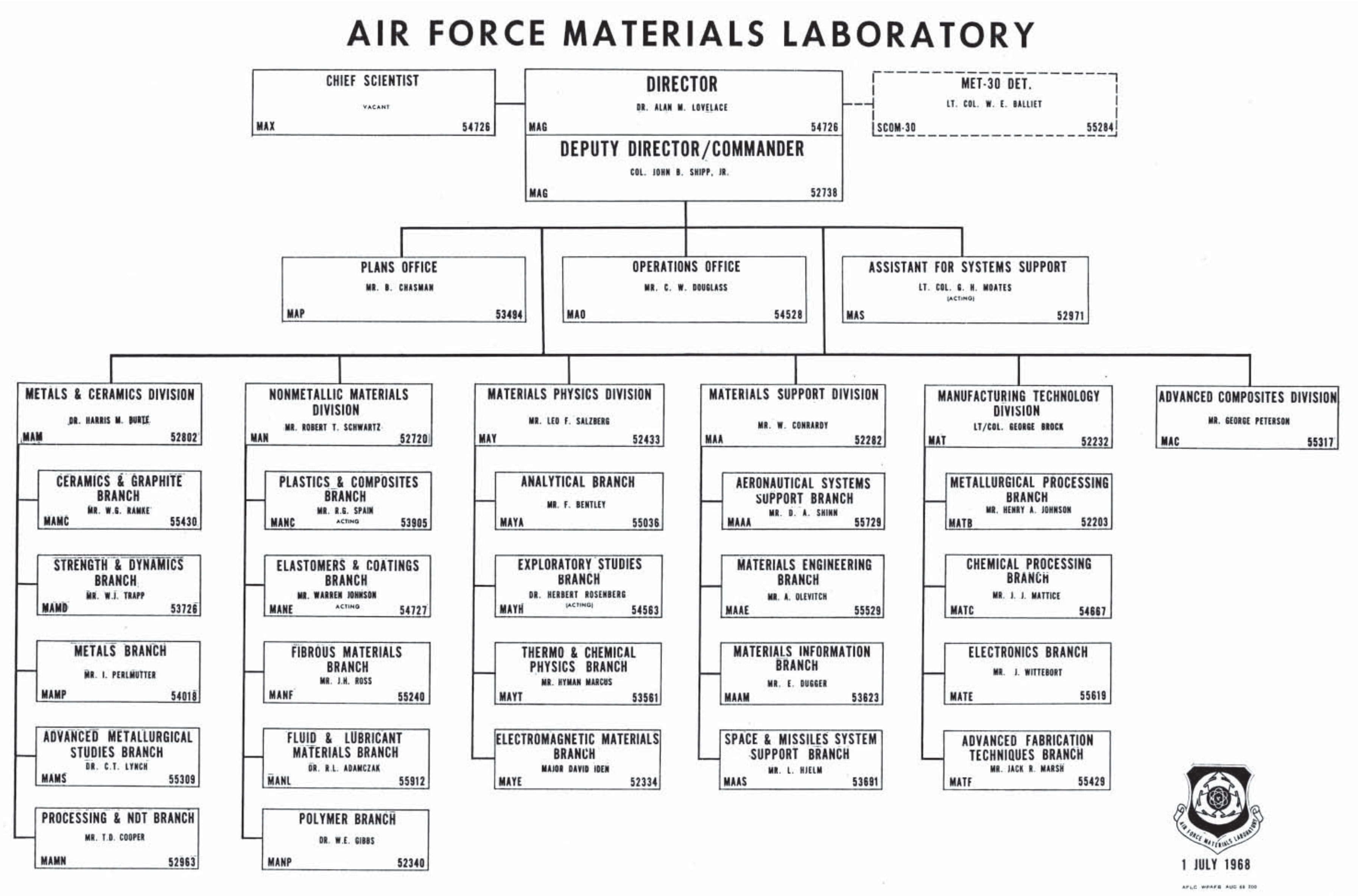


Figure A.16. Organizational Structure, July 1968.

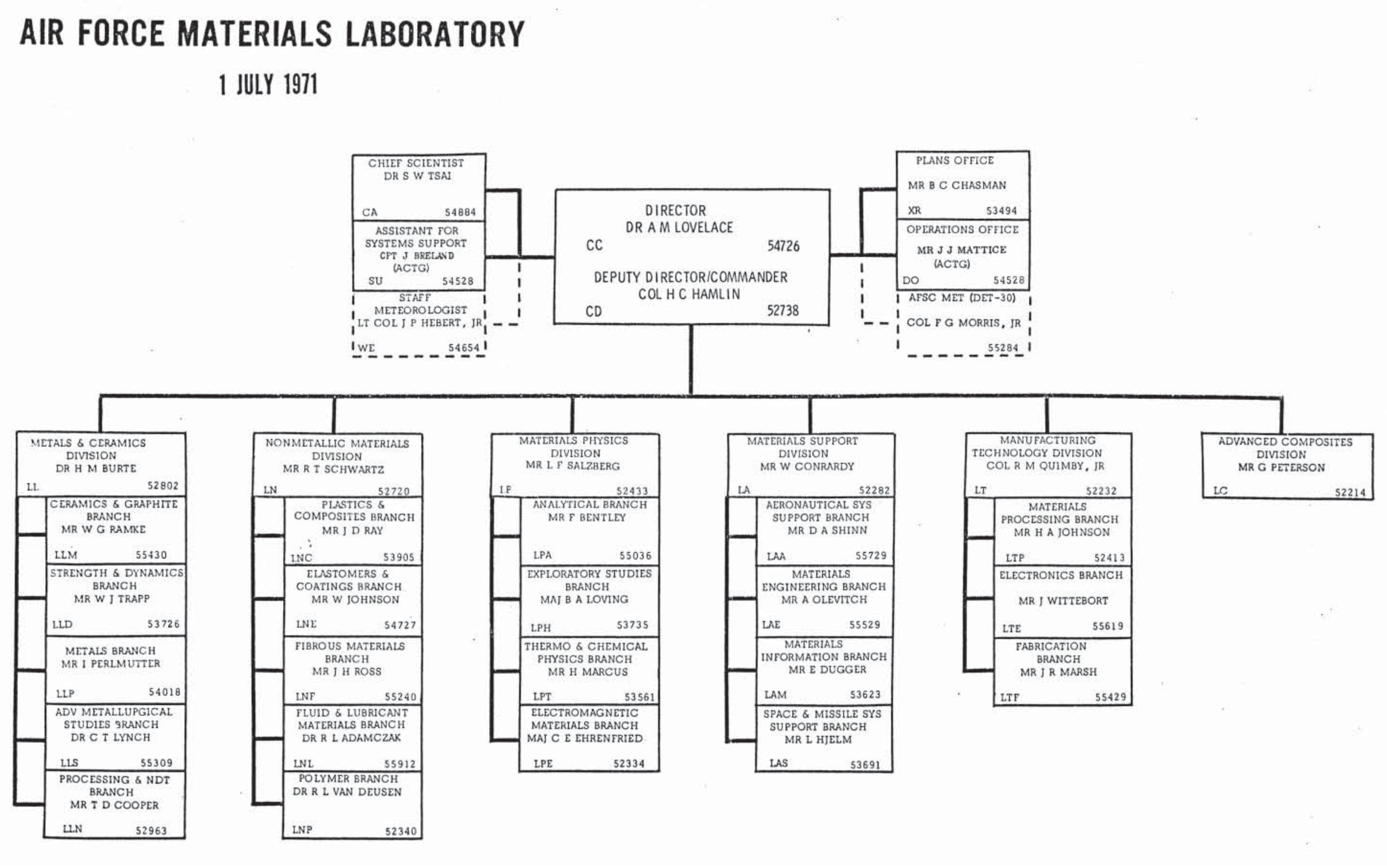


Figure A.17. Organizational Structure, July 1971.

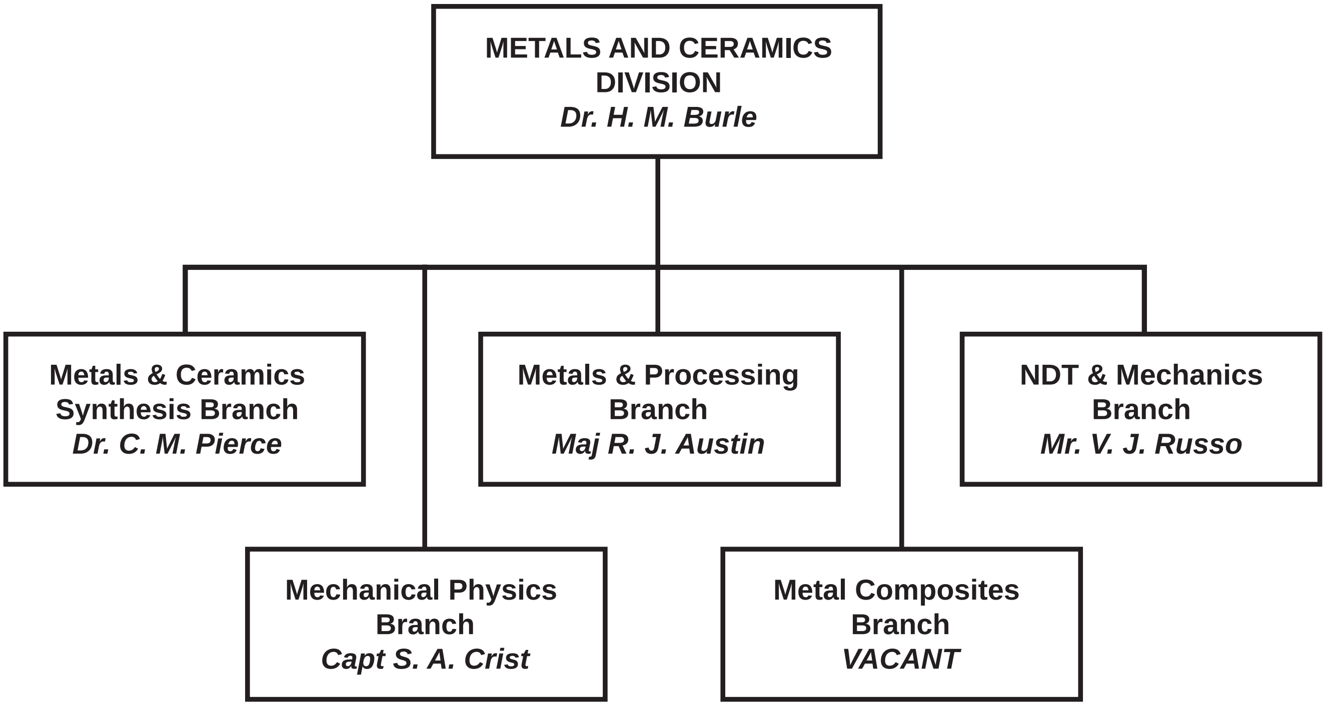


Figure A.18. Metals and Ceramics Division Structure, December 1973.

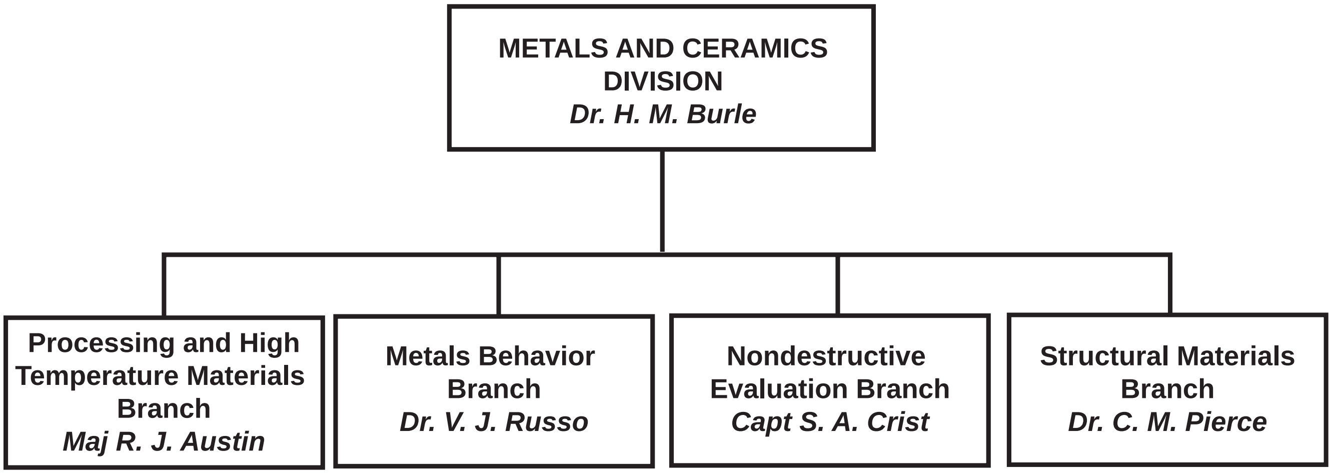


Figure A.19. Metals and Ceramics Division Structure, February 1974.

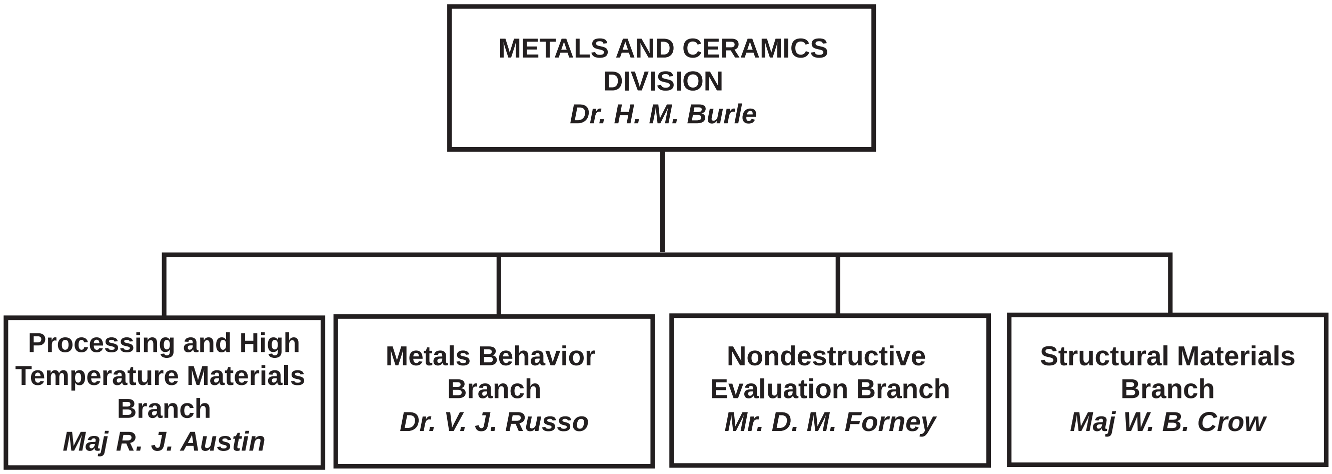


Figure A.20. Metals and Ceramics Division Structure, July 1974.

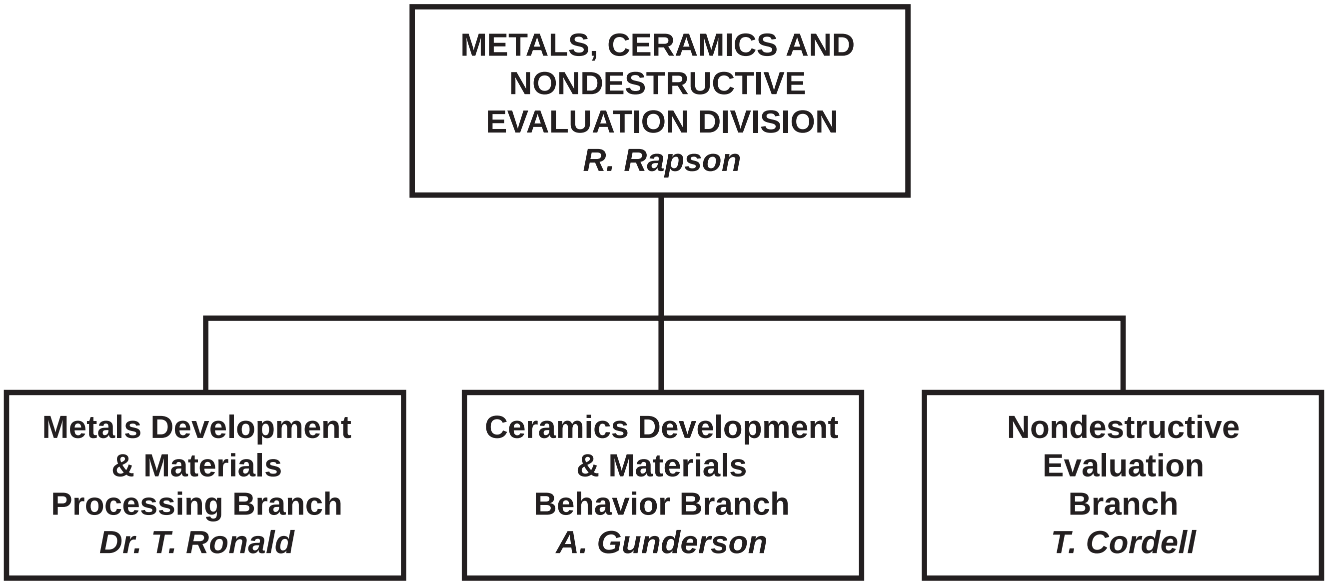


Figure A.21. Metals, Ceramics and NDE Division Structure, 1996.

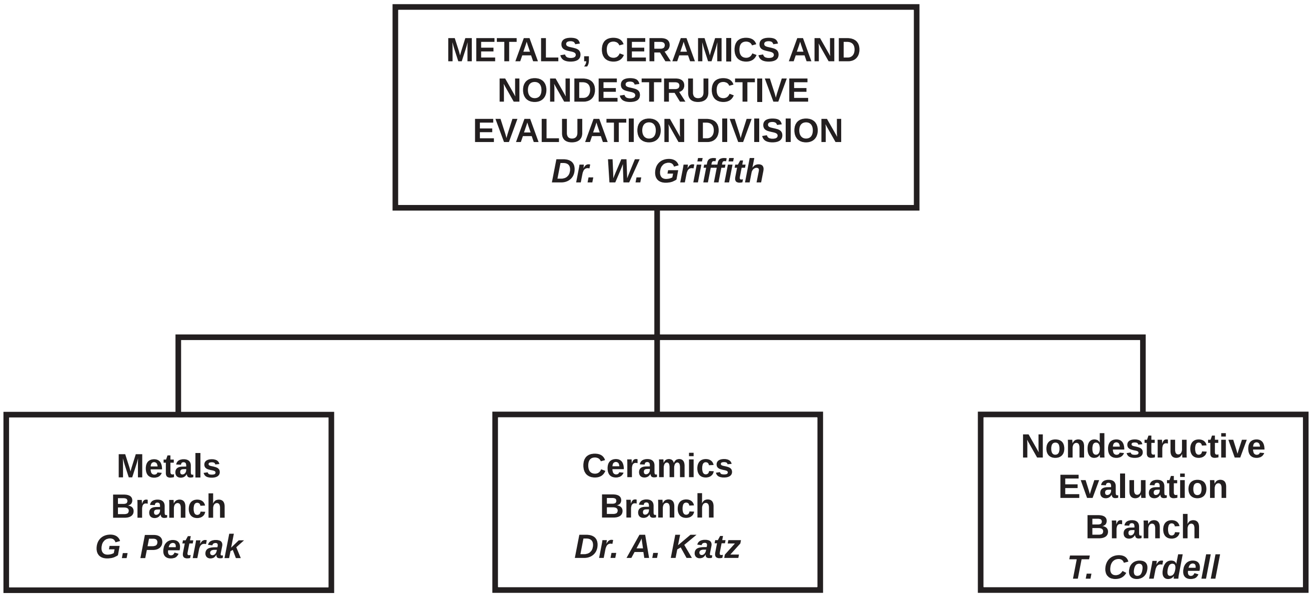


Figure A.22. Metals, Ceramics and NDE Division, 1996.

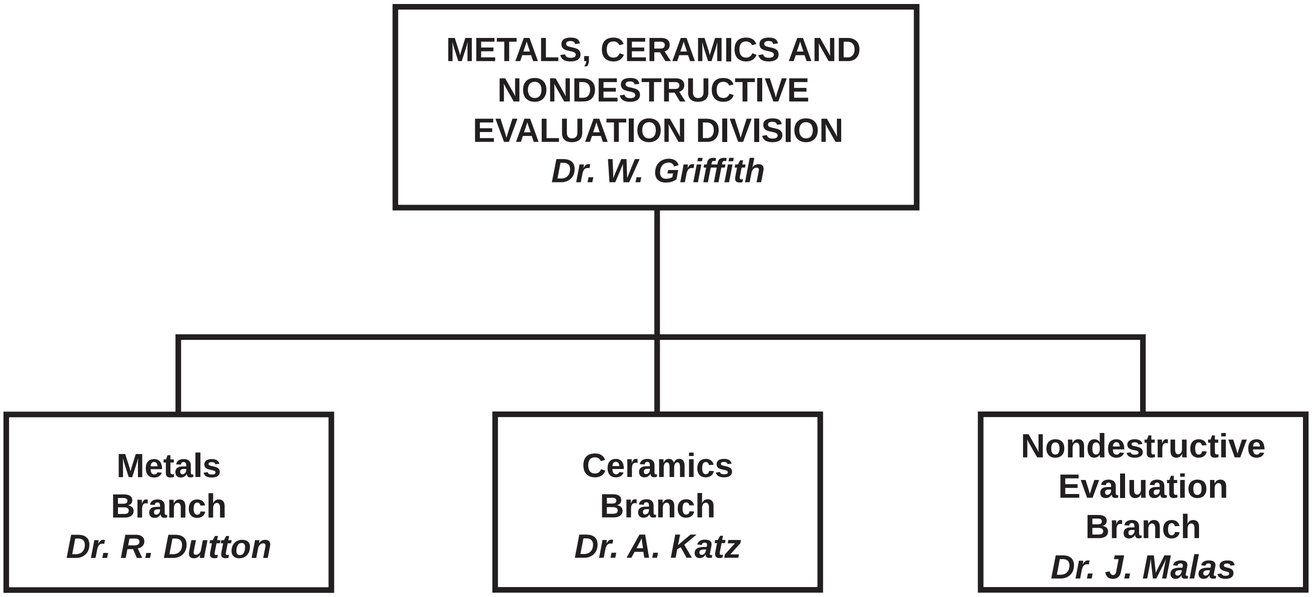
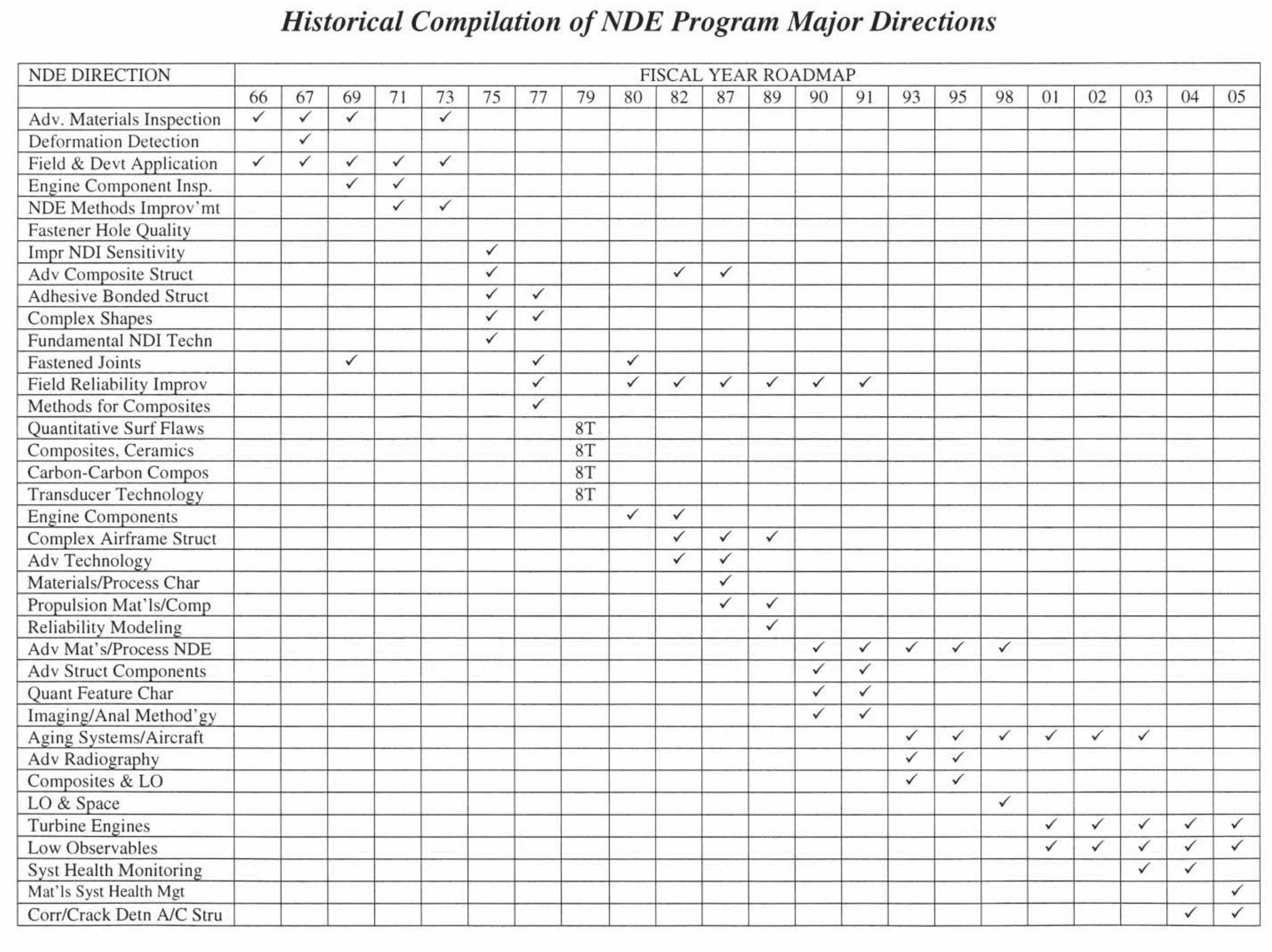


Figure A.23. Metals, Ceramics and Nondestructive Evaluation Division Structure, 2006.

APPENDIX B

Historical Compilation of NDE Program Major Directions/Thrusts

Historically, the NDE program has been planned and organized annually along specific directions of concentration. Listed here are the directions of focus during the indicated fiscal year time periods.



Historical Compilation of NDE Program Major Directions

NDE DIRECTION	FISCAL YEAR ROADMAP																					
	66	67	69	71	73	75	77	79	80	82	87	89	90	91	93	95	98	01	02	03	04	05
Adv. Materials Inspection	✓	✓	✓		✓																	
Deformation Detection		✓																				
Field & Devt Application	✓	✓	✓	✓	✓																	
Engine Component Insp.			✓	✓																		
NDE Methods Improv'mt				✓	✓																	
Fastener Hole Quality																						
Impr NDI Sensitivity						✓																
Adv Composite Struct						✓				✓	✓											
Adhesive Bonded Struct						✓	✓															
Complex Shapes						✓	✓															
Fundamental NDI Techn						✓																
Fastened Joints			✓				✓		✓													
Field Reliability Improv							✓		✓	✓	✓	✓	✓	✓								
Methods for Composites							✓															
Quantitative Surf Flaws								8T														
Composites, Ceramics								8T														
Carbon-Carbon Compos								8T														
Transducer Technology								8T														
Engine Components									✓	✓												
Complex Airframe Struct										✓	✓	✓										
Adv Technology										✓	✓											
Materials/Process Char											✓											
Propulsion Mat'ls/Comp											✓	✓										
Reliability Modeling												✓										
Adv Mat's/Process NDE													✓	✓	✓	✓	✓					
Adv Struct Components													✓	✓								
Quant Feature Char													✓	✓								
Imaging/Anal Method'gy													✓	✓								
Aging Systems/Aircraft															✓	✓	✓	✓	✓	✓		
Adv Radiography															✓	✓						
Composites & LO															✓	✓						
LO & Space																	✓					
Turbine Engines																		✓	✓	✓	✓	✓
Low Observables																		✓	✓	✓	✓	✓
Syst Health Monitoring																				✓	✓	
Mat'ls Syst Health Mgt																						✓
Corr/Crack Detn A/C Stru																					✓	✓

APPENDIX C

Supplemental Information - Events That Influenced Program Scope & Growth

This Appendix contains additional information and expansion of discussions regarding some of the topics addressed in Chapters 3 or 4, as noted there.

- Appendix C-1. Catastrophic In-Flight Failure, F-111 Wing Pivot Fitting.

- Appendix C-2. Paper "NDI in the United States Air Force," British Journal of NDT, May 1976.

- Appendix C-3. Inauguration of the AFML-ARPA NDE Science Center Program

- Appendix C-4. Establishment of Manufacturing Technology Funding Authority to Expedite NDE Technology Transition

- Appendix C-5. White Paper "Nondestructive Inspection and Evaluation (NDI/E): Successful Technology Transition and Who the Customers Are," issued by the WRDC/ML NDE Program to AFSC/XT, October 1989.

APPENDIX C-1

Supplemental Information - Events That Influenced Program Scope & Growth

Appendix C-1. Catastrophic In-Flight Failure, F-111 Wing Pivot Fitting. The following dissertation is included in reference (AJ), "F-111 Systems Engineering Case Study for the Air Force Institute of Technology (AFIT) Center for Systems Engineering," January 2005.

Richey, G. Keith.

Wing Carry Through Box Failure and Impact on Subsequent Aircraft Development

Donald M. Forney
December 7, 2003

Description of Aircraft and its Mission

The F-111 aircraft, the first U.S. production swing-wing flight vehicle, was prototyped as a supersonic all-weather multipurpose tactical fighter bomber as a result of the Department of Defense plan for a single aircraft to fulfill both a Navy fleet-defense inceptor requirement and an Air Force supersonic strike aircraft requirement (Figure 1). Its variable sweep wings enabled both short distance take offs and sustained low level supersonic flight. Serving as the baseline design, the U.S. Air Force F-111A proved to be too heavy to be tailored to the constraints of carrier-based naval operations. Thus the F-111B Navy version did not reach production status (1).

This aircraft was designed to operate from tree top-level to altitudes above 60,000 feet, able to fly from slow approach speed to supersonic velocity at sea level and more than twice the speed of sound at higher altitudes. The aircraft weighed 47,480 pounds empty, with a maximum takeoff weight of 100,000 pounds. The first two prototype aircraft flew in December 1964. In October 1967, the first production F-111A aircraft was delivered to Nellis Air Force Base, Nevada. In all, 563 F-111s in several variants were built, including 35 for the Royal Australian Air Force.

The multiple roles and wide speed range of this aircraft placed significant requirements on its aerodynamic configurations (e.g. thin airfoils, engine compartment and air inlet restrictions) resulting in new constraints on wing and fuselage structural configurations, and leaving a very minimum of volume space available to the structural designer (2). The resulting higher design unit loadings led to the requirement for a very high strength and high stiffness material. Based on a comparison of stress corrosion cracking resistance, fatigue properties, and fracture toughness index KIC to give an order of merit, D6ac steel, heat treated to 200-220,000 psi ultimate tensile strength, and some application at 260,000 – 280,000 psi, was chosen from among several other high strength steels. Figure 2 illustrates the principal critical F-111 structural components fabricated from D6ac steel. These included the wing pivot fitting, the wing carry through box (WCTB), major fuselage frames and longerons, as well as the more conventional use of nose and landing gear. In addition, literally hundreds of small detail D6ac steel parts were used throughout the airplane. The total weight of steel in the airplane exceeded 7,000 pounds or approximately 30% of the structural weight. The majority was concentrated in the wing pivot fitting and the WCTB and wing supporting structure. Figure 3 shows a pivot fitting being readied for mating to a WCTB during manufacture. The remainder of the airframe structure was fabricated mostly from aluminum alloys. The design load factors (Nz values) were -3 g to +7.33 g, and the original design life goals were 4,000 flight hours and ten years of service.

Safe-Life versus Static Strength Criteria

The F-111A was among the first aircraft systems to be developed using the "safe life" design philosophy. Following several disastrous aircraft failures (e.g., De Havilland Comet transport fuselages, 1954 and AF B-47 bomber wings in the mid to late 1950s), which were later attributed to metal fatigue, the importance of adding the effect of cyclic fatigue loading to the traditional static strength model and designing to a target safe fatigue life was recognized as an essential major design philosophy shift (3). This design approach was introduced in the new Air Force Aircraft Structural Integrity Program (ASIP) methodology developed in the late 1950s and early 1960s (4). Expanded data bases of fatigue tests of aircraft materials and representative component parts generally supported the upgraded design process. The safe-life methodology initially utilized a Minor's rule fatigue analysis process incorporating the cumulative effects of cyclic loading on the subsequent strength and the remaining safe (fatigue) life of the airframe.

Structural Tests and Issues during Development

A full-scale static strength test program was conducted, and after several local redesigns to correct strength deficiencies, the test was completed successfully. Next, a full-scale fatigue test program was initiated in 1968, with the entire program lasting about six years. The goal was to demonstrate the original 4,000 flight hour safe-life design of the full F-111 airframe and various representative components to a safety factor of 4x, or 16,000 test hours, as required by ASIP, using a relatively severe block-type spectrum loading (2). However, after less than 600 cyclic test hours, failure occurred unexpectedly in the WCTB at approximately 80% simulated flight usage. As a result of the severe damage to the test article, the test program was revised to continue testing on separate major components (i.e., wing, fuselage, etc.) rather than the complete airframe. This failure, which occurred on 26 August 1968, was the initial event in the series of subsequent F-111 structural problems. A fatigue crack initiated in a taper lok bolt hole, associated with fastening the rear spar web stressed door to the spar assembly, and failure progressed rapidly through the lower rear spar and lower box cover plate – causing complete failure of the WCTB. A thorough investigation concluded that the hole was cracked either before or during the installation of the taper lok bolt. A re-inspection of over 5,000 taper lok holes in all of the WCTBs manufactured by that time found no cracks; however, the quality of some holes required rework and improvement.

A second failure of the test article WCTB, which occurred in February 1969 after 2,800 test hours, originated in a 3/16 inch diameter straight through hole in the lower plate of the box. The hole, which was located at the intersection of a spanwise and a chordwise plate stiffening element, had been used to secure a mounting bracket for hydraulic lines. The small fatigue zone on the fracture face consisted of multiple origins on the interior surface of the hole, producing an effective crack length of approximately 0.6 inch and depth of 0.35 inch. Investigation revealed that small sharp indentations were present in the hole from post-heat treatment grit blasting. Cracking was initiated by local bending effects not accounted for in the original fatigue analysis. To correct this condition, the holes were taper-reamed and a taper lok bolt installed. Subsequently, all holes in the WCTB were inspected to reveal over half of the 23 holes similar to the above hole were cracked; thus, all received the corrective action.

Concern over the inability of available NDI/E practices to detect these cracks initially led the manufacturer, General Dynamics Corporation, to create a new patented technique named magnetic rubber inspection (MRI), a variant of the established magnetic particle inspection (MPI), which uses a fast-curing liquid rubber containing dispersed black magnetic particles. After the liquid is introduced into the area to be inspected, an applied magnetic field causes the particles to migrate through the liquid and concentrate in vivid dark lines at cracks in the test surface shown in Figure 4. Once cured, the solid reversed replica is removed from the test surface. The example shown is a reversed replica of an aircraft flap actuator that reveals cracks in the roots of several gear teeth when viewed under low magnification.

A new WCTB test specimen was fitted with all of the changes considered appropriate from the earlier test failures and underwent testing based on an improved fatigue analysis and a load spectrum more accurately reflecting programmed fleet usage. A failure occurred in June 1969 after demonstration of a test life equivalent to 8,000 hours of operation at the spectrum loads representing the projected TAC usage – with no scatter factor applied. This failure was located in the outboard closure bulkhead of the WCTB, in the return flange of the bulkhead at the rear spar. An investigation which included a strain survey in the failure location, revealed a very high strain gradient at the front and rear spar joints with the more flexible lugs. A very simple fix of eliminating two bolts through the flange at the front and rear spars permitted the upper plate to flex slightly with respect to the main box structure and eliminate the local area of very high strain which had led to the fatigue failure.

A fourth WCTB was modified incorporating all of the changes from the previous tests and tested to the latest spectrum described above. This structural configuration complied almost 20,000 test hours, equivalent to 5,000 flying hours for the predicted TAC usage. A planned extension to 24,000 test hours, or 6,000 hours service life was under consideration. It is noteworthy that modifications of the WCTB to reach the extended service life required a total of less than five pounds of additional material.

At 12,400 test hours, a failure occurred in the wing pivot fitting. This failure resulted in the development of a boron-epoxy-reinforced composite doubler modification, which was the first use of advanced composites to reduce the stress levels in metallic aircraft structures (5). The wing then completed the 24,000 test hours without any further significant events. This patch became a fleet fix. In 1994, a chordwise fatigue crack discovered in the lower wing skin of a RAAF F-111 was attributed to a local stress concentration in a fuel drain hole and secondary bending. A boron-epoxy bond patch repair was retrofitted successfully under the RAAF ASIP guidelines (6).

F-111 In-Flight Failure and Discussion of Cause

The Air Force's F-111 program suffered a major setback when, on 22 December 1969, F-111A aircraft SIN 67-049 experienced a catastrophic failure and loss of the left wing during a relatively high load factor pull-up from a low altitude practice rocket-firing pass at Nellis AFB, Nevada (Figure 5). The accident was initially attributed to the presence of a defect in the steel pivot fitting. The Air Force immediately grounded the F-111 fleet pending the investigation into the causes and circumstances of the failure. The grounding eventually lasted for approximately seven months. As soon as the part containing the flaw was recovered from the field and examined by the manufacturer and Air Force experts, it was concluded that the failure originated from a pre-existing sharp-edged forging defect in the D6ac steel lower plate of the wing pivot fitting (dark half oval) as shown in Figure 6 (2). This 0.9 inch surface length defect evidently had passed undetected through numerous inspections during manufacture and grew a short distance by fatigue (narrow lighter band) to a critical size after a total of only 107 flying hours.

Subsequent investigations revealed that the ultrasonic and magnetic particle inspection procedures used during manufacturing NDI/E were incapable of detecting this flaw.

Startup and Implementation of a Recovery Program

As a result of the Nellis accident, the Air Force convened a special ad hoc committee of its Scientific Advisory Board to investigate the failure and recommend a "Recovery Program." (5, 7). This committee representing a broad based expertise met with General Dynamics and the Air Force Systems Program Office frequently over a period of 18 months in 1970 and 1971. Early on it was apparent to the committee that it would be very difficult to assure the structural safety of the F-111 using the then available conventional nondestructive inspection and evaluation (NDI/E) methods and procedures because of the low fracture toughness of the D6ac steel and the resulting very small critical flaw sizes, and the even smaller flaw sizes that must be found to avoid more failures. Furthermore, very limited accessibility to some potential-flaw locations for effective NDI/E posed significant obstacles. The detailed evaluation of these procedures by the USAF NDI Review Team revealed numerous inadequate capabilities. These difficulties led the committee to recommend to the Air Force that every F-111 aircraft be subjected to a fracture-mechanics-based low-temperature proof load test (2, 5, and 7). Subsequently, major improvements in ultrasonic, MPI and other methods were instituted. MPI flux field distributions were improved to better detect the F-111 target flaws. A new ultrasonic Delta Scan method developed by NASA, which greatly facilitates the detection of a crack oriented vertically to the part surface, was adapted to the critical F-111 parts. This modification subsequently led to the release of additional parts from dependence on proof testing (7). The proof test were scheduled to be repeated at periodic intervals to be determined from the predicted rate of crack growth in the individual aircraft based on its actual measured use obtained from the Individual Aircraft Tracking Program (IATP). This fracture-mechanics-based proof testing concept had been developed and successfully used for the pressurized structures in the Apollo space program as well as in other missile and space efforts.

The rationale for the proof test "inspection" was simply that any part containing a crack or flaw in excess of the critical size for the test conditions imposed would fracture under the peak load. By passing this "inspection," it could be assumed that a part contained only subcritical flaws or cracks, or none at all. In making the critical crack length determination, the objective was to get as small a length as possible – in other words, make the resolution of the inspection as fine as one could. It has been Air Force practice to allow laboratory proof tests of structures (load to design limit load) and still certify the aircraft for flight usage (assuming past test inspection revealed no permanent deformation). Any time a structure is loaded in a ground test to greater than limit load, the structure is usually not considered suitable for subsequent flight operation. Therefore, the maximum stress one could subject the critical component to is limit design stress. Thus one input parameter to the crack length determination was established. The fracture toughness index K_{IC} for representative parts from the critical structures areas in question had been determined as part of the previous test and flight failure assessment programs. In the case of high strength steels, K_{IC} varies with temperature – decreasing in value as temperature is reduced below ambient or room temperature. For instance, in the case of D6ac steel with a room temperature K_{IC} = 75 Ksi $\sqrt{in}$, the K_{IC} value at -60°F = 40Ksi $\sqrt{in}$, a reduction of approximately 46%. Again, to insure against as small a flaw as possible, it was desirable to conduct the proof test program as close to the lowest temperature called out in AF qualification specifications for the various components and equipments of the aircraft (-65°F). However, practical test problems limited this low temperature to -40°F which was used in the cold proof test program.

An extensive engineering analysis was made of the F-111 primary structure which established approximately 30 flight-critical D6ac parts. Of these, fifteen (15) individual D6ac steel parts (forgings) were identified as Class I critical items requiring immediate re-inspection. The location of these parts in the airframe is represented in Figure 2. The critical crack lengths, which, according to theory, would result in fracture, were also calculated in order to establish the required inspection levels (sample calculation shown in Attachment 1). Meanwhile, a rigorous test program indicated a significant difference in material toughness between the coupons used in the original test program, and the forgings used on the aircraft. Unfortunately, the test specimens to determine the toughness of the steel had a section thickness different from the material placed on the aircraft. The material located on the aircraft had a toughness substantially lower, approximately half, than the toughness of the material used in the test program due to the difference in thermal behavior during heat treatment.

At the outset of the program, the NDI procedures in use were deemed inadequate to accomplish the necessary levels of inspection on 12 of the 15 critical parts (7). Thus the cold proof test was adopted as an alternate “inspection” technique. As confidence levels for the improving NDI/E continued to increase, more parts were included in the list to depend on NDI/E. However, pre-proof test NDI/E was still applied for the purpose of screening out all detectable flaws before proof loading to avoid any catastrophic failure of the entire airframe by proof loading a massively defective part. Thus, with the stress in the part determined, and the fracture index of the material (K_{IC}) selected, the critical crack length “a” was calculated for each of the critical D6ac forged steel parts. If all the critical parts were subjected to a proof test stress (limit design stress), at temperature of -40°F, and if no failures occurred, it would be assured that there were no flaws present at or greater than the critical size (a) calculated. Within a year after the accident, 11 of the 15 Class I critical items were released for conventional NDI/E and 4 remained for proof testing. These parts are listed in Attachment 2.

The remaining problem was then to develop a practical means to load the F-111 aircraft in order that limit stress could be applied to these critical areas. The structural arrangement of the F-111 was such that this could be done quite readily. The three pylon attach fittings (hard points) on each wing allowed the introduction of large local loads without danger of local overloading of the wings. These three load points, together with the application of a smaller load by means of a clamp towards the wing tip, - along with a specific wing sweep position – allowed the application of design limit bending moment (positive) at the wing pivot fitting and through the wing center box. Local load limitations prevented the application of full design limit bending moment (negative) from being applied. Only 90% design limit load (negative) was possible. At a load of +7.33g, wing tip deflection reached over two meters (Figure 7) (8).

By reacting the applied wing loads at the nose gear, main gear, arresting hook, and by means of special load fittings in place of the horizontal tail, it was possible to apply limit loads to the fuselage longerons, the nacelle bulkhead, and critical areas of the Fuselage Station 770 bulkhead. It was not possible to load the vertical tail; therefore, the rudder torque tube assembly was not loaded, and since the horizontal tails were removed during the test, the horizontal tail box beam fitting was not tested. It was necessary to rely on improved inspection techniques to ascertain the integrity and quality of these areas.

To insure positive test control, and to guard against any possibility of “overload” during the test, an elaborate and complex computer controlled load application system and test monitoring system was utilized. In addition – since the steel in the load jigs and fixtures would exhibit, to a limited extent, increased fracture sensitivity at the -40°F test temperature – it was necessary to construct the proof test set-up so that these loading jigs and fixtures were insulated to the extent that they remained above the temperature of +50°F. An important innovation utilized to enhance the monitoring of the cold proof test was the use of acoustic pickups to detect unidentified noise emissions during loading. Through this setup, it became possible to locate and replace many broken taper lok fasteners which otherwise would have gone unnoticed (8).

The essence of the concept was that, if the structure successfully survived the cold proof test load, it could not have contained any flaws larger than the critical sizes at that load level. It had to be assumed then that it did contain flaws just smaller than the critical sizes at the cold proof test load level and reduced fracture toughness, and to cause failure in service they would have to grow to the larger critical sizes at the lower operational load levels, warmer temperatures and higher fracture toughness levels. The time for this to happen would then be calculated from the use spectrum generated from in-flight loading history recorders mounted in each airplane as part of the individual aircraft tracking program (IATP), discussed later In effect, the proof test is a potentially destructive inspection procedure that culls out any flaws that would cause an in-service failure. During the 25 year life of the cold proof test program, there were 11 failures recorded, including three in the Royal Australian Air Force fleet referenced earlier (2, 5, 7, 9).

Adoption of Damage-Tolerant Design Methodology

The catastrophic wing failure and loss of and F-111 aircraft at Nellis Air Force Base, Nevada in December 1969 graphically highlighted the fundamental shortcomings of the safe-life approach that failed to account for any unknown or “rogue” flaws. It was this failure that provided much of the impetus for the Air Force to abandon the safe-life approach and adopt damage tolerance requirements on all of its aircraft in the early 1970s (5). This landmark shift was incorporated in the Air Force ASIP process. Featured in the revised ASIP plan were new durability and damage tolerance analysis (DADTA) tasks and an Individual Aircraft Tracking Program (IATP) upgraded to a program based on crack growth or fracture mechanics (although the proof test intervals had been based on crack growth predictions from the inception of the proof test program).

In summary, the Air Force specification MIL-A 83444 “Airplane Damage Tolerance Requirements” requires the detection of cracks before they propagate to failure (10). In designing a critical structural element or component, 83444 requires the demonstrated ability to consistently detect small initial flaws/cracks in both the manufacturing and in-service operational settings. Without such demonstrated capabilities, the existence of larger threshold flaws must be assumed initially and a more conservative (less efficient) damage tolerant design must be adopted (11). Inspection intervals for each critical element or component are established using crack growth calculations based on measured materials fracture properties, together with loading spectra and other usage information from IATP measurements, in order that a propagating crack will be detected before it causes failure.

In the late 1970s, a complete DADTA was conducted on the F-111 (5). It initially considered over 400 potentially critical areas, which were subsequently scaled down to about 100 to be analyzed in detail. At the time of retirement of the remaining F-111 fleet in 1996, approximately 20 areas of the structure were being tracked and analyzed, which resulted in periodic updates to the Force Structural Maintenance Plan (FSMP) and adjustments in the inspection requirements to account for use changes and base reassignments. Although the first repeat proof testing of the F-111A/E/D aircraft fleet was set to occur at 1,500 accumulated hours, this interval was increased to 3,600 hours for subsequent proof tests based on the DADTA and force tracking data (5). During the course of the overall program, virtually all of the active F-111 aircraft were proof tested at least three times and some four times.

As part of the Air Force postproduction force management process, inspections and modifications derived from the ASIP tasks and results of DADTAs for active aircraft fleets have been implemented over the last three decades with marked success, and safety has been protected. These individual aircraft model updates, including FSMPs and IATPs about every five years, are considered important (5).

Post-Event Evolution of Related Advanced Technologies and Processes

Influenced by the F-111 incident, and the lasting attention it received, the Air Force, and the aerospace community in general, increased significantly research and development activities to produce new tools and methods to help assure the structural integrity of aircraft fleets. These included the following areas:

(a). Advanced structural analysis methods. The practical application of finite element structural analyses (FEA) received emphasis starting in early 1960s with the advent of high speed digital computers. Research focused on improving the mathematical definition of the elements used to represent the structure and extending the applicability of the finite element method to increasing complex structural configurations. The F-111 accident accelerated the development pace in the 1970s toward a more practical tool for local stress analyses, including fracture mechanics applications, which helped the transition to the new damage-tolerance design approach and adoption as a formal part of ASIP. As demonstrated by the late 1970s, increasing the polynomial degree of the shape functions beyond the first or second order, commonly called the p-version of FEA, yielded immense dividends in performing local stress analyses (12) and assuring designs with adequate damage tolerance.

(b) Improved performance aircraft structural materials. The inadequacy of the safe-life design approach used for the F-111 aircraft, and the adoption of the damage tolerance methodology pointed to the need for broader and more accurate characterization of specific materials properties related to structural integrity, including fracture toughness, crack growth rate, fatigue life under appropriate loading, and others. Research concentrated also on overcoming limitations such as embrittlement and corrosion in some structural materials through improved processing techniques and heat treatments. In addition, efforts were increased to develop new and modified titanium alloys and processing methods resulting in improved fracture toughness, formability, weldability, corrosion resistance and lower cost.

(c) New and improved NDI/E capabilities. The general inadequacy of the NDE/I state of the art, as revealed in part by the F-111 incident, resulted in a significant increase in R&D efforts by the Air Force as well as the aerospace industry. Emphasis was placed on both improving capabilities of existing inspection methods and the creation of new approaches and supporting instrumentation and equipment to more reliably reveal smaller, more obscure structural cracks, hidden corrosion, and other defects related to structural integrity. These have included ultrasonics, electromagnetics, radiography, including computed tomography, thermal imaging, and several others. The major emphasis has been to transition these successful tool developments and improvements as quickly as possible to the operational maintenance environment.

References

1. Military Analysis Network, "F-111," www.fas.org/man/dod-101/sys/ac/f-111.htm

2. Hinders, U.A., "F-111 Design Experience – Use of High Strength Steel," AIAA 2nd Aircraft Design and Operations Meeting

3. Redmond, Gerald, "From "Safe Life" to Fracture Mechanics – F111 Aircraft Cold Temperature Proof Testing at RAAF Amberley," 10th APCNDT Brisbane Technology 2001 and Beyond

4. King, Troy T., "Some Developments in the Air Force Aircraft Structural Integrity Program (ASIP)," Air Force Conference on Fatigue and Fracture of Aircraft Structures and Materials, Miami Beach, FL, 15-18 December 1969, AFFDL TR 70-144.

5. "Aging of U.S. Air Force Aircraft," National Materials Advisory Board, Publication NMAB-488-2, 1997.

6. Saunder, Terry, "Aircraft Structural Integrity Management in the Royal Australian Air Force," Proceedings of the 1994 USAF Structural Integrity Program Conference, WL-TR-96-4030, February 1996.

7. Forney, D.M. and Lowndes, H. B., "Application of F-111 NDI and Cold Proof Test Concepts to Future Weapon Systems," Special Report, Air Force Systems Command, Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio, 1 December 1970

8. "Cold Proof Load Test." F-111.net/cold.htm.

9. Kaplan, Mitchell P., Wolff, Timothy A., "Life Extension and Damage Tolerance of Aircraft," Willis & Kaplan, Inc., Copyright © 2003

10. MIL-A-83444, *Airplane Damage Tolerance Requirements*, **Date**

11. Forney, Don M., “The Development of Improved NDI/E to Meet Structural Integrity Requirements,” Proceedings of the 1988 USAF Structural Integrity Program Conference, WRDC-TR-89-4071, May 1989.

12. Taylor, Brett D., “Control of Error in Local Stress Analysis with PROBE, a New p-Version FEA Program,” Proceedings of the 1988 USAF Structural Integrity Program Conference, WRDC-TR-89-4071, May 1989.

Figure 1.

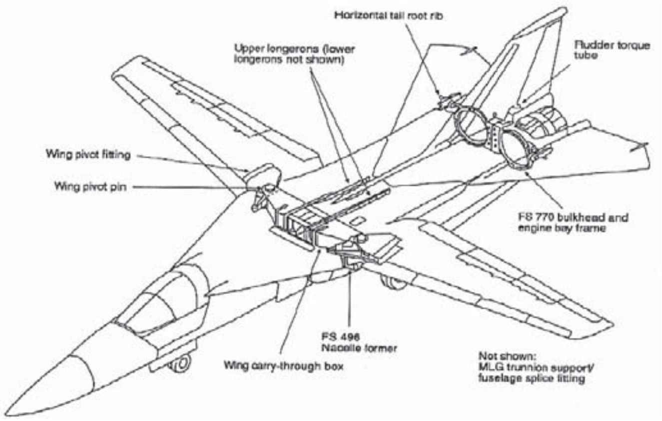


Figure 2.

Figure 3.

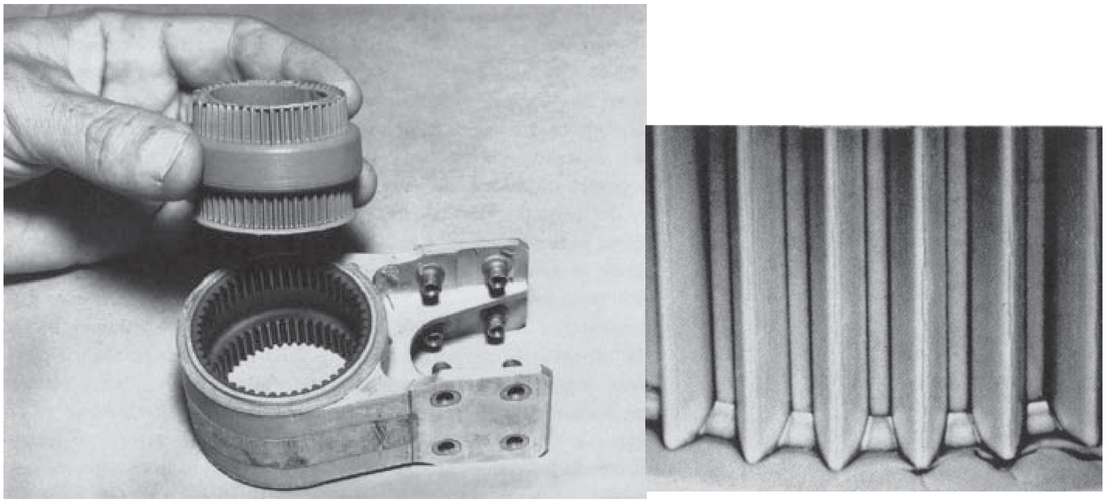


Figure 4.

Figure 5.

Figure 6.

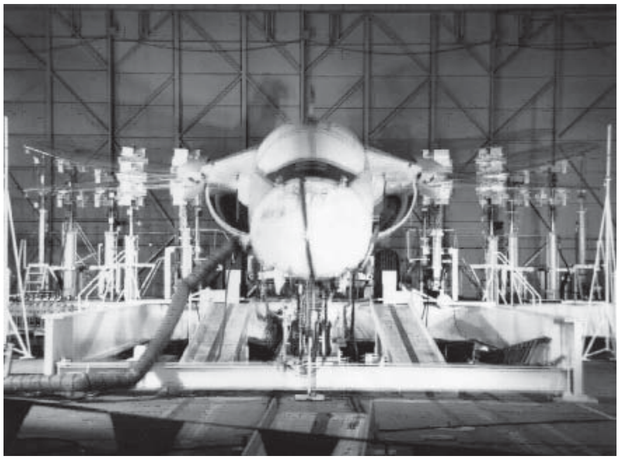
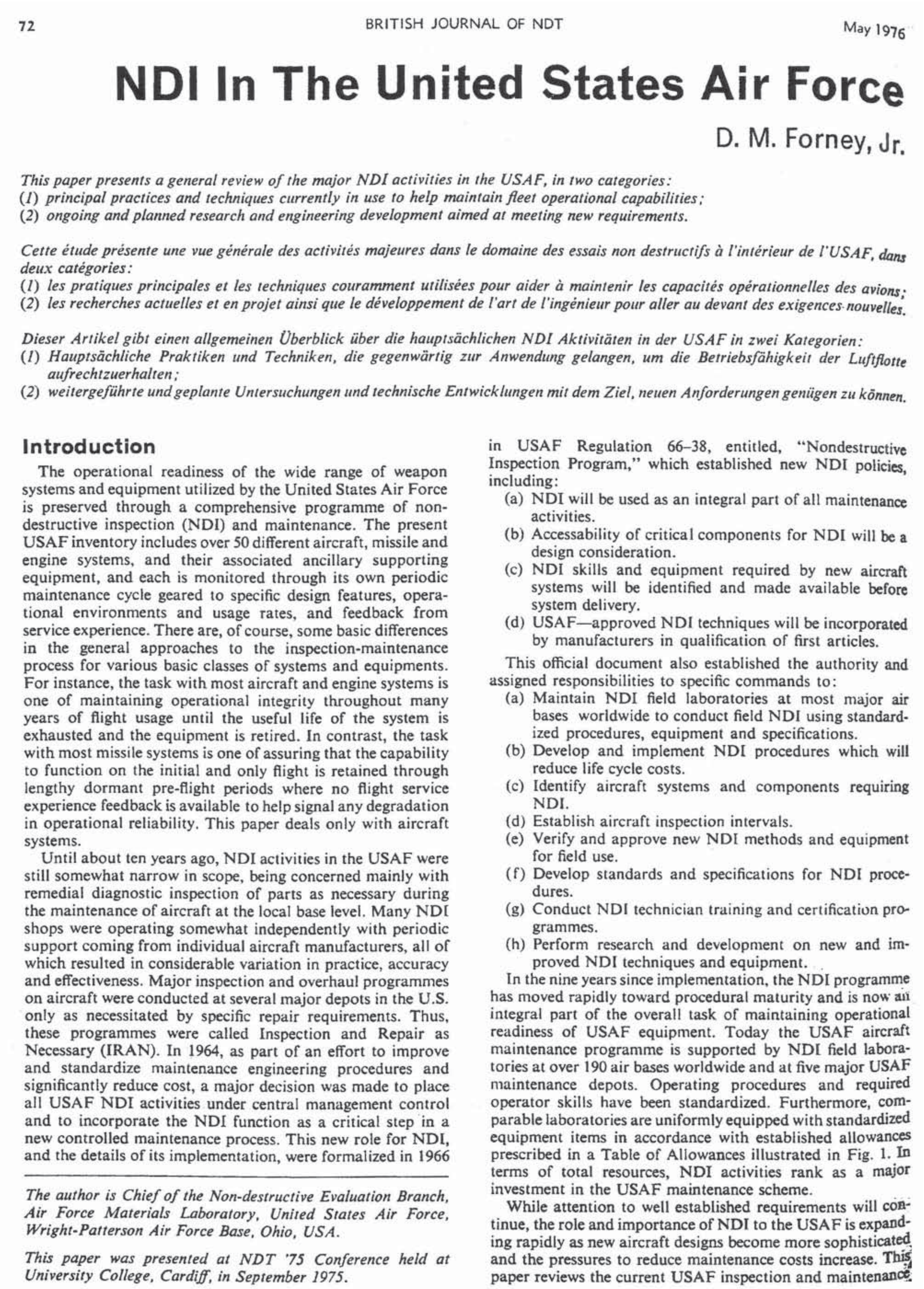


Figure 7.

APPENDIX C-2

NDI in the United States Air Force (Excerpt from Paper). The following excerpted paper presented an extended description of the state of the USAF in-service NDI processes and procedures at that time. The remainder of the paper, not included, summarized many of the ML NDE R&D program activities at that point in time.



72 BRITISH JOURNAL OF NDT May 1976

NDI In The United States Air Force

D. M. Forney, Jr.

This paper presents a general review of the major NDI activities in the USAF, in two categories:
(1) principal practices and techniques currently in use to help maintain fleet operational capabilities;
(2) ongoing and planned research and engineering development aimed at meeting new requirements.

Cette étude présente une vue générale des activités majeures dans le domaine des essais non destructifs à l'intérieur de l'USAF, dans deux catégories:
(1) les pratiques principales et les techniques couramment utilisées pour aider à maintenir les capacités opérationnelles des avions;
(2) les recherches actuelles et en projet ainsi que le développement de l'art de l'ingénieur pour aller au devant des exigences nouvelles.

Dieser Artikel gibt einen allgemeinen Überblick über die hauptsächlichen NDI Aktivitäten in der USAF in zwei Kategorien:
(1) Hauptsächliche Praktiken und Techniken, die gegenwärtig zur Anwendung gelangen, um die Betriebsfähigkeit der Luftflotte aufrechtzuerhalten;
(2) weitergeführte und geplante Untersuchungen und technische Entwicklungen mit dem Ziel, neuen Anforderungen genügen zu können.

Introduction

The operational readiness of the wide range of weapon systems and equipment utilized by the United States Air Force is preserved through a comprehensive programme of non-destructive inspection (NDI) and maintenance. The present USAF inventory includes over 50 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. There are, of course, some basic differences in the general approaches to the inspection-maintenance process for various basic classes of systems and equipments. For instance, the task with most aircraft and engine systems is one of maintaining operational integrity throughout many years of flight usage until the useful life of the system is exhausted and the equipment is retired. In contrast, the task with most missile systems is one of assuring that the capability to function on the initial and only flight is retained through lengthy dormant pre-flight periods where no flight service experience feedback is available to help signal any degradation in operational reliability. This paper deals only with aircraft systems.

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 programmes on aircraft were conducted at several major depots in the U.S. only as necessitated by specific repair requirements. Thus, these programmes 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, "Nondestructive Inspection Program," which established new NDI policies, including:

(a) NDI will be used as an integral part of all maintenance activities.
(b) Accessability 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 programmes.
(h) Perform research and development on new and improved NDI techniques and equipment.

In the nine years since implementation, the NDI programme 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 programme is supported by NDI field laboratories at over 190 air bases worldwide and at five major USAF maintenance depots. Operating procedures and required operator skills have been standardized. Furthermore, comparable laboratories are uniformly equipped with standardized equipment items in accordance with established allowances prescribed in a Table of Allowances illustrated in Fig. 1. In terms of total resources, NDI activities rank as a major investment in the USAF maintenance scheme.

While attention to well established requirements will continue, the role and importance of NDI to the USAF is expanding rapidly as new aircraft designs become more sophisticated and the pressures to reduce maintenance costs increase. This paper reviews the current USAF inspection and maintenance

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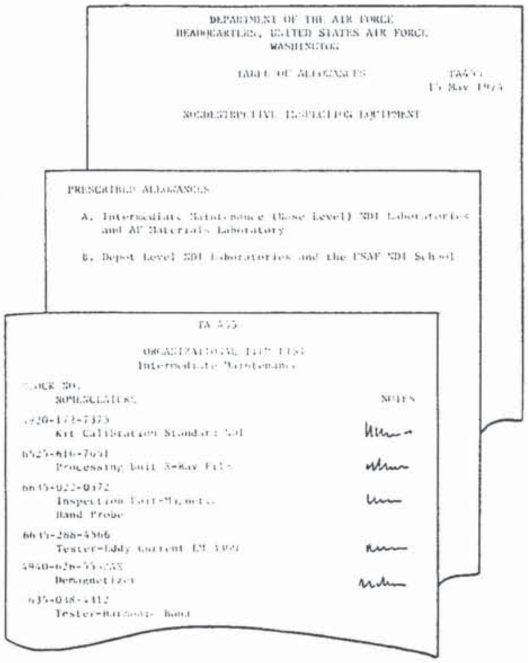
programme concept and discusses new system requirements and trends which will significantly affect NDI in the future. A brief review is also given of some of the ongoing and planned research and development projects being undertaken by the USAF to satisfying these requirements.



DEPARTMENT OF THE AIR FORCE
HEADQUARTERS, UNITED STATES AIR FORCE
WASHINGTON

TABLE OF ALLOWANCES

NONDESTRUCTIVE INSPECTION EQUIPMENT

PRESCRIBED ALLOWANCES

A. Intermediate Maintenance (Base Level) NDI Laboratories and AF Materials Laboratory

B. Depot Level NDI Laboratories and the USAF NDI School

TA 455

Intermediate Maintenance

STOCK NO. NOMENCLATURE	NOTES
Kit Calibration Standard	
Processing Unit X-Ray Film	
Inspection Unit-Magnetic Hand Probe	
Tester-Eddy Current	
Demagnetizer	
Tester-Hardness	

Fig. 1

Representation of USAF NDI Laboratory Inspection Equipment Table of Allowance TA 455

Current NDI Program

The current inspection and maintenance programme in the USAF is designed to emphasize field maintenance procedures which cause a minimum disruption of the flight-ready status of aircraft (termed "on-condition" maintenance) and to anticipate and avoid problems before they occur. A particular version of this programme 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 experience 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 so as to be consistent with those found to be necessary during the system design, development and full scale test programmes, and occasionally modified by service experience. 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, TO33B, 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 technican level manual and NDI technicans are required to have full knowledge of the skills involved.

The individual system programmes call for most of the NDI and maintenance tasks to be performed at base level facilities in a series of periodic inspection "packages". Occasionally a periodic inspection may also be performed at the depot level. A typical aircraft maintenance cycle is illustrated in Table 1.

Preflight and Basic Postflight are walkaround visual inspections conducted daily on the air base flight line as flight operations occur to assure the absence of observable damage, leakage, or other conditions which would degrade flight safety or jeopardize the mission.

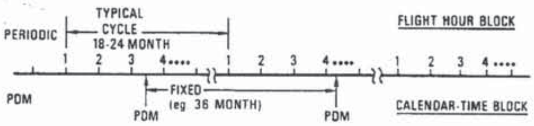
Special Inspections are conducted at any time as necessitated by any occasion where an individual aircraft has experienced an unexpected incident, such as a hard landing, excessive "g" manoeuvres, a severe environmental condition, etc., which may have introduced damage of some type.

Periodic Inspections are usually conducted on aircraft on an accumulated flight hour basis, for example, every 10 to 100 hours, or frequently longer (however, there are some cases where isochronal phasing is used). Each part or subsystem of an aircraft requiring periodic inspection, according to the −36 and −6 NDI manuals governing that aircraft system, is scheduled into one or more of the periodic inspections. Some areas require frequent inspection, for example, every other periodic inspection or every fourth one. Others may require only infrequent inspection. An inspection cycle is considered completed and a new one started when every inspection point has been inspected at least once. Some periodic inspection packages can be completed within a few hours to a day and are typified by removal of access doors and selected panels, in situ application of portable NDI equipment such as X-ray and low frequency ultrasonic units for NDI, removal and NDI of removable components such as wheels, and so on.

TABLE 1

PROGRAMMED INSPECTION AND MAINTENANCE PROCESS

INSPECTION TASK	INTERVAL
1. ORGANIZATIONAL AND INTERMEDIATE (BASE LEVEL) MAINTENANCE (O&I)	
PREFLIGHT	BEFORE FIRST FLIGHT OF THE DAY
BASIC POSTFLIGHT	AFTER EACH FLIGHT
SPECIAL INSPECTION	AS NECESSARY
PERIODIC INSPECTION	
● AIRFRAME	FLIGHT HOUR BLOCKS
● ENGINE	FLIGHT HOUR BLOCKS
● FUNCTIONAL SUBSYSTEMS	FLIGHT HOUR BLOCKS
● CORROSION	CALENDAR TIME BLOCKS
2. PHASED/ISOCHRONAL INSPECTION	AFTER SEVERAL PERIODIC INSPECTIONS
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



Flight controls and engine controls may be adjusted and realigned (re-trimmed).

Phased/Isochronal Inspections are additional inspection procedures conducted in the maintenance dock at several hundred flight hour (e.g., 500 to 1500 hr.) intervals. These are more comprehensive inspections usually requiring two to three days to perhaps a month to complete during which, for example, engines are removed, fuel cells are drained and inspected, numerous panels are removed to examine critical structural locations for cracks, wear or corrosion, and a larger number of selected components are removed for detailed NDI. Superimposed on the flight-hour based inspections, including both periodic and phased blocks, are corrosion control packages for the detection and repair of corrosion damage and the rejuvenation of control prevention measures as needed. These inspection procedures are scheduled by calendar time, corrosion being a process in time more than in usage rate and may be as frequent as every 30 to 60 days. The corrosion inspection frequency varies with aircraft type, mission and geographic location.

Programmed Depot Maintenance (*PDM*) operations are scheduled periodically for aircraft systems in order to accomplish specialized maintenance as well as major modification tasks which (a) require equipment, skills, tools or facilities, or disassembly/assembly procedures not available at the base level or (b) are more economical to perform at a central location. PDMs characteristically involve extensive NDI coverage conducted in conjunction with the depot maintenance or modification tasks.

Analytical Condition Inspections (*ACI*) are conducted periodically at the depot level to systematically disassemble and inspect a small but representative sample of each aircraft fleet in an operational status to ascertain the presence of hidden defects, deteriorating conditions, corrosion, fatigue/overstress, or failures in the structure. High time, high usage aircraft are usually chosen to maximize the timely discovery of discrepancies before they become fleet critical. The extensive and detailed use of a wide range of NDI procedures characterizes this inspection. The ACI provides information to:

- evaluate flight safety conditions
- identify and document all discrepancies
- validate replacement/wearout factors
- determine adequacy of inspection intervals
- add or eliminate critical NDI points as necessary
- verify the general structural condition
- recommend in detail necessary fleet corrective actions.

The Lead the Force (*LTF*) aircraft inspection programme provides for the monitoring, through regular NDI at the air base level, of selected aircraft of each model that are operated at an accelerated pace to accrue flying hours 15 to 25% ahead of the main body of its fleet. These inspections help provide advanced information on the development of discrepancies or changes in flight safety which will require corrective action. Generally, inspections conducted on LTF aircraft are more extensive than required by the system NDI manual to assure that no unanticipated discrepancy is overlooked.

New Factors Expand Importance of NDI

The continuing programme to increase the strength and effectiveness of the USAF at minimum cost is applying considerable pressure to improve supporting NDI capabilities. Behind this pressure are several significant new factors affecting aircraft systems:

A. Adoption of new airplane damage tolerant design requirements.

B. Trend toward aircraft life extension rather than replacement.

C. Efforts to reduce operational and support (O&S) costs (cost of ownership).

D. Emergence of new structural concepts and materials.

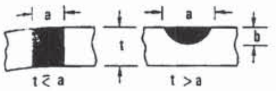
A. *New Design Requirements*

Since 1961, USAF aircraft have been designed, manufactured and operated in accordance with the technical requirements of an Aircraft Structural Integrity Programme (ASIP) established to assure that they have adequate integrity and service life.(1) Fatigue design was based on a safe-life concept and a full scale verification fatigue test. 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. It was further specified that damage growth rates should be slow enough that no reduction in strength should occur before the second inspection following such damage initiation in order to allow for the possibility that the first inspection failed to detect the damage.

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 NDI. The analysis indicated that the flaw had escaped detection primarily because the sensitivity and coverage of standard magnetic particle inspection procedures utilized were inadequate to detect the tight, oxidized flaw in a part of the unusual shape and size of the wing pivot fitting involved. Also, the sound wave transmission used during ultrasonic inspection had been directed almost parallel to the flaw surfaces and the energy return, if any, was insufficient to achieve detection. It was ultimately concluded that the fracture condition existed basically because of the existence of smaller critical crack sizes and more rapid subcritical crack growth properties of the component steel than realized, as well as a general overconfidence in NDI capabilities and practices under the circumstances. In order to ascertain the basic integrity of the remaining F-111 aircraft, and to assure the uniqueness of the one flaw, a rigorous proof test and detailed NDI programme of each aircraft was completed successfully.(2) Tests will be repeated on each aircraft after additional flight hour increments.

The F-111 incident, together with various deficiencies experienced with other aircraft systems, led to the issuance of a new set of ASIP requirements in 1972, now contained in Military Standard MIL-STD-1530,(3) 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 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,(4) 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-crack 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 given.

INITIAL FLAW SIZE ASSUMPTIONS



PRIMARY DAMAGE* –INCHES		
	SLOW CRACK GROWTH	FAIL SAFE
a	0.250	0.100
b	0.125	0.050

LOCATIONS OTHER THAN HOLES

*PRIMARY DAMAGE ASSUMED AT MOST CRITICAL LOCATIONS IN STRUCTURE

Fig. 2

Specified initial flaw sizes presume the inspection of 100% of all fracture critical regions of all designated structural components and a fairly conservative assumption of NDI capability. The provisions of this specification are too extensive to present; however, a short excerpt is repeated here and shown in Fig. 2 to illustrate the point. At locations in a slow crack growth structure other than holes, the assumed initial flaw shall be a through the thickness flaw 0.25 inch in length when the material thickness is equal to or less than 0.125 inch. For material thicknesses greater than 0.125 inch, the assumed initial flaw shall be a semicircular surface flaw with a length equal to 0.25 inch and a depth equal to 0.125 inch. At locations in a fail-safe structure other than holes, a through-the-thickness flaw 0.10 inch in length is assumed for thickness of 0.05 inch or less and a 0.10 inch semicircular flaw of 0.05 inch depth for material thicknesses greater than 0.05 inch. The case of inspectability of a given structural component also influences the allowable flaw size assumption such that the less accessible the inspection point, the more conservative the design must be to insure the necessary safe period of unrepaired service usage. The degrees of inspectability cited in 83444 are shown in Table 2.

TABLE 2

DEGREES OF INSPECTABILITY (MIL-A-83444)

DEGREE OF INSPECTABILITY	TYPICAL INSPECTION INTERVAL	AIRCRAFT MUST BE CAPABLE OF THE FOLLOWING MINIMUM PERIOD OF UNREPAIRED SERVICE USAGE
IN-FLIGHT EVIDENT	ONE FLIGHT	RETURN TO BASE
GROUND EVIDENT	ONE FLIGHT	ONE FLIGHT
WALKAROUND VISUAL	TEN FLIGHTS	5 × INSPECTION INTERVAL
SPECIAL VISUAL	ONE YEAR	2 × INSPECTION INTERVAL
DEPOT OR BASE LEVEL	1/4 LIFETIME	2 × INSPECTION INTERVAL
NON-INSPECTABLE	ONE LIFETIME	TWO LIFETIMES

Where designs are to be based on initial flaw size assumptions smaller than those specified in 83444, an NDI demonstration programme must be performed by the manufacturer under production conditions and in the production environment for each NDI procedure to be used to verify that all flaws equal to or greater than the designs flaw size will be detected with at least 90% probability and with a 95% confidence level. Once approved, the demonstrated procedures must be incorporated in the manufacturing process unabridged.

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. These life requirement changes are shown in Table 3.*

TABLE 3

AIRCRAFT SERVICE LIFE REQUIREMENTS

AIRCRAFT TYPE	YEARS OF SERVICE	FLIGHT HOURS*	
		PRE-1972 ASD-TN-66-57	POST-1972 MIL-STD-1530
FIGHTER	15	4,000	8,000
BOMBER	25	10,000	15,000
TANKER	25	10,000	20,000
CARGO	25	15-30,000	25-50,000
TRAINER	25	15,000	15-25,000

* EXCEPTIONS MAY OCCUR IN SPECIFIC CASES

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. For example, the F-106 interceptor was recently recertified by means of a new full-scale fatigue test, for 8,000 hours service life, although still based on the safe life concept. Several minor structural modifications were identified to make this possible. Increased NDI monitoring will be conducted to insure against any new problems. The F-4C/D and E models have also just undergone an ASIP re-assessment to determine the necessary engineering changes and additional inspection requirements to meet the 8,000 hour service life goal with the incorporation of adequate damage tolerance. Fig. 3 shows some of the analysis items included. A decision on various life extension options is awaiting an economic tradeoff study. Many first line aircraft systems will eventually undergo this structural integrity and durability reassessment. It is anticipated that upgraded NDI 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 NDI is an important limitation on the number of aircraft available to meet mission requirements at

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**A revision to MIL-STD-1530 is currently being considered in which a general service life for particular aircraft types will no longer be specified. Rather, the service life (hours and years) will be dictated by particular or unique operational requirements with each new aircraft system having its own service life requirements.*

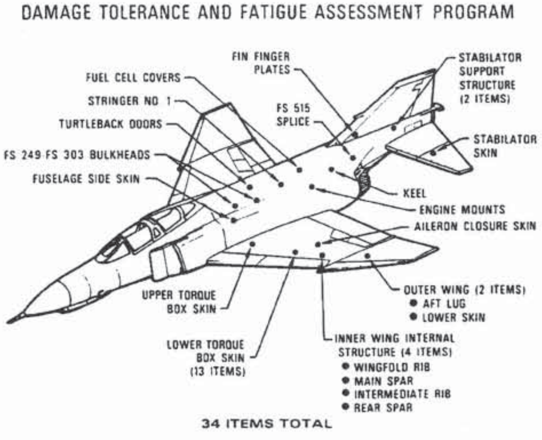


Fig. 3

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 NDI more economical

A number of detailed studies are being performed to improve the current cycles used for programmed NDI and maintenance such as described earlier in Table 1 (for instance, Refs. 5 and 6). Some of the important findings identified to date which will produce some valuable changes in the near future include:

- A reduction in the duplication of inspection effort between the depot and base level operations is needed.
- Aircraft availability time is sometimes lost to repetitive, improperly structured inspections.
- Flight operation delays are experienced on occasion when in an unnecessary dismantled condition.
- The inspection dock workload is unnecessarily variable, because scheduling inspection by flying hours rather than calendar time does not create the steady wordload input that a job shop needs to operate efficiently.
- There is inadequate coordination of inspection requirements between the aircraft designer and the maintainability engineer.
- Deployed units have a heavy inspection workload, which cuts down their operational capability and readiness.

The USAF is presently conducting an extensive Maintenance Posture Improvement Programme 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 programme flexible enough to accommodate changing conditions, economics and fleet management schemes. The interface between NDI and corrosion control requirements is an example of the factors being considered.

There are, as can be imagined, many instances where the cost of NDI 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 centres" in the many NDI functions, and to devise alternative techniques, technique modifications, simpler procedures or cheaper inspection materials.

APPENDIX C-3

Inauguration of the AFML-ARPA NDE Science Center Program, Drs. R. Bruce Thompson and Donald O. Thompson, current and former directors of the Center for Nondestructive Evaluation (CNDE), Iowa State University, Ames, IA.

The principal initial efforts of the NDE Science Center program were focused on fundamental developments that underlie all NDE inspection technology. They included the development of mathematical descriptions of probe field-flaw interactions beginning with ultrasonics and extending to eddy current and x-ray technologies. Direct solutions of these problems are key to the design of inspections and to the determination of quantitative probabilities of detection, coupling NDE to the world of statistics. These direct theories also provided the foundation for the development of inverse theories that are key to flaw sizing capabilities and provided a mechanism for NDE coupling to the world of materials and fracture mechanics.

An extensive experimental program was conducted in support of these theoretical studies. Included were the development of a new set of quantitative measurement techniques and new ways of fabricating samples (using diffusion bonding techniques) to produce simulated defects of simple and controlled shapes. In addition, new probes were developed, efforts that included key stages in the development of EMAT technology. Other important projects dealt with determining material properties, including the characterization of composites, adhesive bonds and ceramics. For example, studies of the NDE of adhesive bond strength led to a better understanding of the key issues in this “holy grail” problem of NDE.

After the relocation to Iowa State University, other programs were brought into the Center for NDE that were leveraged by and extended the AFML/DARPA work. Central was the NSF Industry/University Cooperative Research program that more actively involved industry in the development of NDE’s science base and its application to current corporate problems. Major efforts were made to develop a cadre of DoD (especially aerospace) companies as members of the Center. This materially enhanced and leveraged technology transfer between the AFML/DARPA work and technology users. Additional programs were added under the sponsorship of other federal agencies to further that technology. Included was a NIST program that let to concentrated development of the model-based tools begun in the AFML/DARPA program, making the first demonstrations of the computer-based simulation technology for ultrasonics, eddy currents, and x-rays that allows NDE to play a full role in the quantitative design phase of a product or system (instead of its traditional role as an after-the-fact-only technology). The model-based approaches are key to the successful evolution of unified life cycle engineering concepts and to more cost effective inspection routines. Most recently, these and related technologies are being applied to a wide range of aerospace problems associated with aging civilian aircraft (under FAA support), space vehicles (under NASA support) and military aircraft (under AFRL support).

Since its inception, the program was a model of both horizontally and vertically integrated interdisciplinary research and development. The research was led by a group that included Dr. Michael J. Buckley, AFML, DARPA, Government Program Monitor; Dr. Donald O. Thompson, Rockwell International Science Center, Program Manager; and Drs. R. Bruce Thompson and George Alers, Project Managers. Many highly respected researchers formed the research team, including Profs. B. Auld and G. Kino, Stanford University; Prof. R. M. White, University of California, Berkeley; Prof. J. A. Krumhansl, Cornell University; Prof. Jan Achenbach, Northwestern University; Prof. Robert L. Thomas, Wayne State University; Prof. W. Knauss, California Institute of Technology; and Prof. Frank Kelly, University of Akron, and Drs. D. Kaelble, A. Evans, N. Paton, O. Buck, B. Tittman, J. Richardson, all of the Rockwell International Science Center. The program also benefited from numerous enlightening discussions with Dr. Harris Burte, Principal Scientist and Mr. Don Forney, NDE Branch Chief, AFML.

APPENDIX C-4

Establishment of Manufacturing Technology Funding Authority to Expedite NDE Technology Transition, James Mattice, former Chief, ML Manufacturing Technology Division.

In the early-mid 1970s, basic S&T advances in integrating advanced sensors, imaging techniques, information processing and precision micromechanical devices established the basis for significant practical advances in NDE capabilities in production and field environments. However, lack of adequate resources to design, build and demonstrate fully capable devices and equipment posed a potential severe limitation to timely technology transition. The AF Manufacturing Technology (ManTech) Program, housed in the same AF Laboratory as the NDE S&T organization, was called upon to "scale-up" and demonstrate these technologies as they routinely accomplished with other process-based manufacturing technologies in a production environment.

While the technical possibilities were great, management barriers evolved. ManTech program management in the Lab was faced with many competing process technology opportunities (composites, electronics, net shape metal forming, specialty chemical processing, etc.) that were understood well by both technical and management staffs. No NDE technical experts resided in the ManTech program office to advocate the techniques. ManTech program overseers at HQ AFSC and the Air Staff did not recognize NDE as a critical production or maintenance process function. However, after forming collaborative investment planning teams with NDE Lab researchers, ManTech program management took this issue on with the Washington Staffs and demonstrated that the business case was overwhelming by approaching the growing production quality issue on several fronts (including inspecting-in quality as an integral part of the production process, "productionizing" NDE in depot inspection operations, and postulating production NDE capability as a critical part of emerging "retirement for cause" critical component life management strategies).

Having overcome "Washington resistance" and obtaining General Officer support on the basis of tangible benefits and cost avoidance/savings, the remaining challenge was local Lab technical priorities. Coincidently, the Lab, including ManTech, was under increasing pressure to respond to the critical requirements of "the other Industrial Base" – the AF Depots. With a well documented shortfall in depot O&M inspection capability an opportunity to make a difference became evident. This series of events culminated in the decision to make a sustained investment (X years; Y dollars) in the previously designed NDE development roadmaps that had been crafted by the Lab researchers, ManTech personnel, and depot and industry stakeholders. A few researchers migrated to the ManTech organization to fill the skill void and some remained to become part of the ManTech culture and workforce. Thus, S&T - ManTech NDE program became the cornerstone of a decade of exciting development, demonstration and transition to depot and industry applications with huge benefits of cost savings, cost avoidance and new fleet management concepts implemented in government and commercial inspection environments.

APPENDIX C-5

White Paper "Nondestructive Inspection and Evaluation (NDI/E): Successful Technology Transition and Who the Customers Are." Donald M. Forney, Chief, ML Nondestructive Evaluation Branch.

1.0 PURPOSE

During the 1989 AFSC Spring Program Review of the WRDC/ML program, AFSC/XT tasked ML to prepare a white paper to (a) examine who the customers are for nondestructive inspection and evaluation (NDI/E) technology and (b) identify factors contributing to successful transition of technology (AFSC/XT tasking letter dated 12 May 1989, para 12a; WRDC/CC tasking letter to WRDC/ML dated 22 May 1989).

2.0 BACKGROUND

The Air Force depends heavily upon reliable, accurate nondestructive inspection and evaluation (NDI/E) methods and procedures to help validate quality, monitor functional integrity and detect failure causing defects and conditions in weapons system components and materials. In fact, today it is well established that NDI/E capabilities influence and/or may actually limit many design, materials selection and manufacturing processes and maintenance practices.

Historically, the use of NDI/E by the Air Force evolved from very limited, relatively unsophisticated applications during WW II and into the 1950's to more organized need driven procedures in the 1960's and beyond. Since the mid sixties, several key events have had a profound influence on the direction taken by the developing NDI/E state of the art and have formed the uniquely strong and well established customer relationships that exist today. Some of these events are outlined here:

(1) The publication of AFR 66 38 "Nondestructive Inspection Program" in 1965 established for the first time uniform Air Force objectives, procedures, equipment, training and a host of instructions/guidelines to govern Air Force wide NDI/E mission activities. Furthermore, this regulation formalized the requirement to conduct a continuing research and development program to advance the NDI/E state of the art. AFLC/AFSC Supplement 1 to AFR 66 38 was issued to assign certain specific responsibilities (AFSC's Materials Laboratory, for example, was designated as the cognizant organization to conduct the ongoing R&D to advance the NDI/E state of the art). In general, the weapon systems contractors were given the responsibility to determine and establish appropriate NDI/E programs to satisfy manufacturing quality control needs and to incorporate improved inspectability of components in their designs.

(2) In December 1969, a low flight time F 111 crashed after losing its left wing during a low level practice bombing run, killing both crew members. The resulting investigation revealed the cause to be the catastrophic fracture of the D6ac high strength steel outer wing pivot fitting due to the presence of a manufacturing introduced one inch surface crack that had been missed repeatedly by NDI during fabrication (no in service NDI had yet been required or performed). The national impact of this incident led Air Force Secretary Robert Seamans to order landmark changes in fundamental structural design procedures (from "safe life" to "damage tolerance"). Additionally, since this event exposed serious deficiencies in NDI/E practices within the aerospace industry generally, he challenged them to increase their capabilities and their vigilance during weapon system manufacture. Moreover, he called for a significant increase in the Air Force's NDI/E R&D level of effort to expedite the development/availability of the needed major improvements in flaw detection capabilities. At that time, the NDI/E R&D budget [at the Materials Laboratory] consisted of approximately $550K (combined 6.1 and 6.2 funds) annually.

(3) By 1974, the new damage tolerance design philosophy was in place and governed by MIL STD 1530 "Aircraft Structural Integrity Program (ASIP)". A year later, MIL A 83444 "Airplane Damage Tolerance Requirements" was published. Contained therein were specific flaw sizes the designer had to assume were present in critical components designed from that point forward in the absence of experimentally demonstrated capabilities to detect with NDI/E any smaller sizes with 90% probability at a confidence limit of 95%. A damage tolerance assessment of all previously designed weapon systems commenced shortly thereafter. Recently, structural integrity requirements were extended to turbine engine critical components with the issuance of MIL STD 1783 "Engine Structural Integrity Program (ENSIP)", with similar requirements tied directly to the available

demonstrated NDI/E capabilities.

(4) In 1978, the Air Force Logistics Command published results of a major two year study to measure field inspection capabilities typical across the operational Air Force (5 Air Logistics Centers and 15 air bases were sampled). This unique assessment, the first of its kind around the world, revealed a significant and serious in service NDI/E capability shortfall in inspecting airframe components such that the smallest flaws detectable with even modest reliability (50% probability for example) were generally up to an order of magnitude too large. The need for swift correction action was documented by AF and AFLC Inspector General inspections, AF Studies Board reports, Joint Logistics Commanders (JLC) Joint Technical Coordinating Group on NDI (JTCG NDI), Air Staff tasking through PMD L Y1038(1) and other sources. By 1984, the results of a similar study by AFLC at two engine maintenance depots on turbine engine components also indicated a capability shortfall, although not as severe (due principally to the RELATIVELY more controlled inspection environment).

(5) As a result of the findings of the JLC JTCG NDI study of USAF NDI/E deficiencies, and of the concerns of the two Air Force commanders (AFSC Gen Marsh and AFLC Gen Mullins), Hq AFSC requested in September 1983 that an out of cycle 6.3 NDI/E program be inserted by AFWAL/ML in the FY86 POM to establish a strong, appropriately funded advanced technology demonstration and transfer path that was missing up to that point. The program “Nondestructive Inspection and Evaluation (NDI/E)” was incorporated in the AF FY86 POM as PE 63454F PDP 220 but did not achieve congressional approval as a new PE. The program was resubmitted successfully in the FY87 POM as Project 3153 within the established PE 63211F PDP 046 but recovered only about 20% of the funding level approved originally by Hq AFSC and Hq USAF for PE 63454F. Commencing in FY90, Project 3153 will be contained in the newly established PE 63112F, pending congressional approval. Both AFLC/CC’s since Gen Mullins (Gens O’Laughlin and Hansen) have sent strong support letters to AFSC/CC.

3.0 DISCUSSION

Over the past fifteen years a responsive and focused NDI/E R&D and Manufacturing Technology program has been evolved, to the extent possible with available resources, to help bring about the critical capability improvement needs highlighted by the aforementioned events and to accelerate the technology transition process. Attention was given to defining and recognizing the key technology gaps limiting highly accurate, reliable, cost effective NDI/E to support both operational and planned weapon systems and to initiate appropriate R&D efforts. Priority has been given to:

(a) increasing flaw detection reliability through the technical upgrade of existing or development of new instrumentation and refined test procedures;

(b) improving/modifying existing methods to satisfy specific high priority requirements of particular concern to the Air Force;

(c) exploring and developing new technical approaches where satisfactory established approaches do not exist;

(d) establishing a strong NDI/E science base for both existing methods and new concepts where none had evolved from the past.

Directions (a), (b) and (c) have generally responded to the needs of particular customer communities aerospace manufacturers and related SPO’s; AFLC and the Air Logistics Centers, and the MAJCOM NDI/E communities. Direction (d) has focused on stimulating the scientific community to develop the higher order knowledge and understanding of existing NDI/E methods and new approaches....a critical step to increasing accuracy, broadening applications and elevating capabilities.

Considering the urgency placed on the need for swift and major improvement of the state of the art, the level of funding for this technical area has remained significantly low. In FY70, the NDI/E R&D budget contained only about $550K (6.1/6.2 combined). Ten years later (FY80), annual funding had been increased only to $1.4M (6.1/6.2) and $2M of Manufacturing Technology funds (7.8). Similarly, after an additional nine years (FY89), the WRDC NDI/E technology development funding consisted of only $2.2M 6.1/6.2 and $2M 6.3 (Materials Laboratory), and of $0.9M of 7.8 funds (ManTech Directorate) to complete three ongoing efforts (no new NDI/E programs are planned). After accounting for inflation, the growth is minor. Many opportunities for achieving the required technology advances have remained unfunded.

3.1 Principal Customers for NDI/E R&D Technology

The requirement for highly accurate NDI/E within the Air Force, together with the noted continuing shortfall of capabilities in many applications, has created a strong pull for new technology by customers both within and outside the Air Force. These customers for AF NDI/E R&D results include:

3.1.1 Weapon System Designers/Manufacturers

The structural integrity programs (ASIP and ENSIP) require systems designers to assume that sub detection threshold sized flaws are present (at the most strength reducing location and orientation) in safety of flight component designs. The result is reduced design efficiencies, shorter, more frequent required inspection periods and increased manufacturing and maintenance costs. Furthermore, previously designed weapon systems have undergone detailed damage tolerance and durability assessments (DTDA) to identify any redesign requirements and revise NDI/E requirements as necessary. Development of new NDI/E technology to increase the reliable detectability of smaller flaws, thus minimizing the increased cost of achieving damage tolerance, is a major R&D objective. The transition path for the AF generated technology is both to the aerospace design community and the Air Force weapon system SPO's and Acquisition Division engineering offices. The capability to reliably detect smaller flaws translates directly to the design and manufacture of more efficient components.

3.1.2 Operational Air Force Commands (AFLC and other MAJCOMS)

In maintaining the operational readiness of weapons systems, the Air Force performs a wide range of NDI/E tasks in the operational setting (air bases, depots) in accordance with the procedures and equipment designated in appropriate NDI/E Technical Orders (TO's) for each weapon system prepared by the system manufacturer, in cooperation with the SPO. Changes in NDI/E requirements or procedures are occasionally made after system delivery to accommodate new needs and/or upgrade capabilities with new technology. Such improvements are sought in several possible ways:

(a) An Air Logistics Center may make necessary modifications of procedures/methods directly when the technology is available and/or timing is short;

(b) The Air Force Coordinating Office for Logistics Research (AFCOLR) at Hq USAF initiates Logistics Needs (LN's) in a continuing process to document new NDI/E capability requirements on behalf of the operational commands. Since the program inception in 1980, over thirty (30) LN's have been issued for improved NDI/E capabilities, the majority requiring lengthy R&D efforts to produce the required results. These needs range from the specific for example, improved methods to inspect landing gear and wheel components, characterization of flame sprayed coatings on turbine engine blades; to broad developments such as new NDI/E capabilities for advanced composite and turbine engine components, detection of interior structure flaws and inaccessible corrosion; to significant generic methods improvements including ultrasonics, eddy current, radiography (including computed tomography) and penetrants.

(c) Ongoing direct communication between AFLC, other MAJCOMS and the NDI/E people within AFSC (primarily WRDC/ML) occurs through participation in (1) the annual Air Force Wide NDI Meeting each February under the auspice of AFR 66 38 (the annually updated ML R&D roadmaps are briefed here in detail); (2) special meetings, a current example being the AFLC sponsored Symposium on the Applications of NDI/E Technology of Military Aircraft Engines, 17 18 October 1989; (3) special topic ad hoc meetings throughout each year to discuss specific project needs, problem solutions, future plans, etc.; (4) the quarterly meeting of the AFLC General Officers Steering Group on NDI/E; (5) Other related activities.

3.1.3 Science and Engineering Development Community

The institutional/industrial R&D organizations and academia conduct follow on or related technology transfer projects, frequently for other funding agencies, using generic information from Air Force tech base efforts. The AF can be a beneficiary of the subsequent technology development and transfer efforts.

4.1 Factors Contributing to Successful Technology Transfer

Historically, the insertion of new and improved NDI/E technology into the operational setting has been particularly difficult and frequently limited for a host of reasons. Speaking generally, while the potential user/customer may recognize the need for improved capabilities, he is still focused on maintaining schedule, staying within budget, utilizing equipment/materials/methods already on hand if possible, minimizing changes needed to accommodate new technology, minimizing new training requirements, avoiding any follow on development requirements, etc.

In general, most cases of successful transition have satisfied or adequately accommodated the bulk of the important factors. These factors include:

(1) Is There a Well Established Customer Requirement?

(2) Can Development be Completed in Time to Impact Requirement?

(3) Is A Strong Customer Advocacy Involved Early?

(4) Is Cost to Implement Reasonable?

(5) Is Optimum Sustained Development Funding Available?

(6) Are Adequate Field Trials/Corrective Actions Assured?

(7) Are Solution Complexities and Training Needs Minimized?

(8) Has Reliability of Solution Been Established/Demonstrated?

(9) Can Customer Implement Without Requiring More Development?

A number of new technology NDI/E systems or equipment items have, in fact, been developed and implemented successfully into Air Force as well as industrial operational applications. There are also several instances in which transition and useful application of R&D products have not been successful. Some examples are discussed below.

4.1.1 Examples of Successful Tech Transfer within the Air Force

4.1.1.1 a. Retirement for Cause NDI/E System

A major new and innovative NDI/E system for inspecting high performance turbine engine disks, at customer specified throughput rates, has been developed successfully and installed at the San Antonio ALC, Kelly AFB, TX to perform periodic inspections in support of the life extension program for the F100 turbine engine through the process termed “retirement for cause” (retirement only upon detection of a safety limiting crack as opposed to retirement at a prescribed usage life without regard for the presence/absence of a crack). This system incorporates advances in ultrasonic and eddy current methods, automated scanning and data analysis, and archiving of the results. The savings in application of this system to the F 100 engine alone have been established at one billion dollars. A similar system is scheduled for installation soon at the Oklahoma City ALC. Analysis of the key technology transition factors listed above shows:

(1) AFLC, ASD F100 engine SPO, Hq AFSC and the contractor (Pratt & Whitney) agreed that an RFC NDI/E system was essential to satisfy very difficult NDI/E requirements set forth by the ENSIP analysis of critical components. Implementation was needed as soon as possible;

(2) Although extremely short, time was available to develop/implement a suitable system as a high priority task before the expected heavy workload was to hit;

(3) An Air Force wide working group was formed, including high level management and numerous AFLC and ALC members (customers) to pinpoint required/desired system features/capabilities, performance specifications, data packages, facilities and approvals for implementation;

(4) Costs to develop, estimated originally at $15M, were acceptable in view of the enormous expected payoffs. With numerous features now added to the original design, costs may exceed $30M; however, the expected savings computed by Pratt & Whitney and the USAF from implementation still far outweigh even this growth in investment.

(5) To guarantee adequate funding, the Materials Laboratory invested $15M of multiyear funding and

protected the commitment, including adding more funds, through outyear prioritization. Subsequently, ASD and AFLC added an equivalent amount to complete the project;

(6) The system underwent extensive performance and reliability trials which allowed for identification of some needed modifications which improved performance and reliability further. The resulting system has performed a significant workload since implementation, exceeding system consistency and reliability goals.

(7) Although involving some complex new technology, AFLC accepted the need and provided for training to be accomplished;

(8) See 6.

(9) No further development was necessary by AFLC prior to committing the system to production. However, the customer (AFLC) recognizes numerous opportunities for further improvements which may be considered by them in the future.

4.1.1.2 Automated Real time Inspection System (ARIS) for Composites

An advanced computer based, portable, single inspector operated ultrasonic NDI/E system is being developed currently for use in the field environment to scan composite structural components without need for their removal or for special fixturing. The device is designed to overcome most of the deficiencies of current manual methods which usually use two inspectors and have no data analysis, flaw imaging and storage capabilities, and are, furthermore, less accurate. In terms of the technology transition factors: (1) Two LN's, one dating to 1980, together with additional inputs from AFLC, TAC and ATC, have established and maintained this requirement; (2) Although development time has been typically long, customer interest remains high since no alternative approach has emerged; (3) Hq AFLC/MM/MA and ALC advocacy has remained strong; thus a transition pull exists; (4) Estimated system cost is below that of an emerging competitive commercial unit; (5) Based on the requirements and the technological opportunities, WRDC/ML has sustained the required development funding (6.2 and 7.8); (6) Extensive field trials at twelve (12) Air Force operational bases (coordinated with Hq AFLC) and the Navy (Cherry Point NAS) are underway. Meanwhile, ARIS has been evaluated successfully by the Canadian Defence Forces, the UK Royal Air Force, and was used to perform a special inspection of the SR 71 fleet radomes; (7) Many field inspection personnel have operated ARIS without difficulty, indicating it is not too complex; (8) To date, ARIS has proven to be operationally reliable and easy to use in the field environment.

4.1.1.3 Another development activity with strong customer interest and high technology transfer potential is X ray Computed Tomography (CT). Developed initially as a medical diagnostic tool and known more popularly as "CATscan", CT has been developed further by WRDC/ML and adapted successfully to the much more difficult problem of large aerospace hardware NDI/E. New equipment and methods have been scaled up and demonstrated for the inspection of large missile system components. Follow on work is establishing additional high payoff NDI/E applications to a wide range of Air Force hardware where current methods are inadequate.

4.1.2 Examples of Successful Tech Transfer By Aerospace Contractors

4.1.2.1 Automated Eddy Current NDI/E System for Turbine Engine Disks

A production prototype of a computer controlled, automated eddy current scanning system for engine disks was developed for engine depot inspection applications. This system, designated EC II, was intended to replace a number of manual NDI/E operations resulting in higher flaw detection accuracy and reliability and with a significant increase in throughput. This development was in response to Logistics Need AFALD AFWAL/ML 3008 79 02 "NDI Techniques for Engine Disks" issued by AFLC. Extensive field trials validated excellent performance of the resulting system. The prototype development contractor, General Electric Aircraft Engines, continued system improvement efforts independently and since 1983 has installed 23 units in U.S. and allied Air Force and commercial facilities.

4.1.2.2 Turbine Engine Blade Radiography and Infrared NDI/E Systems

Computer automated blade defect imaging systems have been developed through Air Force mantech (7.8) programs by General Electric Aircraft Engines (GEAE). An X ray Inspection Module (XIM) was produced to x ray computed tomography (CT) images of blade interior geometries and an Infrared Inspection Module (IRIM) was produced to detect/image cooling hole/passage blockage. GEAE continued further development following successful demonstrations of the Air Force prototypes and has implemented XIM in blade manufacturing and IRIM in the San Antonio ALC for blade condition NDI/E during engine teardowns.

4.1.2.3 Mobile Automated Ultrasonic Scanner (MAUS)

A prototype portable ultrasonic scanning head to inspect over large composite surfaces rapidly has been developed jointly by WRDC/ML and McDonnell Aircraft Company under a WRDC/ML 6.2 program to establish reliable NDI/E methods for large composite structural components. Following the successful 6.2 program, McDonnell has produced a commercial product which it is marketing currently. Air Force interests in this unit will be pursued via a planned 6.3 program (PE63112F Proj 3153) start in FY91 the develop a rapid large area composite NDI/E system for in service applications.

4.1.2.4 Capacitance Hole Probe Inspection System (CHP)

A production prototype nondestructive microprocessor based fastener hole quality verification system was developed jointly by Lockheed Georgia Company and AFWAL/ML (Mantech 7.8 program) as a possible replacement for laborious, subjective visual and other qualitative manual methods based on operator judgement. Lockheed Georgia Company completed development independently and has commercialized the CHP through its GETEX Division. To date, reported sales have been made to McDonnell Aircraft, Lockheed Ga Co, Northrop, AVCO, Martin Marietta, Rockwell International and Vought. The Warner Robbins ALC has several CHP units and are utilizing them for hole inspections on C 130 and C 141 aircraft.

4.1.2.5 Air Force Exploratory Development Efforts

A number of exploratory development (6.2) efforts have provided enabling technology for industry pickup leading to subsequent technology transition. To exemplify this briefly, two from a number of references are cited:

(a) Advanced ultrasonic pulser receiver instrument employed in the Retirement for Cause NDE system described in 4.1.1.1. The 6.2 contractor, Systems Research Labs, further developed and commercialized the breadboard unit.

(b) Advanced eddy current probe design developed by United Technologies Pratt & Whitney based directly on 6.2 precursor technology from an AFWAL/Materials Laboratory program and being used to inspect engine disks.

4.1.3 Example of Unsuccessful/Limited Tech Transition

4.1.3.1 Ultrasonic Fastener Hole Scanner (Autoscan) A light weight, portable, microprocessor based ultrasonic scanner was developed to nondestructively detect fastener hole corner or midbore radial fatigue cracks under installed fasteners (CUFs) without requiring expensive or damage risking fastener removal. Normal procedures in place required fastener removal and NDI with an eddy current probe, followed by installation of a new fastener. The system prototype, named “Autoscan”, was produced with a mantech program (7.8 funds) based on enabling technology developed earlier with a WRDC/ML 6.2 program. In terms of the critical technology transfer factors: (1) The development was initiated in response to an urgent requirement established by the C 5A SPO on the basis of results of full scale fatigue tests as well as critical crack size calculations during the ASIP damage and durability assessments, and by Hq USAF acting on advice from the C 5A Scientific Advisory Board. The NDI of thousands of fastener holes per aircraft was to be required; (2) It was possible to design and schedule the 6.2 7.8 multiyear program to meet the projected capability need dates; (3) A steering group with the following membership was formed to guide and expedite the development effort to assure compliance as soon as possible: Hq AFLC, NDI Managers from the five Air Logistics Centers (San Antonio ALC as lead), C 5A SPO, Lockheed Ga Co. and WRDC/ML. However, after the successful initial field trials, customer support eroded in light of updated engineering projections that the problem was overestimated and that the impending C 5A fleet re winging would eliminate the requirement. As a result, the normal second round of trials, during which final changes/corrective actions are usually made, was not started; (4) Initial cost to implement estimates based on design/manufacturing experience was considered reasonable at approximately $70K per unit in view of the cost (approx. $200 per hole) using normal fastener removal procedures; (5) Sustained funding was provided to meet schedule, including additions to assure that add on requirements by the customers (C 5A SPO and AFLC) were accommodated. However, when customer pull faded as described in (3), further funding to complete field trials was not programmed due to reduced priority; (6) Initial field trials of Autoscan that began in 1981 were completed successfully. However, before any follow up work could be initiated, during which any changes/corrective actions are typically performed, the program was discontinued. Thus, the proper trials and upgrades were not performed or completed; (7) Initial field trials demonstrated successful system performance in the hangar environment with most technicians reporting ease of operation without undue training/preparation required. Of course, as expected, a number of suggested improvements and changes were documented for the rework phase; (8) High flaw detection reliability was measured with laboratory samples. A similar evaluation on flight hardware was not accomplished due to lack of flawed components. Field technicians reported mixed opinions about the operational/mechanical reliability of the prototype units, thus providing data with which to render the necessary changes/improvements. However, as cited above, follow up effort was not initiated; (9) After the initial trials, AFLC procured five prototype Autoscans for possible applications at the ALC's. The units did not enter service, however, due to lack of workload at the time. To implement successfully, system development would still have to be completed. A new Logistics Need, LN No. 88030, "NDI Techniques for Cracking in Second Layer Structure" has been issued to meet recently identified systems NDI requirements. No new funding to pursue this new requirement has been programmed by either WRDC/ML or WRDC/MT.

5.0 SUMMARY

The Air Force depends heavily upon reliable, accurate NDI/E methods and procedures to help validate quality, monitor functional integrity and detect failure causing defects and conditions in weapon systems components and materials. As part of this mission, an ongoing R&D program is being conducted to produce and implement improvements in capabilities and reliability, to establish new capabilities where none exist, and to reduce overall maintenance time and costs. Some significant technology developments and applications have emanated from this program as exemplified here; however, the extremely inadequate ongoing funding available for this highly visible program continues to delay many technology developments that could resolve numerous documented NDI/E deficiencies.

This White Paper discusses the major customers for technology advances and analyzes the principal factors that appear to be most responsible for successful transfer/implementation of the new/improved technology.

5.1 NDI/E Technology Customers

Major customers for NDI/E technology developments include (a) weapon systems designers/manufacturers, (b) the operational USAF commands, notably AFLC, (c) the science and engineering development community engaged in advancing the NDI/E state of the art.

5.2 Major Factors Influencing Successful Technology Transfer

Among the principal factors which influence the degree of success of NDI/E technology transfer and implementation into practice are (a) a well established customer requirement together with a strong customer advocacy throughout the development and implementation phases, (b) sustained funding at the appropriate level and a development cycle time acceptable to the customer, (c) strong field trials and modification/rework phases, including a demonstration of operational reliability, and (d) a reasonable cost to implement. Without these ingredients firmly in place, successful technology transfer is doubtful.

APPENDIX D

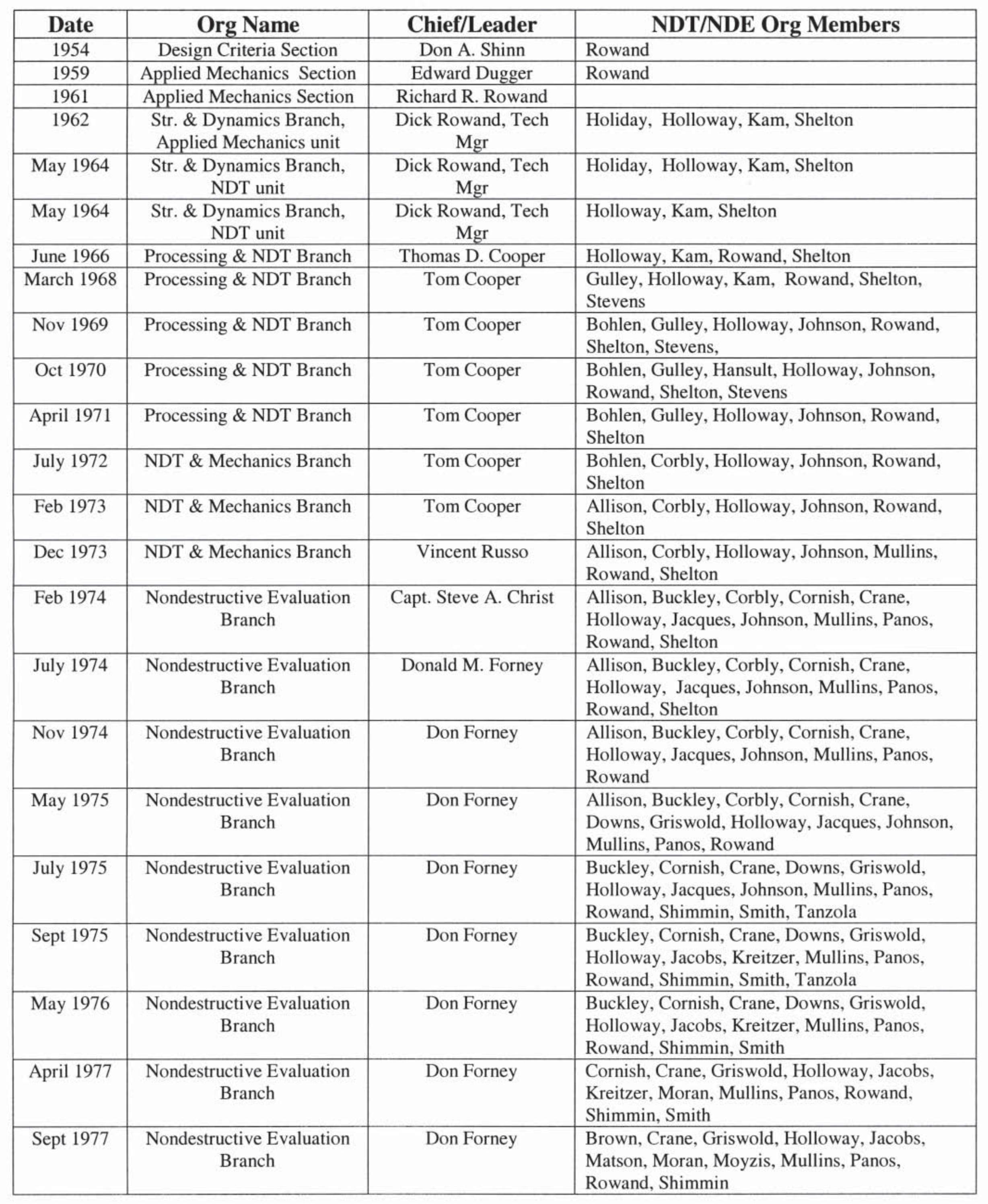
Historical Roster of NDE Organization Members

This Appendix presents listings of those individuals who were assigned to NDT/I/E organizations, to the extent that available historical files provided. Appendix D-1 provides a listing of people assigned over time as the NDE program organization evolved to its present configuration. Appendix D-2 presents an alphabetical list of organization members with the period of their service provided.

APPENDIX D-1

NDE Branch History

Assigned NDE Organization Members

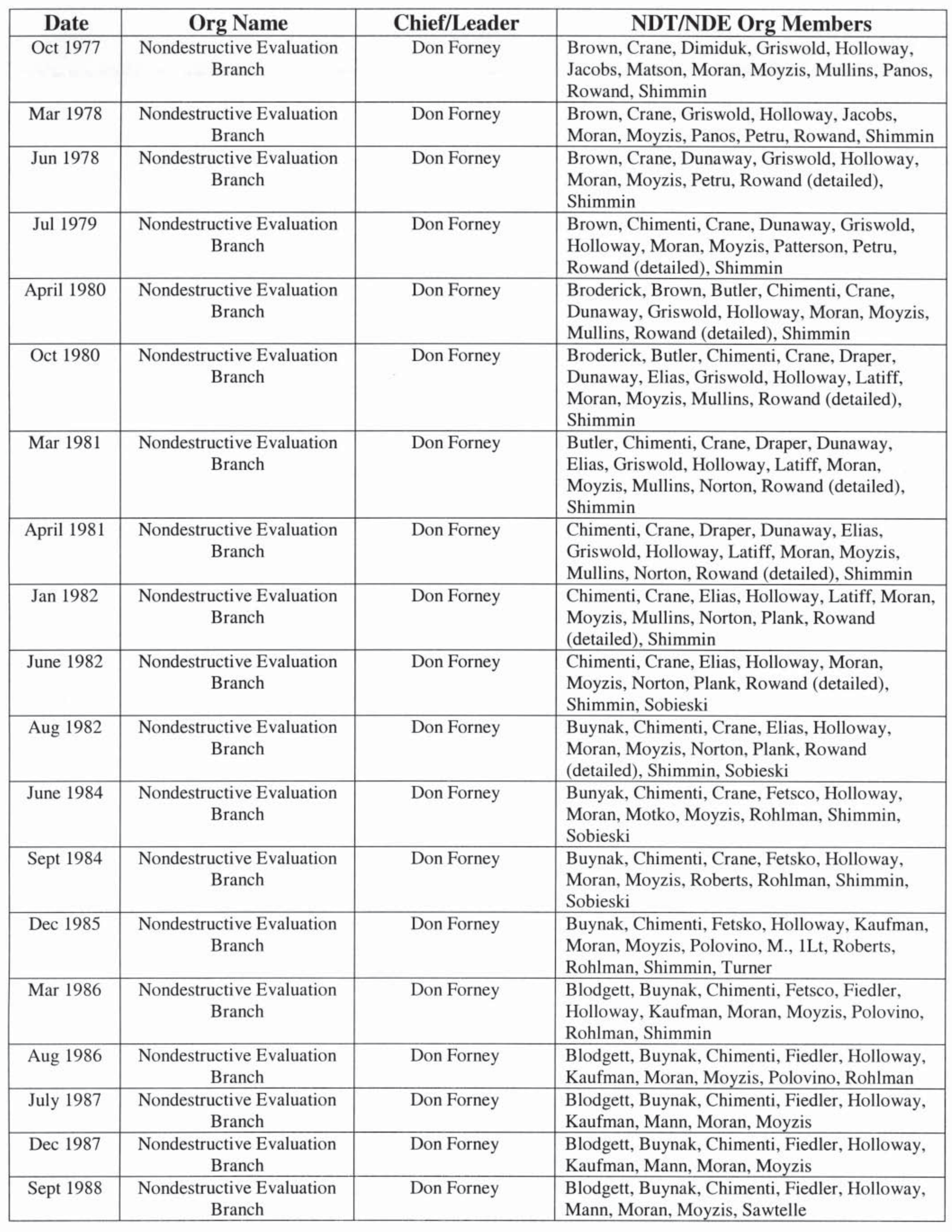


Date	Org Name	Chief/Leader	NDT/NDE Org Members
1954	Design Criteria Section	Don A. Shinn	Rowand
1959	Applied Mechanics Section	Edward Dugger	Rowand
1961	Applied Mechanics Section	Richard R. Rowand	
1962	Str. & Dynamics Branch, Applied Mechanics unit	Dick Rowand, Tech Mgr	Holiday, Holloway, Kam, Shelton
May 1964	Str. & Dynamics Branch, NDT unit	Dick Rowand, Tech Mgr	Holiday, Holloway, Kam, Shelton
May 1964	Str. & Dynamics Branch, NDT unit	Dick Rowand, Tech Mgr	Holloway, Kam, Shelton
June 1966	Processing & NDT Branch	Thomas D. Cooper	Holloway, Kam, Rowand, Shelton
March 1968	Processing & NDT Branch	Tom Cooper	Gulley, Holloway, Kam, Rowand, Shelton, Stevens
Nov 1969	Processing & NDT Branch	Tom Cooper	Bohlen, Gulley, Holloway, Johnson, Rowand, Shelton, Stevens,
Oct 1970	Processing & NDT Branch	Tom Cooper	Bohlen, Gulley, Hansult, Holloway, Johnson, Rowand, Shelton, Stevens
April 1971	Processing & NDT Branch	Tom Cooper	Bohlen, Gulley, Holloway, Johnson, Rowand, Shelton
July 1972	NDT & Mechanics Branch	Tom Cooper	Bohlen, Corbly, Holloway, Johnson, Rowand, Shelton
Feb 1973	NDT & Mechanics Branch	Tom Cooper	Allison, Corbly, Holloway, Johnson, Rowand, Shelton
Dec 1973	NDT & Mechanics Branch	Vincent Russo	Allison, Corbly, Holloway, Johnson, Mullins, Rowand, Shelton
Feb 1974	Nondestructive Evaluation Branch	Capt. Steve A. Christ	Allison, Buckley, Corbly, Cornish, Crane, Holloway, Jacques, Johnson, Mullins, Panos, Rowand, Shelton
July 1974	Nondestructive Evaluation Branch	Donald M. Forney	Allison, Buckley, Corbly, Cornish, Crane, Holloway, Jacques, Johnson, Mullins, Panos, Rowand, Shelton
Nov 1974	Nondestructive Evaluation Branch	Don Forney	Allison, Buckley, Corbly, Cornish, Crane, Holloway, Jacques, Johnson, Mullins, Panos, Rowand
May 1975	Nondestructive Evaluation Branch	Don Forney	Allison, Buckley, Corbly, Cornish, Crane, Downs, Griswold, Holloway, Jacques, Johnson, Mullins, Panos, Rowand
July 1975	Nondestructive Evaluation Branch	Don Forney	Buckley, Cornish, Crane, Downs, Griswold, Holloway, Jacques, Johnson, Mullins, Panos, Rowand, Shimmin, Smith, Tanzola
Sept 1975	Nondestructive Evaluation Branch	Don Forney	Buckley, Cornish, Crane, Downs, Griswold, Holloway, Jacobs, Kreitzer, Mullins, Panos, Rowand, Shimmin, Smith, Tanzola
May 1976	Nondestructive Evaluation Branch	Don Forney	Buckley, Cornish, Crane, Downs, Griswold, Holloway, Jacobs, Kreitzer, Mullins, Panos, Rowand, Shimmin, Smith
April 1977	Nondestructive Evaluation Branch	Don Forney	Cornish, Crane, Griswold, Holloway, Jacobs, Kreitzer, Moran, Mullins, Panos, Rowand, Shimmin, Smith
Sept 1977	Nondestructive Evaluation Branch	Don Forney	Brown, Crane, Griswold, Holloway, Jacobs, Matson, Moran, Moyzis, Mullins, Panos, Rowand, Shimmin

APPENDIX D-1 *(Cont'd)*

NDE Branch History

Assigned NDE Organization Members



Date	Org Name	Chief/Leader	NDT/NDE Org Members
Oct 1977	Nondestructive Evaluation Branch	Don Forney	Brown, Crane, Dimiduk, Griswold, Holloway, Jacobs, Matson, Moran, Moyzis, Mullins, Panos, Rowand, Shimmin
Mar 1978	Nondestructive Evaluation Branch	Don Forney	Brown, Crane, Griswold, Holloway, Jacobs, Moran, Moyzis, Panos, Petru, Rowand, Shimmin
Jun 1978	Nondestructive Evaluation Branch	Don Forney	Brown, Crane, Dunaway, Griswold, Holloway, Moran, Moyzis, Petru, Rowand (detailed), Shimmin
Jul 1979	Nondestructive Evaluation Branch	Don Forney	Brown, Chimenti, Crane, Dunaway, Griswold, Holloway, Moran, Moyzis, Patterson, Petru, Rowand (detailed), Shimmin
April 1980	Nondestructive Evaluation Branch	Don Forney	Broderick, Brown, Butler, Chimenti, Crane, Dunaway, Griswold, Holloway, Moran, Moyzis, Mullins, Rowand (detailed), Shimmin
Oct 1980	Nondestructive Evaluation Branch	Don Forney	Broderick, Butler, Chimenti, Crane, Draper, Dunaway, Elias, Griswold, Holloway, Latiff, Moran, Moyzis, Mullins, Rowand (detailed), Shimmin
Mar 1981	Nondestructive Evaluation Branch	Don Forney	Butler, Chimenti, Crane, Draper, Dunaway, Elias, Griswold, Holloway, Latiff, Moran, Moyzis, Mullins, Norton, Rowand (detailed), Shimmin
April 1981	Nondestructive Evaluation Branch	Don Forney	Chimenti, Crane, Draper, Dunaway, Elias, Griswold, Holloway, Latiff, Moran, Moyzis, Mullins, Norton, Rowand (detailed), Shimmin
Jan 1982	Nondestructive Evaluation Branch	Don Forney	Chimenti, Crane, Elias, Holloway, Latiff, Moran, Moyzis, Mullins, Norton, Plank, Rowand (detailed), Shimmin
June 1982	Nondestructive Evaluation Branch	Don Forney	Chimenti, Crane, Elias, Holloway, Moran, Moyzis, Norton, Plank, Rowand (detailed), Shimmin, Sobieski
Aug 1982	Nondestructive Evaluation Branch	Don Forney	Buynak, Chimenti, Crane, Elias, Holloway, Moran, Moyzis, Norton, Plank, Rowand (detailed), Shimmin, Sobieski
June 1984	Nondestructive Evaluation Branch	Don Forney	Bunyak, Chimenti, Crane, Fetsco, Holloway, Moran, Motko, Moyzis, Rohlman, Shimmin, Sobieski
Sept 1984	Nondestructive Evaluation Branch	Don Forney	Buynak, Chimenti, Crane, Fetsko, Holloway, Moran, Moyzis, Roberts, Rohlman, Shimmin, Sobieski
Dec 1985	Nondestructive Evaluation Branch	Don Forney	Buynak, Chimenti, Fetsko, Holloway, Kaufman, Moran, Moyzis, Polovino, M., 1Lt, Roberts, Rohlman, Shimmin, Turner
Mar 1986	Nondestructive Evaluation Branch	Don Forney	Blodgett, Buynak, Chimenti, Fetsco, Fiedler, Holloway, Kaufman, Moran, Moyzis, Polovino, Rohlman, Shimmin
Aug 1986	Nondestructive Evaluation Branch	Don Forney	Blodgett, Buynak, Chimenti, Fiedler, Holloway, Kaufman, Moran, Moyzis, Polovino, Rohlman
July 1987	Nondestructive Evaluation Branch	Don Forney	Blodgett, Buynak, Chimenti, Fiedler, Holloway, Kaufman, Mann, Moran, Moyzis
Dec 1987	Nondestructive Evaluation Branch	Don Forney	Blodgett, Buynak, Chimenti, Fiedler, Holloway, Kaufman, Mann, Moran, Moyzis
Sept 1988	Nondestructive Evaluation Branch	Don Forney	Blodgett, Buynak, Chimenti, Fiedler, Holloway, Mann, Moran, Moyzis, Sawtelle

APPENDIX D-1 *(Cont'd)*

NDE Branch History

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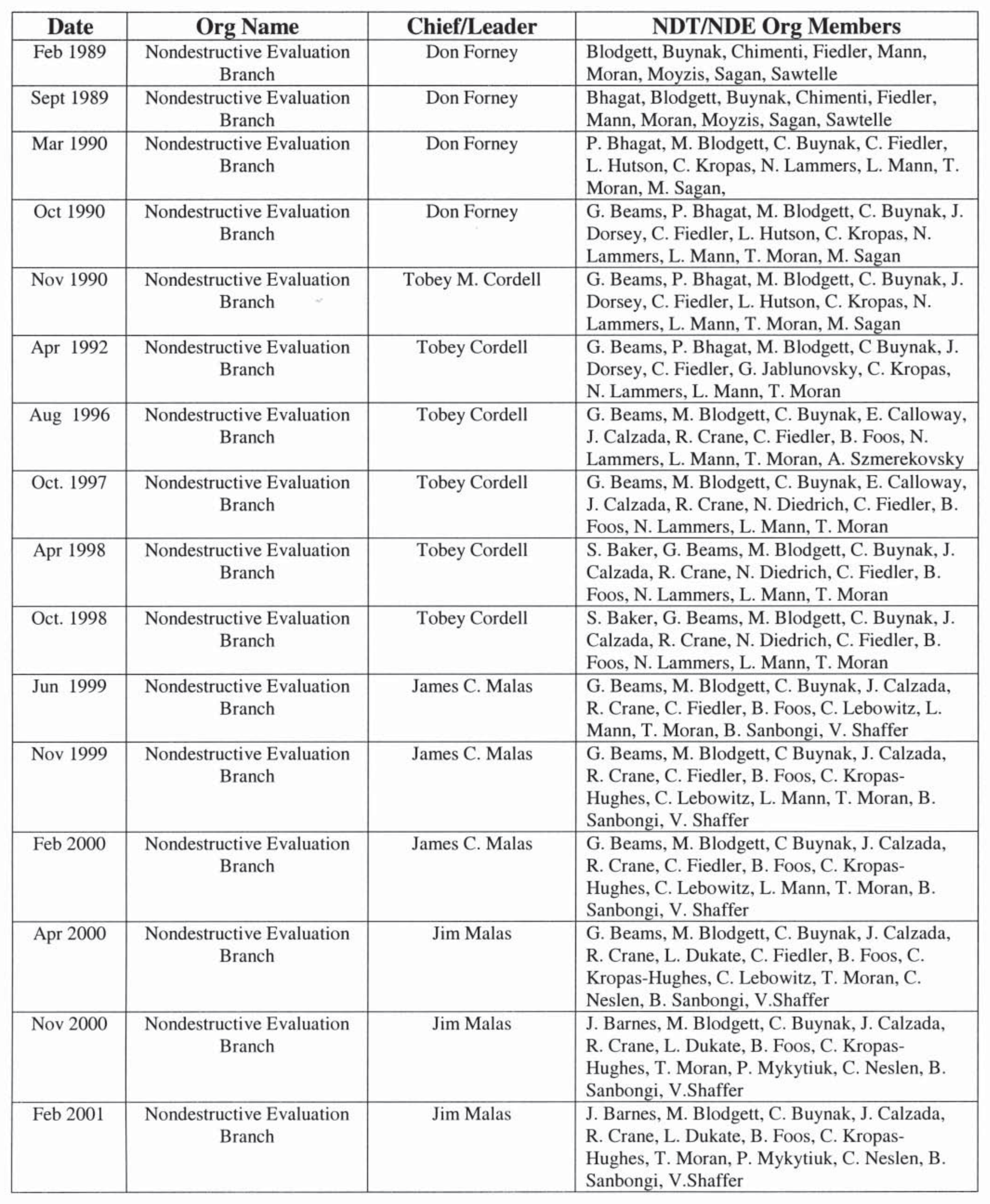

Date	Org Name	Chief/Leader	NDT/NDE Org Members
Feb 1989	Nondestructive Evaluation Branch	Don Forney	Blodgett, Buynak, Chimenti, Fiedler, Mann, Moran, Moyzis, Sagan, Sawtelle
Sept 1989	Nondestructive Evaluation Branch	Don Forney	Bhagat, Blodgett, Buynak, Chimenti, Fiedler, Mann, Moran, Moyzis, Sagan, Sawtelle
Mar 1990	Nondestructive Evaluation Branch	Don Forney	P. Bhagat, M. Blodgett, C. Buynak, C. Fiedler, L. Hutson, C. Kropas, N. Lammers, L. Mann, T. Moran, M. Sagan,
Oct 1990	Nondestructive Evaluation Branch	Don Forney	G. Beams, P. Bhagat, M. Blodgett, C. Buynak, J. Dorsey, C. Fiedler, L. Hutson, C. Kropas, N. Lammers, L. Mann, T. Moran, M. Sagan
Nov 1990	Nondestructive Evaluation Branch	Tobey M. Cordell	G. Beams, P. Bhagat, M. Blodgett, C. Buynak, J. Dorsey, C. Fiedler, L. Hutson, C. Kropas, N. Lammers, L. Mann, T. Moran, M. Sagan
Apr 1992	Nondestructive Evaluation Branch	Tobey Cordell	G. Beams, P. Bhagat, M. Blodgett, C Buynak, J. Dorsey, C. Fiedler, G. Jablunovsky, C. Kropas, N. Lammers, L. Mann, T. Moran
Aug 1996	Nondestructive Evaluation Branch	Tobey Cordell	G. Beams, M. Blodgett, C. Buynak, E. Calloway, J. Calzada, R. Crane, C. Fiedler, B. Foos, N. Lammers, L. Mann, T. Moran, A. Szmerekovsky
Oct. 1997	Nondestructive Evaluation Branch	Tobey Cordell	G. Beams, M. Blodgett, C. Buynak, E. Calloway, J. Calzada, R. Crane, N. Diedrich, C. Fiedler, B. Foos, N. Lammers, L. Mann, T. Moran
Apr 1998	Nondestructive Evaluation Branch	Tobey Cordell	S. Baker, G. Beams, M. Blodgett, C. Buynak, J. Calzada, R. Crane, N. Diedrich, C. Fiedler, B. Foos, N. Lammers, L. Mann, T. Moran
Oct. 1998	Nondestructive Evaluation Branch	Tobey Cordell	S. Baker, G. Beams, M. Blodgett, C. Buynak, J. Calzada, R. Crane, N. Diedrich, C. Fiedler, B. Foos, N. Lammers, L. Mann, T. Moran
Jun 1999	Nondestructive Evaluation Branch	James C. Malas	G. Beams, M. Blodgett, C. Buynak, J. Calzada, R. Crane, C. Fiedler, B. Foos, C. Lebowitz, L. Mann, T. Moran, B. Sanbongi, V. Shaffer
Nov 1999	Nondestructive Evaluation Branch	James C. Malas	G. Beams, M. Blodgett, C Buynak, J. Calzada, R. Crane, C. Fiedler, B. Foos, C. Kropas-Hughes, C. Lebowitz, L. Mann, T. Moran, B. Sanbongi, V. Shaffer
Feb 2000	Nondestructive Evaluation Branch	James C. Malas	G. Beams, M. Blodgett, C Buynak, J. Calzada, R. Crane, C. Fiedler, B. Foos, C. Kropas-Hughes, C. Lebowitz, L. Mann, T. Moran, B. Sanbongi, V. Shaffer
Apr 2000	Nondestructive Evaluation Branch	Jim Malas	G. Beams, M. Blodgett, C. Buynak, J. Calzada, R. Crane, L. Dukate, C. Fiedler, B. Foos, C. Kropas-Hughes, C. Lebowitz, T. Moran, C. Neslen, B. Sanbongi, V.Shaffer
Nov 2000	Nondestructive Evaluation Branch	Jim Malas	J. Barnes, M. Blodgett, C. Buynak, J. Calzada, R. Crane, L. Dukate, B. Foos, C. Kropas-Hughes, T. Moran, P. Mykytiuk, C. Neslen, B. Sanbongi, V.Shaffer
Feb 2001	Nondestructive Evaluation Branch	Jim Malas	J. Barnes, M. Blodgett, C. Buynak, J. Calzada, R. Crane, L. Dukate, B. Foos, C. Kropas-Hughes, T. Moran, P. Mykytiuk, C. Neslen, B. Sanbongi, V.Shaffer

APPENDIX D-1 *(Cont'd)*

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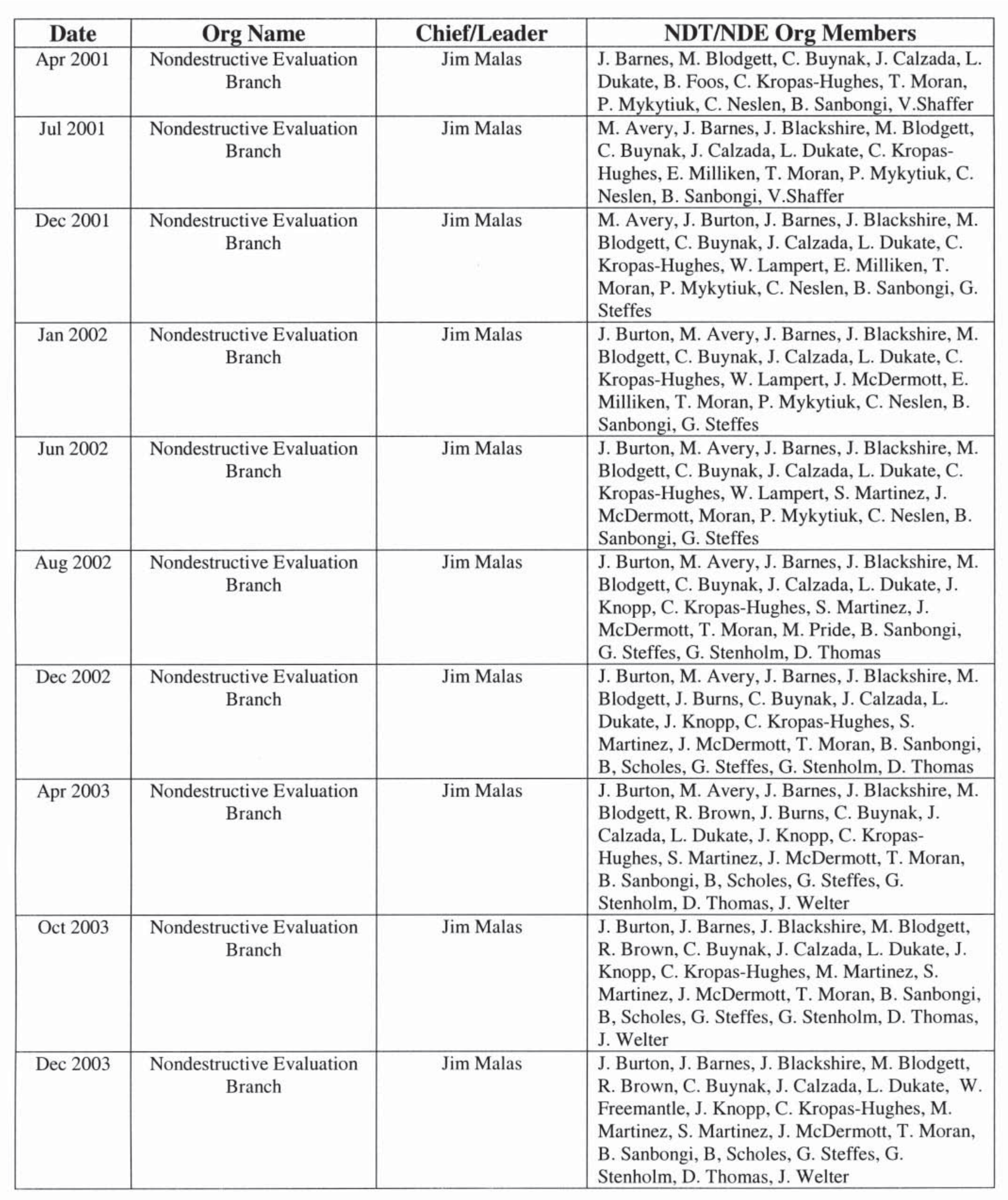


Date	Org Name	Chief/Leader	NDT/NDE Org Members
Apr 2001	Nondestructive Evaluation Branch	Jim Malas	J. Barnes, M. Blodgett, C. Buynak, J. Calzada, L. Dukate, B. Foos, C. Kropas-Hughes, T. Moran, P. Mykytiuk, C. Neslen, B. Sanbongi, V.Shaffer
Jul 2001	Nondestructive Evaluation Branch	Jim Malas	M. Avery, J. Barnes, J. Blackshire, M. Blodgett, C. Buynak, J. Calzada, L. Dukate, C. Kropas-Hughes, E. Milliken, T. Moran, P. Mykytiuk, C. Neslen, B. Sanbongi, V.Shaffer
Dec 2001	Nondestructive Evaluation Branch	Jim Malas	M. Avery, J. Burton, J. Barnes, J. Blackshire, M. Blodgett, C. Buynak, J. Calzada, L. Dukate, C. Kropas-Hughes, W. Lampert, E. Milliken, T. Moran, P. Mykytiuk, C. Neslen, B. Sanbongi, G. Steffes
Jan 2002	Nondestructive Evaluation Branch	Jim Malas	J. Burton, M. Avery, J. Barnes, J. Blackshire, M. Blodgett, C. Buynak, J. Calzada, L. Dukate, C. Kropas-Hughes, W. Lampert, J. McDermott, E. Milliken, T. Moran, P. Mykytiuk, C. Neslen, B. Sanbongi, G. Steffes
Jun 2002	Nondestructive Evaluation Branch	Jim Malas	J. Burton, M. Avery, J. Barnes, J. Blackshire, M. Blodgett, C. Buynak, J. Calzada, L. Dukate, C. Kropas-Hughes, W. Lampert, S. Martinez, J. McDermott, Moran, P. Mykytiuk, C. Neslen, B. Sanbongi, G. Steffes
Aug 2002	Nondestructive Evaluation Branch	Jim Malas	J. Burton, M. Avery, J. Barnes, J. Blackshire, M. Blodgett, C. Buynak, J. Calzada, L. Dukate, J. Knopp, C. Kropas-Hughes, S. Martinez, J. McDermott, T. Moran, M. Pride, B. Sanbongi, G. Steffes, G. Stenholm, D. Thomas
Dec 2002	Nondestructive Evaluation Branch	Jim Malas	J. Burton, M. Avery, J. Barnes, J. Blackshire, M. Blodgett, J. Burns, C. Buynak, J. Calzada, L. Dukate, J. Knopp, C. Kropas-Hughes, S. Martinez, J. McDermott, T. Moran, B. Sanbongi, B, Scholes, G. Steffes, G. Stenholm, D. Thomas
Apr 2003	Nondestructive Evaluation Branch	Jim Malas	J. Burton, M. Avery, J. Barnes, J. Blackshire, M. Blodgett, R. Brown, J. Burns, C. Buynak, J. Calzada, L. Dukate, J. Knopp, C. Kropas-Hughes, S. Martinez, J. McDermott, T. Moran, B. Sanbongi, B, Scholes, G. Steffes, G. Stenholm, D. Thomas, J. Welter
Oct 2003	Nondestructive Evaluation Branch	Jim Malas	J. Burton, J. Barnes, J. Blackshire, M. Blodgett, R. Brown, C. Buynak, J. Calzada, L. Dukate, J. Knopp, C. Kropas-Hughes, M. Martinez, S. Martinez, J. McDermott, T. Moran, B. Sanbongi, B, Scholes, G. Steffes, G. Stenholm, D. Thomas, J. Welter
Dec 2003	Nondestructive Evaluation Branch	Jim Malas	J. Burton, J. Barnes, J. Blackshire, M. Blodgett, R. Brown, C. Buynak, J. Calzada, L. Dukate, W. Freemantle, J. Knopp, C. Kropas-Hughes, M. Martinez, S. Martinez, J. McDermott, T. Moran, B. Sanbongi, B, Scholes, G. Steffes, G. Stenholm, D. Thomas, J. Welter

APPENDIX D-1 *(Cont'd)*

NDE Branch History

Assigned NDE Organization Members

Date	Org Name	Chief/Leader	NDT/NDE Org Members
Jan 2004	Nondestructive Evaluation Branch	Jim Malas	J. Barnes, J. Blackshire, M. Blodgett, R. Brown, C. Buynak, J. Calzada, L. Dukate, W. Freemantle, J. Knopp, C. Kropas-Hughes, M. Martinez, S. Martinez, J. McDermott, T. Moran, B. Sanbongi, B, Scholes, N. Smith, G. Steffes, G. Stenholm, D. Thomas, J. Welter
May 2004	Nondestructive Evaluation Branch	Jim Malas	J. Blackshire, M. Blodgett, R. Brown, C. Buynak, J. Calzada, L. Dukate, W. Freemantle, J. Knopp, C. Kropas-Hughes, R. Marshall, M. Martinez, S. Martinez, J. McDermott, T. Moran, K. Navarra, B. Sanbongi, B, Scholes, N. Smith, G. Steffes, G. Stenholm, D. Thomas, J. Welter
Sep 2004	Nondestructive Evaluation Branch	Jim Malas	J. Blackshire, M. Blodgett, R. Brown, C. Buynak, J. Calzada, L. Dukate, W. Freemantle, J. Knopp, C. Kropas-Hughes, R. Marshall, M. Martinez, S. Martinez, T. Moran, K. Navarra, B. Sanbongi, B, Scholes, N. Smith, G. Steffes, G. Stenholm, D. Thomas, J. Welter
Nov 2004	Nondestructive Evaluation Branch	Jim Malas	J. Blackshire, M. Blodgett, C. Buynak, J. Calzada, L. Dukate, W. Freemantle, J. Knopp, C. Kropas-Hughes, R. Marshall, M. Martinez, S. Martinez, T. Moran, K. Navarra, B. Sanbongi, B, Scholes, N. Smith, G. Steffes, G. Stenholm, J. Welter
Feb 2005	Nondestructive Evaluation Branch	Jim Malas	J. Blackshire, M. Blodgett, C. Buynak, J. Calzada, L. Dukate, W. Freemantle, J. Knopp, R. Marshall, S. Martinez, T. Moran, K. Navarra, S. Piddock, B. Sanbongi, B, Scholes, N. Smith, G. Steffes, G. Stenholm, J. Welter
Oct 05	Nondestructive Evaluation Branch	Jim Malas	J. Blackshire, M. Blodgett, C. Buynak, J. Calzada, A. Clooney, L. Dukate, W. Freemantle, J. Knopp, R. Marshall, S. Martinez, S. Mazdiyasni, T. Moran, K. Navarra, C. Neslen, S. Piddock, B. Sanbongi, B, Scholes, N. Smith, G. Steffes, G. Stenholm, J. Welter
Apr 2006	Nondestructive Evaluation Branch	Jim Malas	A. Albert, J. Blackshire, M. Blodgett, C. Buynak, J. Calzada, A. Clooney, L. Dukate, W. Freemantle, K. Jata, J. Knopp, E. Lindgren, R. Marshall, S. Martinez, S. Mazdiyasni, T. Moran, K. Navarra, C. Neslen, S. Piddock, B. Sanbongi, B, Scholes, N. Smith, G. Steffes, G. Stenholm, J. Welter

APPENDIX D-2

NDE Branch History

Cumulative Roster of All Members 1959 - April 2006

Albert, Alan P., Capt. (4/06 -)
Allison, John E., 2-1/Lt. (2/73 - 5/75)
Avery, Michael P. (7/01 - 4/03)
Barnes, John H. (11/00 – 1/04)
Beams, Gail L. (10/90 – 4/02)
Bhagat, Pramode K., Dr. (9/89 – 4/92)
Blackshire, James, Dr., (7/01 -)
Blodgett, Mark P., Dr. (3/86 -)
Bohlen, James W. (11/69 – 7/72)
Broderick, Thomas F. (Coop) (4/80 – 10/80)
Brown, Rebecca (9/77 – 4/80)
Brown, Richard A. (4/03 – 9/04)
Buckley, Michael J., Dr. (2/74 – 5/76)
Burton, Judith P. (12/01 – 12/03)
Butler (formerly Johnson), Doris (4/71 – 3/81)
Buynak, Charles F. (8/82 -)
Calloway, Jacqueline E. (8/96 – 6/98)
Calzada, Juan G. (8/96 -)
Chimenti, Dale E., Dr. (7/79 – 9/89)
Clooney, Adam (Coop) (10/05 -)
Cooper, Thomas D. (6/66 – 12/73)
Corbly, Dennis M., Dr. (7/72 – 5/75)
Cordell, Tobey M., (11/90 – 1/99)
Cornish, Kayann H. (2/72 – 4/77)
Crane, Robert L., Dr. (2/74 – 9/84), (8/96 - 2/02)
Crist, Stephen A., Capt. Dr. (2/74 – 6/74)
Diedrich, Nathan D. 2Lt. (10/97 – 10/98)
Dimiduk, Dennis, M. (Coop) (10/77)
Dorsey, Joseph J. (10/90 – 4/92)
Downs, June (11/74 – 5/76)
Draper, Karen, (10/80 – 4/81)
Ducate, Larry L. (4/02 -)
Dunaway, Cheryl, (6/78 – 4/81)
Elias, Charles M. (10/80 – 8/82)
Fetsko, R. J. (Coop) (6/84 – 3/86)
Fiedler, Curtis J., Dr. (3/86 – 4/00)
Foos, Bryan C. (6/96 – 4/01)
Forney, Donald M. (7/74 – 10/90)
Freemantle, William (2Lt.), (12/03 –)
Griswold, Roger D. (11/74 - 4/81)
Gulley, Lee R., Capt. (3/68 – 4/71)
Hansult, Charles C., Maj. (10/70)
Holiday, H., TSgt. (1962 – 5/64)
Holloway, James A. (1962 – 9/88)
Hutson, L. R., Ms (Student Aide) (3/90 – 4/92)
Jata, Kumar (10/03 -)
Jacobs, Dorothy E. (5/75 – 6/78)
Jablunovsky, Greg, 1Lt. (1/92 - 1/95)
Jaques, William J., Capt. (11/74 – 8/75)
Kamm, Harold W. (1962 – 3/68)
Kaufman, Marion (12/85 – 12/87)
Knopp, Jeremy S. (8/02 -)
Kreitzer, Mary K. (5/76 – 4/77)
Kropas (Kropas-Hughes), Claudia V., Dr. (3/90 – 4/92), (11/99 -2/04)
Lammers, Nancy E. (3/90 – 10/98)
Latiff, Robert H., Capt. (10/80 – 1/82)
Libowitz, Carol A. (6/99 – 1/01)
Lindgren, Eric A., Dr. (1/06 -)
Malas, James C., Dr. (2/99 -)
Mann, Laura L. (7/87 – 2/00)
Marshall, Robert, (2/04 -)
Martinez, Mayra (10/03 – 11/04)
Martinez, Sonia A., Dr. (6/02 -)
Mazdiyasni, Siamack (9/05 -)
McDermott, Jane E. (1/02 – 1/04)
Moran, Thomas J., Dr. (4/77 -)
Moyzis, Joseph A., Dr. (9/77 – 3/90)
Mullins, Freddy D. (12/73 – 10/77)
Mykytiuk, Phillip D. (11/00 – 6/02)
Navarra, Kelly (5/04 -)
Neslen, Craig L., Capt. (11/00 – 6/02), (10/05 –)
Norton, Nancy M. (3/81 – 8/82)
Panos, Rodney M., Dr. (2/74 – 3/78)
Petru, John A. (3/78 – 7/79)
Piddock, Sarah (2/05 -)
Plank, Tami J. (1/82 – 8/82)
Polovino, M., 1Lt. (12/85 – 8/86)
Roberts, J. A. (9/84 – 12/85)
Rohlman, J. (Coop) (6/84 – 8/86)
Rowand, Richard R. (1954 – 1983)
Russo, Vincent J., Dr. (12/73 – 2/74)
Sagan, M.R., (Coop) (2/89 – 11/90)
Sanbongi, Bryan D. (11/98 -)
Sawtelle, Sheila (9/88 – 9/89)
Scholes, Brett A. (12/02 –)
Shaffer, Vicki R. (6/99 – 7/01)
Shelton, William L. (1962 – 9/74)
Shimmin, Kenneth D. (7/75 – 8/86)
Smith, Nikki L. (1/04 -)
Smith, Paul (7/75 – 4/77)
Sobieski, Susan (6/82 – 9/84)
Steffes, Gary A., 1Lt. (12/01 -)
Stenholm, Garrett J. (8/02 -)

APPENDIX D-2 *(Cont'd)*

NDE Branch History

Cumulative Roster of All Members 1959 - April 2006

Stevens, H. L. (Coop) (3/68 – 10/70)
Szmerekovsky, Andrew G., Capt. (1/95 – 1/97)
Tanzola, John, Capt. (7/75 – 5/76)
Thomas, Dustin T. 1Lt. (8/02 - 9/04)
Welter, John T. (4/03 -)

APPENDIX E
Summary of Honors, Awards and Achievements

To the extent that records are available, the major honors, awards, achievements and other notable recognitions earned by NDE Program members over the years are listed here, organized in various categories for convenient review.

Charles J. Cleary Award for Scientific Achievement

- 1979 Finalist - Dr. Thomas J. Moran, *A Method of Increasing the Sensitivity of Ultrasonic Measurements*

Recognized for demonstrating the concept of a predetermined pseudorandom binary code which can be used instead of truly random noise. This eliminates the need for the water delay path, and accelerates the signal correlation by several orders of magnitude. Dr. Moran showed how this concept and related equipment could be used to obtain signals with substantially improved signal-to-noise ratio in the NDE inspection environment.

- 1981 Finalist – Dr. Dale E. Chimenti, *Behavior of Finite Beam Ultrasonic Waves on a Layered Halfspace*

Recognized for his original work in studying the behavior of finite aperture ultrasonic beams when incident upon a fluid-solid interface at the Rayleigh critical angle. Recognizing the lack of adequate work on this problem in the case of a layered halfspace, a potentially useful situation in NDE, he began effort on a theoretical model to describe reflection from a layered halfspace loaded by a fluid. An unexpected finding was the nonmonotic behavior of the beam displacement parameter as a function of frequency.

- 1985 Finalist - Dr. Dale E. Chimenti, *Guided Ultrasonic Waves in Fluid-Coupled Composite Laminates*

Recognized for his theoretical work on the behavior of plate waves in composites. While studying the dispersion characteristics of these waves, Dr. Chimenti identified anomalous behavior in the dispersion curve. Using this knowledge, he developed a nondestructive scanning technique based on these leaky plate waves. Dr. Chimenti devised a scheme which permits easy discrimination between critical defects and unimportant plate features.

- 1987 Winners – Charles F. Buynak & Dr. Thomas J. Moran, *Characterization of Impact Damage in Composites*

Recognized for their combined effort to produce the near-perfect correlation of the image data from the new software-gated ultrasonic technique invented by Dr. Moran, to image all major defects not shadowed by the other defects, with the comprehensive, meticulous experimental destructive analysis (deplying) techniques by Mr. Buynak, revealing the detailed delamination characteristics in graphite/epoxy and graphite/PEEK composites.

- 1999 Finalist – Dr. Claudia Kropas-Hughes, *A Computational Means Of Fusing Image Data*

Recognized for demonstrating the use of concepts from the human biological neural system for developing a computational means of fusing image data. Dr. Kropas-Hughes determined a feature set through the use of human-visual-system models, and developed a new neural network architecture – the Autoassociative-Heteroassociative Neural Network to accomplish the desired data fusion.

- 2000 Winner – Dr. Mark P. Blodgett, *Ultrasonic and Eddy Current Nondestructive Evaluation Methods for Microstructure Characterization of Ti-6Al-4V*

Recognized for developing experimental procedures to study the elastic and electrical properties of various forged titanium alloys. These experiments revealed some unusual properties in terms of the ultrasonic velocity, attenuation, and scattering. He also developed an eddy current materials characterization technique to map electrical property variations in various titanium microstructures. In addition, a laser interferometric ultrasonic detection experiment was developed to map microstructure-related spatial variations in the amplitude and phase of propagating acoustic waves.

- 2003 Winner – Dr. James L. Blackshire, *Laser Ultrasonic Imaging of Structural Microcracks*

Recognized for discovering and using a novel near-field ultrasonic scattering process for detecting and imaging structural microcracks. Developed a microcrack detection capability that is substantially better than existing, state-of-the-art NDE techniques. Showed a direct correlation between the observed ultrasonic displacement level and the local crack depth, which provides a potentially revolutionary NDE measurement capability for imaging surface-breaking cracks in full 3-dimensional form.

Robert T. Schwartz Engineering Achievement Award

- 1980 Finalists – Drs. Robert L. Crane & Thomas J. Moran, *Application of X-Ray Computed Tomography to the Inspection of Aerospace Components*

Recognized for their uncommon insight to explore the potential of X-ray Computed Tomography (CT) to detect difficult-to-image defects in carbon/carbon composites used in aerospace applications. Using the medical CT unit at the Wright-Patterson Medical Center, they succeeded not only in easily imaging large delaminations, but several heretofore undetected tight delaminations and apparent density variations as well.. Metallographic sectioning was performed and point-by-point densities were measured to validate the observations. Based on all of the above, the Laboratory management approved a major program to produce an X-Ray CT system capability.

- 1983 Finalist – Dr. Robert L. Crane, *Application of X-Ray Computed Tomography to the Inspection of Aerospace Components*

Recognized for his work to validate the accuracy of CT measurements applicable to carbon-carbon composite materials and led several efforts to make technical improvements. He prepared the technical work statement for s $4 million ManTech program to produce systems capable of inspecting missile systems, including the Peacekeeper class ICBM.

- 1989 Finalist – Dr. Thomas J. Moran, *Evaluation and Application of X-Ray Computed Tomography to Advanced Aerospace Materials and Structures*

Recognized for his guidance and engineering management of MLs initiative to lead the evaluation and application of x-ray computed tomography to advanced aerospace applications. Dr. designed and initiated contract efforts and guiding work to create an in-house research capability. He has contributed significantly to 15 contract programs aimed at creating a strong CT technology base and additional in-house development work, either as project author, a key advisor or lead engineer. Dr. Moran's advocacy is evidenced by the increase in the number of such machines – over 50 are currently in use.

- 2002 Winners – Lt. Gary J. Steffes & Charles F. Buynak, *Rapid Transition of Nondestructive Evaluation Systems Technologies to Air Force Sustainment Applications*

Recognized for aggressive leadership in the rapid, interactive advanced technology development programs with the Air Force maintenance depot, commercial and field customers. Lt. Steffes is co-program manager of three major Advanced Technology Demonstration (ATD) programs in the thrust "Advanced NDE for Aging Structures." Mr Buynak is the Direction Leader for "Aging Aircraft NDE", integrating multiple AFRL initiatives to sustain the aging fleet. He has been the lead manager of NDE efforts for Computed Tomography, Digital Radiography, Large Area Composites Inspection, and Retirement-for-Cause (RFC) systems in various stages of major transition to Air Force field uses.

Federal Laboratories

- 1997 – Charles F. Buynak

Recognized for numerous efforts in transferring NDE technology beyond the Air Force. His efforts led to the use of the Mobile Automated Scanner for commercial aerospace applications. Additionally, the system was adapted for the quality inspection service task on Indianapolis race car tub inspection and racing boat hull. These efforts led to the determination of the racing component's integrity and capability for high performance racing usage.

Hq AFMC Engineering and Technical Management Award - Junior Military Engineer

- 2003 Finalist – Lt. Gary J. Steffes

Recognized for his efforts from Jan 2003 through Dec 2003 to design and integrate two radiographic inspection systems into Tinker AFB and Robins AFB. He also managed the integration and creation of three separate software systems by drawing on user requirements and inspection needs to reduce depot inspection time of the B-52, F-15, KC-135, E-3 and C-5 aircraft. Lt. Steffes also designed automated equipment to enhance NDI capabilities and reduce environmental and safety hazards. The superior performance of Lt. Steffes reflects great credit upon himself, the Air Force Materiel Command, and the United States Air Force.

The AFRL Corporate Award (Team)

- 2004 Finalists -Charles F. Buynak and Lt. Gary Steffes, *Technology Transition of Digital Radiography*

Recognized for their outstanding engineering achievements in the technology transition of digital radiography. This team conceived and developed high absorption x-ray scintillator materials, digital x-ray detector systems, and designed several x-ray manipulation systems to increase ALC component throughput during aircraft depot cycles.

FAA-ATA 2004 NDT "Better Way" Award

- 2004 Finalists – Lt. Gary Steffes and Mr. Charles Buynak with team members from Aging Aircraft Systems Squadron (ASC/AAAV), Marietta X-ray Inc., GE Inspection Technologies, WR-ALC and OC-ALC. *USAF Digital Radiography Insertion Program (DRIP)*

Recognized for transitioning digital radiography systems as part of the Digital Radiography Insertion Program (DRIP) into the Engine Oil Tank and Cooler Inspection facility (Nov 02) and the Advanced Composite Repair Center (Mar 03), respectively, at the Oklahoma City Air Logistics Center (OC-ALC). An additional system, the Multi-Axis X-Ray (MAX) system, was transitioned to the Warner Robins Air Logistics Center (WR-ALC) in July 2004.

American Society for Testing and Materials Charles W. Briggs Award

- 2004 Winner – Dr. Claudia Kropas-Hughes

An award for formal recognition of continuous and outstanding contributions of an individual to the work of ASTM International Committee E07 on Nondestructive Testing through its various Subcommittees, Sections and Task Groups. The award was established in 1978 and is administered by an Awards Committee of Committee E07.

AFRL Scientific/Technical Achievement Award

- 2005 Winner – Dr. James L. Blackshire

Air Force John L. McLucas Basic Research Award

- 2005 Honorable Mention – Dr. James L. Blackshire

Significant Air Force Management Awards

- Air Force Meritorious Civilian Service Award
  1990 – Thomas D. Cooper
  1990 - Donald M. Forney
- Exemplary Civilian Service Award
  200X – Dr. James Malas

Outstanding Engineer and Scientist Award – Dayton Area Affiliate Societies Council

- 1984 – Dr. Robert L. Crane
- 1990 – Thomas D. Cooper
- 1995 – Donald M. Forney
- 1997 – Dr. James C. Malas
- 2005 – Tobey M. Cordell

AFRL Fellows

- 1998 – Dr. Robert L. Crane
- 1998 – Dr. James C. Malas

Appendix E

NDE Fellows

- 1984 – Thomas D. Cooper, Fellow, American Society of Nondestructive Testing
- 1996 – Donald M. Forney, Distinguished Fellow, Center for Nondestructive Evaluation, Iowa State University
- 2002 – Dr. Claudia Kropas-Hughes, Fellow, American Society of Nondestructive Testing

Federal Laboratories

- 1997 – Charles F. Buynak

Recognized for numerous efforts in transferring NDE technology beyond the Air Force. His efforts led to the use of the Mobile Automated Scanner for commercial aerospace applications. Additionally, the system was adapted for the quality inspection service task on Indianapolis race car tub inspection and racing boat hull. These efforts led to the determination of the racing component's integrity and capability for high performance racing usage.

Chairpersons

- 2005 – Dr. Claudia Kropas-Hughes, Program Chair, ASNT Fall Conference & Quality Testing Show, Columbus, OH.
- 2006 – Dr. James Malas, Chairman of the ASNT Reliability Studies and ASNT Technology Transfer Committees

Keynotes, Honor Lectures

- 1987 – Donald M. Forney, keynote, ASM INTERNATIONAL Conference on Production Nondestructive Testing – The Developing Key to Process Control, Dearborn, MI November 1987.
- 1990 – Donald M. Forney – Keynote Plenary Session, Progress in QNDE Conference, La Jolla, CA, July 1990. "Evolving Partnership for NDE in Materials Engineering and Extended Life Cycle Performance," [E.1]
- 1991 – Thomas D. Cooper, ASNT Mehl Honor Lecture, Boston, MA September 1991. "ASNT and Aerospace – What about the Next 50 Years." [E.2]
- 1996 – Tobey M. Cordell, Keynote, ASNT Fall Conference, Seattle, Washington, October 1996. "NDE – A Full Spectrum Technology."
- 2002 – Dr. Claudia Kropas-Hughes, Keynote, Indian Society of NDT International Conference NDE2000, Chenei, India, December 2002. "NDE in the Digital Age: A Future Perspective." [E.3]

ASNT Outstanding Paper of the Year

- 2002 – "Thermoelectric Nondestructive Evaluation of Residual Stress in Shot-Peened Metals," Hector Carreon, Peter B. Nagy and Mark Blodgett, *Research in Nondestructive Evaluation, 2000.*

Patents and Diclosures

- T.J. Moran, Dispersive Electromagnetic Surface Acoustic Wave Transducer, Patent No . 4,058,002, issued November 15, 1977
- T.J. Moran, "Phase Shift Keyed Pseudorandom Binary Noise Nondestructive Evaluation Ultrasonics System, Invention Disclosure, June 13, 1978
- T.J. Moran, C.F. Buynak and R.W. Martin, Digital rf Ultrasonic C-Scan System for Nondestructive Evaluation, Patent No. 4,947,351 issued August 7, 1990

References

E.1 Forney, Donald M., *“Evolving Partnership for NDE in Materials Engineering and Extended Life Cycle Performance,”* Review of Progress in Quantitative Nondestructive Evaluation, Eds. D.O. Thompson and D.E. Chimenti, 10A, pp. 13-33, 1991.

E.2 Cooper, Thomas D., ., *“ASNT and Aerospace – What About the Next 50 Years?”* Materials Evaluation, Vol 49 No.12, December 1991, pp. 1526-1535.

E.3 Kropas-Hughes, C.V., *“Autoassociative-Heteroassociative Neural Network (A-HNN),”* Engineering Applications for Artificial Intelligence, 2000.13: pp 603-609.

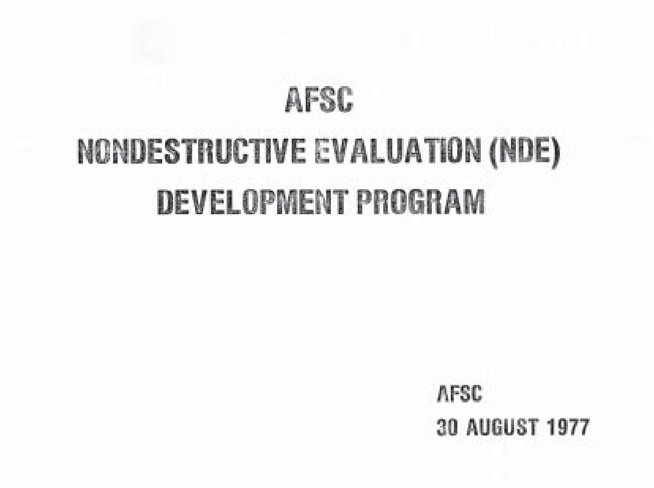
APPENDIX F
Examples of Historical Documents

Compiled in this Appendix are a collection of exhibits of historical significance for further review, as noted:

- Appendix F-1. Original Keystone Informational Briefing on 30 August 1977 by the NDE Focal Point to AFSC/CC.
- Appendix F-2. Original ML Focal Area 4 NDE Program Roadmap for the Planning Period FY 78 – FY 83.
- Appendix F-3. AF Regulation 66-38 Nondestructive Inspection (NDI) Program 14 March 1980.
- Appendix F-4. Original ML Focal Area 4 NDE Program Roadmaps for the Planning Period of FY 82 - FY 87.
- Appendix F-5. Original ML Focal Area 4 NDE Program Roadmaps for the Planning Period of FY 90 - FY 97.
- Appendix F-6. Original ML Focal Area 4 NDE Program Roadmaps for the Planning Period of FY 97 - FY 03.
- Appendix F-7. Example of Combined Roadmaps and Associated Narratives, FY 97 – 03.
- Appendix F-8. Original ML Focal Area 4 NDE Program Roadmaps for the Planning Period of FY 04 - FY 10.

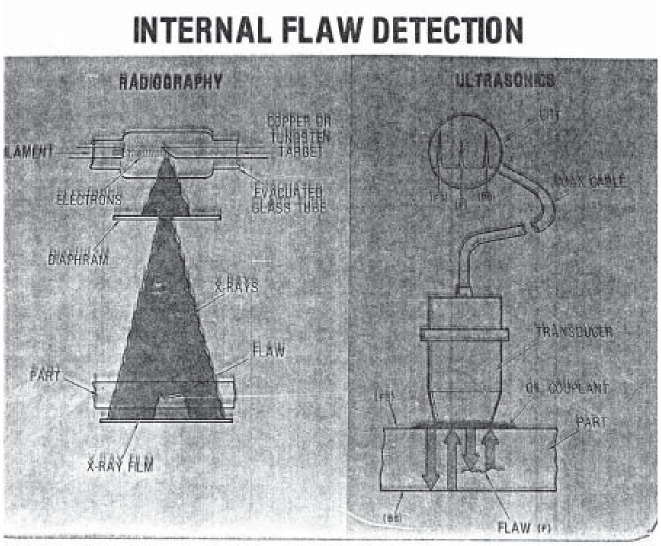
APPENDIX F-1

Original Keystone Informational Briefing on 30 August 1977.

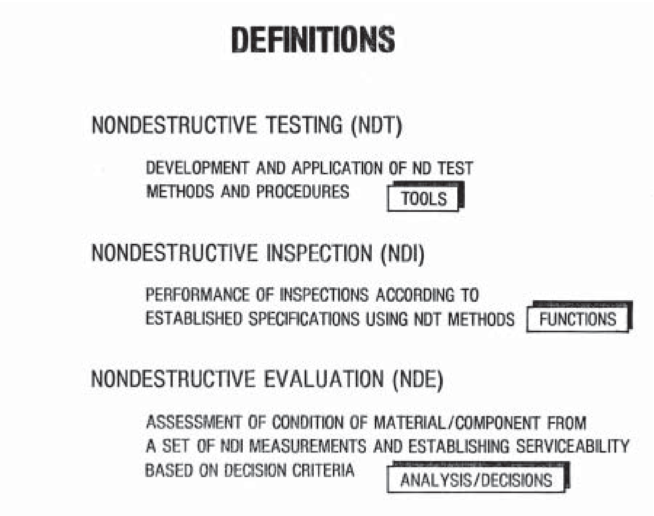


AFSC
NONDESTRUCTIVE EVALUATION (NDE)
DEVELOPMENT PROGRAM

AFSC
30 AUGUST 1977



INTERNAL FLAW DETECTION



DEFINITIONS

NONDESTRUCTIVE TESTING (NDT)

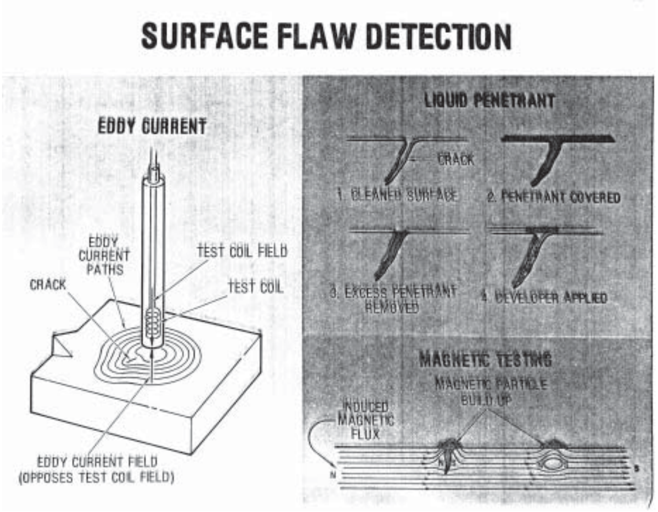
DEVELOPMENT AND APPLICATION OF ND TEST METHODS AND PROCEDURES **TOOLS**

NONDESTRUCTIVE INSPECTION (NDI)

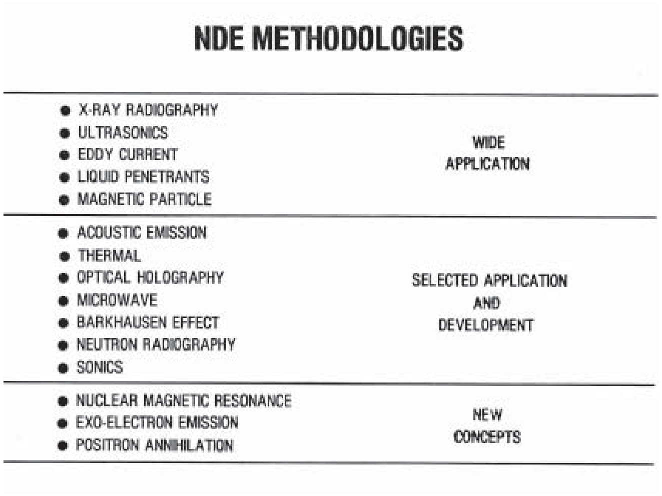
PERFORMANCE OF INSPECTIONS ACCORDING TO ESTABLISHED SPECIFICATIONS USING NDT METHODS **FUNCTIONS**

NONDESTRUCTIVE EVALUATION (NDE)

ASSESSMENT OF CONDITION OF MATERIAL/COMPONENT FROM A SET OF NDI MEASUREMENTS AND ESTABLISHING SERVICEABILITY BASED ON DECISION CRITERIA **ANALYSIS/DECISIONS**

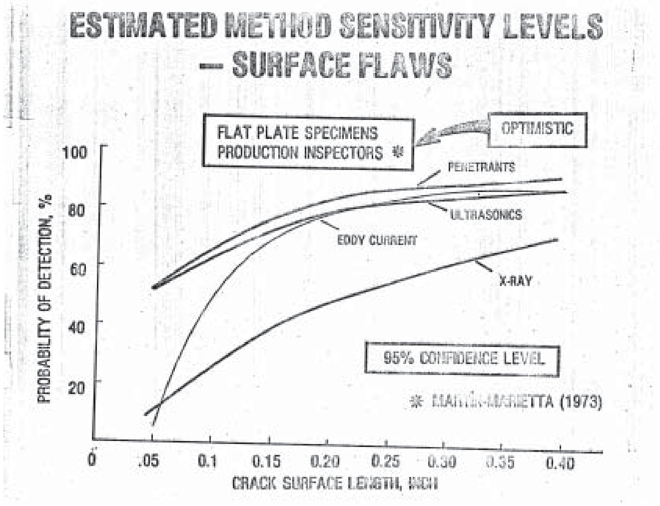


SURFACE FLAW DETECTION

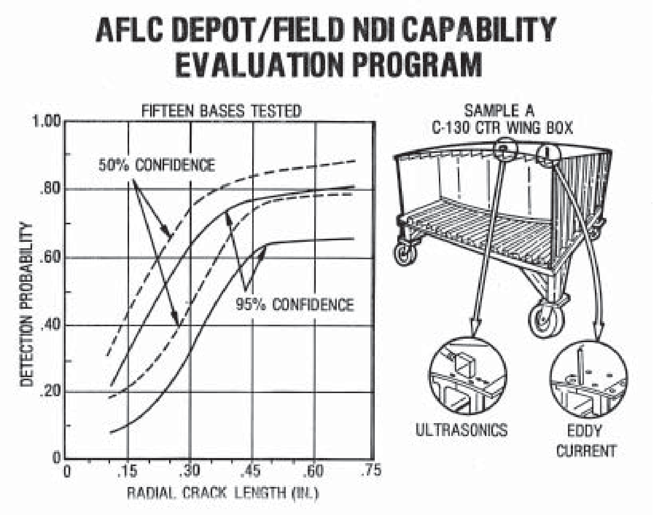


NDE METHODOLOGIES

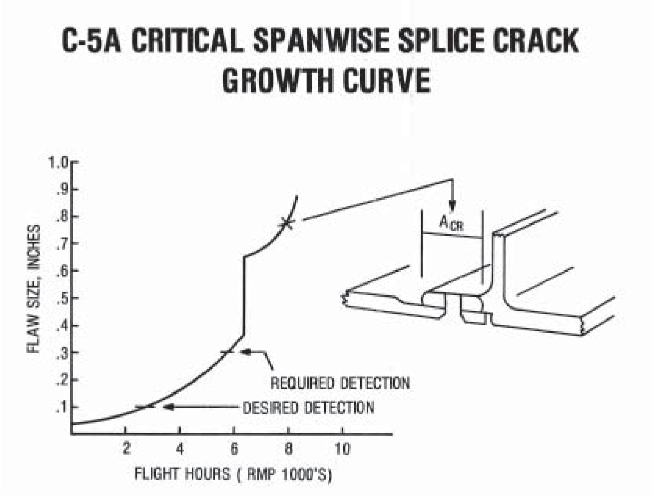
● X-RAY RADIOGRAPHY ● ULTRASONICS ● EDDY CURRENT ● LIQUID PENETRANTS ● MAGNETIC PARTICLE	WIDE APPLICATION
● ACOUSTIC EMISSION ● THERMAL ● OPTICAL HOLOGRAPHY ● MICROWAVE ● BARKHAUSEN EFFECT ● NEUTRON RADIOGRAPHY ● SONICS	SELECTED APPLICATION AND DEVELOPMENT
● NUCLEAR MAGNETIC RESONANCE ● EXO-ELECTRON EMISSION ● POSITRON ANNIHILATION	NEW CONCEPTS



ESTIMATED METHOD SENSITIVITY LEVELS — SURFACE FLAWS



AFLC DEPOT/FIELD NDI CAPABILITY EVALUATION PROGRAM

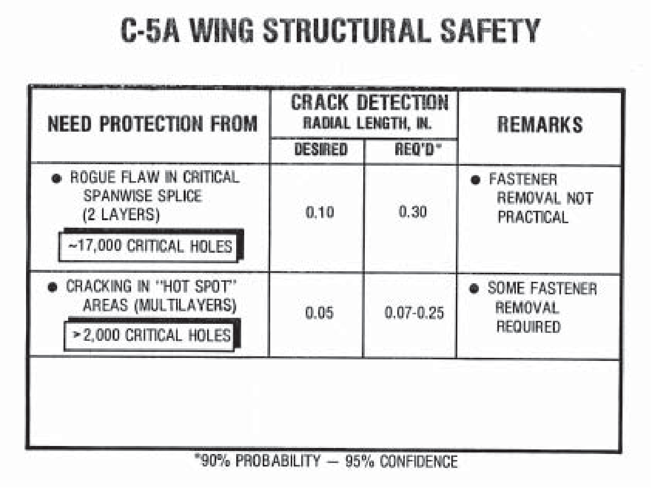


C-5A CRITICAL SPANWISE SPLICE CRACK GROWTH CURVE

NDE DEVELOPMENT EFFORT

IN SUPPORT OF THE

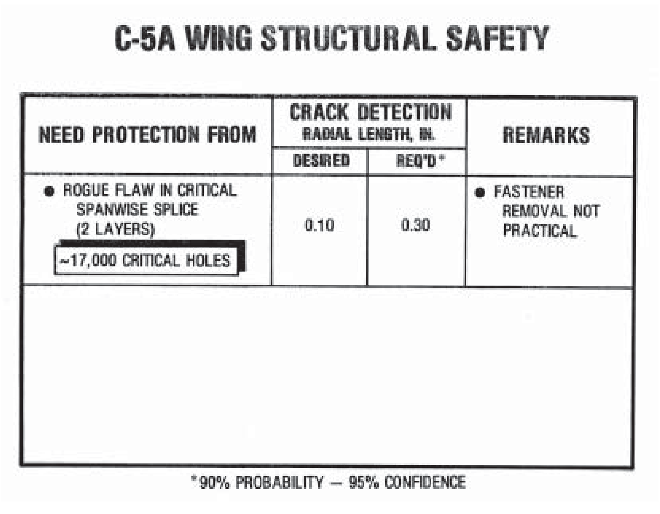
C-5A



C-5A WING STRUCTURAL SAFETY

NEED PROTECTION FROM	CRACK DETECTION RADIAL LENGTH, IN.		REMARKS
	DESIRED	REQ'D*	
● ROGUE FLAW IN CRITICAL SPANWISE SPLICE (2 LAYERS) ~17,000 CRITICAL HOLES	0.10	0.30	● FASTENER REMOVAL NOT PRACTICAL
● CRACKING IN "HOT SPOT" AREAS (MULTILAYERS) >2,000 CRITICAL HOLES	0.05	0.07-0.25	● SOME FASTENER REMOVAL REQUIRED

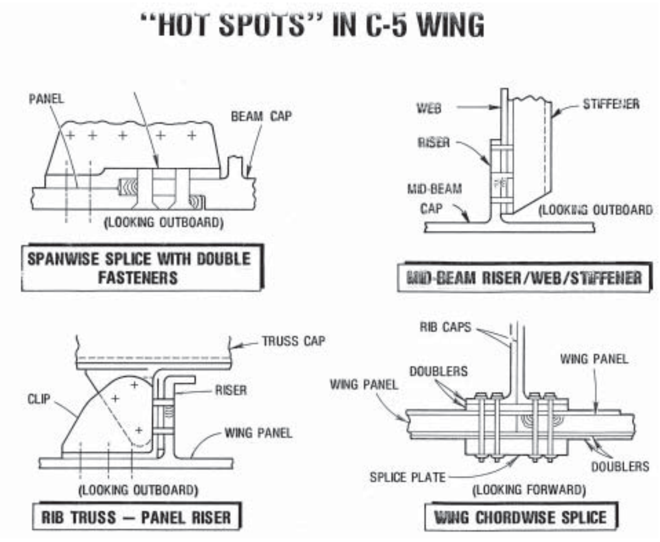
*90% PROBABILITY — 95% CONFIDENCE



C-5A WING STRUCTURAL SAFETY

NEED PROTECTION FROM	CRACK DETECTION RADIAL LENGTH, IN.		REMARKS
	DESIRED	REQ'D*	
● ROGUE FLAW IN CRITICAL SPANWISE SPLICE (2 LAYERS) ~17,000 CRITICAL HOLES	0.10	0.30	● FASTENER REMOVAL NOT PRACTICAL

*90% PROBABILITY — 95% CONFIDENCE



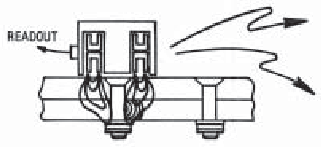
"HOT SPOTS" IN C-5 WING

C-5A WING STRUCTURAL SAFETY

NEED PROTECTION FROM	CRACK DETECTION RADIAL LENGTH, IN.		REMARKS
	DESIRED	REQ'D *	
● ROGUE FLAW IN CRITICAL SPANWISE SPLICE (2 LAYERS) ~17,000 CRITICAL HOLES	0.10	0.30	● FASTENER REMOVAL NOT PRACTICAL
● CRACKING IN "HOT SPOT" AREAS (MULTILAYERS) >2,000 CRITICAL HOLES	0.05	0.07-0.25	● SOME FASTENER REMOVAL REQUIRED
● GENERALIZED CRACKING (2 LAYERS) ~17,000 CRITICAL HOLES	0.010	0.010-0.030 (ESTIMATED)	● BEYOND NEAR TERM PROJECTED NDE CAPABILITY

*90% PROBABILITY — 95% CONFIDENCE

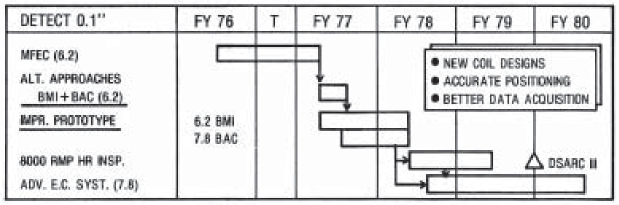
EDDY CURRENT METHOD FOR C-5A (INTERIOR LAYER)



TWO APPROACHES

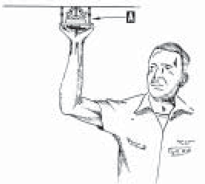
BATTELLE MULTIFREQUENCY (AFML)
COMPUTER ANAL/READOUT
TESTED: 0.3"–0.5" DETECTION

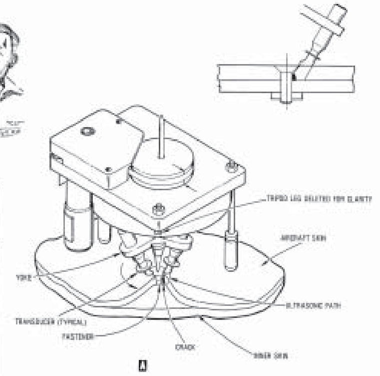
BOEING LOW FREQUENCY (PRIVATE)
METER READOUT
TESTED: 0.5"–0.7" DETECTION



- NEW COIL DESIGNS
- ACCURATE POSITIONING
- BETTER DATA ACQUISITION

ULTRASONIC SCANNER SYSTEM





AFLC, PRAM
FIELD EVAL RESULTS

- GOOD IN PRINCIPLE
- SHORTCOMINGS IN FIELD
  - HARD TO ADJUST
  - HARD TO CENTER
  - MECH/ELEC OPERATION VARIABILITY

DETECTION OF CRACKS UNDER INSTALLED FASTENERS

FUNDING $ MILLIONS

SUPPORTING C-5A	FY 77	FY 78	FY 79	FY 80	TOTALS
IMPROVED ULTRASONIC SCANNER (7.8)			—	—	
IMPROVED EDDY CURRENT (6.2, 7.8)			—	—	
SUBTOTAL			—	—	
GENERIC CAPABILITY					
ADV. UT SCANNER EQUIP. (7.8)	—				
ADV. EC EQUIP. (7.8)	—				
SUBTOTAL	—				
TOTALS					

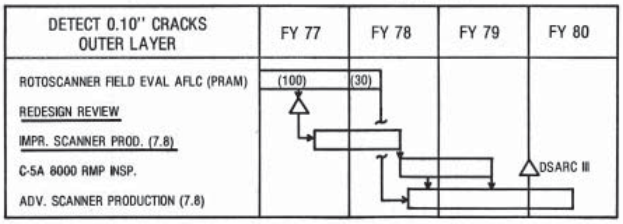
IMPROVED ULTRASONIC SCANNER FOR C-5A (OUTER LAYER)

IMPROVEMENTS

- OPTIMIZE ACCURACY
- RELIABLE POSITIONING
- SENSITIVE TUNING
- LESS OPERATOR FATIGUE

APPROACH

- REDESIGN BY MFG-USER TEAM
- COMBINE LATEST ELECTRONICS, MECHANICAL TECHNOLOGY
- PROTOTYPE PERFORM. EVAL, DEBUGGING



OTHER FLEET AIRCRAFT REQUIREMENTS

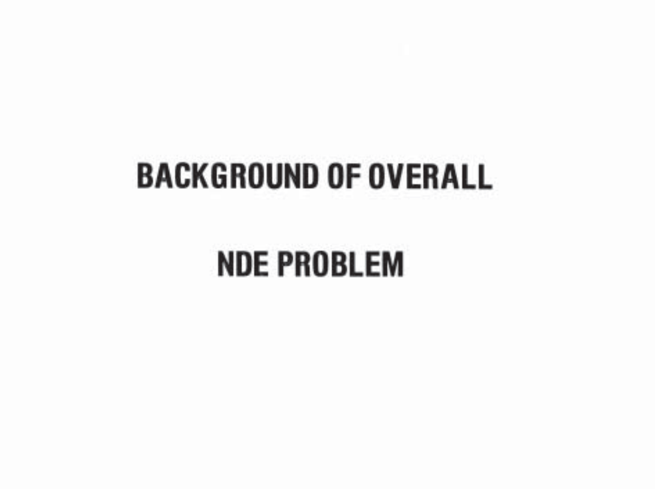
RAPID, RELIABLE, LOW COST INSPECTION OF HOLES
WITHOUT FASTENER REMOVAL

DETECTION NEEDS

- 0.100" RADIAL LENGTH
  CANDIDATES: F-4, A-7, C-141, B-52
- 0.030"– 0.100" RADIAL LENGTH
  CANDIDATES: POTENTIALLY SOME FIGHTER A/C

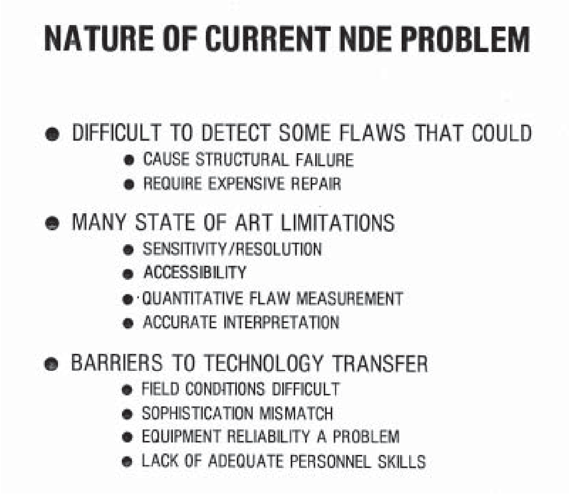
PAYOFF

- SIGNIFICANTLY LOWER INSPECTION COSTS
- EARLY DETECTION CAN REDUCE REPAIR COSTS
- AVOID POTENTIAL HOLE DAMAGE



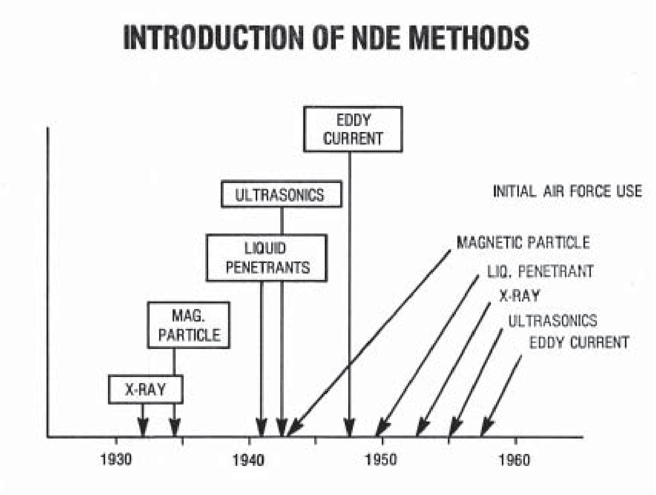
BACKGROUND OF OVERALL

NDE PROBLEM



NATURE OF CURRENT NDE PROBLEM

- DIFFICULT TO DETECT SOME FLAWS THAT COULD
  - CAUSE STRUCTURAL FAILURE
  - REQUIRE EXPENSIVE REPAIR
- MANY STATE OF ART LIMITATIONS
  - SENSITIVITY/RESOLUTION
  - ACCESSIBILITY
  - QUANTITATIVE FLAW MEASUREMENT
  - ACCURATE INTERPRETATION
- BARRIERS TO TECHNOLOGY TRANSFER
  - FIELD CONDITIONS DIFFICULT
  - SOPHISTICATION MISMATCH
  - EQUIPMENT RELIABILITY A PROBLEM
  - LACK OF ADEQUATE PERSONNEL SKILLS



INTRODUCTION OF NDE METHODS

EDDY CURRENT

ULTRASONICS

LIQUID PENETRANTS

MAG. PARTICLE

X-RAY

INITIAL AIR FORCE USE

MAGNETIC PARTICLE

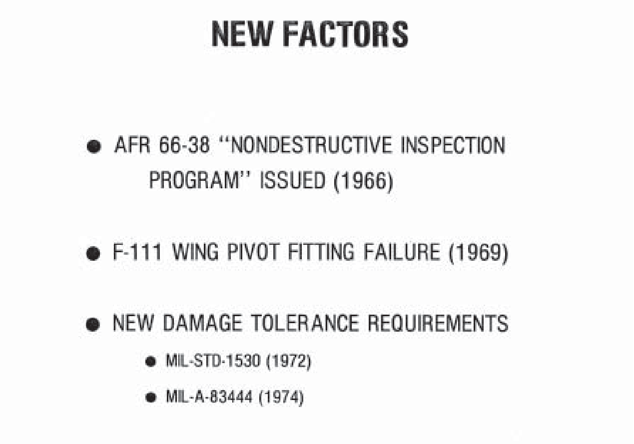
LIQ. PENETRANT

X-RAY

ULTRASONICS

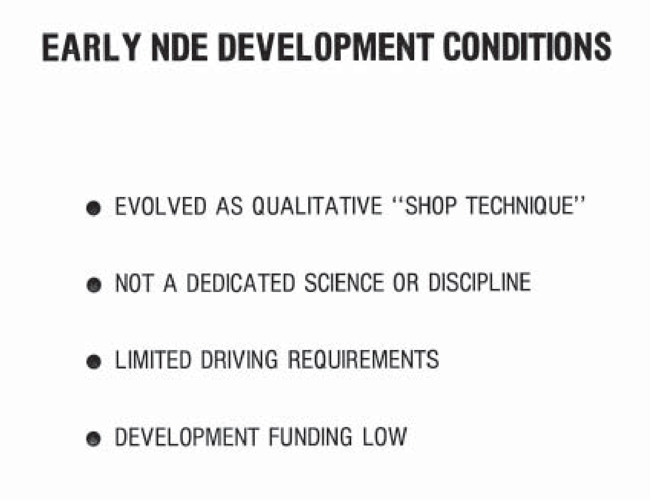
EDDY CURRENT

1930 1940 1950 1960



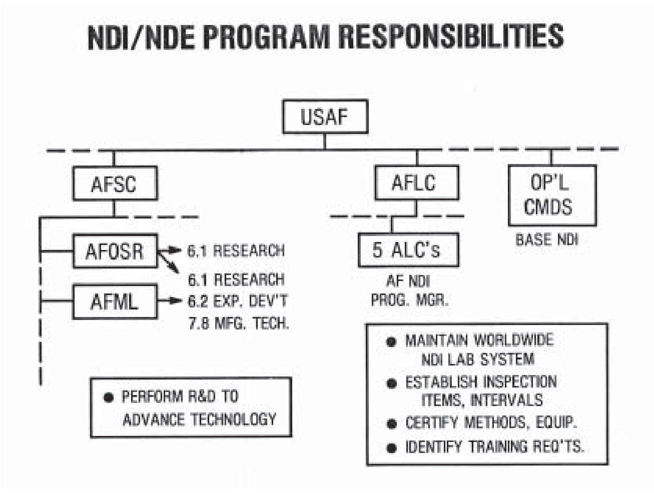
NEW FACTORS

- AFR 66-38 "NONDESTRUCTIVE INSPECTION PROGRAM" ISSUED (1966)
- F-111 WING PIVOT FITTING FAILURE (1969)
- NEW DAMAGE TOLERANCE REQUIREMENTS
  - MIL-STD-1530 (1972)
  - MIL-A-83444 (1974)



EARLY NDE DEVELOPMENT CONDITIONS

- EVOLVED AS QUALITATIVE "SHOP TECHNIQUE"
- NOT A DEDICATED SCIENCE OR DISCIPLINE
- LIMITED DRIVING REQUIREMENTS
- DEVELOPMENT FUNDING LOW



NDI/NDE PROGRAM RESPONSIBILITIES

USAF

AFSC

AFLC

OP'L CMDS

BASE NDI

AFOSR → 6.1 RESEARCH

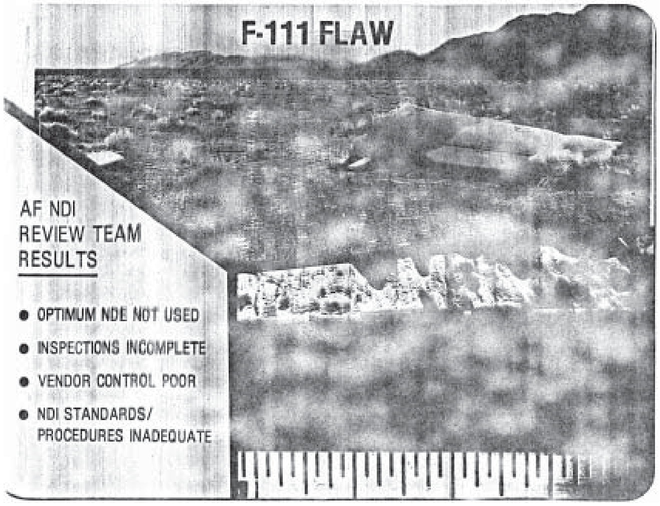
AFML → 6.1 RESEARCH, 6.2 EXP. DEV'T, 7.8 MFG. TECH.

- PERFORM R&D TO ADVANCE TECHNOLOGY

5 ALC's

AF NDI PROG. MGR.

- MAINTAIN WORLDWIDE NDI LAB SYSTEM
- ESTABLISH INSPECTION ITEMS, INTERVALS
- CERTIFY METHODS, EQUIP.
- IDENTIFY TRAINING REQ'TS.



F-111 FLAW

AF NDI
REVIEW TEAM
RESULTS

- OPTIMUM NDE NOT USED
- INSPECTIONS INCOMPLETE
- VENDOR CONTROL POOR
- NDI STANDARDS/ PROCEDURES INADEQUATE

CURRENT NDE DEVELOPMENT PROGRAM

FOCUS

- CONCENTRATE ON FEW KEY REQUIREMENTS
  - NDE OF FASTENED JOINTS: C-5A WING
  - IMPROVE IN-SERVICE NDE RELIABILITY
  - IN-SERVICE NDE OF COMPOSITE STRUCTURES
- CONTINUE STRONG FUNDAMENTAL PROGRAM
  - QUANTITATIVE ULTRASONICS
  - SMALL, TIGHT SURFACE FLAWS
  - NEW PHYSICAL PHENOMENA

IMPROVEMENTS FOLLOWING 1969 F-111 CRASH

AEROSPACE INDUSTRY (UNDER USAF PRESSURE)

- UPDATED, TIGHTENED NDE PROCEDURES
- HIRED MORE EXPERTISE, IMPROVED TRAINING/CERT.
- GRADUALLY INCREASED IRAD PROGRAMS

INTERNAL AIR FORCE

- NO ACROSS-THE-BOARD PROCEDURAL IMPROVEMENT
- FAILED TO INSTITUTE INSPECTOR CERTIFICATION REQ'T
- ISSUED AFR 66-38 AFLC/AFSC SUP. 1 (1971)
- EXPANDED NDE DEVELOPMENT PROGRAM
  - FOCUS ON STRUCTURAL INTEGRITY
  - COHERENT SCIENCE-BASE PROGRAM

NDE DEVELOPMENT THRUSTS
FY 77-79

RESEARCH

- ADV. ACOUSTICS SCIENCE
  - EM TRANSDUCERS
  - ACOUSTIC EMISSION
  - PARTICLE EMISSION
- NEW PHYSICAL METHODS
  - POSITRON ANNIHILATION
  - OPTICAL DETECTION
  - X-RAY STRAIN PROBES

TECHNOLOGY BASE

- QUANTITATIVE ULTRASONICS
  - TRANSDUCERS
  - SIGNAL ACQUISITION/PROCESSING
- QUANT. NDE OF SURFACE FLAWS
- NDE OF ADVANCED MAT'LS
  - COMPOSITES
  - CERAMICS,
  - ADHESIVE BONDS

APPLICATIONS

- NDE OF FASTENED JOINTS
- FIELD RELIABILITY IMPR.
- COMPOSITES IN-SERV. NDE
- NDE OF COMPLEX SHAPES
- ADHESIVE BOND EVAL

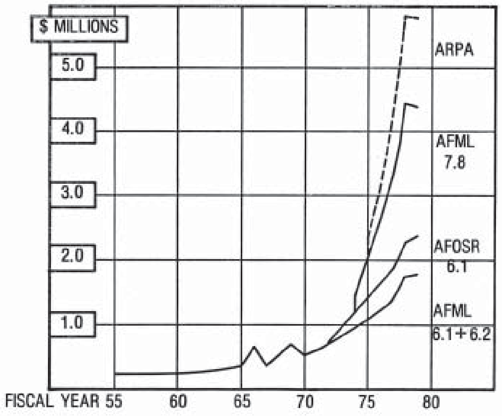
SYSTEMS SUPPORT

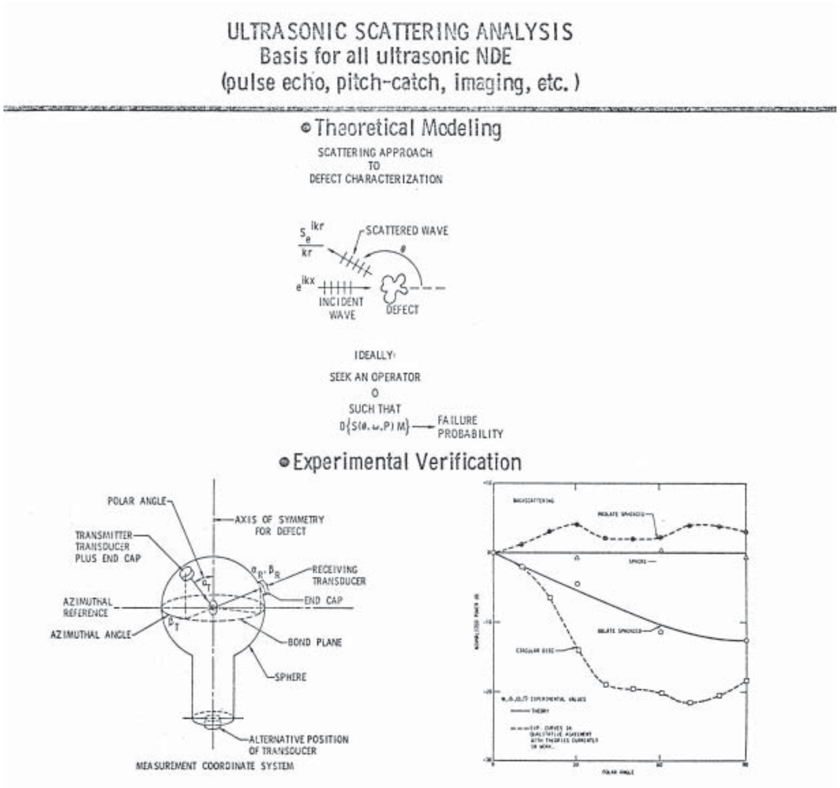
- NDE ADVICE TO SPO'S
- AID FIELD UNITS WITH NDE PROBLEMS
- NDE SPECIFICATIONS
- SPECIAL NDE METHOD IMPROVEMENT PROJECTS

CURRENT

NDE DEVELOPMENT PROGRAM

AFSC NDE DEVELOPMENT FUNDING





ULTRASONIC SCATTERING ANALYSIS

Basis for all ultrasonic NDE
(pulse echo, pitch-catch, imaging, etc.)

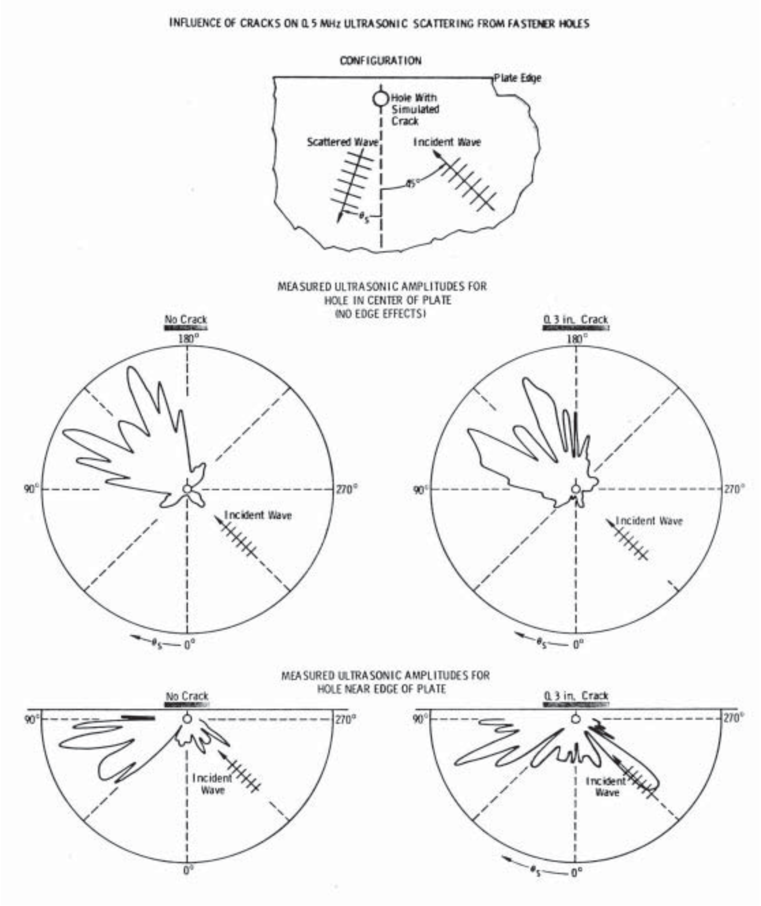
- Theoretical Modeling

SCATTERING APPROACH
TO
DEFECT CHARACTERIZATION

IDEALLY:

SEEK AN OPERATOR
O
SUCH THAT
$O\{S(\theta, \omega, P) M\} \longrightarrow$ FAILURE PROBABILITY

- Experimental Verification

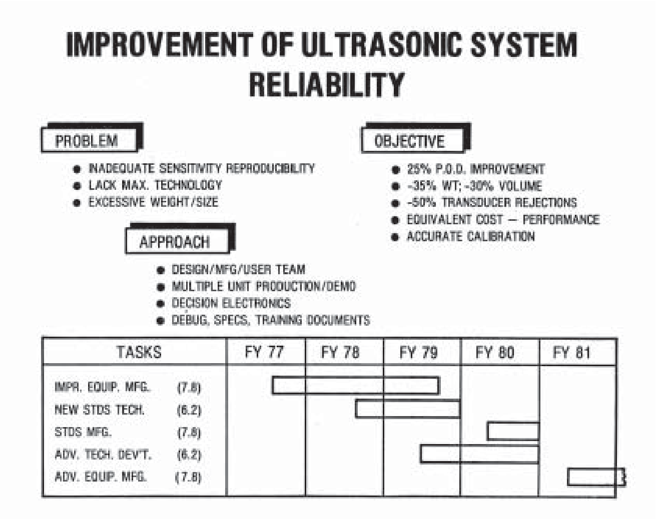


INFLUENCE OF CRACKS ON 0.5 MHz ULTRASONIC SCATTERING FROM FASTENER HOLES

CONFIGURATION

MEASURED ULTRASONIC AMPLITUDES FOR
HOLE IN CENTER OF PLATE
(NO EDGE EFFECTS)

MEASURED ULTRASONIC AMPLITUDES FOR
HOLE NEAR EDGE OF PLATE



IMPROVEMENT OF ULTRASONIC SYSTEM RELIABILITY

PROBLEM

- INADEQUATE SENSITIVITY REPRODUCIBILITY
- LACK MAX. TECHNOLOGY
- EXCESSIVE WEIGHT/SIZE

OBJECTIVE

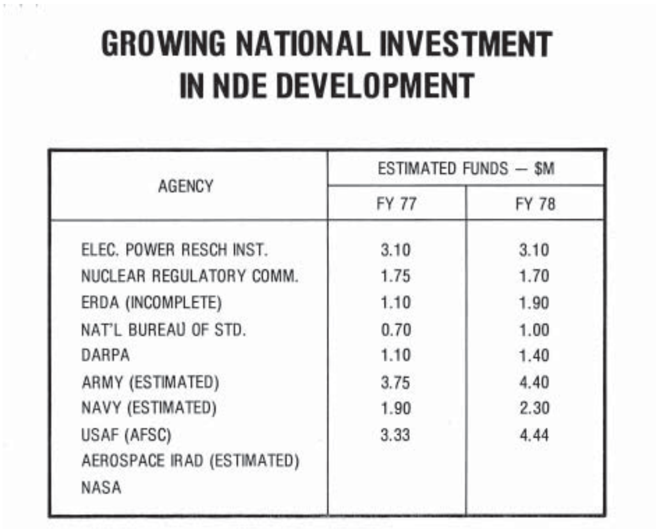
- 25% P.O.D. IMPROVEMENT
- -35% WT; -30% VOLUME
- -50% TRANSDUCER REJECTIONS
- EQUIVALENT COST — PERFORMANCE
- ACCURATE CALIBRATION

APPROACH

- DESIGN/MFG/USER TEAM
- MULTIPLE UNIT PRODUCTION/DEMO
- DECISION ELECTRONICS
- DEBUG, SPECS, TRAINING DOCUMENTS

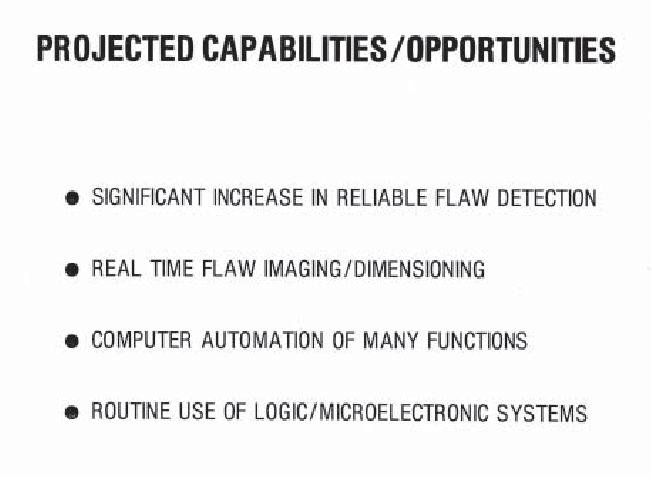
TASKS		FY 77	FY 78	FY 79	FY 80	FY 81
IMPR. EQUIP. MFG.	(7.8)					
NEW STDS TECH.	(6.2)					
STDS MFG.	(7.8)					
ADV. TECH. DEV'T.	(6.2)					
ADV. EQUIP. MFG.	(7.8)					

OUTLOOK



GROWING NATIONAL INVESTMENT IN NDE DEVELOPMENT

AGENCY	ESTIMATED FUNDS — $M	
	FY 77	FY 78
ELEC. POWER RESCH INST.	3.10	3.10
NUCLEAR REGULATORY COMM.	1.75	1.70
ERDA (INCOMPLETE)	1.10	1.90
NAT'L BUREAU OF STD.	0.70	1.00
DARPA	1.10	1.40
ARMY (ESTIMATED)	3.75	4.40
NAVY (ESTIMATED)	1.90	2.30
USAF (AFSC)	3.33	4.44
AEROSPACE IRAD (ESTIMATED)		
NASA		



PROJECTED CAPABILITIES/OPPORTUNITIES

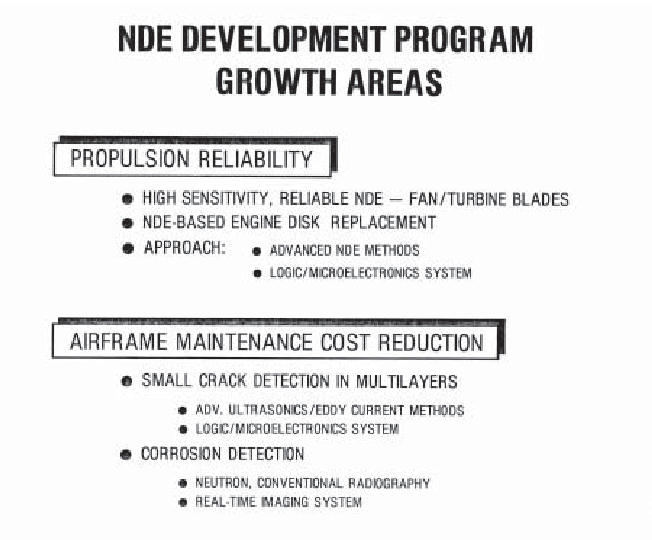
- SIGNIFICANT INCREASE IN RELIABLE FLAW DETECTION
- REAL TIME FLAW IMAGING/DIMENSIONING
- COMPUTER AUTOMATION OF MANY FUNCTIONS
- ROUTINE USE OF LOGIC/MICROELECTRONIC SYSTEMS

USAF NATIONAL LEADERSHIP

- SEMI-ANNUAL AFLC/AFSC NDI MANAGERS MEETING
- BI-ANNUAL MAJCOM NDI MANAGERS MEETING

- ANNUAL ARPA/AFML WORKSHOP "QUANTATIVE NDE"
- NATIONAL WORKSHOP ON "NDE OF RESIDUAL STRESS"
- AF REVIEW WITH INDUSTRY "USAF NDE DEVELOPMENT PROGRAM"

- AF — INITIATED NMAB STUDY "ECON/MGT ASPECTS OF NDE"
- FIRST GOVERNMENT-WIDE NDE PROGRAM MANAGERS MEETING — WASHINGTON, DECEMBER 1977



NDE DEVELOPMENT PROGRAM GROWTH AREAS

PROPULSION RELIABILITY

- HIGH SENSITIVITY, RELIABLE NDE — FAN/TURBINE BLADES
- NDE-BASED ENGINE DISK REPLACEMENT
- APPROACH:
  - ADVANCED NDE METHODS
  - LOGIC/MICROELECTRONICS SYSTEM

AIRFRAME MAINTENANCE COST REDUCTION

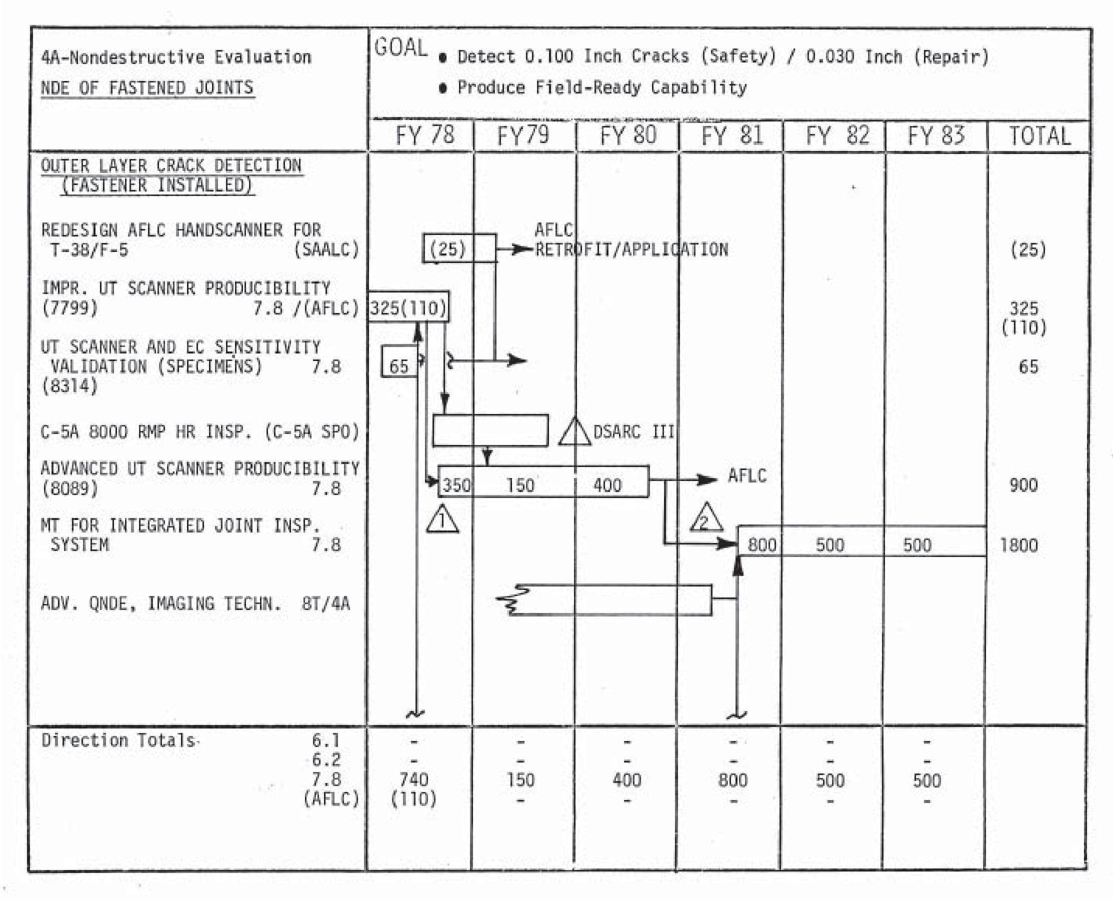
- SMALL CRACK DETECTION IN MULTILAYERS
  - ADV. ULTRASONICS/EDDY CURRENT METHODS
  - LOGIC/MICROELECTRONICS SYSTEM
- CORROSION DETECTION
  - NEUTRON, CONVENTIONAL RADIOGRAPHY
  - REAL-TIME IMAGING SYSTEM

SOME NEEDED CHANGES

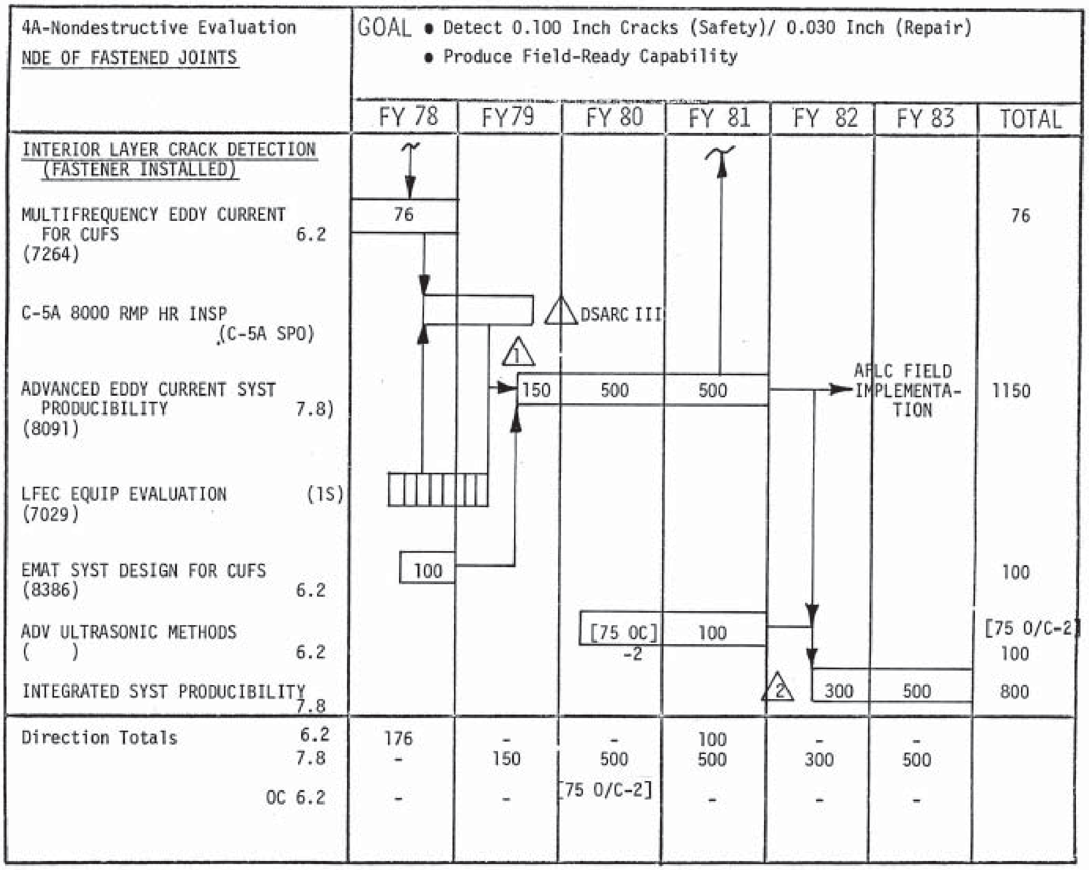
- STRENGTHEN NDE REQUIREMENTS FOR SYSTEMS
- IMPROVE TECHNOLOGY TRANSFER PROCESS
- INSTALL INSPECTOR PROFICIENCY CERTIFICATION
- EXPAND NDE DEVELOPMENT PROGRAM
- CORRECT SHORTAGE OF HIGH TECHNOLOGY NDE EXPERTISE IN USAF

APPENDIX F-2

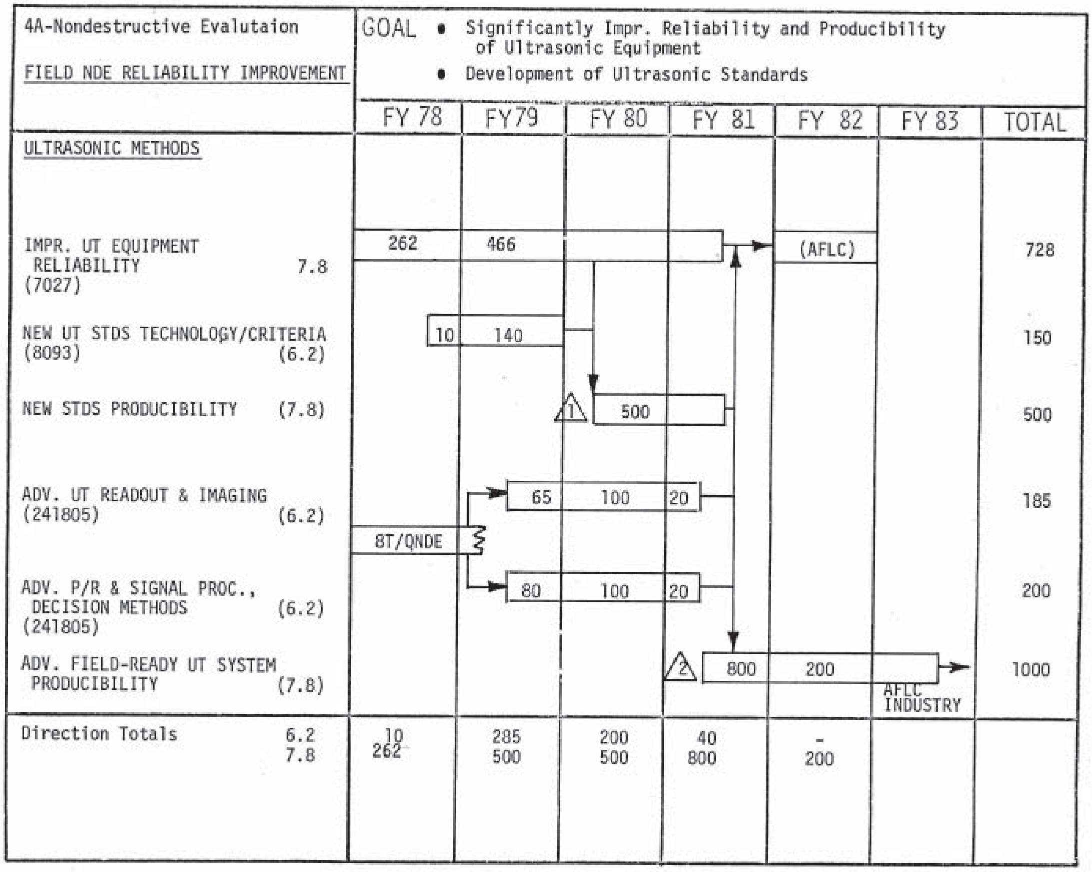
Original ML Focal Area 4 NDE Program Roadmap for the Planning Period FY 78 – FY 83.



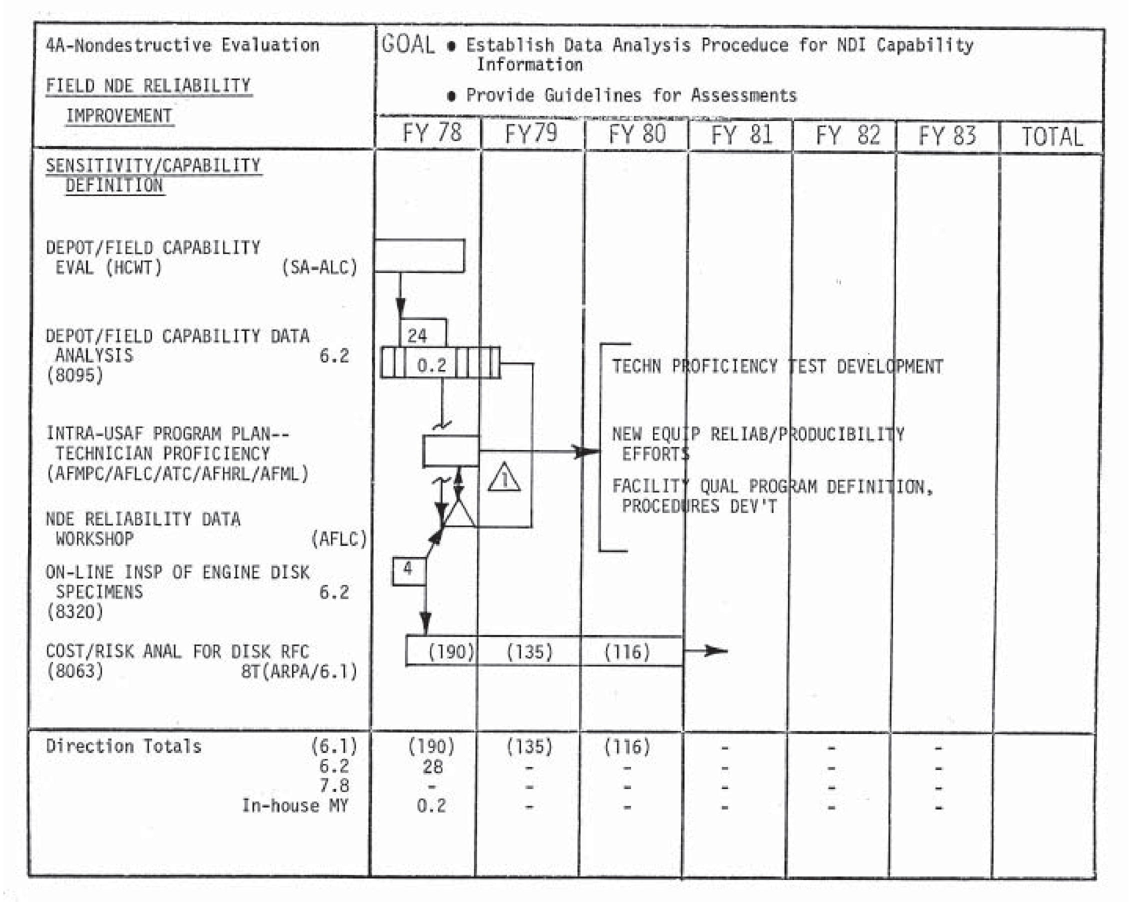
4A-Nondestructive Evaluation NDE OF FASTENED JOINTS	GOAL • Detect 0.100 Inch Cracks (Safety) / 0.030 Inch (Repair) • Produce Field-Ready Capability					
	FY 78	FY79	FY 80	FY 81	FY 82	FY 83	TOTAL
OUTER LAYER CRACK DETECTION (FASTENER INSTALLED)							
REDESIGN AFLC HANDSCANNER FOR T-38/F-5 (SAALC)	(25)	AFLC RETROFIT/APPLICATION					(25)
IMPR. UT SCANNER PRODUCIBILITY (7799) 7.8 /(AFLC)	325(110)						325 (110)
UT SCANNER AND EC SENSITIVITY VALIDATION (SPECIMENS) 7.8 (8314)	65						65
C-5A 8000 RMP HR INSP. (C-5A SPO)			DSARC III				
ADVANCED UT SCANNER PRODUCIBILITY (8089) 7.8	350	150	400	AFLC			900
MT FOR INTEGRATED JOINT INSP. SYSTEM 7.8				800	500	500	1800
ADV. QNDE, IMAGING TECHN. 8T/4A							
Direction Totals 6.1	-	-	-	-	-	-	
6.2	-	-	-	-	-	-	
7.8	740	150	400	800	500	500	
(AFLC)	(110)	-	-	-	-	-	



4A-Nondestructive Evaluation NDE OF FASTENED JOINTS	GOAL • Detect 0.100 Inch Cracks (Safety)/ 0.030 Inch (Repair) • Produce Field-Ready Capability						
	FY 78	FY79	FY 80	FY 81	FY 82	FY 83	TOTAL
INTERIOR LAYER CRACK DETECTION (FASTENER INSTALLED)							
MULTIFREQUENCY EDDY CURRENT FOR CUFS 6.2 (7264)	76						76
C-5A 8000 RMP HR INSP (C-5A SPO)			△ DSARC III				
ADVANCED EDDY CURRENT SYST PRODUCIBILITY 7.8) (8091)		△1 150	500	500		AFLC FIELD IMPLEMENTA-TION	1150
LFEC EQUIP EVALUATION (1S) (7029)							
EMAT SYST DESIGN FOR CUFS (8386) 6.2	100						100
ADV ULTRASONIC METHODS ( ) 6.2			[75 OC] -2	100			[75 O/C-2] 100
INTEGRATED SYST PRODUCIBILITY 7.8					△2 300	500	800
Direction Totals 6.2	176	-	-	100	-	-	
7.8	-	150	500	500	300	500	
OC 6.2	-	-	[75 O/C-2]	-	-	-	



4A-Nondestructive Evalutaion FIELD NDE RELIABILITY IMPROVEMENT	GOAL • Significantly Impr. Reliability and Producibility of Ultrasonic Equipment • Development of Ultrasonic Standards						
	FY 78	FY79	FY 80	FY 81	FY 82	FY 83	TOTAL
ULTRASONIC METHODS							
IMPR. UT EQUIPMENT RELIABILITY 7.8 (7027)	262	466			(AFLC)		728
NEW UT STDS TECHNOLOGY/CRITERIA (8093) (6.2)	10	140					150
NEW STDS PRODUCIBILITY (7.8)			△1 500				500
ADV. UT READOUT & IMAGING (241805) (6.2)		65	100	20			185
	8T/QNDE						
ADV. P/R & SIGNAL PROC., DECISION METHODS (241805) (6.2)		80	100	20			200
ADV. FIELD-READY UT SYSTEM PRODUCIBILITY (7.8)				△2 800	200	AFLC INDUSTRY	1000
Direction Totals 6.2	10	285	200	40	-		
7.8	262	500	500	800	200		



4A-Nondestructive Evaluation

FIELD NDE RELIABILITY IMPROVEMENT

GOAL
- Establish Data Analysis Proceduce for NDI Capability Information
- Provide Guidelines for Assessments

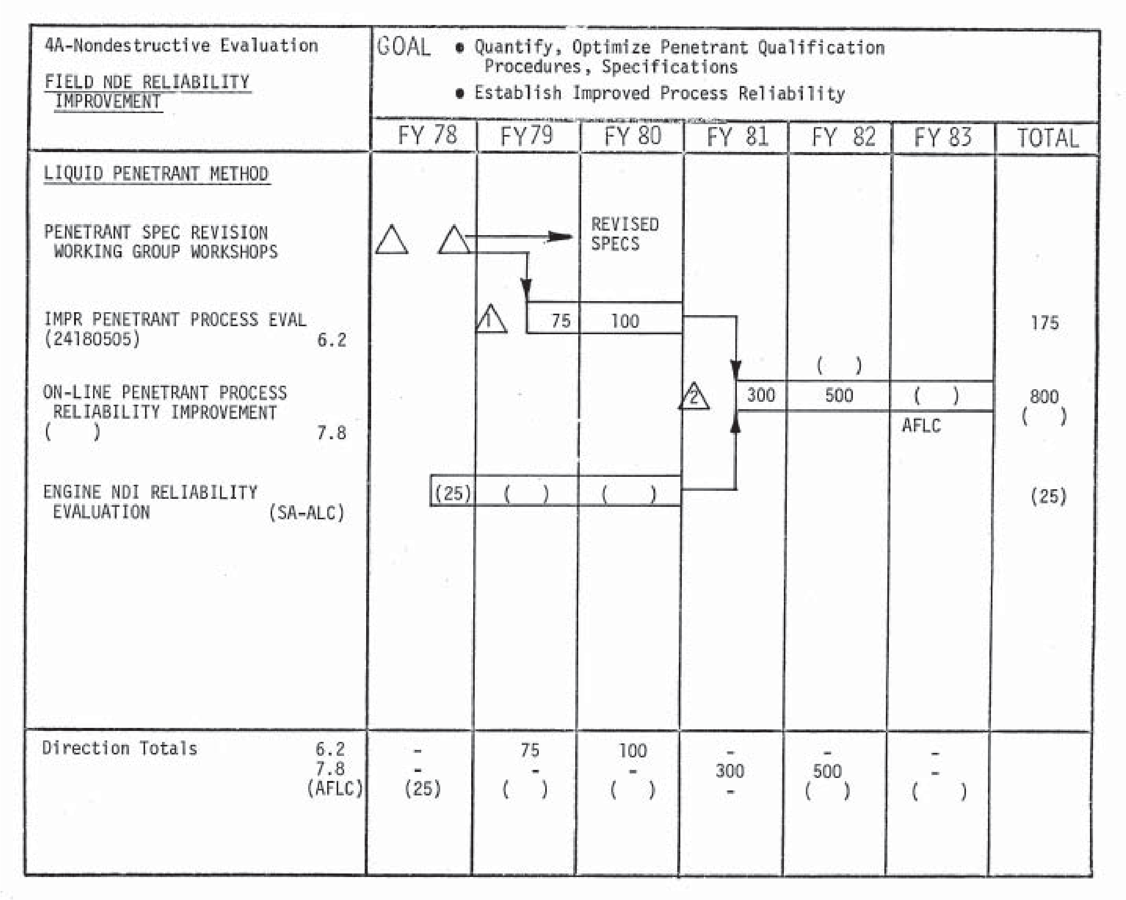
	FY 78	FY79	FY 80	FY 81	FY 82	FY 83	TOTAL
SENSITIVITY/CAPABILITY DEFINITION							
DEPOT/FIELD CAPABILITY EVAL (HCWT) (SA-ALC)							
DEPOT/FIELD CAPABILITY DATA ANALYSIS 6.2 (8095)	24 0.2						
INTRA-USAF PROGRAM PLAN--TECHNICIAN PROFICIENCY (AFMPC/AFLC/ATC/AFHRL/AFML)		1					
NDE RELIABILITY DATA WORKSHOP (AFLC)							
ON-LINE INSP OF ENGINE DISK SPECIMENS 6.2 (8320)	4						
COST/RISK ANAL FOR DISK RFC (8063) 8T(ARPA/6.1)	(190)	(135)	(116)				

TECHN PROFICIENCY TEST DEVELOPMENT

NEW EQUIP RELIAB/PRODUCIBILITY EFFORTS

FACILITY QUAL PROGRAM DEFINITION, PROCEDURES DEV'T

Direction Totals	FY 78	FY79	FY 80	FY 81	FY 82	FY 83	TOTAL
(6.1)	(190)	(135)	(116)	-	-	-	
6.2	28	-	-	-	-	-	
7.8	-	-	-	-	-	-	
In-house MY	0.2	-	-	-	-	-	



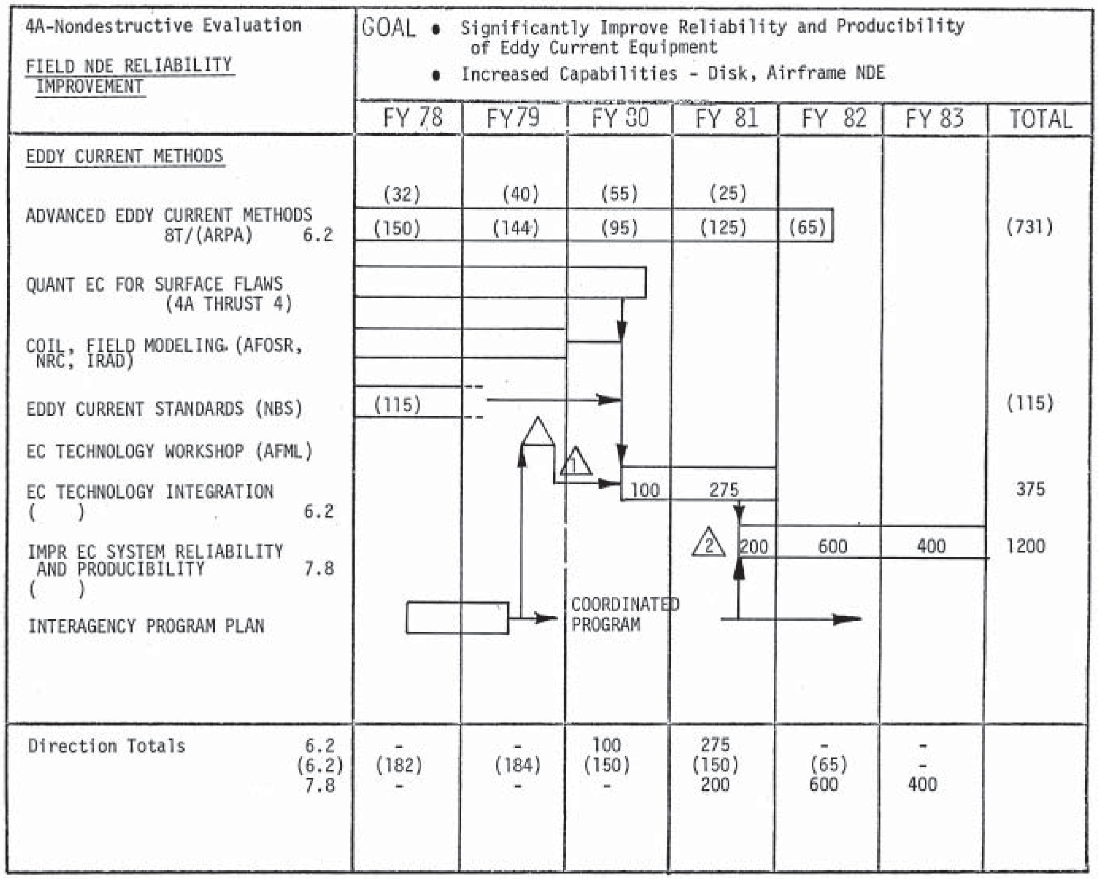
4A-Nondestructive Evaluation

FIELD NDE RELIABILITY IMPROVEMENT

GOAL
- Quantify, Optimize Penetrant Qualification Procedures, Specifications
- Establish Improved Process Reliability

	FY 78	FY79	FY 80	FY 81	FY 82	FY 83	TOTAL
LIQUID PENETRANT METHOD							
PENETRANT SPEC REVISION WORKING GROUP WORKSHOPS			REVISED SPECS				
IMPR PENETRANT PROCESS EVAL (24180505) 6.2		1 75	100				175
ON-LINE PENETRANT PROCESS RELIABILITY IMPROVEMENT ( ) 7.8			2	300	( ) 500	( ) AFLC	800 ( )
ENGINE NDI RELIABILITY EVALUATION (SA-ALC)	(25)	( )	( )				(25)

Direction Totals	FY 78	FY79	FY 80	FY 81	FY 82	FY 83	TOTAL
6.2	-	75	100	-	-	-	
7.8	-	-	-	300	500	-	
(AFLC)	(25)	( )	( )	-	( )	( )	

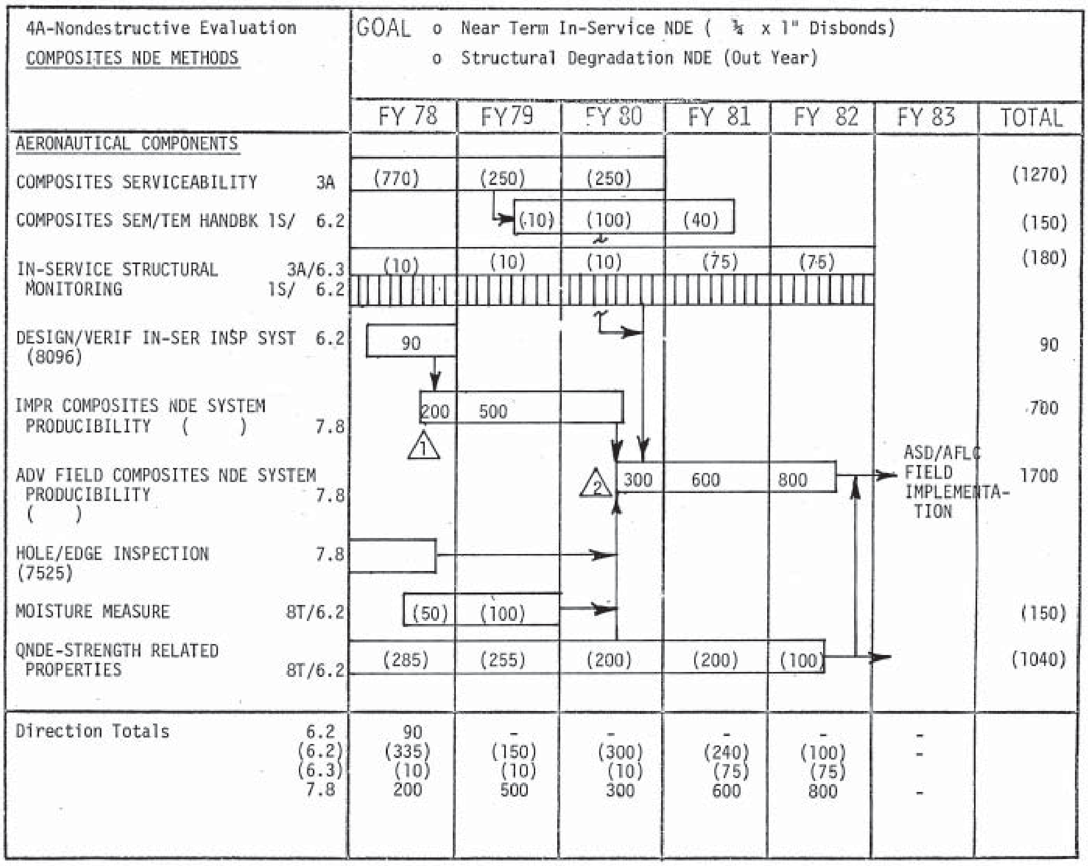


4A-Nondestructive Evaluation

FIELD NDE RELIABILITY IMPROVEMENT

GOAL • Significantly Improve Reliability and Producibility of Eddy Current Equipment
• Increased Capabilities - Disk, Airframe NDE

	FY 78	FY79	FY 80	FY 81	FY 82	FY 83	TOTAL
EDDY CURRENT METHODS							
ADVANCED EDDY CURRENT METHODS 8T/(ARPA) 6.2	(32) (150)	(40) (144)	(55) (95)	(25) (125)	(65)		(731)
QUANT EC FOR SURFACE FLAWS (4A THRUST 4)							
COIL, FIELD MODELING (AFOSR, NRC, IRAD)							
EDDY CURRENT STANDARDS (NBS)	(115)						(115)
EC TECHNOLOGY WORKSHOP (AFML)							
EC TECHNOLOGY INTEGRATION ( ) 6.2			100	275			375
IMPR EC SYSTEM RELIABILITY AND PRODUCIBILITY ( ) 7.8				200	600	400	1200
INTERAGENCY PROGRAM PLAN			COORDINATED PROGRAM				
Direction Totals 6.2 (6.2) 7.8	- (182) -	- (184) -	100 (150) -	275 (150) 200	- (65) 600	- - 400	

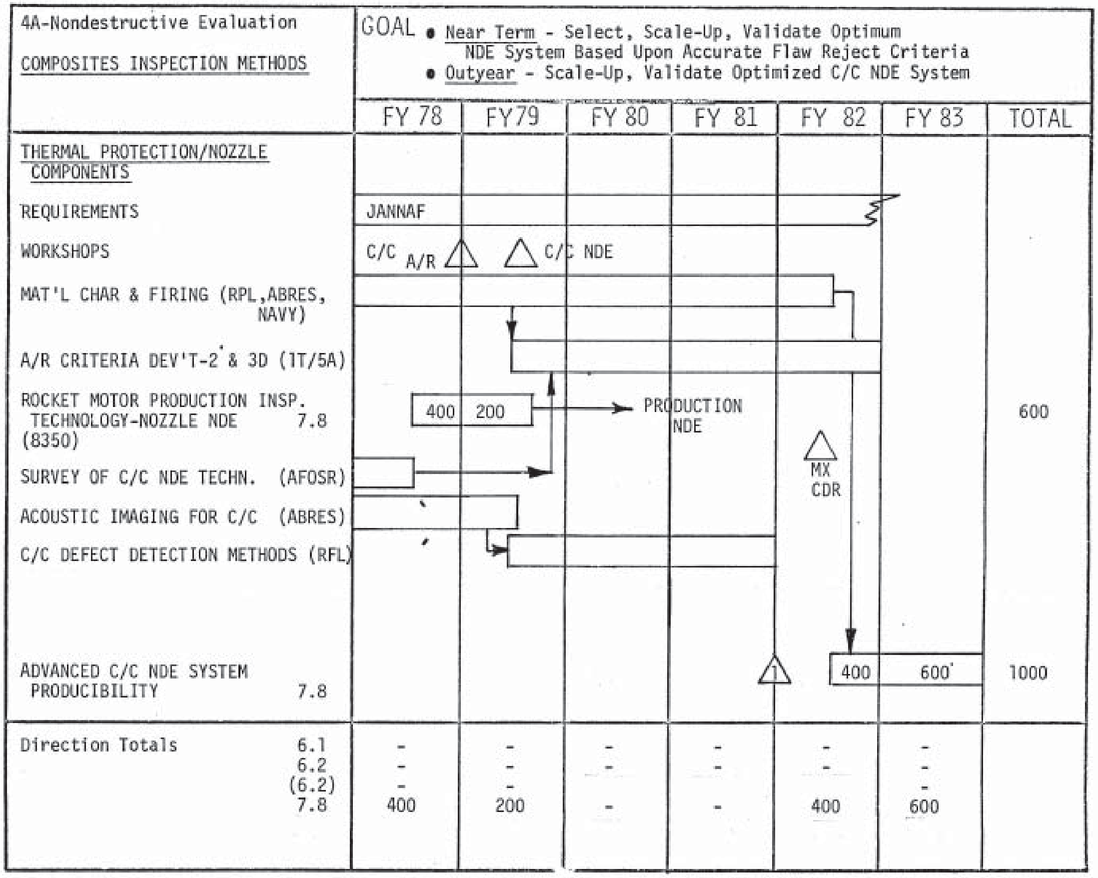


4A-Nondestructive Evaluation

COMPOSITES NDE METHODS

GOAL o Near Term In-Service NDE (¼ x 1" Disbonds)
o Structural Degradation NDE (Out Year)

	FY 78	FY79	FY 80	FY 81	FY 82	FY 83	TOTAL
AERONAUTICAL COMPONENTS							
COMPOSITES SERVICEABILITY 3A	(770)	(250)	(250)				(1270)
COMPOSITES SEM/TEM HANDBK 1S/ 6.2		(10)	(100)	(40)			(150)
IN-SERVICE STRUCTURAL MONITORING 3A/6.3 1S/ 6.2	(10)	(10)	(10)	(75)	(75)		(180)
DESIGN/VERIF IN-SER INSP SYST (8096) 6.2	90						90
IMPR COMPOSITES NDE SYSTEM PRODUCIBILITY ( ) 7.8	200	500					700
ADV FIELD COMPOSITES NDE SYSTEM PRODUCIBILITY ( ) 7.8			300	600	800	ASD/AFLC FIELD IMPLEMENTATION	1700
HOLE/EDGE INSPECTION (7525) 7.8							
MOISTURE MEASURE 8T/6.2	(50)	(100)					(150)
QNDE-STRENGTH RELATED PROPERTIES 8T/6.2	(285)	(255)	(200)	(200)	(100)		(1040)
Direction Totals 6.2 (6.2) (6.3) 7.8	90 (335) (10) 200	- (150) (10) 500	- (300) (10) 300	- (240) (75) 600	- (100) (75) 800	- - - -	

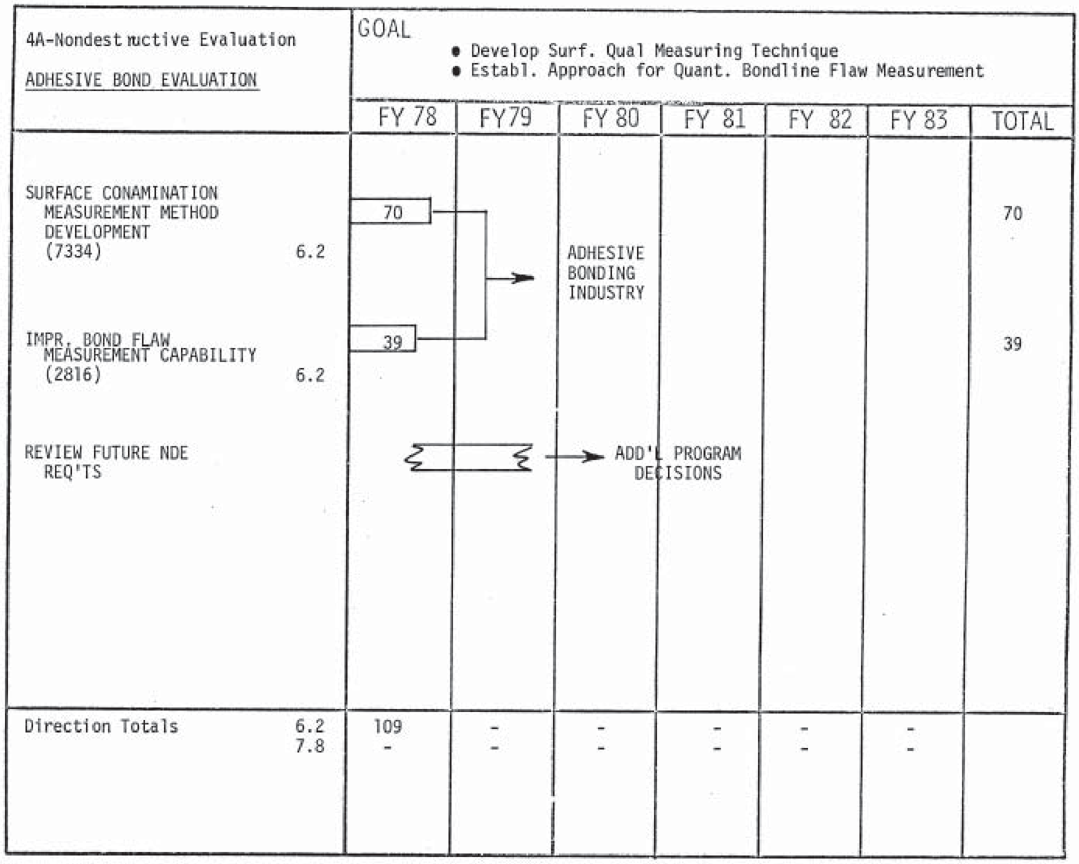


4A-Nondestructive Evaluation

COMPOSITES INSPECTION METHODS

GOAL
- Near Term - Select, Scale-Up, Validate Optimum NDE System Based Upon Accurate Flaw Reject Criteria
- Outyear - Scale-Up, Validate Optimized C/C NDE System

	FY 78	FY79	FY 80	FY 81	FY 82	FY 83	TOTAL
THERMAL PROTECTION/NOZZLE COMPONENTS							
REQUIREMENTS	JANNAF						
WORKSHOPS	C/C A/R	C/C NDE					
MAT'L CHAR & FIRING (RPL,ABRES, NAVY)							
A/R CRITERIA DEV'T-2 & 3D (1T/5A)							
ROCKET MOTOR PRODUCTION INSP. TECHNOLOGY-NOZZLE NDE 7.8 (8350)	400	200	PRODUCTION NDE				600
SURVEY OF C/C NDE TECHN. (AFOSR)					MX CDR		
ACOUSTIC IMAGING FOR C/C (ABRES)							
C/C DEFECT DETECTION METHODS (RFL)							
ADVANCED C/C NDE SYSTEM PRODUCIBILITY 7.8				1	400	600	1000
Direction Totals 6.1 6.2 (6.2) 7.8	- - - 400	- - - 200	- - -	- - -	- - 400	- - - 600	

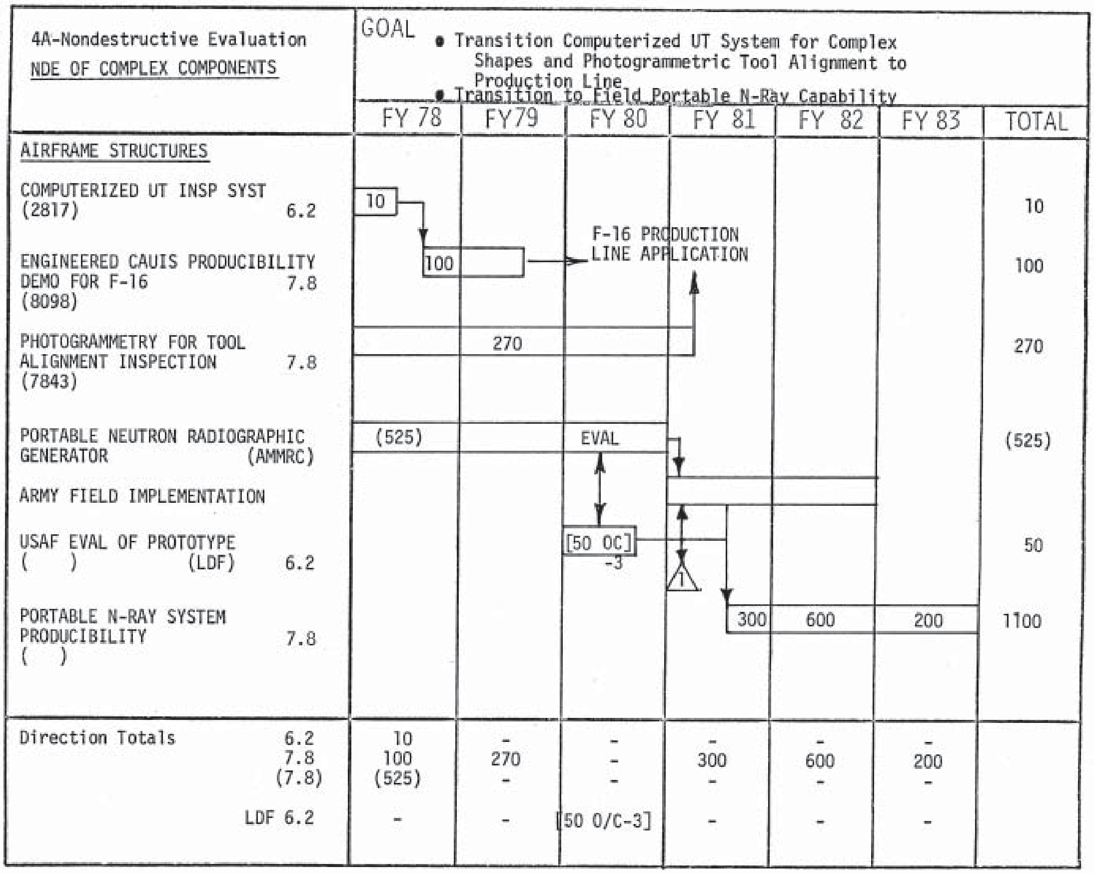


4A-Nondestructive Evaluation

ADHESIVE BOND EVALUATION

GOAL
- Develop Surf. Qual Measuring Technique
- Establ. Approach for Quant. Bondline Flaw Measurement

	FY 78	FY79	FY 80	FY 81	FY 82	FY 83	TOTAL
SURFACE CONAMINATION MEASUREMENT METHOD DEVELOPMENT (7334) 6.2	70		ADHESIVE BONDING INDUSTRY				70
IMPR. BOND FLAW MEASUREMENT CAPABILITY (2816) 6.2	39						39
REVIEW FUTURE NDE REQ'TS			ADD'L PROGRAM DECISIONS				
Direction Totals 6.2 7.8	109 -	- -	- -	- -	- -	- -	

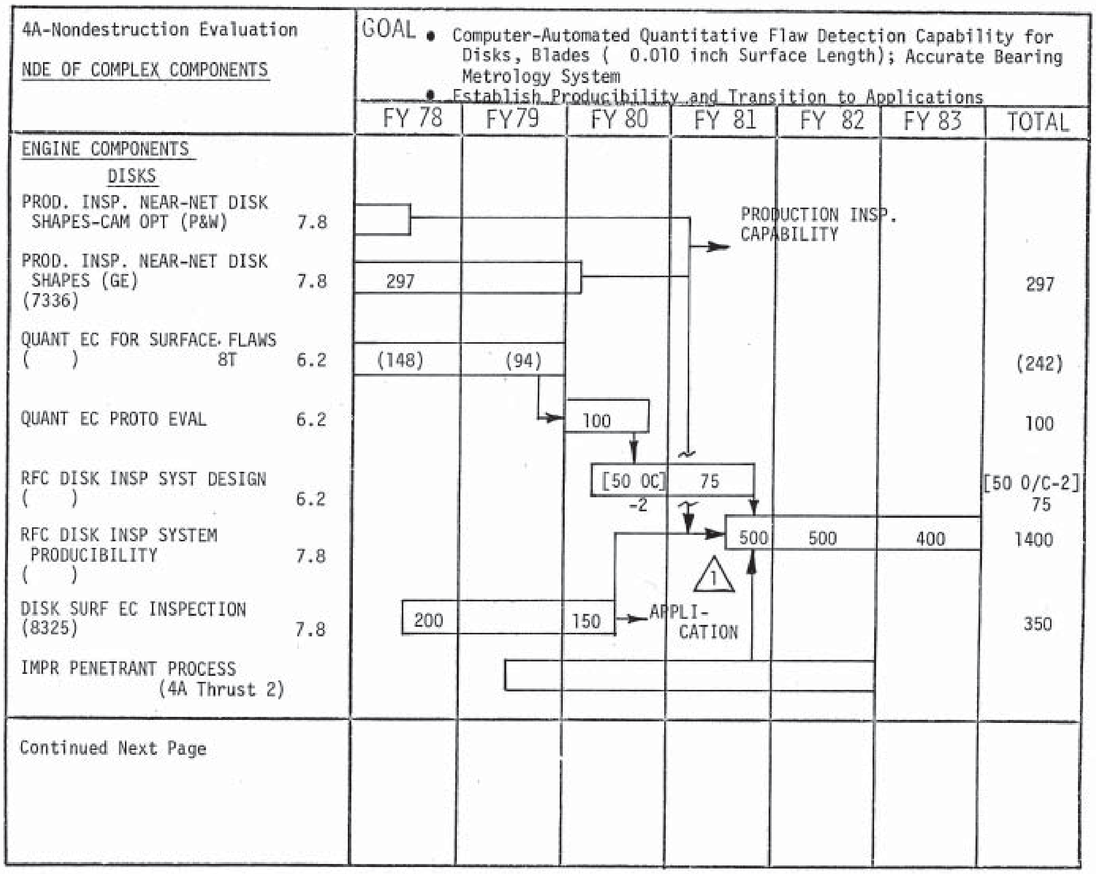


4A-Nondestructive Evaluation

NDE OF COMPLEX COMPONENTS

GOAL
- Transition Computerized UT System for Complex Shapes and Photogrammetric Tool Alignment to Production Line
- Transition to Field Portable N-Ray Capability

	FY 78	FY79	FY 80	FY 81	FY 82	FY 83	TOTAL
AIRFRAME STRUCTURES							
COMPUTERIZED UT INSP SYST (2817) 6.2	10						10
ENGINEERED CAUIS PRODUCIBILITY DEMO FOR F-16 (8098) 7.8		100					100
PHOTOGRAMMETRY FOR TOOL ALIGNMENT INSPECTION (7843) 7.8		270					270
PORTABLE NEUTRON RADIOGRAPHIC GENERATOR (AMMRC)	(525)		EVAL				(525)
ARMY FIELD IMPLEMENTATION							
USAF EVAL OF PROTOTYPE ( ) (LDF) 6.2			[50 OC] -3				50
PORTABLE N-RAY SYSTEM PRODUCIBILITY ( ) 7.8				300	600	200	1100
Direction Totals 6.2	10	-	-	-	-	-	
7.8	100	270	-	300	600	200	
(7.8)	(525)	-	-	-	-	-	
LDF 6.2	-	-	[50 0/C-3]	-	-	-	

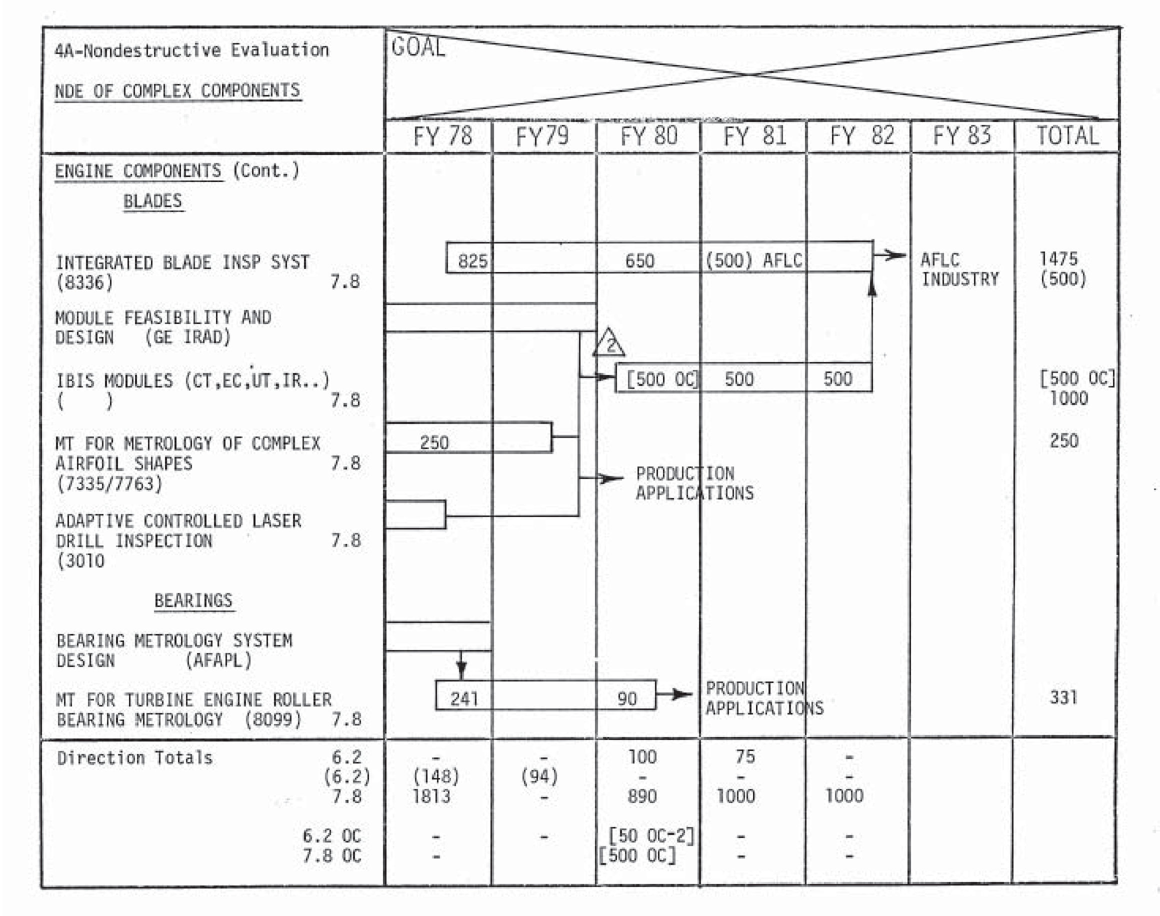


4A-Nondestruction Evaluation

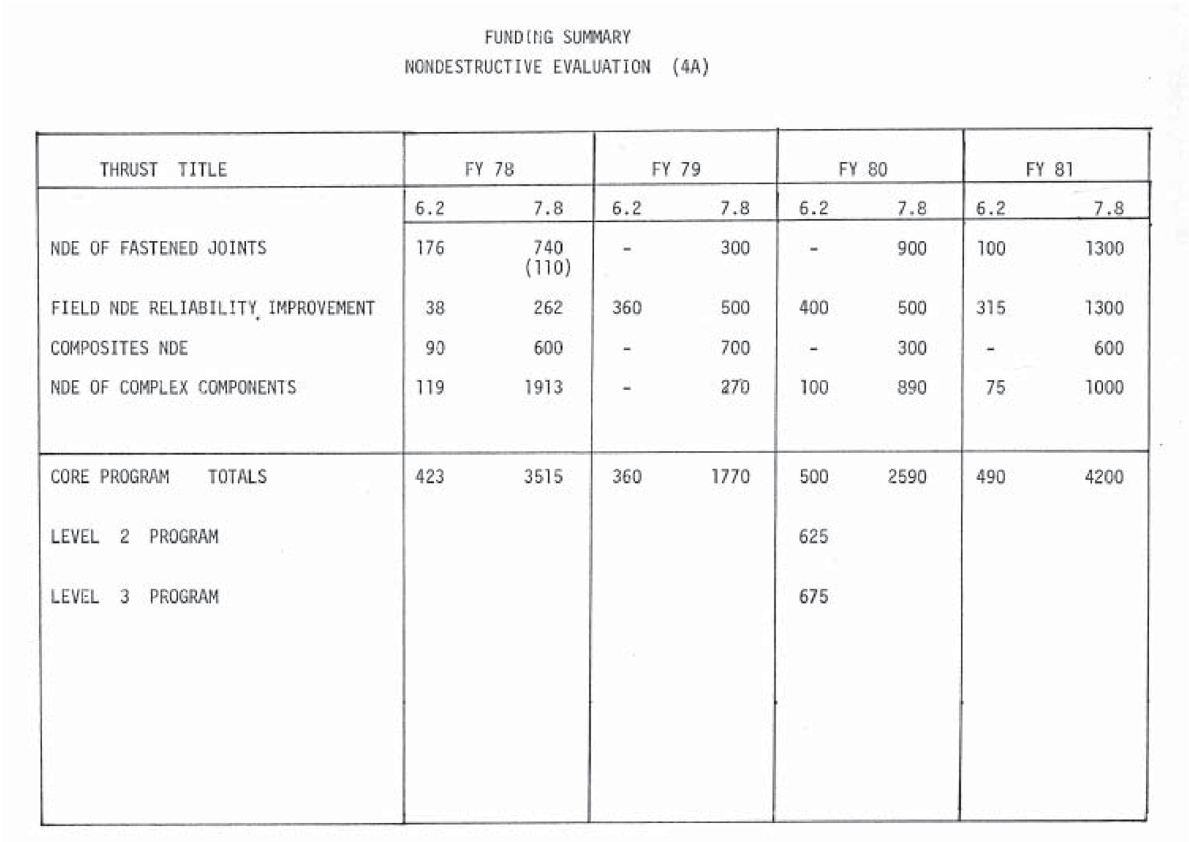
NDE OF COMPLEX COMPONENTS

GOAL
- Computer-Automated Quantitative Flaw Detection Capability for Disks, Blades (0.010 inch Surface Length); Accurate Bearing Metrology System
- Establish Producibility and Transition to Applications

	FY 78	FY79	FY 80	FY 81	FY 82	FY 83	TOTAL
ENGINE COMPONENTS							
DISKS							
PROD. INSP. NEAR-NET DISK SHAPES-CAM OPT (P&W) 7.8							
PROD. INSP. NEAR-NET DISK SHAPES (GE) (7336) 7.8	297						297
QUANT EC FOR SURFACE FLAWS ( ) 8T 6.2	(148)	(94)					(242)
QUANT EC PROTO EVAL 6.2			100				100
RFC DISK INSP SYST DESIGN ( ) 6.2			[50 OC] -2	75			[50 0/C-2] 75
RFC DISK INSP SYSTEM PRODUCIBILITY ( ) 7.8				500	500	400	1400
DISK SURF EC INSPECTION (8325) 7.8	200		150				350
IMPR PENETRANT PROCESS (4A Thrust 2)							
Continued Next Page							



4A-Nondestructive Evaluation NDE OF COMPLEX COMPONENTS	FY 78	FY79	FY 80	FY 81	FY 82	FY 83	TOTAL
ENGINE COMPONENTS (Cont.)							
BLADES							
INTEGRATED BLADE INSP SYST (8336) 7.8	825		650	(500) AFLC		AFLC INDUSTRY	1475 (500)
MODULE FEASIBILITY AND DESIGN (GE IRAD)							
IBIS MODULES (CT,EC,UT,IR..) ( ) 7.8			[500 OC]	500	500		[500 OC] 1000
MT FOR METROLOGY OF COMPLEX AIRFOIL SHAPES (7335/7763) 7.8	250		PRODUCTION APPLICATIONS				250
ADAPTIVE CONTROLLED LASER DRILL INSPECTION (3010 7.8							
BEARINGS							
BEARING METROLOGY SYSTEM DESIGN (AFAPL)							
MT FOR TURBINE ENGINE ROLLER BEARING METROLOGY (8099) 7.8	241		90	PRODUCTION APPLICATIONS			331
Direction Totals 6.2	-	-	100	75	-		
(6.2)	(148)	(94)	-	-	-		
7.8	1813	-	890	1000	1000		
6.2 OC	-	-	[50 OC-2]	-	-		
7.8 OC	-		[500 OC]	-	-		



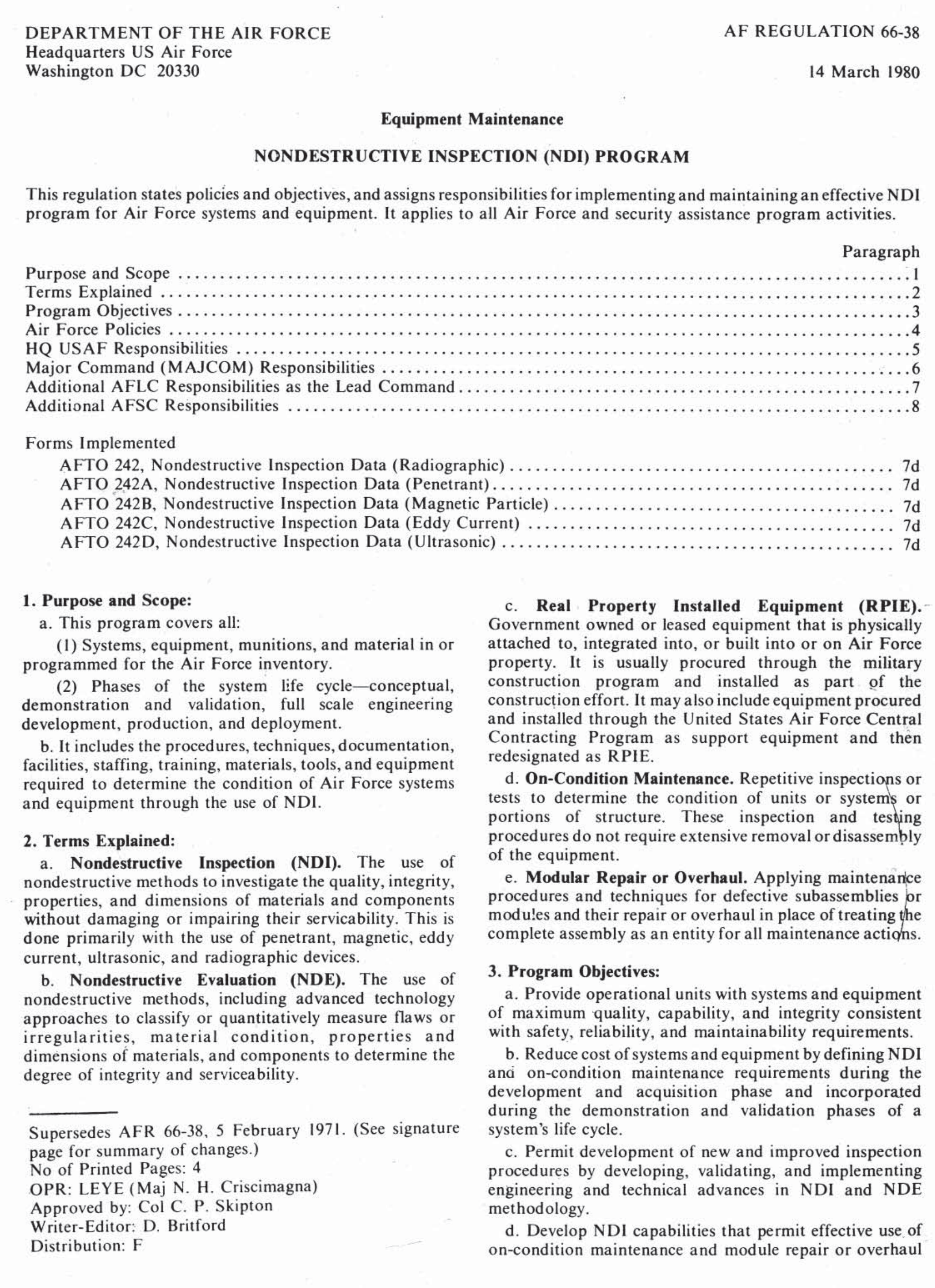
FUNDING SUMMARY

NONDESTRUCTIVE EVALUATION (4A)

THRUST TITLE	FY 78		FY 79		FY 80		FY 81	
	6.2	7.8	6.2	7.8	6.2	7.8	6.2	7.8
NDE OF FASTENED JOINTS	176	740 (110)	-	300	-	900	100	1300
FIELD NDE RELIABILITY IMPROVEMENT	38	262	360	500	400	500	315	1300
COMPOSITES NDE	90	600	-	700	-	300	-	600
NDE OF COMPLEX COMPONENTS	119	1913	-	270	100	890	75	1000
CORE PROGRAM TOTALS	423	3515	360	1770	500	2590	490	4200
LEVEL 2 PROGRAM					625			
LEVEL 3 PROGRAM					675			

APPENDIX F-3

AF Regulation 66-38 Nondestructive Inspection (NDI) Program 14 March 1980.



DEPARTMENT OF THE AIR FORCE
Headquarters US Air Force
Washington DC 20330

AF REGULATION 66-38

14 March 1980

Equipment Maintenance

NONDESTRUCTIVE INSPECTION (NDI) PROGRAM

This regulation states policies and objectives, and assigns responsibilities for implementing and maintaining an effective NDI program for Air Force systems and equipment. It applies to all Air Force and security assistance program activities.

1. Purpose and Scope:

a. This program covers all:

(1) Systems, equipment, munitions, and material in or programmed for the Air Force inventory.

(2) Phases of the system life cycle—conceptual, demonstration and validation, full scale engineering development, production, and deployment.

b. It includes the procedures, techniques, documentation, facilities, staffing, training, materials, tools, and equipment required to determine the condition of Air Force systems and equipment through the use of NDI.

2. Terms Explained:

a. **Nondestructive Inspection (NDI).** The use of nondestructive methods to investigate the quality, integrity, properties, and dimensions of materials and components without damaging or impairing their servicability. This is done primarily with the use of penetrant, magnetic, eddy current, ultrasonic, and radiographic devices.

b. **Nondestructive Evaluation (NDE).** The use of nondestructive methods, including advanced technology approaches to classify or quantitatively measure flaws or irregularities, material condition, properties and dimensions of materials, and components to determine the degree of integrity and serviceability.

c. **Real Property Installed Equipment (RPIE).** Government owned or leased equipment that is physically attached to, integrated into, or built into or on Air Force property. It is usually procured through the military construction program and installed as part of the construction effort. It may also include equipment procured and installed through the United States Air Force Central Contracting Program as support equipment and then redesignated as RPIE.

d. **On-Condition Maintenance.** Repetitive inspections or tests to determine the condition of units or systems or portions of structure. These inspection and testing procedures do not require extensive removal or disassembly of the equipment.

e. **Modular Repair or Overhaul.** Applying maintenance procedures and techniques for defective subassemblies or modules and their repair or overhaul in place of treating the complete assembly as an entity for all maintenance actions.

3. Program Objectives:

a. Provide operational units with systems and equipment of maximum quality, capability, and integrity consistent with safety, reliability, and maintainability requirements.

b. Reduce cost of systems and equipment by defining NDI and on-condition maintenance requirements during the development and acquisition phase and incorporated during the demonstration and validation phases of a system's life cycle.

c. Permit development of new and improved inspection procedures by developing, validating, and implementing engineering and technical advances in NDI and NDE methodology.

d. Develop NDI capabilities that permit effective use of on-condition maintenance and module repair or overhaul

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Supersedes AFR 66-38, 5 February 1971. (See signature page for summary of changes.)
No of Printed Pages: 4
OPR: LEYE (Maj N. H. Criscimagna)
Approved by: Col C. P. Skipton
Writer-Editor: D. Britford
Distribution: F

concepts and provide the required operational capability at a low life cycle cost.

e. Maintain aerospace safety by detecting cracks or material flaws that could grow to critical lengths before the next inspection.

4. Air Force Policies:

a. NDI methods are used by all activities as part of an on-condition maintenance concept to enhance safety and to reduce maintenance costs, inspection work-hours, and systems or equipment downtime.

b. Accessibility of critical systems or equipment components for NDI will be considered during design and service life. Consider increasing design safety margins for those critical components not accessible for periodic inspection.

c. An NDI program must be developed and maintained by the Air Force NDI program office with help from the designated using and support commands. The program includes personnel training, certification, and equipment control. The need for NDI tools, test equipment, technical orders, and training of appropriate maintenance personnel is identified as early as possible in the system's development phase and provided for before or along with the delivery of system or equipment. NDI resources must be managed and maintained throughout all life cycle phases. When economically sound, and consistent with operational needs, this NDI capability should be consolidated so that one activity performs all NDI at a geographical location such as a base or depot.

d. NDI requirements are defined during the demonstration and validation phase, and included in specifications, drawings, and other contractual documents. NDI techniques for the system or equipment are developed and validated during the full-scale engineering development phase of the program. Government standards and handbooks are cited in contracts to require contractors to merge NDI requirements into the design and planning functions. Engineering activities will use NDI where applicable for qualification, preproduction, and first article testing. Government quality assurance personnel will use NDI techniques to assess products offered to the government for acceptance.

5. HQ USAF Responsibilities:

a. Directorate of Maintenance and Supply (HQ USAF/LEY) provides overall program policy.

b. The Directorate of Engineering and Services (HQ USAF/LEE) will coordinate with Air Force Logistics Command (AFLC), Air Force Systems Command (AFSC), and the Air Force Surgeon General (HQ AFMSC/SGPA) on NDI facility designs.

c. The Directorate of Professional Services (HQ AFMSC/SGP) provides the occupational health guidance used by HQ USAF/LEE and AFLC to determine:

(1) Design parameters for NDI facilities and equipment.

(2) Policy and procedures for conducting NDI operations.

6. Major Command (MAJCOM) Responsibilities:

a. Each MAJCOM identifies an office of primary responsibility (OPR) to coordinate the implementation of this program in support of the command mission. Each command:

(1) Appoints a staff level NDI manager to:

(a) Serve as a focal point for command NDI activity.

(b) Draft command directives to implement this regulation.

(c) Make sure that all organizational levels understand their responsibilities.

(d) Conduct a periodic review of each base's NDI facilities, personnel, equipment, and procedures. Work with the Air Force NDI program office in setting up a survey once every 3 years at selected bases.

(e) Coordinate command NDI policies, objectives, and projects with other command staff managers as appropriate.

(2) Maintains and operates, at designated locations, an NDI capability to:

(a) Provide centralized NDI services to host, tenant, and off-base supported Air Force organizations according to AFR 11-4.

(b) Serve as the base level focal point for evaluating new NDI applications and techniques, and for developing new procedures.

(c) Within available resources, provide NDI support to other Department of Defense (DOD) agencies according to AFRs 172-3, and 400-27. Get proper reimbursement for such support where appropriate.

(d) When asked, help supported activities to apply NDI techniques and to resolve NDI problems.

(e) Support the NDI needs of contractors who are working at Air Force locations under DOD support agreements or contracts. This includes support furnished supporting contractors who are engaged in weapon systems site activation activities as well as any support determined to be in the best interest of DOD.

b. Program, establish, and maintain adequate staffing, facilities, materials, and equipment necessary for the NDI program.

c. Program and budget for necessary NDI funds. Make sure NDI receives the appropriate priority in budget requests.

d. Program and plan for NDI training needs. Make effective use of NDI technicians to support current and future workloads.

(1) NDI personnel should be qualified by attending an Air Force approved NDI training program in the NDI methods they are required to use.

(2) All military NDI personnel, including retrainees, must attend NDI basic course C3ABR42732. Nonsupervisory civilians should complete the above course or its equivalent. Military in the grade of staff sergeant and above should attend the advanced course, C3AZR42772. Civilians in immediate supervisory NDI positions should also attend this course or one approved by the Air Force NDI program office.

e. Use NDI methods whenever possible in modifying or altering systems and equipment.

f. Conduct an annual assessment of the command's NDI equipment use and validity of equipment authorizations.

g. Develop guidelines for base level participation for evaluating new NDI applications and techniques and for developing new procedures.

h. Report deficiencies using established collection and reporting procedures. Civil Engineer channels are used when appropriate.

i. Provide guidance to commanders about potential hazards and safe operating procedures for NDI equipment or methods being developed, tested, or evaluated.

7. Additional AFLC Responsibilities as the Lead Command:

a. Set up an Air Force NDI program office to:

(1) Manage an Air Force NDI program that meets all the objectives as stated in paragraph 3.

(2) Plan, develop, and direct the Air Force NDI program as it pertains to funding, policies, procedures, personnel training, and equipment.

(3) Help the MAJCOMs to achieve the most benefits from the Air Force NDI program.

(4) Develop and maintain a long range plan for the Air Force NDI program.

b. Set up a program to review, maintain, and update, the system-peculiar NDI manuals for which AFLC has engineering responsibility.

c. Help the using commands develop NDI techniques to solve specific problems on their systems and equipment.

d. Use information provided by aircraft structural integrity program reports (see AFR 80-13) and the series of AFTO Forms 242, Nondestructive Inspection Data to:

(1) Identify those items requiring NDI.

(2) Determine the effectiveness of NDI application.

(3) Recommend changes in inspection intervals.

e. Review depot level work statements and work specifications for NDI applications.

f. Determine, test, and evaluate requirements for NDI equipment, methods, and applications within areas of engineering responsibility. Act as the single point approval agency for changes in these requirements and for their solutions. Make sure standard equipment is used when possible and provide a list of standard NDI equipment to include in the Air Force Standard/Preferred Item List (see AFR 800-22).

g. Draft and publish guidance and procedures for interchange of data on new or improved NDI procedures, techniques, and equipment. Coordinate with HQ USAF/LEE on matters involving RPIE.

h. Coordinate with AFSC, as required, to make sure that:

(1) Specifications, statements of work, and other contractural documents include clear concise NDI requirements.

(2) NDI methods, procedures, data, and reporting requirements are part of the maintenance concept for new systems, subsystems, and equipment.

(3) NDI methods, procedures, and equipment requirements are verified before introducing the system or equipment into the operational inventory. Potential hazards to NDI personnel are identified and protective equipment requirements or procedures are also verified.

i. Provide the latest technical data to Air Training Command (ATC) for use in their training courses.

j. Conduct field service tests of NDI equipment, review application, and prepare procedures with the assistance and coordination of command NDI managers.

k. Provide NDI team support to commands according to TO 00-25-107.

l. Develop NDI procedures for system managers, item managers, and commands that contribute to:

(1) Improved reliability.

(2) Defect detection.

(3) Safety and mission effectiveness.

(4) Increased work-hour savings and reduced equipment downtime.

m. Serve as the Air Force preparing activity and custodian of specifications used to prepare Air Force NDI technical orders.

n. Work with the MAJCOM managers to set up a schedule for surveying selected bases at each command once every 3 years. Conduct the surveys with appropriate other command personnel.

8. Additional AFSC Responsibilities:

a. Plan, develop, and direct the Air Force NDE research and development program as it pertains to funding, policies, and procedures. Perform research and development on new and improved NDE technology and methods to further the state-of-the-art and capabilities of the Air Force NDI program. This includes developing, improving, and evaluating NDI and NDE methods, techniques, equipment, procedures, specifications, standards, and the role of human factors. During NDE system development, identify potential hazards to NDI personnel and develop adequate protection from these hazards.

b. Develop and include NDI and NDE requirements in contracts for weapon systems and equipment. this includes development of system peculiar technical manuals according to MIL-M-38780 concurrently with new systems development.

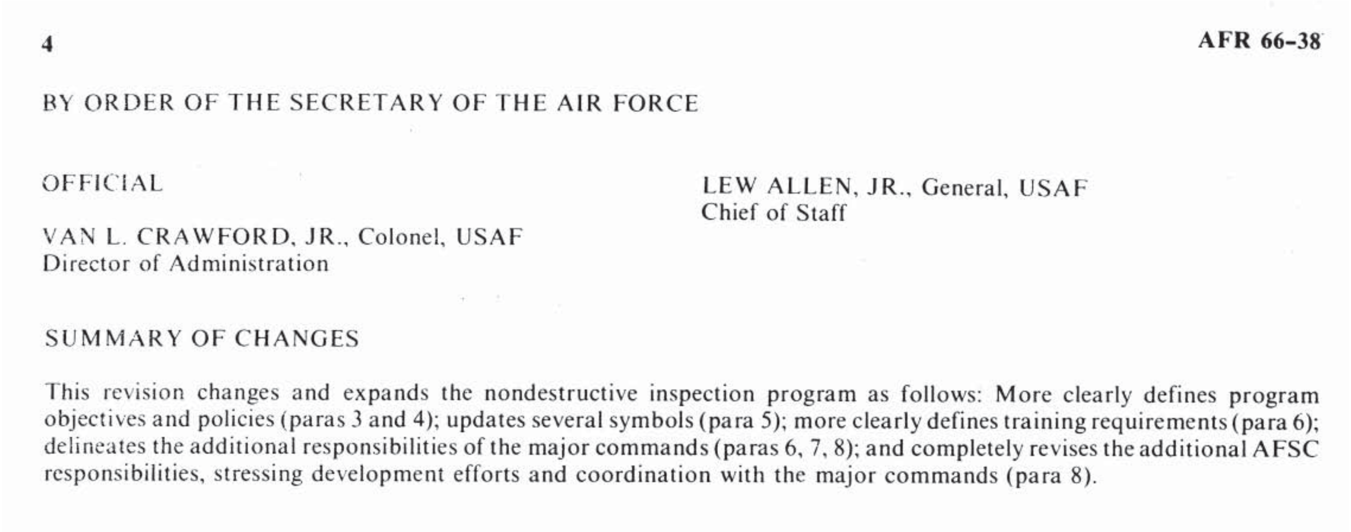
c. Develop life cycle NDI and NDE requirements for systems and equipment test and maintenance programs, including test criteria, NDI equipment, and procedures for using commands.

d. Make sure contractors comply with NDI and NDE contract requirements.

e. Support AFLC, ATC, and using commands in investigating and resolving service problems, field testing equipment, and training and certifying NDI personnel.

f. Coordinate all NDI related efforts in each program office to make sure that the above responsiblities are met. Keep AFLC, ATC, and using commands informed of the results of these efforts.

g. Provide consultation to using commands on medical aspects of NDI and NDE procedures and methods according to AFRs 161-17 and 161-2.



4 **AFR 66-38**

BY ORDER OF THE SECRETARY OF THE AIR FORCE

OFFICIAL

LEW ALLEN, JR., General, USAF
Chief of Staff

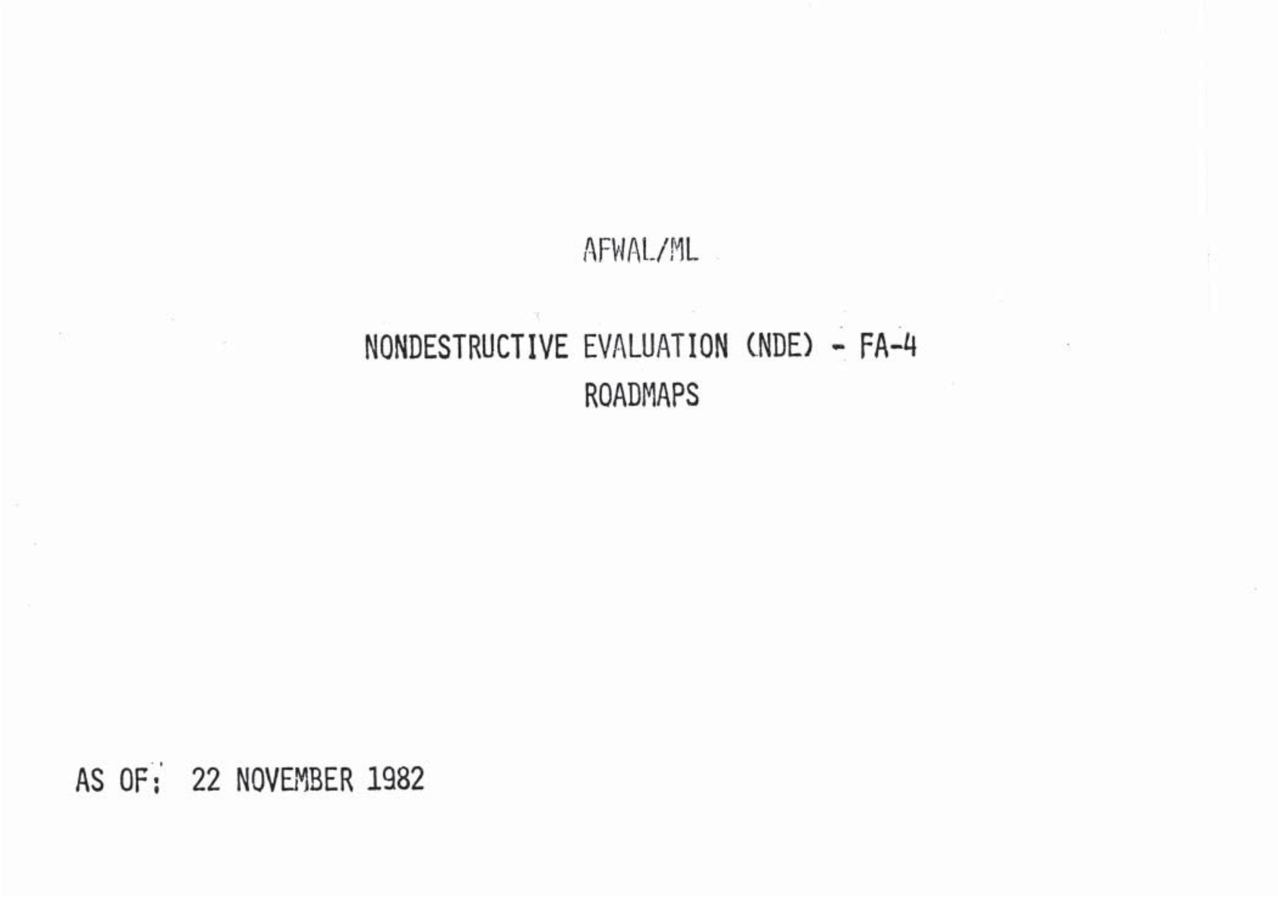
VAN L. CRAWFORD, JR., Colonel, USAF
Director of Administration

SUMMARY OF CHANGES

This revision changes and expands the nondestructive inspection program as follows: More clearly defines program objectives and policies (paras 3 and 4); updates several symbols (para 5); more clearly defines training requirements (para 6); delineates the additional responsibilities of the major commands (paras 6, 7, 8); and completely revises the additional AFSC responsibilities, stressing development efforts and coordination with the major commands (para 8).

APPENDIX F-4

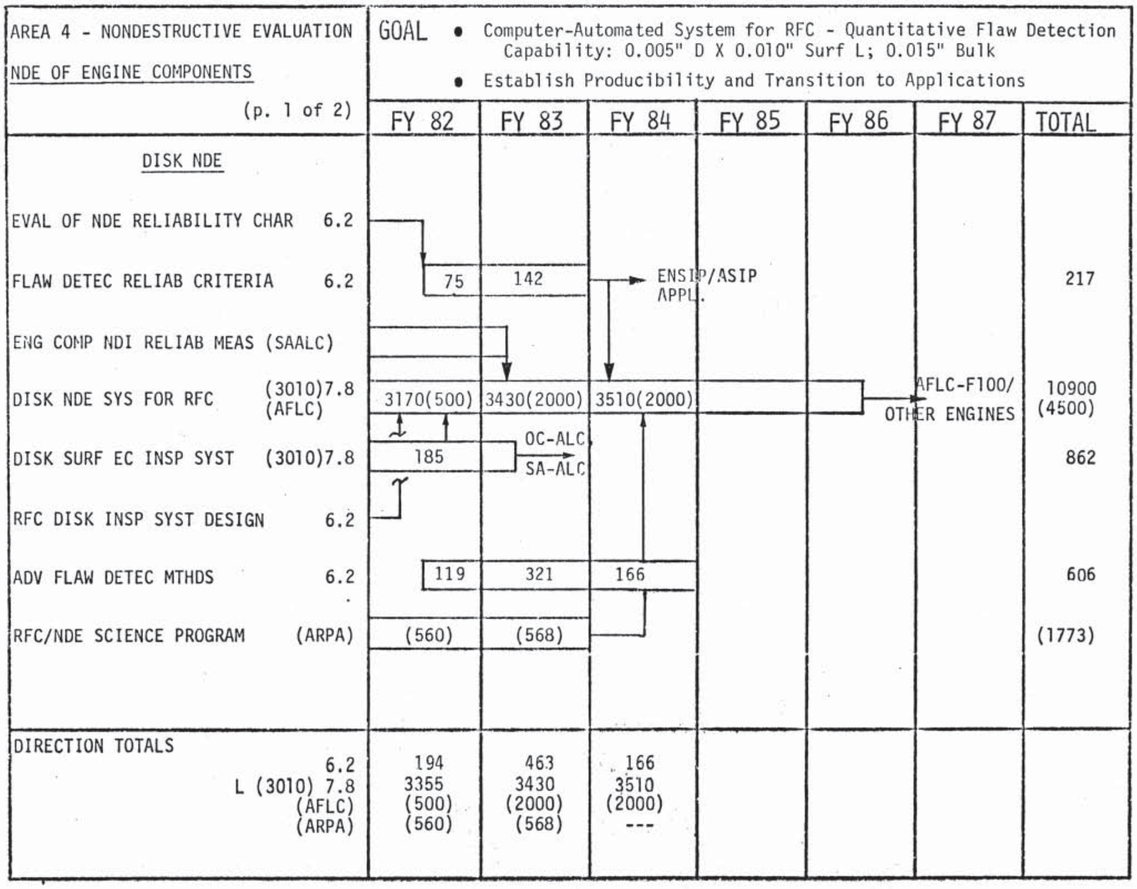
Original ML Focal Area 4 NDE Program Roadmaps for the Planning Period of FY 82 - FY 87.



AFWAL/ML

NONDESTRUCTIVE EVALUATION (NDE) - FA-4
ROADMAPS

AS OF: 22 NOVEMBER 1982



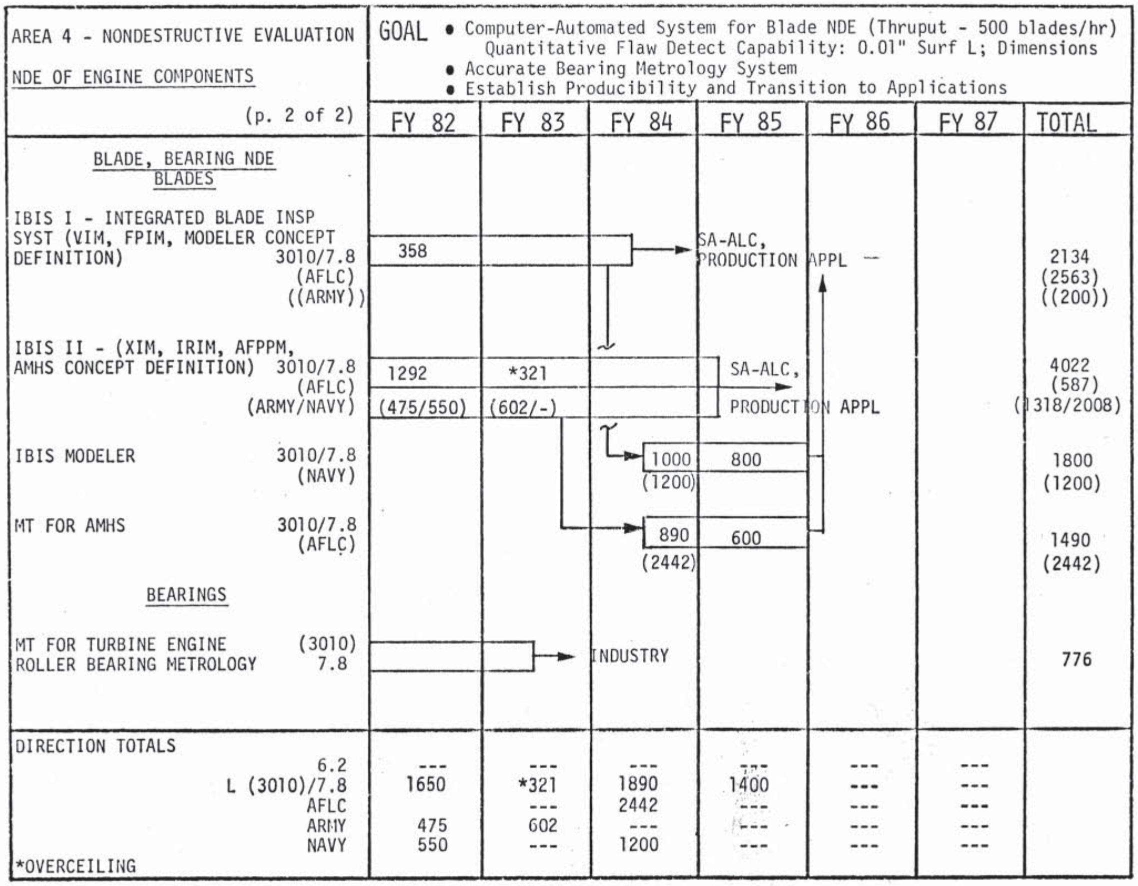
AREA 4 - NONDESTRUCTIVE EVALUATION

NDE OF ENGINE COMPONENTS

(p. 1 of 2)

GOAL
- Computer-Automated System for RFC - Quantitative Flaw Detection Capability: 0.005" D X 0.010" Surf L; 0.015" Bulk
- Establish Producibility and Transition to Applications

	FY 82	FY 83	FY 84	FY 85	FY 86	FY 87	TOTAL
DISK NDE							
EVAL OF NDE RELIABILITY CHAR 6.2							
FLAW DETEC RELIAB CRITERIA 6.2	75	142		ENSIP/ASIP APPL.			217
ENG COMP NDI RELIAB MEAS (SAALC)							
DISK NDE SYS FOR RFC (3010)7.8 (AFLC)	3170(500)	3430(2000)	3510(2000)			AFLC-F100/ OTHER ENGINES	10900 (4500)
DISK SURF EC INSP SYST (3010)7.8	185	OC-ALC, SA-ALC					862
RFC DISK INSP SYST DESIGN 6.2							
ADV FLAW DETEC MTHDS 6.2	119	321	166				606
RFC/NDE SCIENCE PROGRAM (ARPA)	(560)	(568)					(1773)
DIRECTION TOTALS							
6.2	194	463	166				
L (3010) 7.8	3355	3430	3510				
(AFLC)	(500)	(2000)	(2000)				
(ARPA)	(560)	(568)	---				



AREA 4 - NONDESTRUCTIVE EVALUATION

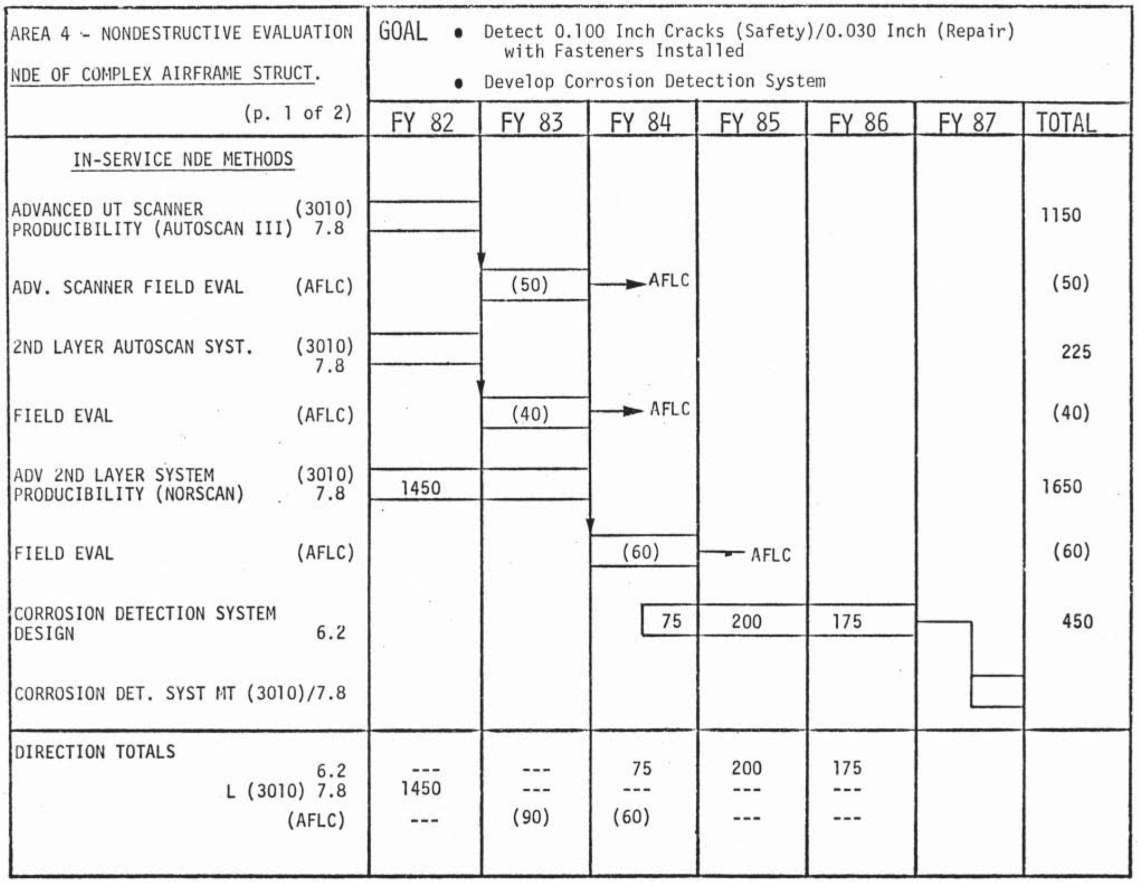
NDE OF ENGINE COMPONENTS

(p. 2 of 2)

GOAL
- Computer-Automated System for Blade NDE (Thruput - 500 blades/hr) Quantitative Flaw Detect Capability: 0.01" Surf L; Dimensions
- Accurate Bearing Metrology System
- Establish Producibility and Transition to Applications

	FY 82	FY 83	FY 84	FY 85	FY 86	FY 87	TOTAL
BLADE, BEARING NDE BLADES							
IBIS I - INTEGRATED BLADE INSP SYST (VIM, FPIM, MODELER CONCEPT DEFINITION) 3010/7.8 (AFLC) ((ARMY))	358			SA-ALC, PRODUCTION APPL —			2134 (2563) ((200))
IBIS II - (XIM, IRIM, AFPPM, AMHS CONCEPT DEFINITION) 3010/7.8 (AFLC) (ARMY/NAVY)	1292 (475/550)	*321 (602/-)		SA-ALC, PRODUCTION APPL			4022 (587) (1318/2008)
IBIS MODELER 3010/7.8 (NAVY)			1000 (1200)	800			1800 (1200)
MT FOR AMHS 3010/7.8 (AFLC)			890 (2442)	600			1490 (2442)
BEARINGS							
MT FOR TURBINE ENGINE ROLLER BEARING METROLOGY (3010) 7.8			INDUSTRY				776
DIRECTION TOTALS							
6.2	---	---	---	---	---	---	
L (3010)/7.8	1650	*321	1890	1400	---	---	
AFLC		---	2442	---	---	---	
ARMY	475	602	---	---	---	---	
NAVY	550	---	1200	---	---	---	

*OVERCEILING



AREA 4 - NONDESTRUCTIVE EVALUATION

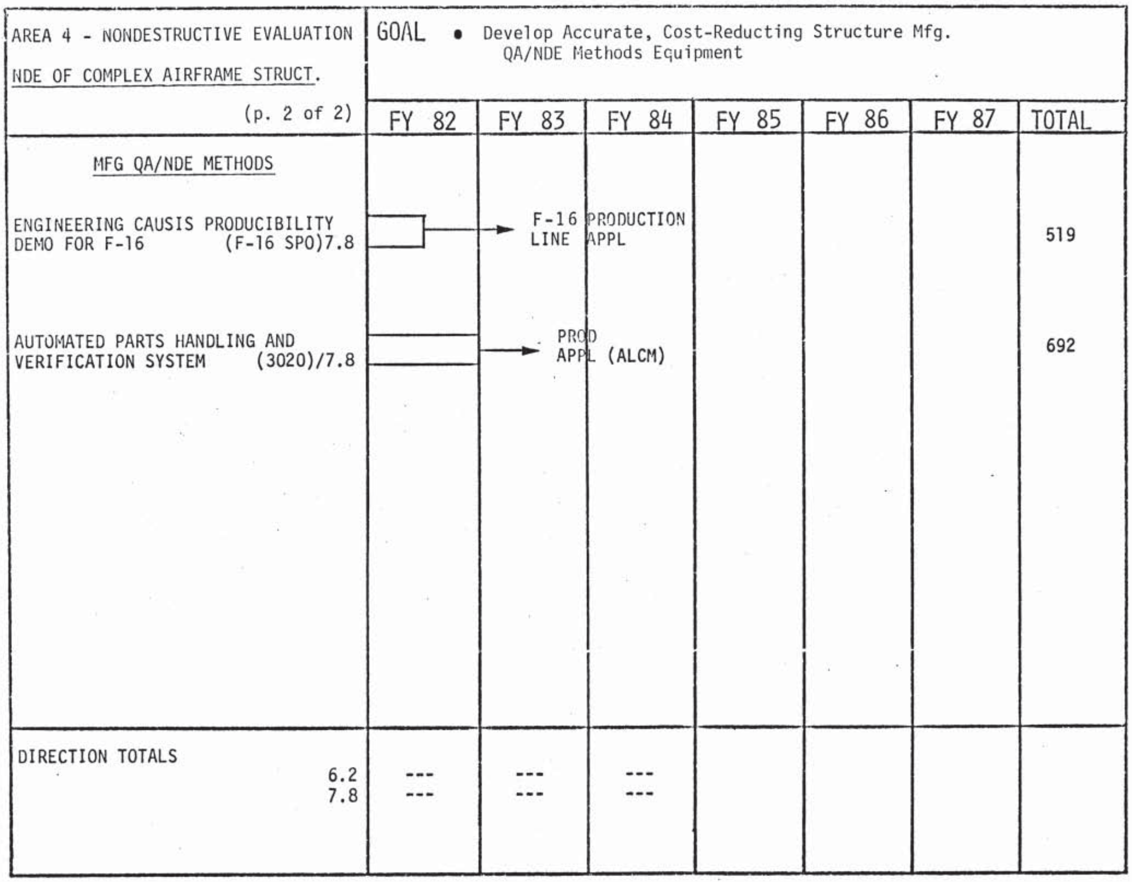
NDE OF COMPLEX AIRFRAME STRUCT.

(p. 1 of 2)

GOAL

- Detect 0.100 Inch Cracks (Safety)/0.030 Inch (Repair) with Fasteners Installed
- Develop Corrosion Detection System

IN-SERVICE NDE METHODS	FY 82	FY 83	FY 84	FY 85	FY 86	FY 87	TOTAL
ADVANCED UT SCANNER PRODUCIBILITY (AUTOSCAN III) (3010) 7.8							1150
ADV. SCANNER FIELD EVAL (AFLC)		(50)	AFLC				(50)
2ND LAYER AUTOSCAN SYST. (3010) 7.8							225
FIELD EVAL (AFLC)		(40)	AFLC				(40)
ADV 2ND LAYER SYSTEM PRODUCIBILITY (NORSCAN) (3010) 7.8	1450						1650
FIELD EVAL (AFLC)			(60)	AFLC			(60)
CORROSION DETECTION SYSTEM DESIGN 6.2			75	200	175		450
CORROSION DET. SYST MT (3010)/7.8							
DIRECTION TOTALS 6.2	---	---	75	200	175		
L (3010) 7.8	1450	---	---	---	---		
(AFLC)	---	(90)	(60)	---	---		



AREA 4 - NONDESTRUCTIVE EVALUATION

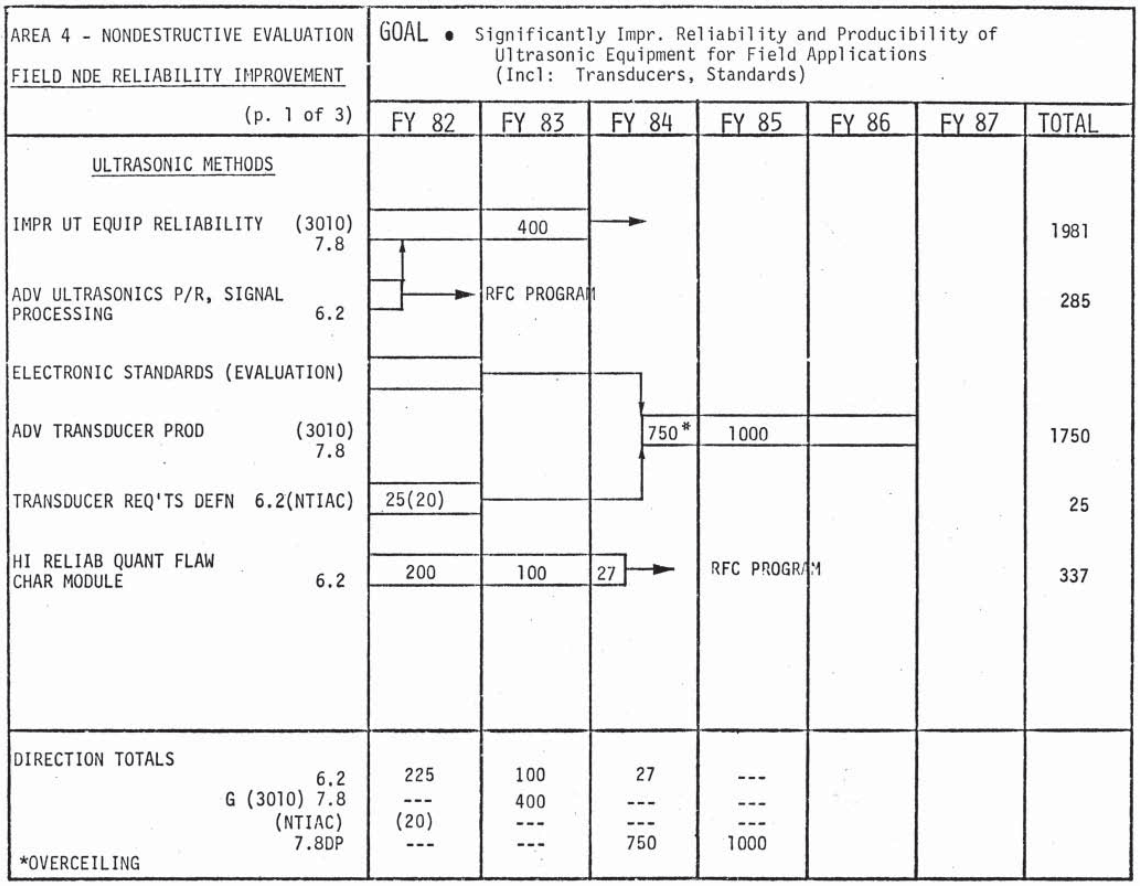
NDE OF COMPLEX AIRFRAME STRUCT.

(p. 2 of 2)

GOAL

- Develop Accurate, Cost-Reducting Structure Mfg. QA/NDE Methods Equipment

MFG QA/NDE METHODS	FY 82	FY 83	FY 84	FY 85	FY 86	FY 87	TOTAL
ENGINEERING CAUSIS PRODUCIBILITY DEMO FOR F-16 (F-16 SPO)7.8		F-16 LINE	PRODUCTION APPL				519
AUTOMATED PARTS HANDLING AND VERIFICATION SYSTEM (3020)/7.8		PROD APPL (ALCM)					692
DIRECTION TOTALS 6.2	---	---	---				
7.8	---	---	---				



AREA 4 - NONDESTRUCTIVE EVALUATION

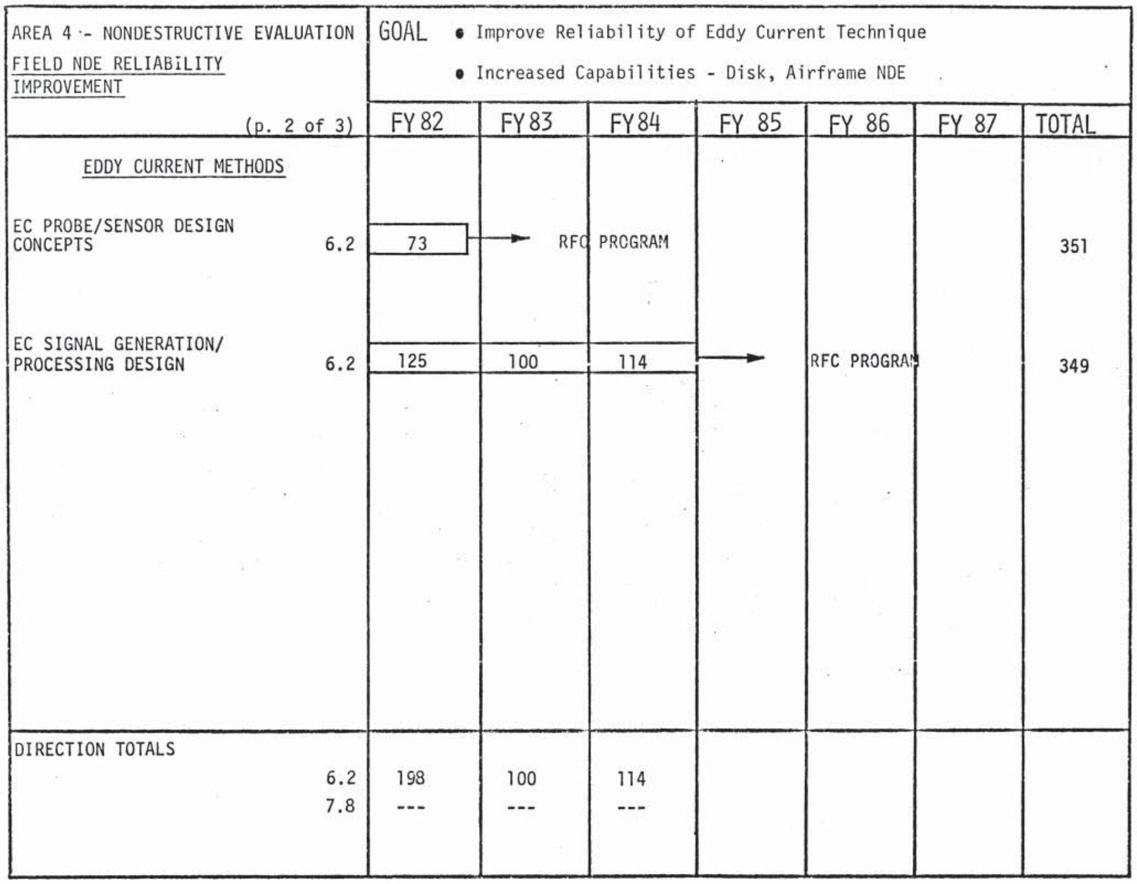
FIELD NDE RELIABILITY IMPROVEMENT

(p. 1 of 3)

GOAL • Significantly Impr. Reliability and Producibility of Ultrasonic Equipment for Field Applications (Incl: Transducers, Standards)

	FY 82	FY 83	FY 84	FY 85	FY 86	FY 87	TOTAL
ULTRASONIC METHODS							
IMPR UT EQUIP RELIABILITY (3010) 7.8		400	→				1981
ADV ULTRASONICS P/R, SIGNAL PROCESSING 6.2	→	RFC PROGRAM					285
ELECTRONIC STANDARDS (EVALUATION)							
ADV TRANSDUCER PROD (3010) 7.8			750*	1000			1750
TRANSDUCER REQ'TS DEFN 6.2(NTIAC)	25(20)						25
HI RELIAB QUANT FLAW CHAR MODULE 6.2	200	100	27 →	RFC PROGRAM			337
DIRECTION TOTALS							
6.2	225	100	27	---			
G (3010) 7.8	---	400	---	---			
(NTIAC)	(20)	---	---	---			
7.8DP	---	---	750	1000			

*OVERCEILING



AREA 4 - NONDESTRUCTIVE EVALUATION

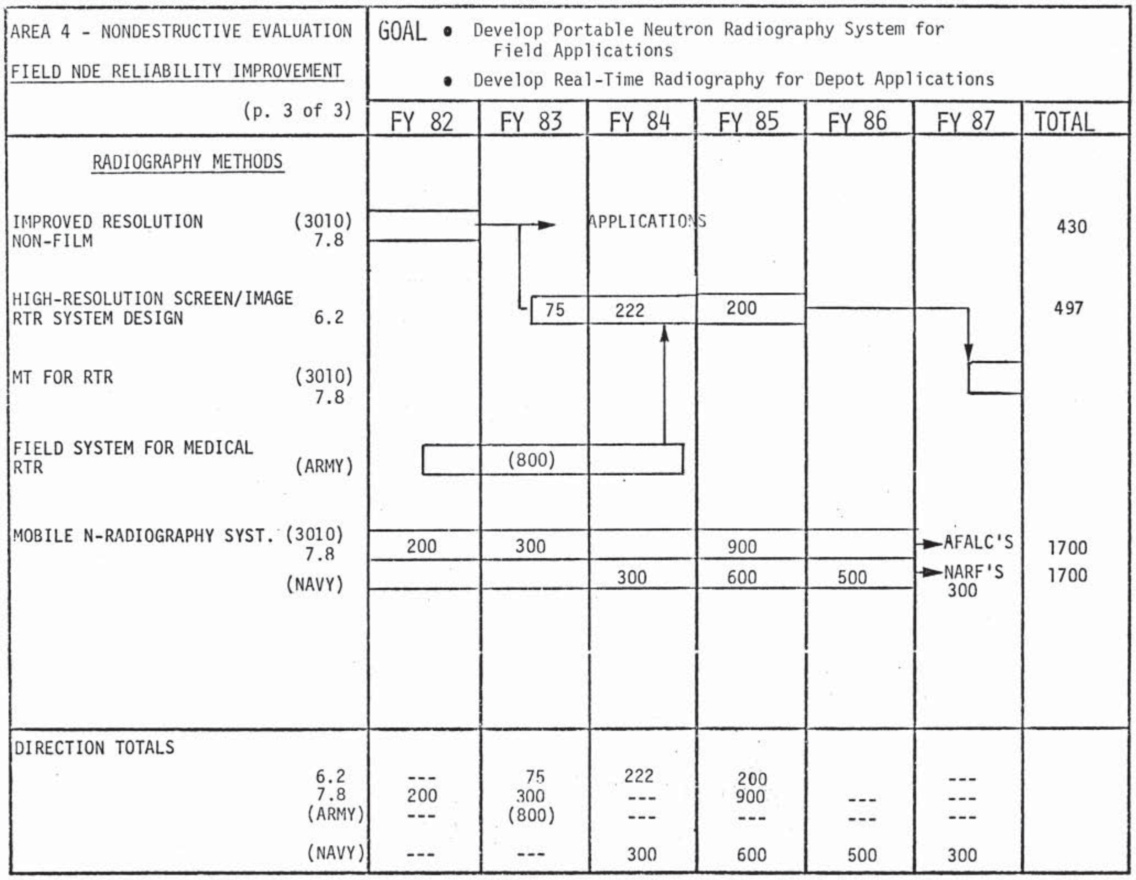
FIELD NDE RELIABILITY IMPROVEMENT

(p. 2 of 3)

GOAL • Improve Reliability of Eddy Current Technique

• Increased Capabilities - Disk, Airframe NDE

	FY 82	FY 83	FY 84	FY 85	FY 86	FY 87	TOTAL
EDDY CURRENT METHODS							
EC PROBE/SENSOR DESIGN CONCEPTS 6.2	73 →	RFC PROGRAM					351
EC SIGNAL GENERATION/ PROCESSING DESIGN 6.2	125	100	114	→	RFC PROGRAM		349
DIRECTION TOTALS							
6.2	198	100	114				
7.8	---	---	---				



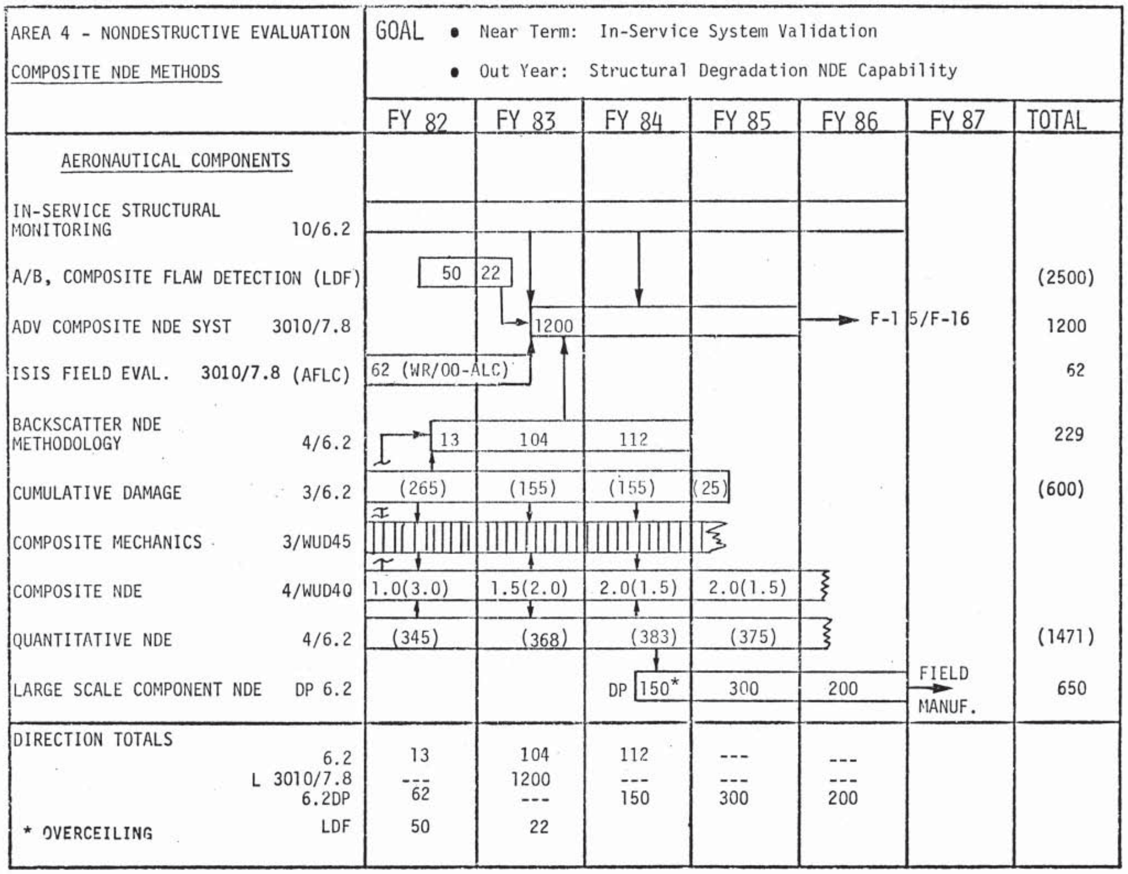
AREA 4 - NONDESTRUCTIVE EVALUATION

FIELD NDE RELIABILITY IMPROVEMENT

(p. 3 of 3)

GOAL
- Develop Portable Neutron Radiography System for Field Applications
- Develop Real-Time Radiography for Depot Applications

	FY 82	FY 83	FY 84	FY 85	FY 86	FY 87	TOTAL
RADIOGRAPHY METHODS							
IMPROVED RESOLUTION NON-FILM (3010) 7.8			APPLICATIONS				430
HIGH-RESOLUTION SCREEN/IMAGE RTR SYSTEM DESIGN 6.2		75	222	200			497
MT FOR RTR (3010) 7.8							
FIELD SYSTEM FOR MEDICAL RTR (ARMY)		(800)					
MOBILE N-RADIOGRAPHY SYST. (3010) 7.8	200	300		900		AFALC'S	1700
(NAVY)			300	600	500	NARF'S 300	1700
DIRECTION TOTALS							
6.2	---	75	222	200	---	---	
7.8	200	300	---	900	---	---	
(ARMY)	---	(800)	---	---	---	---	
(NAVY)	---	---	300	600	500	300	



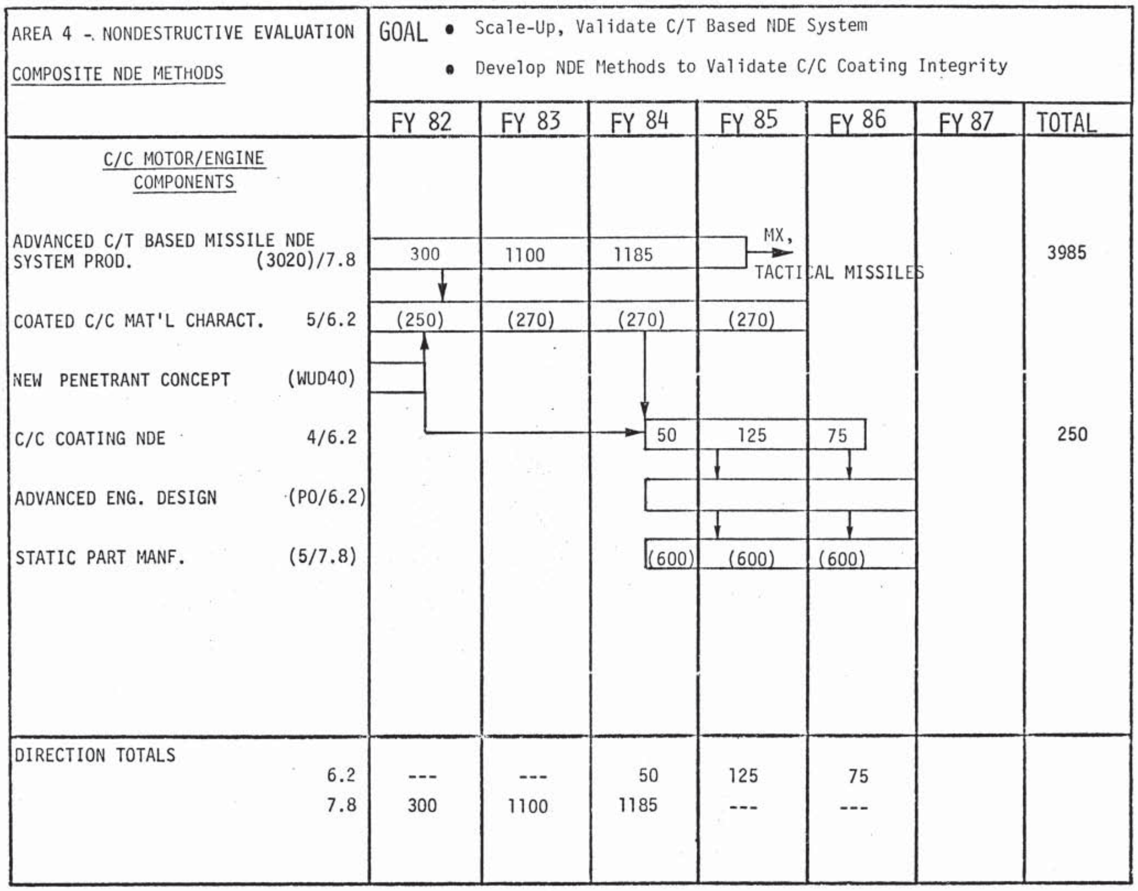
AREA 4 - NONDESTRUCTIVE EVALUATION

COMPOSITE NDE METHODS

GOAL
- Near Term: In-Service System Validation
- Out Year: Structural Degradation NDE Capability

	FY 82	FY 83	FY 84	FY 85	FY 86	FY 87	TOTAL
AERONAUTICAL COMPONENTS							
IN-SERVICE STRUCTURAL MONITORING 10/6.2							
A/B, COMPOSITE FLAW DETECTION (LDF)	50	22					(2500)
ADV COMPOSITE NDE SYST 3010/7.8		1200				F-15/F-16	1200
ISIS FIELD EVAL. 3010/7.8 (AFLC)	62 (WR/OO-ALC)						62
BACKSCATTER NDE METHODOLOGY 4/6.2	13	104	112				229
CUMULATIVE DAMAGE 3/6.2	(265)	(155)	(155)	(25)			(600)
COMPOSITE MECHANICS 3/WUD45							
COMPOSITE NDE 4/WUD4Q	1.0(3.0)	1.5(2.0)	2.0(1.5)	2.0(1.5)			
QUANTITATIVE NDE 4/6.2	(345)	(368)	(383)	(375)			(1471)
LARGE SCALE COMPONENT NDE DP 6.2			DP 150*	300	200	FIELD MANUF.	650
DIRECTION TOTALS							
6.2	13	104	112	---	---		
L 3010/7.8	---	1200	---	---	---		
6.2DP	62	---	150	300	200		
LDF	50	22					

* OVERCEILING

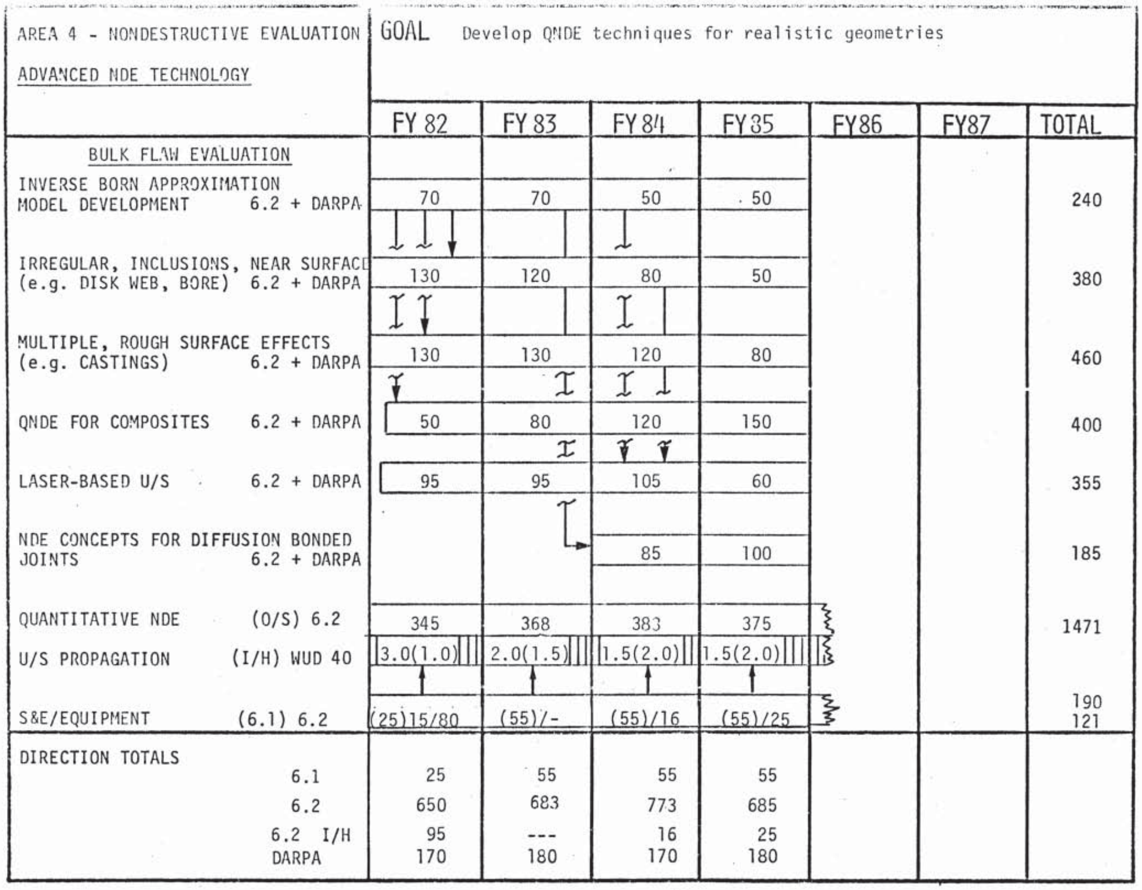


AREA 4 - NONDESTRUCTIVE EVALUATION

COMPOSITE NDE METHODS

GOAL
- Scale-Up, Validate C/T Based NDE System
- Develop NDE Methods to Validate C/C Coating Integrity

	FY 82	FY 83	FY 84	FY 85	FY 86	FY 87	TOTAL
C/C MOTOR/ENGINE COMPONENTS							
ADVANCED C/T BASED MISSILE NDE SYSTEM PROD. (3020)/7.8	300	1100	1185	MX, TACTICAL MISSILES			3985
COATED C/C MAT'L CHARACT. 5/6.2	(250)	(270)	(270)	(270)			
NEW PENETRANT CONCEPT (WUD40)							
C/C COATING NDE 4/6.2			50	125	75		250
ADVANCED ENG. DESIGN (PO/6.2)							
STATIC PART MANF. (5/7.8)			(600)	(600)	(600)		
DIRECTION TOTALS 6.2	---	---	50	125	75		
7.8	300	1100	1185	---	---		

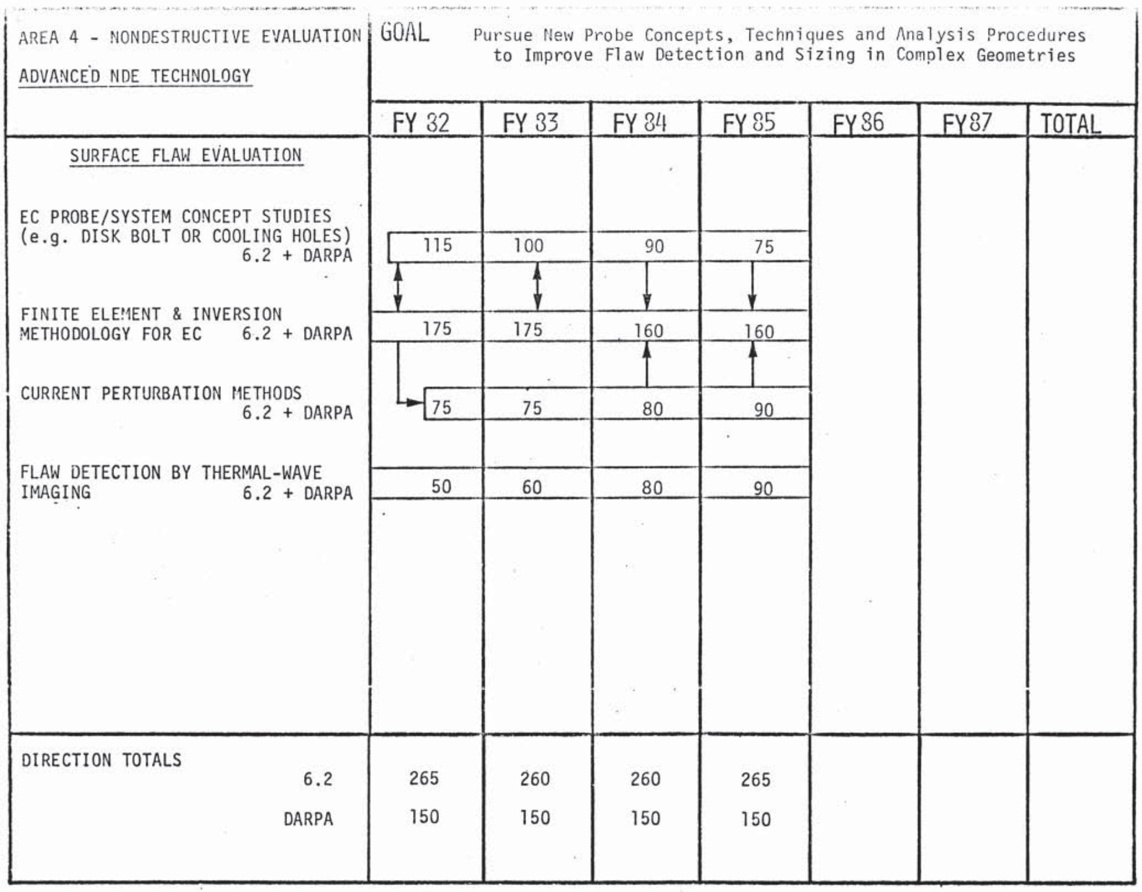


AREA 4 - NONDESTRUCTIVE EVALUATION

ADVANCED NDE TECHNOLOGY

GOAL Develop QNDE techniques for realistic geometries

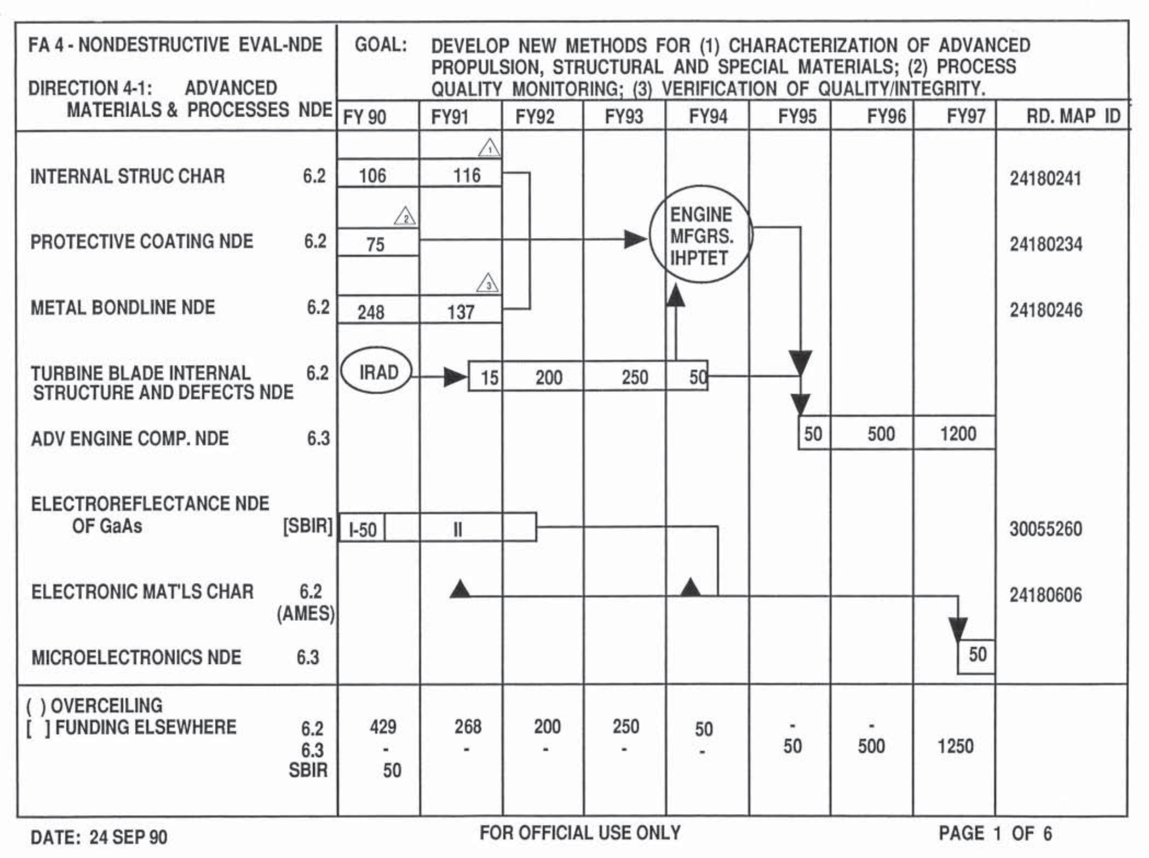
	FY 82	FY 83	FY 84	FY 85	FY86	FY87	TOTAL
BULK FLAW EVALUATION							
INVERSE BORN APPROXIMATION MODEL DEVELOPMENT 6.2 + DARPA	70	70	50	50			240
IRREGULAR, INCLUSIONS, NEAR SURFAC (e.g. DISK WEB, BORE) 6.2 + DARPA	130	120	80	50			380
MULTIPLE, ROUGH SURFACE EFFECTS (e.g. CASTINGS) 6.2 + DARPA	130	130	120	80			460
QNDE FOR COMPOSITES 6.2 + DARPA	50	80	120	150			400
LASER-BASED U/S 6.2 + DARPA	95	95	105	60			355
NDE CONCEPTS FOR DIFFUSION BONDED JOINTS 6.2 + DARPA			85	100			185
QUANTITATIVE NDE (O/S) 6.2	345	368	383	375			1471
U/S PROPAGATION (I/H) WUD 40	3.0(1.0)	2.0(1.5)	1.5(2.0)	1.5(2.0)			
S&E/EQUIPMENT (6.1) 6.2	(25)15/80	(55)/-	(55)/16	(55)/25			190 121
DIRECTION TOTALS 6.1	25	55	55	55			
6.2	650	683	773	685			
6.2 I/H	95	---	16	25			
DARPA	170	180	170	180			



AREA 4 - NONDESTRUCTIVE EVALUATION ADVANCED NDE TECHNOLOGY	GOAL Pursue New Probe Concepts, Techniques and Analysis Procedures to Improve Flaw Detection and Sizing in Complex Geometries						
	FY 82	FY 83	FY 84	FY 85	FY 86	FY 87	TOTAL
SURFACE FLAW EVALUATION							
EC PROBE/SYSTEM CONCEPT STUDIES (e.g. DISK BOLT OR COOLING HOLES) 6.2 + DARPA	115	100	90	75			
FINITE ELEMENT & INVERSION METHODOLOGY FOR EC 6.2 + DARPA	175	175	160	160			
CURRENT PERTURBATION METHODS 6.2 + DARPA	75	75	80	90			
FLAW DETECTION BY THERMAL-WAVE IMAGING 6.2 + DARPA	50	60	80	90			
DIRECTION TOTALS 6.2	265	260	260	265			
DARPA	150	150	150	150			

APPENDIX F-5

Original ML Focal Area 4 NDE Program Roadmaps for the Planning Period of FY 90 - FY 97.



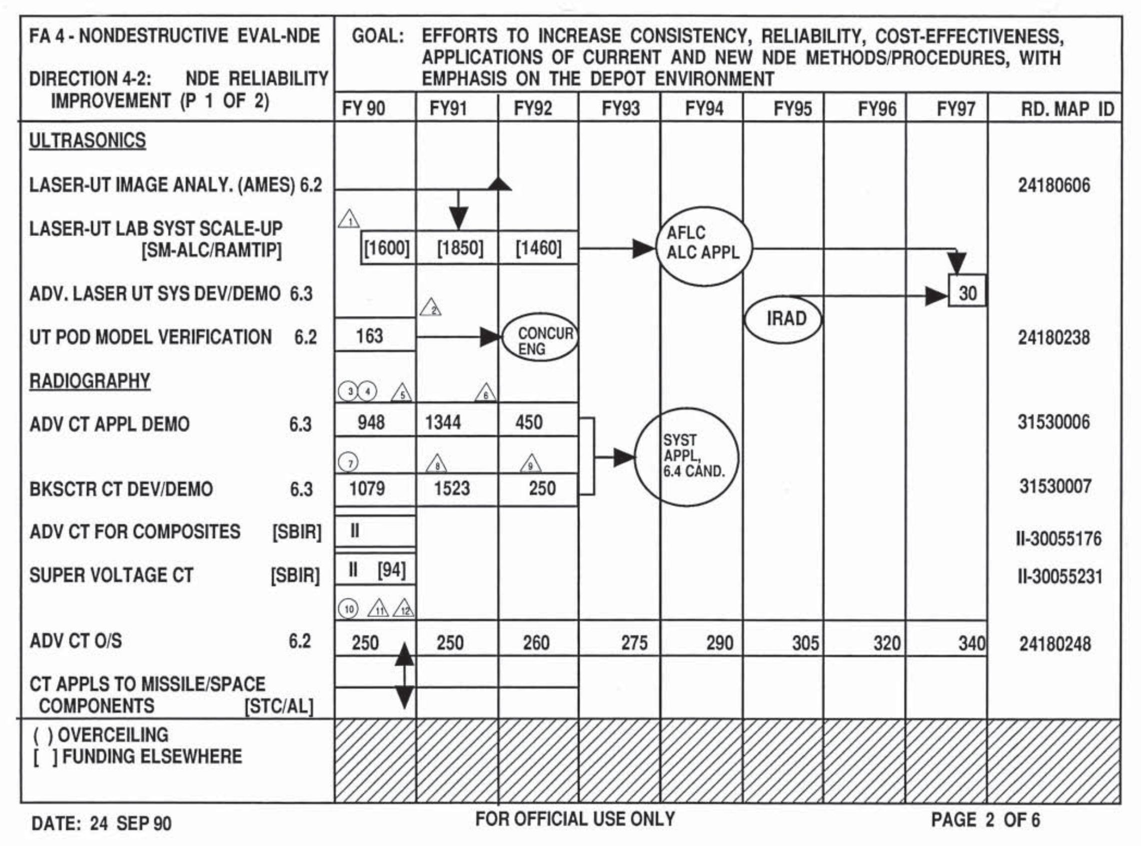
FA 4 - NONDESTRUCTIVE EVAL-NDE

DIRECTION 4-1: ADVANCED MATERIALS & PROCESSES NDE

GOAL: DEVELOP NEW METHODS FOR (1) CHARACTERIZATION OF ADVANCED PROPULSION, STRUCTURAL AND SPECIAL MATERIALS; (2) PROCESS QUALITY MONITORING; (3) VERIFICATION OF QUALITY/INTEGRITY.

		FY 90	FY91	FY92	FY93	FY94	FY95	FY96	FY97	RD. MAP ID
INTERNAL STRUC CHAR	6.2	106	△1 116							24180241
PROTECTIVE COATING NDE	6.2	△2 75				ENGINE MFGRS. IHPTET				24180234
METAL BONDLINE NDE	6.2	248	△3 137							24180246
TURBINE BLADE INTERNAL STRUCTURE AND DEFECTS NDE	6.2	IRAD	15	200	250	50				
ADV ENGINE COMP. NDE	6.3						50	500	1200	
ELECTROREFLECTANCE NDE OF GaAs	[SBIR]	I-50	II							30055260
ELECTRONIC MAT'LS CHAR	6.2 (AMES)									24180606
MICROELECTRONICS NDE	6.3								50	
( ) OVERCEILING [ ] FUNDING ELSEWHERE	6.2 6.3 SBIR	429 - 50	268 -	200 -	250 -	50 -	- 50	- 500	1250	

DATE: 24 SEP 90 FOR OFFICIAL USE ONLY PAGE 1 OF 6



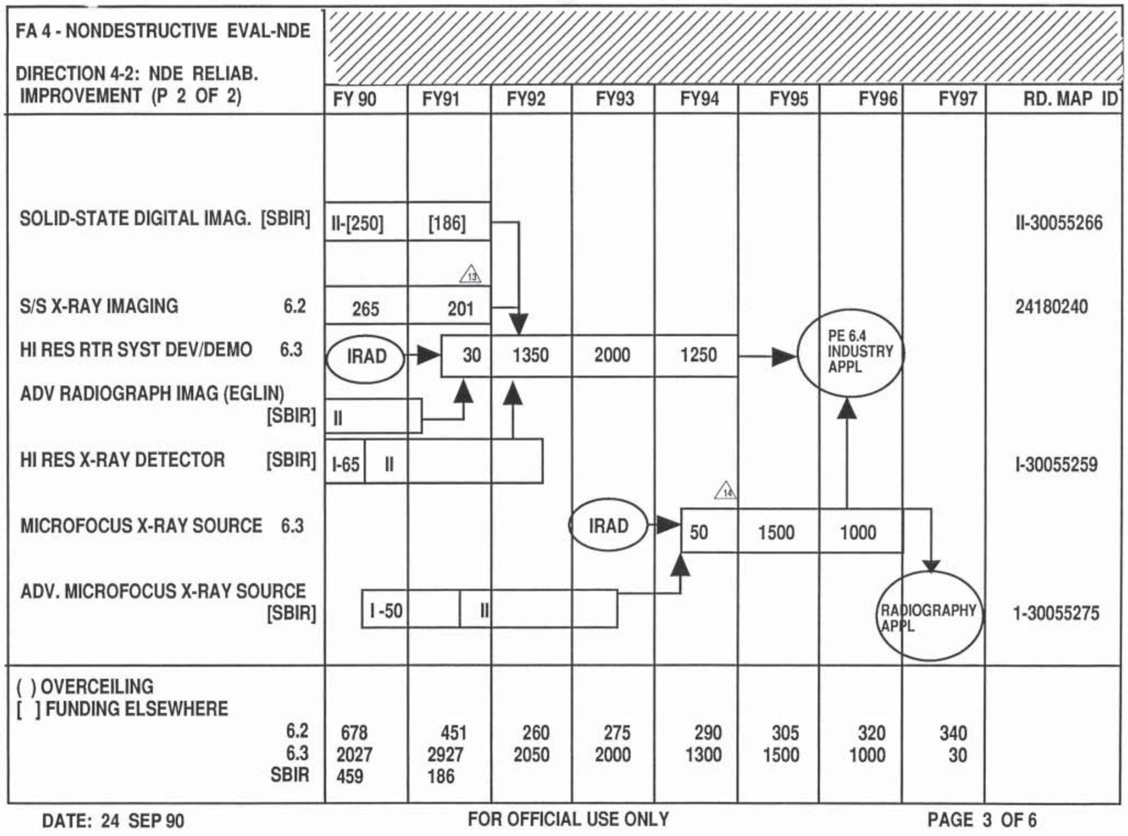
FA 4 - NONDESTRUCTIVE EVAL-NDE

DIRECTION 4-2: NDE RELIABILITY IMPROVEMENT (P 1 OF 2)

GOAL: EFFORTS TO INCREASE CONSISTENCY, RELIABILITY, COST-EFFECTIVENESS, APPLICATIONS OF CURRENT AND NEW NDE METHODS/PROCEDURES, WITH EMPHASIS ON THE DEPOT ENVIRONMENT

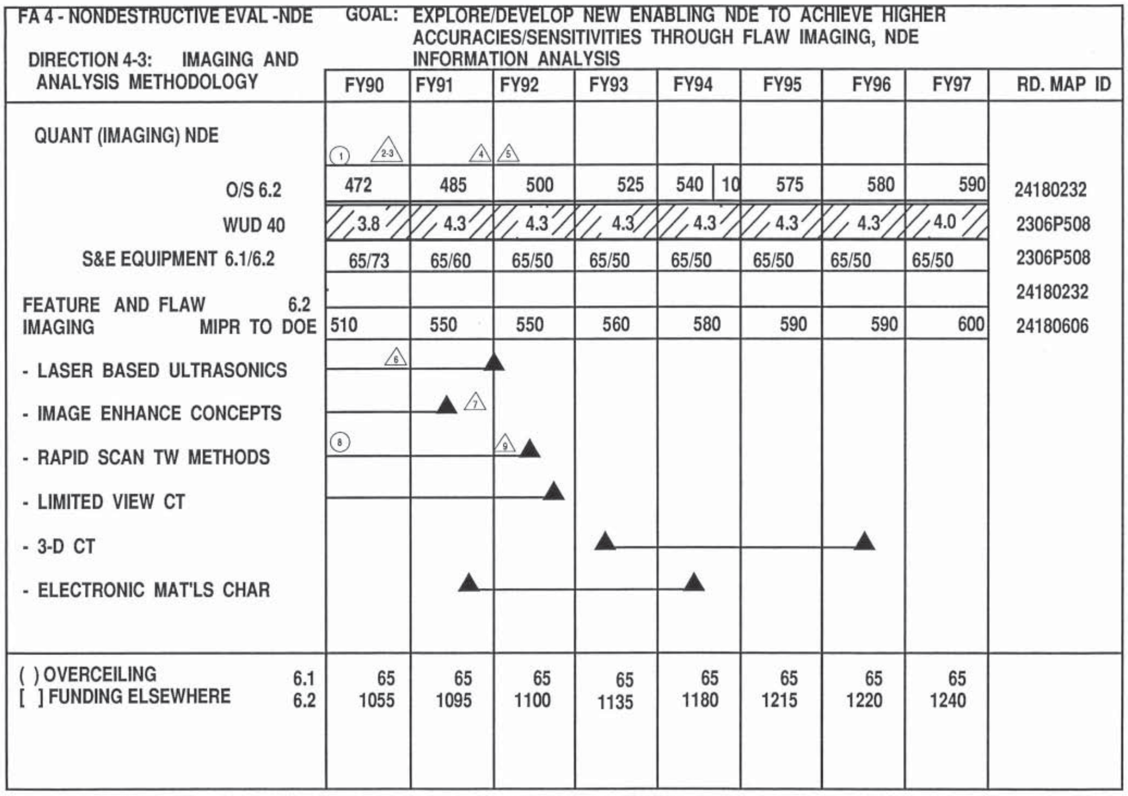
		FY 90	FY91	FY92	FY93	FY94	FY95	FY96	FY97	RD. MAP ID
ULTRASONICS										
LASER-UT IMAGE ANALY. (AMES)	6.2									24180606
LASER-UT LAB SYST SCALE-UP [SM-ALC/RAMTIP]		△1 [1600]	[1850]	[1460]		AFLC ALC APPL			30	
ADV. LASER UT SYS DEV/DEMO	6.3						IRAD			
UT POD MODEL VERIFICATION	6.2	163	△2	CONCUR ENG						24180238
RADIOGRAPHY										
ADV CT APPL DEMO	6.3	③ ④ △5 948	1344	△6 450		SYST APPL, 6.4 CAND.				31530006
BKSCTR CT DEV/DEMO	6.3	⑦ 1079	△8 1523	△9 250						31530007
ADV CT FOR COMPOSITES	[SBIR]	II								II-30055176
SUPER VOLTAGE CT	[SBIR]	II [94]								II-30055231
ADV CT O/S	6.2	⑩ △11 △12 250	250	260	275	290	305	320	340	24180248
CT APPLS TO MISSILE/SPACE COMPONENTS	[STC/AL]									
( ) OVERCEILING [ ] FUNDING ELSEWHERE		▨	▨	▨	▨	▨	▨	▨	▨	▨

DATE: 24 SEP 90 FOR OFFICIAL USE ONLY PAGE 2 OF 6



FA 4 - NONDESTRUCTIVE EVAL-NDE DIRECTION 4-2: NDE RELIAB. IMPROVEMENT (P 2 OF 2)	FY 90	FY91	FY92	FY93	FY94	FY95	FY96	FY97	RD. MAP ID
SOLID-STATE DIGITAL IMAG. [SBIR]	II-[250]	[186]							II-30055266
		△13							
S/S X-RAY IMAGING 6.2	265	201							24180240
HI RES RTR SYST DEV/DEMO 6.3	IRAD	30	1350	2000	1250		PE 6.4 INDUSTRY APPL		
ADV RADIOGRAPH IMAG (EGLIN) [SBIR]	II								
HI RES X-RAY DETECTOR [SBIR]	I-65 II								I-30055259
					△14				
MICROFOCUS X-RAY SOURCE 6.3				IRAD	50	1500	1000		
ADV. MICROFOCUS X-RAY SOURCE [SBIR]	I -50	II						RADIOGRAPHY APPL	1-30055275
( ) OVERCEILING [ ] FUNDING ELSEWHERE									
6.2	678	451	260	275	290	305	320	340	
6.3	2027	2927	2050	2000	1300	1500	1000	30	
SBIR	459	186							

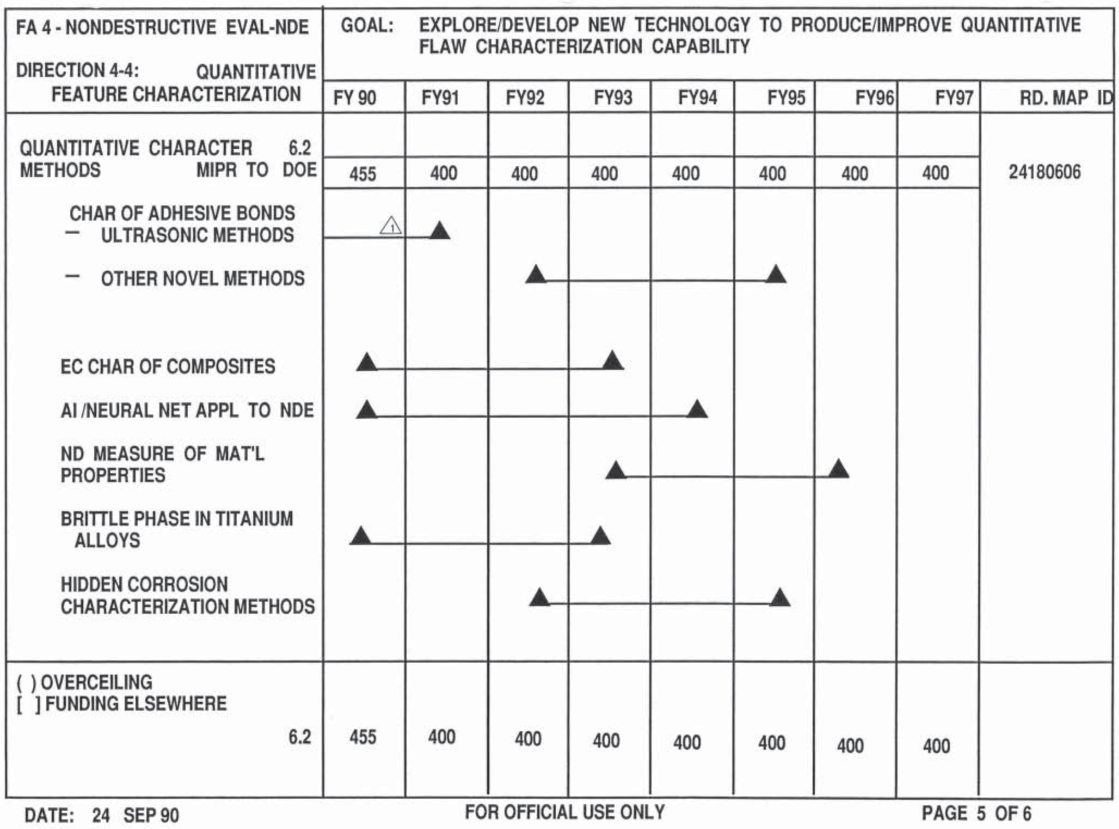
DATE: 24 SEP 90 FOR OFFICIAL USE ONLY PAGE 3 OF 6



FA 4 - NONDESTRUCTIVE EVAL -NDE GOAL: EXPLORE/DEVELOP NEW ENABLING NDE TO ACHIEVE HIGHER ACCURACIES/SENSITIVITIES THROUGH FLAW IMAGING, NDE INFORMATION ANALYSIS

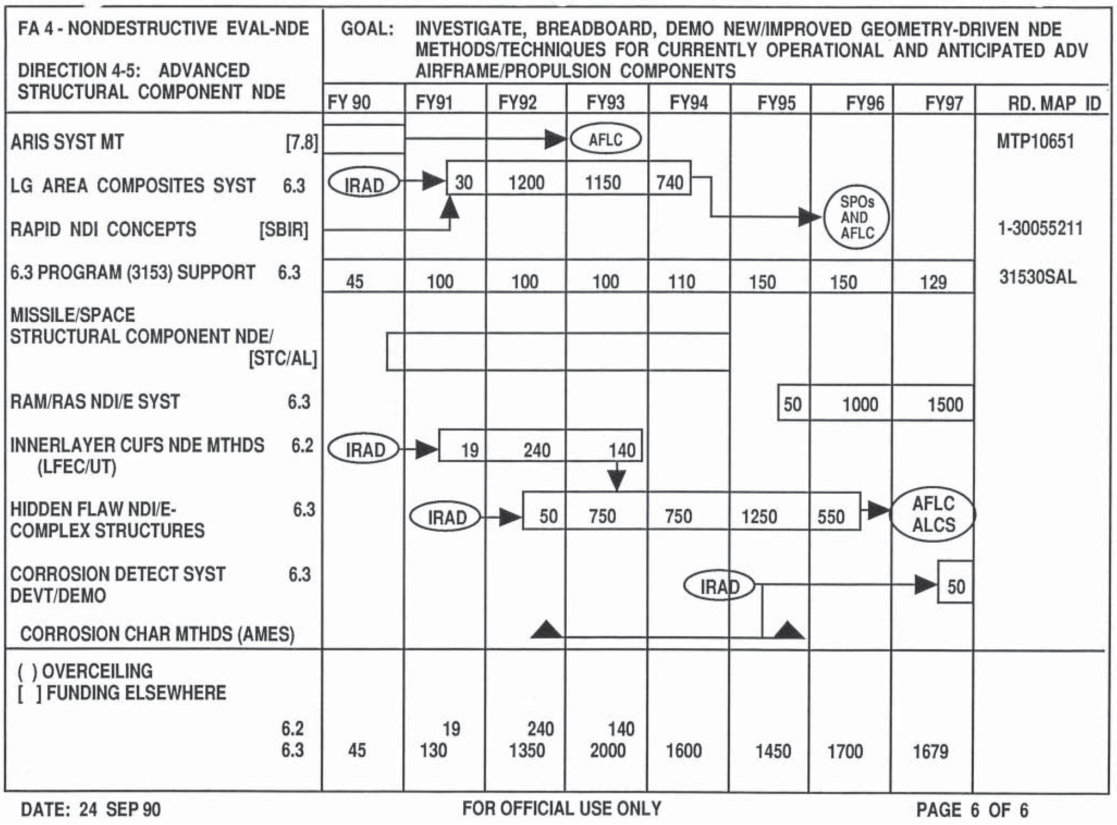
DIRECTION 4-3: IMAGING AND ANALYSIS METHODOLOGY	FY90	FY91	FY92	FY93	FY94	FY95	FY96	FY97	RD. MAP ID
QUANT (IMAGING) NDE	① △2-3	△4	△5						
O/S 6.2	472	485	500	525	540 10	575	580	590	24180232
WUD 40	3.8	4.3	4.3	4.3	4.3	4.3	4.3	4.0	2306P508
S&E EQUIPMENT 6.1/6.2	65/73	65/60	65/50	65/50	65/50	65/50	65/50	65/50	2306P508
FEATURE AND FLAW 6.2									24180232
IMAGING MIPR TO DOE	510	550	550	560	580	590	590	600	24180606
- LASER BASED ULTRASONICS	△6	▲							
- IMAGE ENHANCE CONCEPTS		▲ △7							
- RAPID SCAN TW METHODS	⑧		△9 ▲						
- LIMITED VIEW CT			▲						
- 3-D CT				▲			▲		
- ELECTRONIC MAT'LS CHAR		▲			▲				
( ) OVERCEILING [ ] FUNDING ELSEWHERE									
6.1	65	65	65	65	65	65	65	65	
6.2	1055	1095	1100	1135	1180	1215	1220	1240	

DATE: 24 SEP 90 FOR OFFICIAL USE ONLY PAGE 4 OF 6



FA 4 - NONDESTRUCTIVE EVAL-NDE DIRECTION 4-4: QUANTITATIVE FEATURE CHARACTERIZATION	GOAL: EXPLORE/DEVELOP NEW TECHNOLOGY TO PRODUCE/IMPROVE QUANTITATIVE FLAW CHARACTERIZATION CAPABILITY								
	FY 90	FY91	FY92	FY93	FY94	FY95	FY96	FY97	RD. MAP ID
QUANTITATIVE CHARACTER METHODS 6.2 MIPR TO DOE	455	400	400	400	400	400	400	400	24180606
CHAR OF ADHESIVE BONDS – ULTRASONIC METHODS	△	▲							
– OTHER NOVEL METHODS			▲			▲			
EC CHAR OF COMPOSITES	▲			▲					
AI /NEURAL NET APPL TO NDE	▲				▲				
ND MEASURE OF MAT'L PROPERTIES				▲			▲		
BRITTLE PHASE IN TITANIUM ALLOYS	▲			▲					
HIDDEN CORROSION CHARACTERIZATION METHODS			▲			▲			
( ) OVERCEILING [ ] FUNDING ELSEWHERE 6.2	455	400	400	400	400	400	400	400	

DATE: 24 SEP 90 FOR OFFICIAL USE ONLY PAGE 5 OF 6

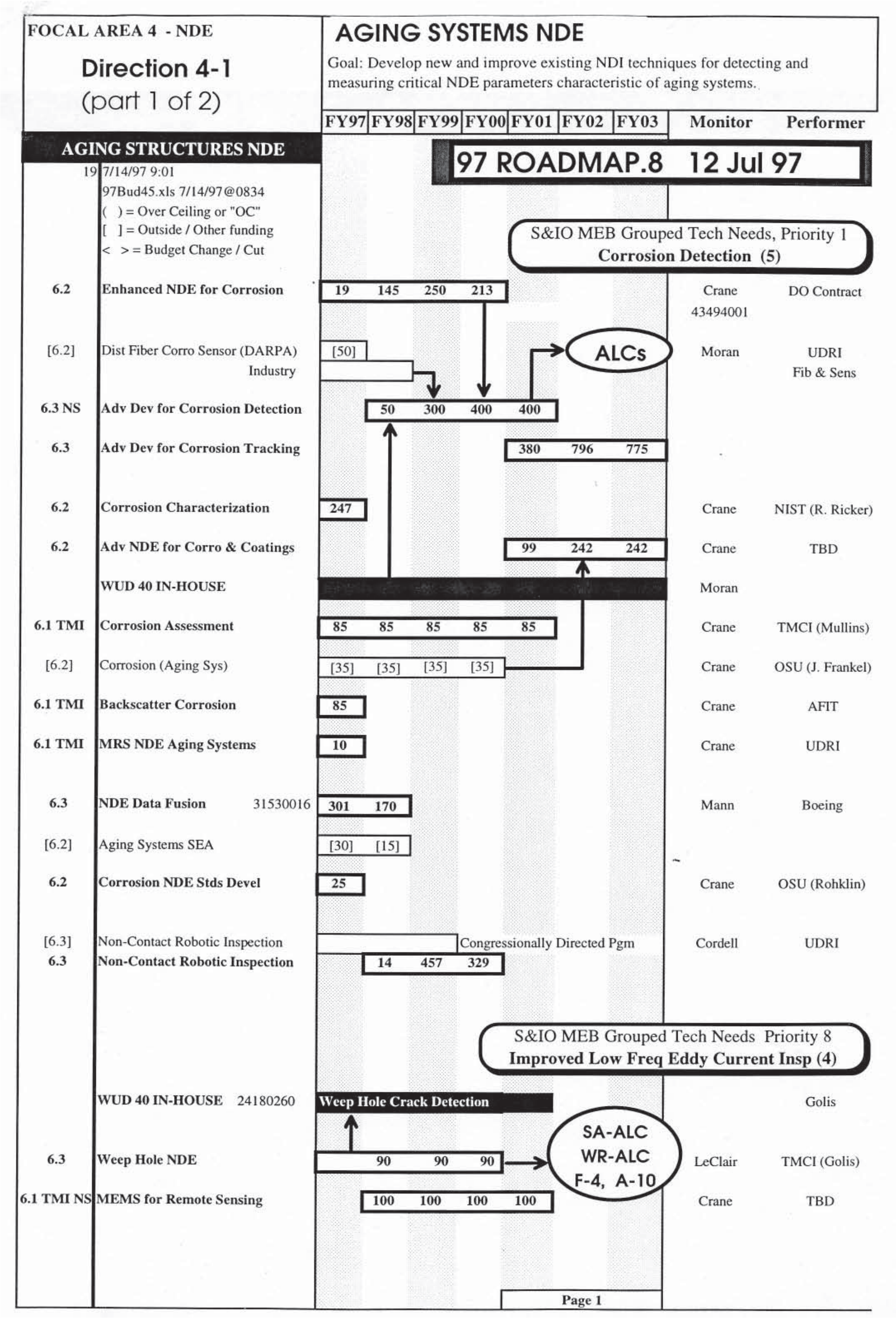


FA 4 - NONDESTRUCTIVE EVAL-NDE DIRECTION 4-5: ADVANCED STRUCTURAL COMPONENT NDE	GOAL: INVESTIGATE, BREADBOARD, DEMO NEW/IMPROVED GEOMETRY-DRIVEN NDE METHODS/TECHNIQUES FOR CURRENTLY OPERATIONAL AND ANTICIPATED ADV AIRFRAME/PROPULSION COMPONENTS								
	FY 90	FY91	FY92	FY93	FY94	FY95	FY96	FY97	RD. MAP ID
ARIS SYST MT [7.8]				AFLC					MTP10651
LG AREA COMPOSITES SYST 6.3	IRAD	30	1200	1150	740		SPOs AND AFLC		
RAPID NDI CONCEPTS [SBIR]									1-30055211
6.3 PROGRAM (3153) SUPPORT 6.3	45	100	100	100	110	150	150	129	31530SAL
MISSILE/SPACE STRUCTURAL COMPONENT NDE/ [STC/AL]									
RAM/RAS NDI/E SYST 6.3						50	1000	1500	
INNERLAYER CUFS NDE MTHDS (LFEC/UT) 6.2	IRAD	19	240	140					
HIDDEN FLAW NDI/E-COMPLEX STRUCTURES 6.3		IRAD	50	750	750	1250	550	AFLC ALCS	
CORROSION DETECT SYST DEVT/DEMO 6.3					IRAD			50	
CORROSION CHAR MTHDS (AMES)			▲			▲			
( ) OVERCEILING [ ] FUNDING ELSEWHERE 6.2		19	240	140					
6.3	45	130	1350	2000	1600	1450	1700	1679	

DATE: 24 SEP 90 FOR OFFICIAL USE ONLY PAGE 6 OF 6

APPENDIX F-6

Original ML Focal Area 4 NDE Program Roadmaps for the Planning Period of FY 97 - FY 03.



FOCAL AREA 4 - NDE

Direction 4-1
(part 1 of 2)

AGING SYSTEMS NDE

Goal: Develop new and improve existing NDI techniques for detecting and measuring critical NDE parameters characteristic of aging systems.

AGING STRUCTURES NDE

19 7/14/97 9:01
97Bud45.xls 7/14/97@0834
( ) = Over Ceiling or "OC"
[ ] = Outside / Other funding
< > = Budget Change / Cut

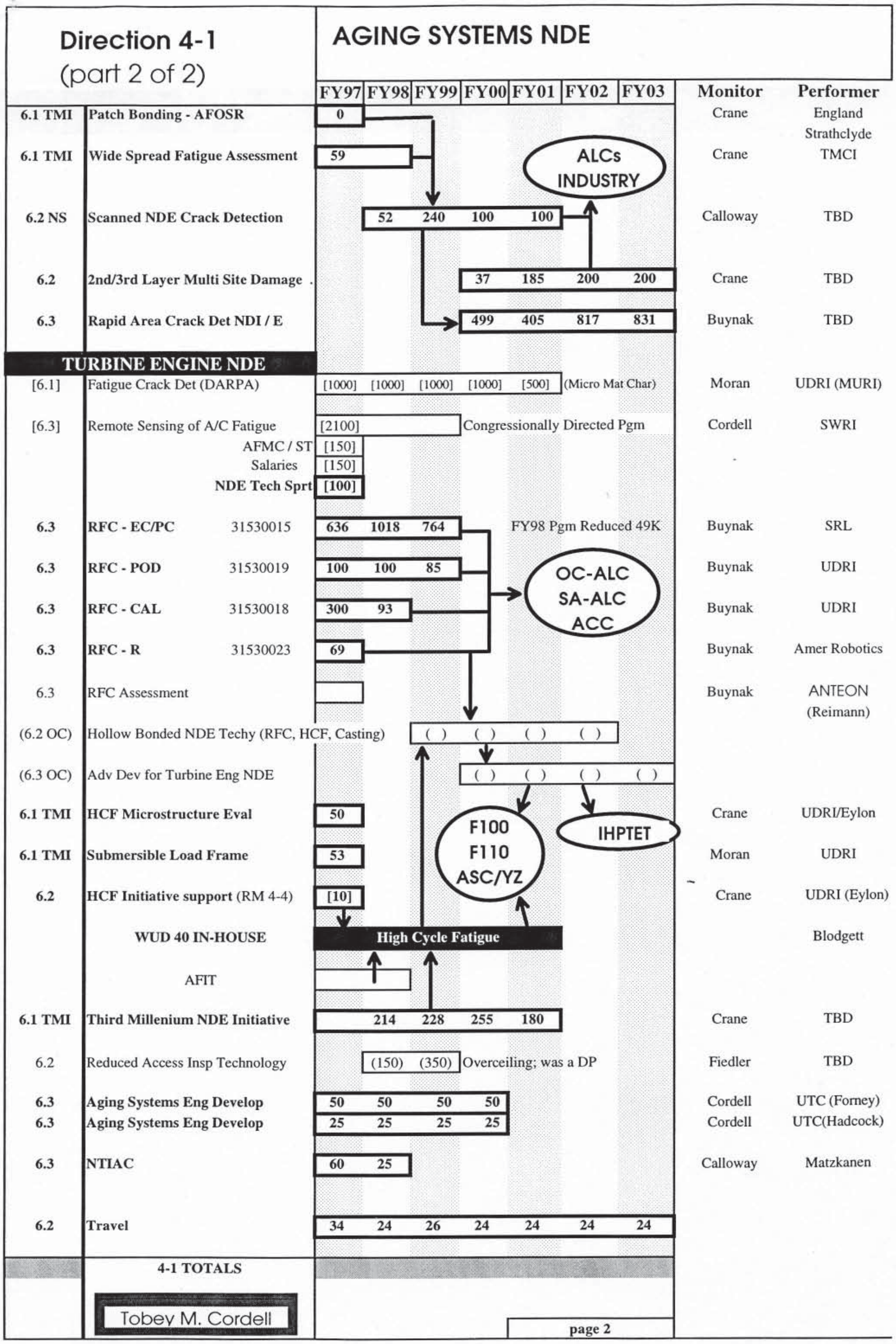
97 ROADMAP.8 12 Jul 97

S&IO MEB Grouped Tech Needs, Priority 1
Corrosion Detection (5)

		FY97	FY98	FY99	FY00	FY01	FY02	FY03	Monitor	Performer
6.2	**Enhanced NDE for Corrosion**	19	145	250	213				Crane 43494001	DO Contract
[6.2]	Dist Fiber Corro Sensor (DARPA)	[50]							Moran	UDRI Fib & Sens
	Industry									
6.3 NS	**Adv Dev for Corrosion Detection**		50	300	400	400				
6.3	**Adv Dev for Corrosion Tracking**					380	796	775		
6.2	**Corrosion Characterization**	247							Crane	NIST (R. Ricker)
6.2	**Adv NDE for Corro & Coatings**					99	242	242	Crane	TBD
	WUD 40 IN-HOUSE								Moran	
6.1 TMI	**Corrosion Assessment**	85	85	85	85	85			Crane	TMCI (Mullins)
[6.2]	Corrosion (Aging Sys)	[35]	[35]	[35]	[35]				Crane	OSU (J. Frankel)
6.1 TMI	**Backscatter Corrosion**	85							Crane	AFIT
6.1 TMI	**MRS NDE Aging Systems**	10							Crane	UDRI
6.3	**NDE Data Fusion** 31530016	301	170						Mann	Boeing
[6.2]	Aging Systems SEA	[30]	[15]							
6.2	**Corrosion NDE Stds Devel**	25							Crane	OSU (Rohklin)
[6.3]	Non-Contact Robotic Inspection	Congressionally Directed Pgm							Cordell	UDRI
6.3	**Non-Contact Robotic Inspection**		14	457	329					

S&IO MEB Grouped Tech Needs Priority 8
Improved Low Freq Eddy Current Insp (4)

		FY97	FY98	FY99	FY00	FY01	FY02	FY03	Monitor	Performer
	WUD 40 IN-HOUSE 24180260	**Weep Hole Crack Detection**								Golis
6.3	**Weep Hole NDE**		90	90	90				LeClair	TMCI (Golis)
6.1 TMI NS	**MEMS for Remote Sensing**		100	100	100	100			Crane	TBD



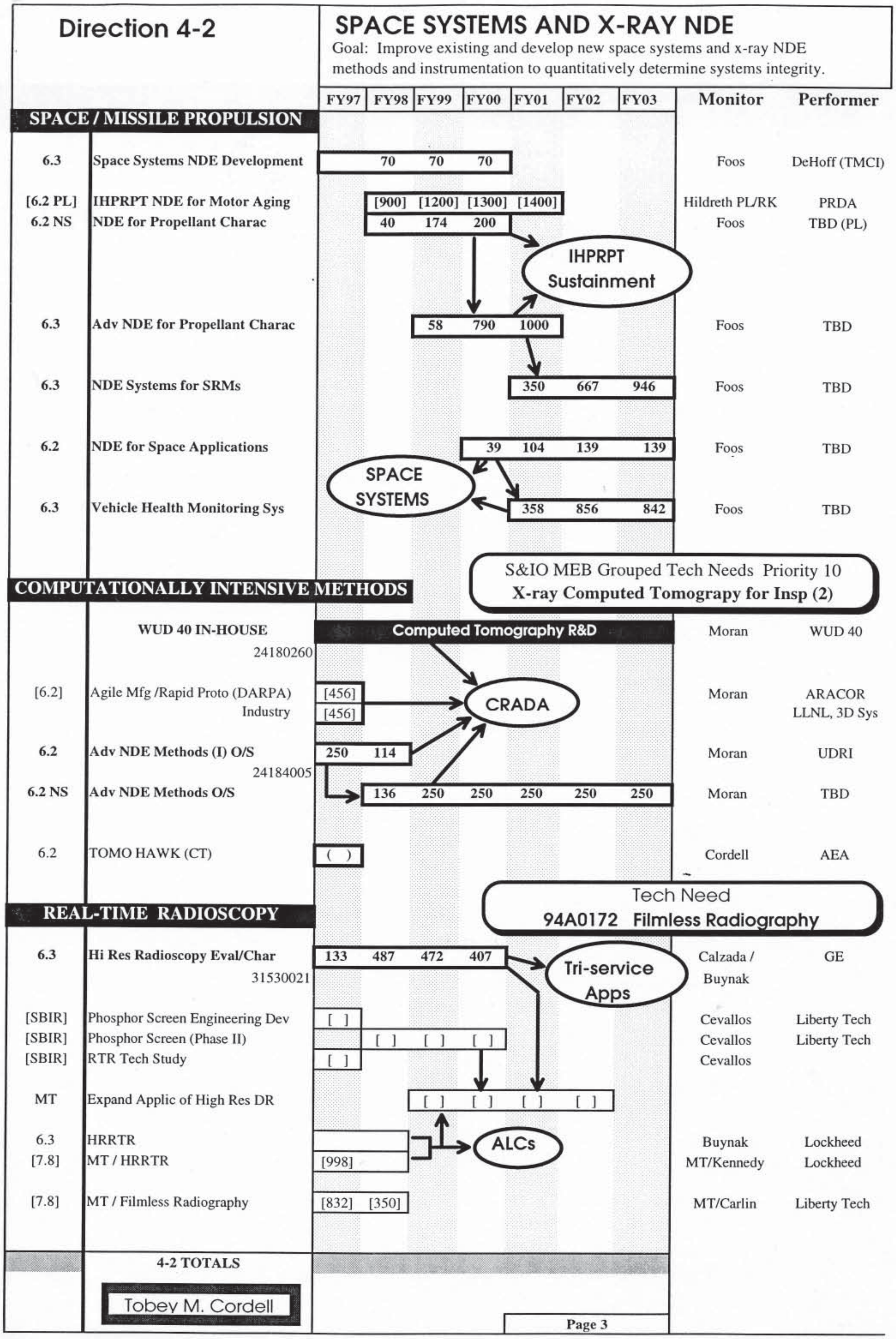
Direction 4-1
(part 2 of 2)

AGING SYSTEMS NDE

		FY97	FY98	FY99	FY00	FY01	FY02	FY03		Monitor	Performer
6.1 TMI	**Patch Bonding - AFOSR**	**0**								Crane	England Strathclyde
6.1 TMI	**Wide Spread Fatigue Assessment**	**59**								Crane	TMCI
6.2 NS	**Scanned NDE Crack Detection**		**52**	**240**	**100**	**100**				Calloway	TBD
6.2	**2nd/3rd Layer Multi Site Damage**				**37**	**185**	**200**	**200**		Crane	TBD
6.3	**Rapid Area Crack Det NDI / E**				**499**	**405**	**817**	**831**		Buynak	TBD
	TURBINE ENGINE NDE										
[6.1]	Fatigue Crack Det (DARPA)	[1000]	[1000]	[1000]	[1000]	[500]			(Micro Mat Char)	Moran	UDRI (MURI)
[6.3]	Remote Sensing of A/C Fatigue	[2100]							Congressionally Directed Pgm	Cordell	SWRI
	AFMC / ST	[150]									
	Salaries	[150]									
	NDE Tech Sprt	**[100]**									
6.3	**RFC - EC/PC** 31530015	**636**	**1018**	**764**					FY98 Pgm Reduced 49K	Buynak	SRL
6.3	**RFC - POD** 31530019	**100**	**100**	**85**						Buynak	UDRI
6.3	**RFC - CAL** 31530018	**300**	**93**							Buynak	UDRI
6.3	**RFC - R** 31530023	**69**								Buynak	Amer Robotics
6.3	RFC Assessment									Buynak	ANTEON (Reimann)
(6.2 OC)	Hollow Bonded NDE Techy (RFC, HCF, Casting)			( )	( )	( )	( )				
(6.3 OC)	Adv Dev for Turbine Eng NDE				( )	( )	( )	( )			
6.1 TMI	**HCF Microstructure Eval**	**50**								Crane	UDRI/Eylon
6.1 TMI	**Submersible Load Frame**	**53**								Moran	UDRI
6.2	**HCF Initiative support** (RM 4-4)	**[10]**								Crane	UDRI (Eylon)
	WUD 40 IN-HOUSE	**High Cycle Fatigue**									Blodgett
	AFIT										
6.1 TMI	**Third Millenium NDE Initiative**		**214**	**228**	**255**	**180**				Crane	TBD
6.2	Reduced Access Insp Technology		(150)	(350)					Overceiling; was a DP	Fiedler	TBD
6.3	**Aging Systems Eng Develop**	**50**	**50**	**50**	**50**					Cordell	UTC (Forney)
6.3	**Aging Systems Eng Develop**	**25**	**25**	**25**	**25**					Cordell	UTC(Hadcock)
6.3	**NTIAC**	**60**	**25**							Calloway	Matzkanen
6.2	**Travel**	**34**	**24**	**26**	**24**	**24**	**24**	**24**			
	4-1 TOTALS										

Tobey M. Cordell

page 2



Direction 4-2

SPACE SYSTEMS AND X-RAY NDE

Goal: Improve existing and develop new space systems and x-ray NDE methods and instrumentation to quantitatively determine systems integrity.

		FY97	FY98	FY99	FY00	FY01	FY02	FY03	Monitor	Performer
SPACE / MISSILE PROPULSION										
6.3	**Space Systems NDE Development**		70	70	70				Foos	DeHoff (TMCI)
[6.2 PL]	**IHPRPT NDE for Motor Aging**		[900]	[1200]	[1300]	[1400]			Hildreth PL/RK	PRDA
6.2 NS	**NDE for Propellant Charac**		40	174	200				Foos	TBD (PL)
6.3	**Adv NDE for Propellant Charac**			58	790	1000			Foos	TBD
6.3	**NDE Systems for SRMs**					350	667	946	Foos	TBD
6.2	**NDE for Space Applications**				39	104	139	139	Foos	TBD
6.3	**Vehicle Health Monitoring Sys**					358	856	842	Foos	TBD
COMPUTATIONALLY INTENSIVE METHODS										
	WUD 40 IN-HOUSE 24180260	Computed Tomography R&D							Moran	WUD 40
[6.2]	Agile Mfg /Rapid Proto (DARPA) Industry	[456] [456]							Moran	ARACOR LLNL, 3D Sys
6.2	**Adv NDE Methods (I) O/S** 24184005	250	114						Moran	UDRI
6.2 NS	**Adv NDE Methods O/S**		136	250	250	250	250	250	Moran	TBD
6.2	TOMO HAWK (CT)	( )							Cordell	AEA
REAL-TIME RADIOSCOPY										
6.3	**Hi Res Radioscopy Eval/Char** 31530021	133	487	472	407				Calzada / Buynak	GE
[SBIR]	Phosphor Screen Engineering Dev	[ ]							Cevallos	Liberty Tech
[SBIR]	Phosphor Screen (Phase II)		[ ]	[ ]	[ ]				Cevallos	Liberty Tech
[SBIR]	RTR Tech Study	[ ]							Cevallos	
MT	Expand Applic of High Res DR			[ ]	[ ]	[ ]	[ ]			
6.3	HRRTR								Buynak	Lockheed
[7.8]	MT / HRRTR	[998]							MT/Kennedy	Lockheed
[7.8]	MT / Filmless Radiography	[832]	[350]						MT/Carlin	Liberty Tech
	4-2 TOTALS									

S&IO MEB Grouped Tech Needs Priority 10
X-ray Computed Tomograpy for Insp (2)

Tech Need
94A0172 Filmless Radiography

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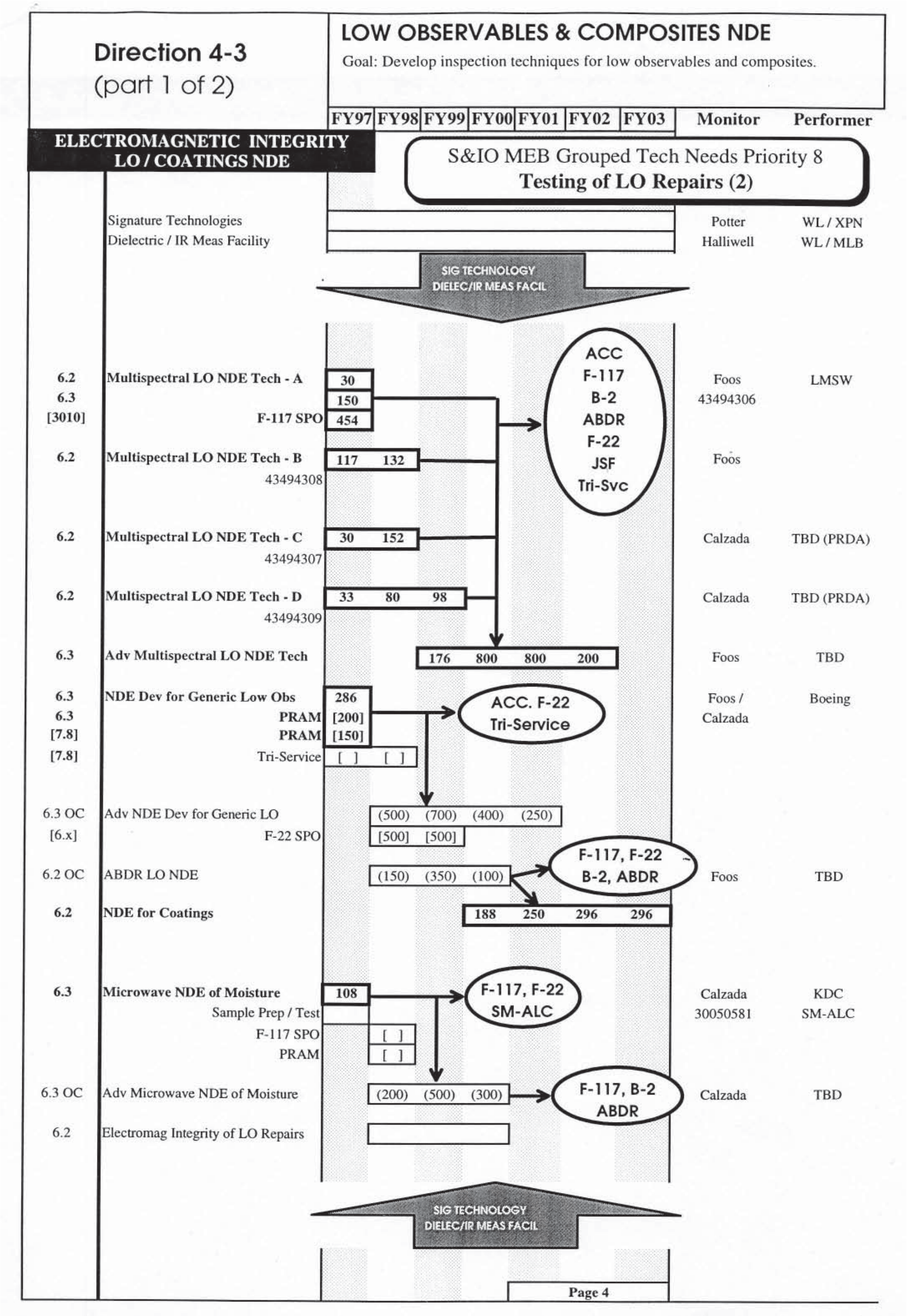
Page 3



Direction 4-3
(part 1 of 2)

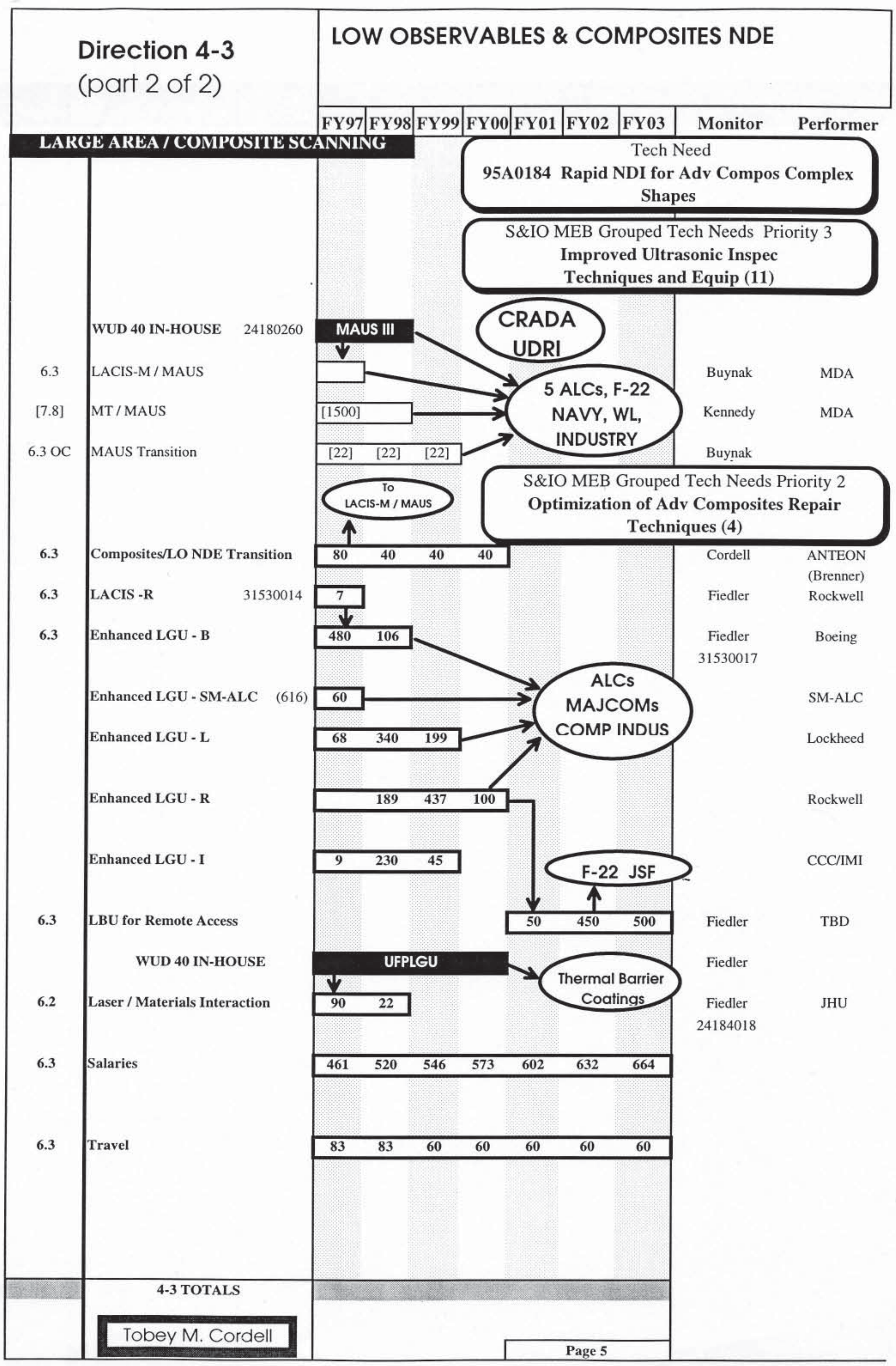
LOW OBSERVABLES & COMPOSITES NDE
Goal: Develop inspection techniques for low observables and composites.

ELECTROMAGNETIC INTEGRITY
LO / COATINGS NDE

S&IO MEB Grouped Tech Needs Priority 8
Testing of LO Repairs (2)

		FY97	FY98	FY99	FY00	FY01	FY02	FY03	Monitor	Performer
	Signature Technologies								Potter	WL / XPN
	Dielectric / IR Meas Facility								Halliwell	WL / MLB
6.2	**Multispectral LO NDE Tech - A**	**30**							Foos 43494306	LMSW
6.3		**150**								
[3010]	**F-117 SPO**	**454**								
6.2	**Multispectral LO NDE Tech - B** 43494308	**117**	**132**						Foos	
6.2	**Multispectral LO NDE Tech - C** 43494307	**30**	**152**						Calzada	TBD (PRDA)
6.2	**Multispectral LO NDE Tech - D** 43494309	**33**	**80**	**98**					Calzada	TBD (PRDA)
6.3	**Adv Multispectral LO NDE Tech**			**176**	**800**	**800**	**200**		Foos	TBD
6.3	**NDE Dev for Generic Low Obs**	**286**							Foos / Calzada	Boeing
6.3	**PRAM**	**[200]**								
[7.8]	**PRAM**	**[150]**								
[7.8]	Tri-Service	[ ]	[ ]							
6.3 OC	Adv NDE Dev for Generic LO		(500)	(700)	(400)	(250)				
[6.x]	F-22 SPO		[500]	[500]						
6.2 OC	ABDR LO NDE		(150)	(350)	(100)				Foos	TBD
6.2	**NDE for Coatings**				**188**	**250**	**296**	**296**		
6.3	**Microwave NDE of Moisture**	**108**							Calzada 30050581	KDC SM-ALC
	Sample Prep / Test									
	F-117 SPO		[ ]							
	PRAM		[ ]							
6.3 OC	Adv Microwave NDE of Moisture		(200)	(500)	(300)				Calzada	TBD
6.2	Electromag Integrity of LO Repairs									

Page 4



Direction 4-3
(part 2 of 2)

LOW OBSERVABLES & COMPOSITES NDE

LARGE AREA / COMPOSITE SCANNING

Tech Need
95A0184 Rapid NDI for Adv Compos Complex Shapes

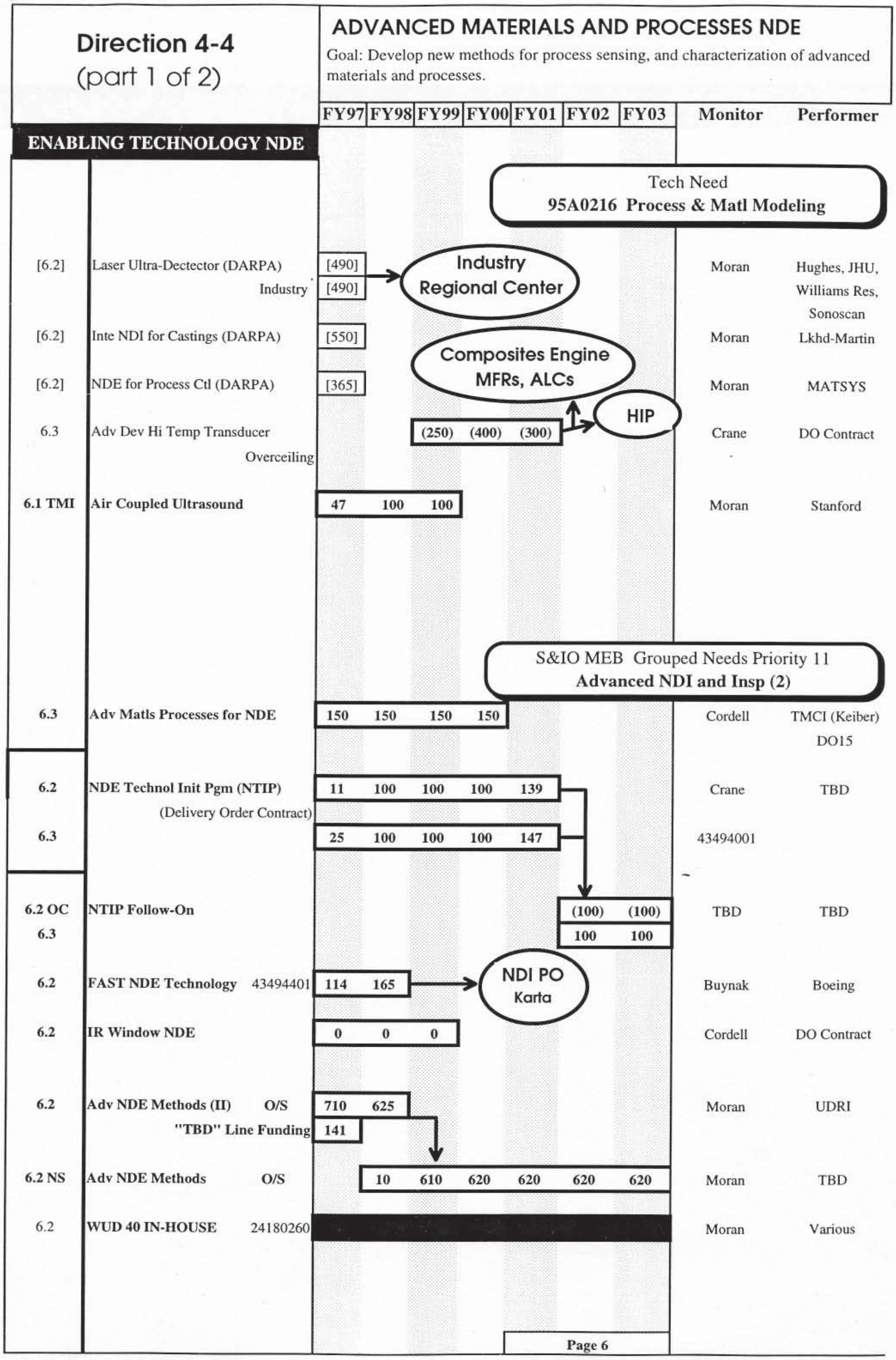
S&IO MEB Grouped Tech Needs Priority 3
Improved Ultrasonic Inspec Techniques and Equip (11)

S&IO MEB Grouped Tech Needs Priority 2
Optimization of Adv Composites Repair Techniques (4)

		FY97	FY98	FY99	FY00	FY01	FY02	FY03	Monitor	Performer
	WUD 40 IN-HOUSE 24180260	MAUS III	MAUS III							
6.3	LACIS-M / MAUS								Buynak	MDA
[7.8]	MT / MAUS	[1500]							Kennedy	MDA
6.3 OC	MAUS Transition	[22]	[22]	[22]					Buynak	
6.3	**Composites/LO NDE Transition**	80	40	40	40				Cordell	ANTEON (Brenner)
6.3	**LACIS -R** 31530014	7							Fiedler	Rockwell
6.3	**Enhanced LGU - B**	480	106						Fiedler 31530017	Boeing
	Enhanced LGU - SM-ALC (616)	60								SM-ALC
	Enhanced LGU - L	68	340	199						Lockheed
	Enhanced LGU - R		189	437	100					Rockwell
	Enhanced LGU - I	9	230	45						CCC/IMI
6.3	**LBU for Remote Access**					50	450	500	Fiedler	TBD
	WUD 40 IN-HOUSE	UFPLGU	UFPLGU	UFPLGU	UFPLGU				Fiedler	
6.2	**Laser / Materials Interaction**	90	22						Fiedler 24184018	JHU
6.3	**Salaries**	461	520	546	573	602	632	664		
6.3	**Travel**	83	83	60	60	60	60	60		
	4-3 TOTALS									

Tobey M. Cordell

Page 5



Direction 4-4
(part 1 of 2)

ADVANCED MATERIALS AND PROCESSES NDE

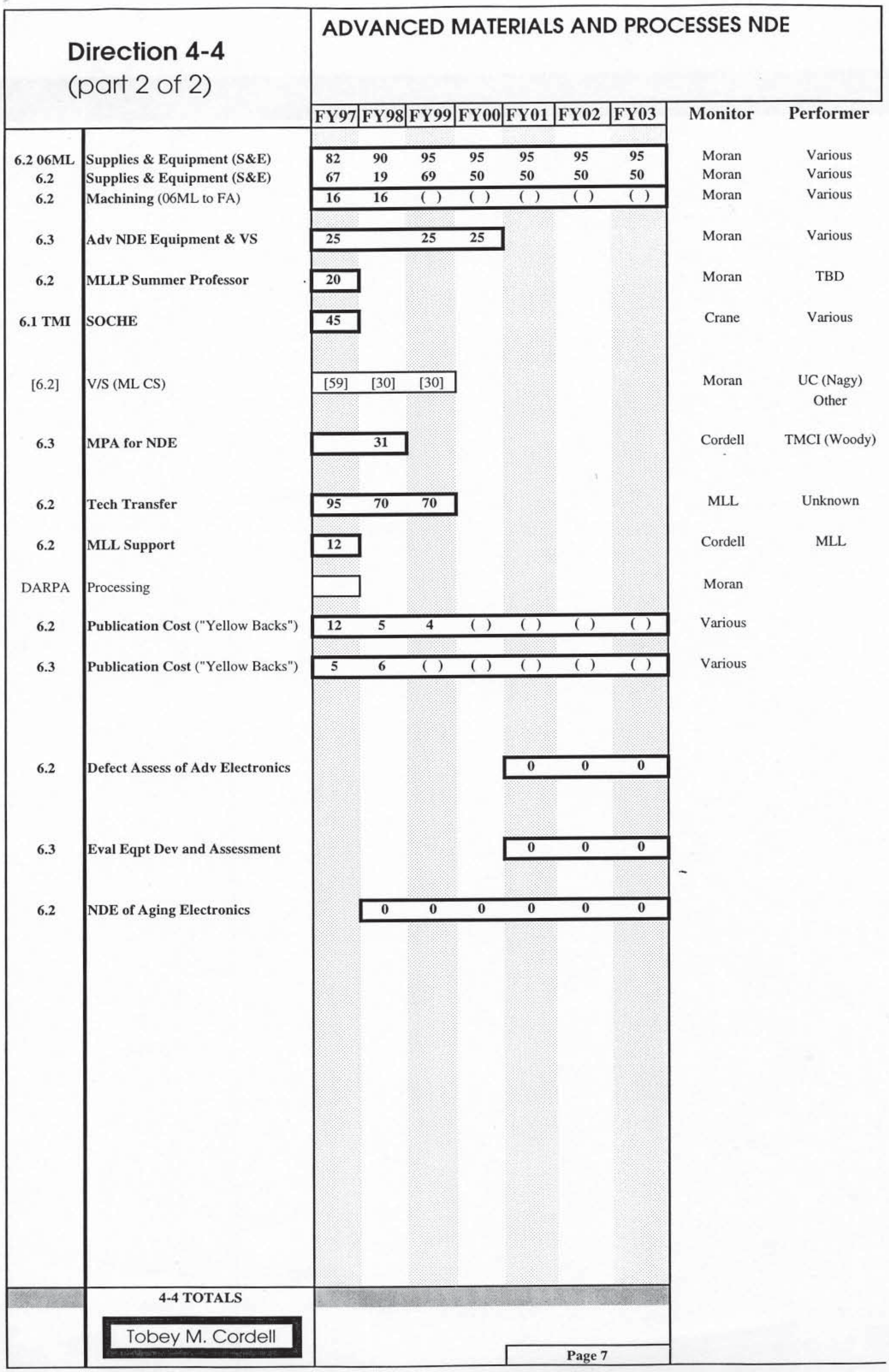
Goal: Develop new methods for process sensing, and characterization of advanced materials and processes.

ENABLING TECHNOLOGY NDE

Tech Need
95A0216 Process & Matl Modeling

		FY97	FY98	FY99	FY00	FY01	FY02	FY03	Monitor	Performer
[6.2]	Laser Ultra-Dectector (DARPA)	[490]							Moran	Hughes, JHU, Williams Res, Sonoscan
	Industry	[490]								
[6.2]	Inte NDI for Castings (DARPA)	[550]							Moran	Lkhd-Martin
[6.2]	NDE for Process Ctl (DARPA)	[365]							Moran	MATSYS
6.3	Adv Dev Hi Temp Transducer Overceiling			(250)	(400)	(300)			Crane	DO Contract
6.1 TMI	**Air Coupled Ultrasound**	**47**	**100**	**100**					Moran	Stanford
6.3	**Adv Matls Processes for NDE**	**150**	**150**	**150**	**150**				Cordell	TMCI (Keiber) DO15
6.2	**NDE Technol Init Pgm (NTIP)**	**11**	**100**	**100**	**100**	**139**			Crane	TBD
6.3	(Delivery Order Contract)	**25**	**100**	**100**	**100**	**147**			43494001	
6.2 OC	**NTIP Follow-On**						**(100)**	**(100)**	TBD	TBD
6.3							**100**	**100**		
6.2	**FAST NDE Technology** 43494401	**114**	**165**						Buynak	Boeing
6.2	**IR Window NDE**	**0**	**0**	**0**					Cordell	DO Contract
6.2	**Adv NDE Methods (II)** O/S	**710**	**625**						Moran	UDRI
	"TBD" Line Funding	**141**								
6.2 NS	**Adv NDE Methods** O/S		**10**	**610**	**620**	**620**	**620**	**620**	Moran	TBD
6.2	**WUD 40 IN-HOUSE** 24180260	■	■	■	■	■	■	■	Moran	Various

S&IO MEB Grouped Needs Priority 11
Advanced NDI and Insp (2)



Direction 4-4
(part 2 of 2)

ADVANCED MATERIALS AND PROCESSES NDE

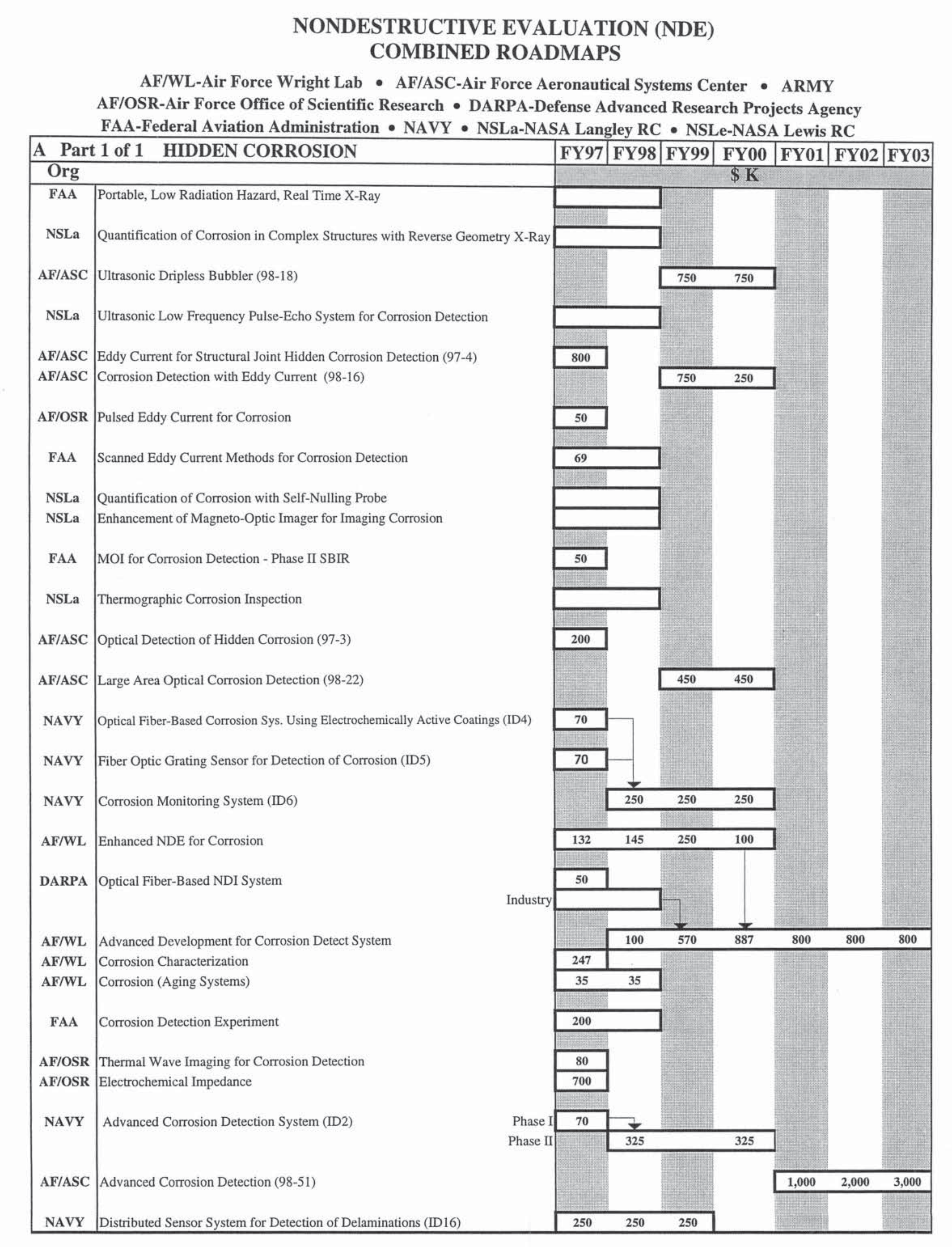
		FY97	FY98	FY99	FY00	FY01	FY02	FY03	Monitor	Performer
6.2 06ML	**Supplies & Equipment (S&E)**	82	90	95	95	95	95	95	Moran	Various
6.2	**Supplies & Equipment (S&E)**	67	19	69	50	50	50	50	Moran	Various
6.2	**Machining** (06ML to FA)	16	16	( )	( )	( )	( )	( )	Moran	Various
6.3	**Adv NDE Equipment & VS**	25		25	25				Moran	Various
6.2	**MLLP Summer Professor**	20							Moran	TBD
6.1 TMI	**SOCHE**	45							Crane	Various
[6.2]	V/S (ML CS)	[59]	[30]	[30]					Moran	UC (Nagy) Other
6.3	**MPA for NDE**		31						Cordell	TMCI (Woody)
6.2	**Tech Transfer**	95	70	70					MLL	Unknown
6.2	**MLL Support**	12							Cordell	MLL
DARPA	Processing								Moran	
6.2	**Publication Cost** ("Yellow Backs")	12	5	4	( )	( )	( )	( )	Various	
6.3	**Publication Cost** ("Yellow Backs")	5	6	( )	( )	( )	( )	( )	Various	
6.2	**Defect Assess of Adv Electronics**					0	0	0		
6.3	**Eval Eqpt Dev and Assessment**					0	0	0		
6.2	**NDE of Aging Electronics**		0	0	0	0	0	0		
	4-4 TOTALS									

Tobey M. Cordell

Page 7

APPENDIX F-7

Example of Combined Roadmaps and Associated Narratives, FY 97 – 03.



NONDESTRUCTIVE EVALUATION (NDE) COMBINED ROADMAPS

AF/WL-Air Force Wright Lab • AF/ASC-Air Force Aeronautical Systems Center • ARMY
AF/OSR-Air Force Office of Scientific Research • DARPA-Defense Advanced Research Projects Agency
FAA-Federal Aviation Administration • NAVY • NSLa-NASA Langley RC • NSLe-NASA Lewis RC

A Part 1 of 1 HIDDEN CORROSION

$ K

Org		FY97	FY98	FY99	FY00	FY01	FY02	FY03
FAA	Portable, Low Radiation Hazard, Real Time X-Ray							
NSLa	Quantification of Corrosion in Complex Structures with Reverse Geometry X-Ray							
AF/ASC	Ultrasonic Dripless Bubbler (98-18)			750	750			
NSLa	Ultrasonic Low Frequency Pulse-Echo System for Corrosion Detection							
AF/ASC	Eddy Current for Structural Joint Hidden Corrosion Detection (97-4)	800						
AF/ASC	Corrosion Detection with Eddy Current (98-16)			750	250			
AF/OSR	Pulsed Eddy Current for Corrosion	50						
FAA	Scanned Eddy Current Methods for Corrosion Detection	69						
NSLa	Quantification of Corrosion with Self-Nulling Probe							
NSLa	Enhancement of Magneto-Optic Imager for Imaging Corrosion							
FAA	MOI for Corrosion Detection - Phase II SBIR	50						
NSLa	Thermographic Corrosion Inspection							
AF/ASC	Optical Detection of Hidden Corrosion (97-3)	200						
AF/ASC	Large Area Optical Corrosion Detection (98-22)			450	450			
NAVY	Optical Fiber-Based Corrosion Sys. Using Electrochemically Active Coatings (ID4)	70						
NAVY	Fiber Optic Grating Sensor for Detection of Corrosion (ID5)	70						
NAVY	Corrosion Monitoring System (ID6)		250	250	250			
AF/WL	Enhanced NDE for Corrosion	132	145	250	100			
DARPA	Optical Fiber-Based NDI System	50						
	Industry							
AF/WL	Advanced Development for Corrosion Detect System		100	570	887	800	800	800
AF/WL	Corrosion Characterization	247						
AF/WL	Corrosion (Aging Systems)	35	35					
FAA	Corrosion Detection Experiment	200						
AF/OSR	Thermal Wave Imaging for Corrosion Detection	80						
AF/OSR	Electrochemical Impedance	700						
NAVY	Advanced Corrosion Detection System (ID2) Phase I	70						
	Phase II		325		325			
AF/ASC	Advanced Corrosion Detection (98-51)					1,000	2,000	3,000
NAVY	Distributed Sensor System for Detection of Delaminations (ID16)	250	250	250				

CRM 97-1
06/05/97

NONDESTRUCTIVE EVALUATION (NDE)

COMBINED ROADMAPS

AF/WL-AIR FORCE WRIGHT LABORATORY
AF/ASC-AIR FORCE AERONAUTICAL SYSTEMS CENTER
AF/OSR-AIR FORCE OFFICE OF SCIENTIFIC RESEARCH
FAA-FEDERAL AVIATION ADMINISTRATION
DARPA-DEFENSE ADVANCED RESEARCH PROJECTS AGENCY
NSLa-NASA LANGLEY RC NSLe-NASA LEWIS RC
ARMY NAVY

SECTION A HIDDEN CORROSION AND DISBOND DETECTION

FAA PORTABLE LOW-RADIATION HAZARD REAL TIME X-RAY

The object is to develop a portable system capable of providing enhanced real-time x-ray images coupled with a detailed quantitative measure of material thickness and the presence of corrosion at selected points of interest. Plans for 1997 are to complete the experimental characterization of the diffraction effects in samples supplied by Pratt & Whitney and Boeing using the germanium or the CdTeZn detector. This effort is expected to produce specifications for a portable x-ray imaging and material characterization system.

NSLa QUANTIFICATION OF CORROSION IN COMPLEX STRUCTURES WITH REVERSE GEOMETRY X-RAY SYSTEM

This task involves working with Digiray to determine the capabilities of the reverse geometry system for the detection of cracks in multilayered structures such as is found at the corners of doorway in aircraft. NASA has an MOU with Digiray to enable rapid transfer of technology between Digiray and NASA. As part of this MOU, NASA is determining the sensitivity of the system to cracks in the inner layers of a multilayer configuration. The delectability of cracks with varying thicknesses of outer layers is being determined. Application: riveted lap joints in the fuselage.

AF/ASC ULTRASONIC DRIPLESS BUBBLER (98-18)

The objective of this project is to replace the tedious and unreliable visual inspection with an ultrasonic dripless bubbler system. Initial development efforts indicate this is a strong potential candidate for detection of hidden corrosion under wing skin fasteners.

NSLa ULTRASONIC LOW FREQUENCY PULSE-ECHO SYSTEM FOR CORROSION DETECTION

This task develops low frequency ultrasonic techniques for the detection and quantification of corrosion and for imaging disbonds in aircraft structures. Data reduction techniques based on the Fourier transform of the ultrasonic response of the aircraft skin are applied to quantify extent of material loss in a corroded region. Disbonds are located by a neural network analysis and the ultrasonic response of the aircraft skin. Convolution techniques map the transducer's response to a given wave form to remove transducer-to-transducer variations. Corrosion techniques have been demonstrated at Tinker Air Force Base and disbond detection has been demonstrated at North West Airlines. The data reduction techniques have been incorporated into a PC based hand scanner to enable imaging corrosion in real-time. Application: Riveted lap joints in the fuselage.

CRM 97-1
06/05/97

AF/ASC EDDY CURRENT APPLICATIONS FOR STRUCTURAL JOINT HIDDEN CORROSION DETECTION (97-4)

Objective is to modify selected commercial off-the-shelf (COTS) eddy current equipment to enhance Air Force applications to the detection of hidden corrosion in typical structural lap splice joints. A MIZ22/ANDESCAN System will serve as the testbed for reengineering efforts.

AF/ASC CORROSION DETECTION WITH EDDY CURRENT (98-16)

The object of this program is to replace the tedious and unreliable visual inspection with an eddy current inspection for detecting hidden corrosion in aircraft. A prototype eddy current system has been successfully demonstrated at OC-ALC for improving inspection reliability in large aircraft lap joints. As a result of this success, continuing to pursue state-of-the-art as well as emerging eddy current technology is warranted to improve inspection reliability in lap joints.

AF/OSR PULSED EDDY CURRENT FOR CORROSION

This effort develops pulsed (time domain) eddy current methods to detect hidden corrosion at joints in the skins of transport aircraft.

FAA SCANNED EDDY CURRENT METHODS FOR CORROSION DETECTION

The object is to develop inspection techniques to detect and characterize corrosion and corrosion related cracking in lap joints. A laboratory pulsed eddy current device has been developed and a second generation prototype has been designed. This project will further develop and integrate pulsed EC technology into a portable scanning instrument. The technology has been licensed to Sierra Matrix. The result of this effort is to obtain a prototype portable pulsed eddy current scanning device capable of quantitatively determining metal skin thickness loss.

NSLa QUANTIFICATION OF CORROSION WITH SELF-NULLING PROBE

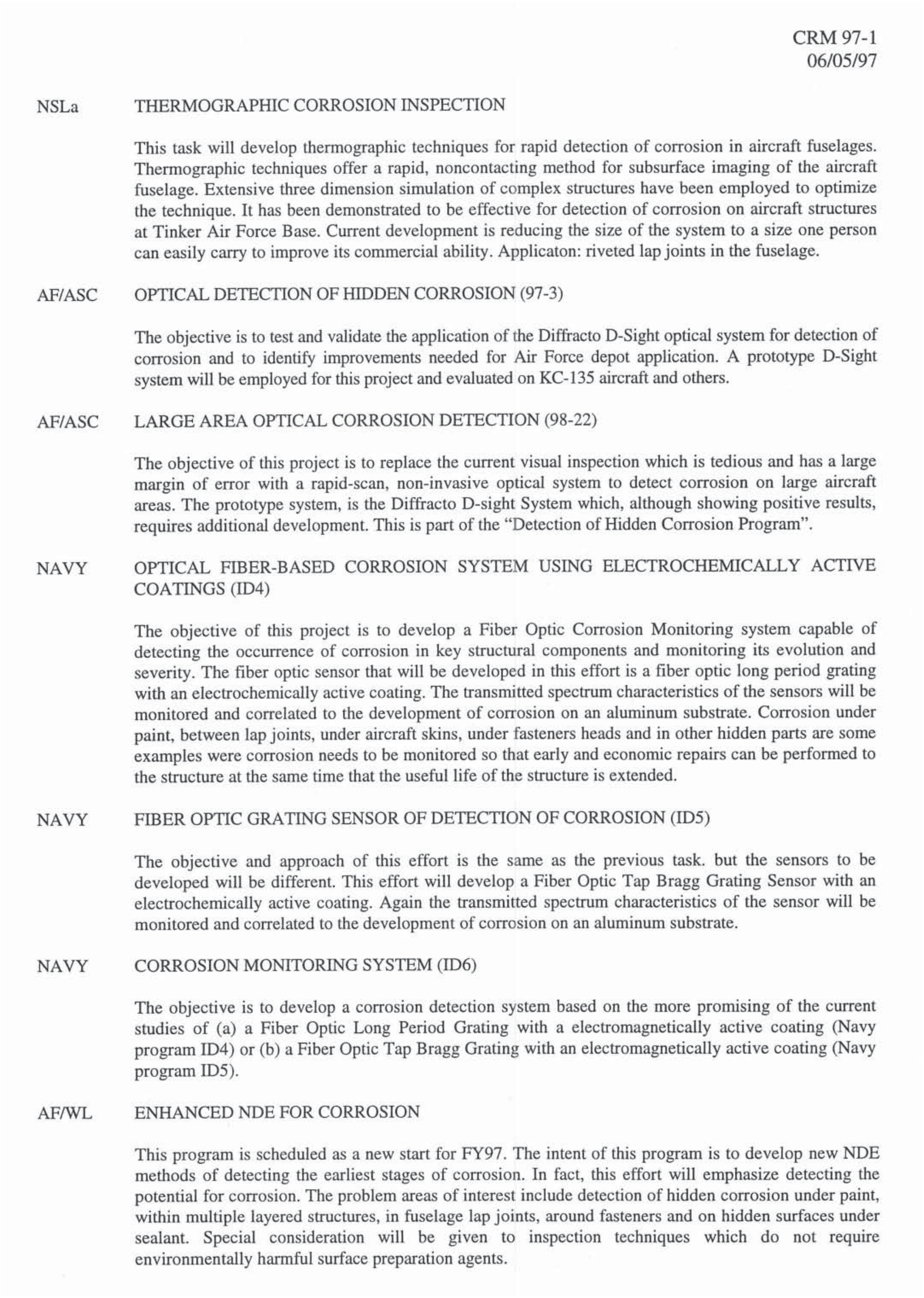
This task will develop techniques for quantification of corrosion based on the self-nulling eddy current probe. The self-nulling eddy current probe is a unique probe developed at NASA Langley Research Center. It represents a low cost, simple to interpret instrument for corrosion quantification. It is in the process of being licensed to a US company. Corrosion quantification is based on measurements of the response of the probe at several frequencies when it is brought in contact with an aircraft structure. Algorithms have been developed for the reduction of this data to the thickness of a single layer and the combined thickness of a double layer independent of the air gap between the layer. The algorithm for a single layer has been incorporated into an instrument. Future work will include incorporating the algorithm for multiple layers into the instrument and field testing. Application: Riveted lap joints in the fuselage.

NSLa ENHANCEMENT OF MAGNETO-OPTIC IMAGER FOR IMAGING CORROSION

This task involves working with PRI to improve the performance of the magneto-optic imager for corrosion detection and quantification. NASA has an MOU with PRI to enable rapid transfer of technology between NASA and PRI. NASA is performing simulations of the magneto-optic inspection process to improve its sensitivity to material loss in the structure. Image processing techniques are being applied to transform the frequency variation of the output of the imager to a corrosion map. Application: Riveted lap joints in the fuselage.

FAA (MOI) MAGNETO-OPTIC IMAGING FOR CORROSION DETECTION - PHASE II SBIR

The objective is to incorporate the concepts of the Phase I SBIR into a working commercial instrument for detection of corrosion in aircraft skin splices. The new MOI instrument will have bi-directional sheet excitation, probe shielding for deeper eddy current penetration and image processing software.



CRM 97-1
06/05/97

NSLa THERMOGRAPHIC CORROSION INSPECTION

This task will develop thermographic techniques for rapid detection of corrosion in aircraft fuselages. Thermographic techniques offer a rapid, noncontacting method for subsurface imaging of the aircraft fuselage. Extensive three dimension simulation of complex structures have been employed to optimize the technique. It has been demonstrated to be effective for detection of corrosion on aircraft structures at Tinker Air Force Base. Current development is reducing the size of the system to a size one person can easily carry to improve its commercial ability. Applicaton: riveted lap joints in the fuselage.

AF/ASC OPTICAL DETECTION OF HIDDEN CORROSION (97-3)

The objective is to test and validate the application of the Diffracto D-Sight optical system for detection of corrosion and to identify improvements needed for Air Force depot application. A prototype D-Sight system will be employed for this project and evaluated on KC-135 aircraft and others.

AF/ASC LARGE AREA OPTICAL CORROSION DETECTION (98-22)

The objective of this project is to replace the current visual inspection which is tedious and has a large margin of error with a rapid-scan, non-invasive optical system to detect corrosion on large aircraft areas. The prototype system, is the Diffracto D-sight System which, although showing positive results, requires additional development. This is part of the "Detection of Hidden Corrosion Program".

NAVY OPTICAL FIBER-BASED CORROSION SYSTEM USING ELECTROCHEMICALLY ACTIVE COATINGS (ID4)

The objective of this project is to develop a Fiber Optic Corrosion Monitoring system capable of detecting the occurrence of corrosion in key structural components and monitoring its evolution and severity. The fiber optic sensor that will be developed in this effort is a fiber optic long period grating with an electrochemically active coating. The transmitted spectrum characteristics of the sensors will be monitored and correlated to the development of corrosion on an aluminum substrate. Corrosion under paint, between lap joints, under aircraft skins, under fasteners heads and in other hidden parts are some examples were corrosion needs to be monitored so that early and economic repairs can be performed to the structure at the same time that the useful life of the structure is extended.

NAVY FIBER OPTIC GRATING SENSOR OF DETECTION OF CORROSION (ID5)

The objective and approach of this effort is the same as the previous task. but the sensors to be developed will be different. This effort will develop a Fiber Optic Tap Bragg Grating Sensor with an electrochemically active coating. Again the transmitted spectrum characteristics of the sensor will be monitored and correlated to the development of corrosion on an aluminum substrate.

NAVY CORROSION MONITORING SYSTEM (ID6)

The objective is to develop a corrosion detection system based on the more promising of the current studies of (a) a Fiber Optic Long Period Grating with a electromagnetically active coating (Navy program ID4) or (b) a Fiber Optic Tap Bragg Grating with an electromagnetically active coating (Navy program ID5).

AF/WL ENHANCED NDE FOR CORROSION

This program is scheduled as a new start for FY97. The intent of this program is to develop new NDE methods of detecting the earliest stages of corrosion. In fact, this effort will emphasize detecting the potential for corrosion. The problem areas of interest include detection of hidden corrosion under paint, within multiple layered structures, in fuselage lap joints, around fasteners and on hidden surfaces under sealant. Special consideration will be given to inspection techniques which do not require environmentally harmful surface preparation agents.

CRM 97-1
06/05/97

DARPA OPTICAL FIBER-BASED NDI SYSTEM

Investigation and development of optical fiber sensor systems which are able to provide information on corrosion in remote locations without need for structure disassembly. Investigations focus on two types of fiber sensors for use as environmental predictors of potential corrosion areas; (1) grating attached to pre-strained sacrificial metal elements and (2) fibers with polymer coatings for fiber grating elements with refractive indices sensitive to moisture and humidity. Successful development will result in significantly reduced corrosion maintenance costs and lead to extended times between mandatory visual inspections.

AF/WL ADVANCED DEVELOPMENT FOR CORROSION DETECTION SYSTEM

This is a new program based on a PRDA. In this regard the contractor/offeror will propose an approach to address the problems associated with the detection and quantification of corrosion in A/C structures. The output of this program will be to another 6.3 effort which will carry the technique through an instrument development phase.

AF/WL CORROSION CHARACTERIZATION

This program is being conducted at NIST in Gaithersburg MD. The objective of the program is to develop a series of corrosion standards that can be used in the ALC to quantify the amount/severity of corrosion in Al A/C structures. The standards developed in this program will be available for trials in ML and at an ALC at the conclusion of the program.

AF/WL CORROSION (AGING SYSTEMS)

This program is being conducted by the OSU Fontana Corrosion Center. The objective is to develop a new method of detecting corrosion using paint. The approach has been to add pH indicators to the paint and to detect pitting corrosion via a color change to the paint. The output of this program will be used by the paint initiative to design the new generation of paints that have little to no VOC's and Cr^{+6} yet provide current levels of protection in addition to their new NDE functionality.

FAA CORROSION DETECTION EXPERIMENT

The objective is to assess and compare the performance of various commercial and emerging inspection systems applied to generic, thin skin faying surface corrosion location or identification tasks. This task will generate a report describing the experimental techniques, the equipment and procedures used and the performance and reliability (Probability of Detection and False Call Rates) of the systems tested.

AF/OSR THERMAL WAVE IMAGING FOR CORROSION DETECTION

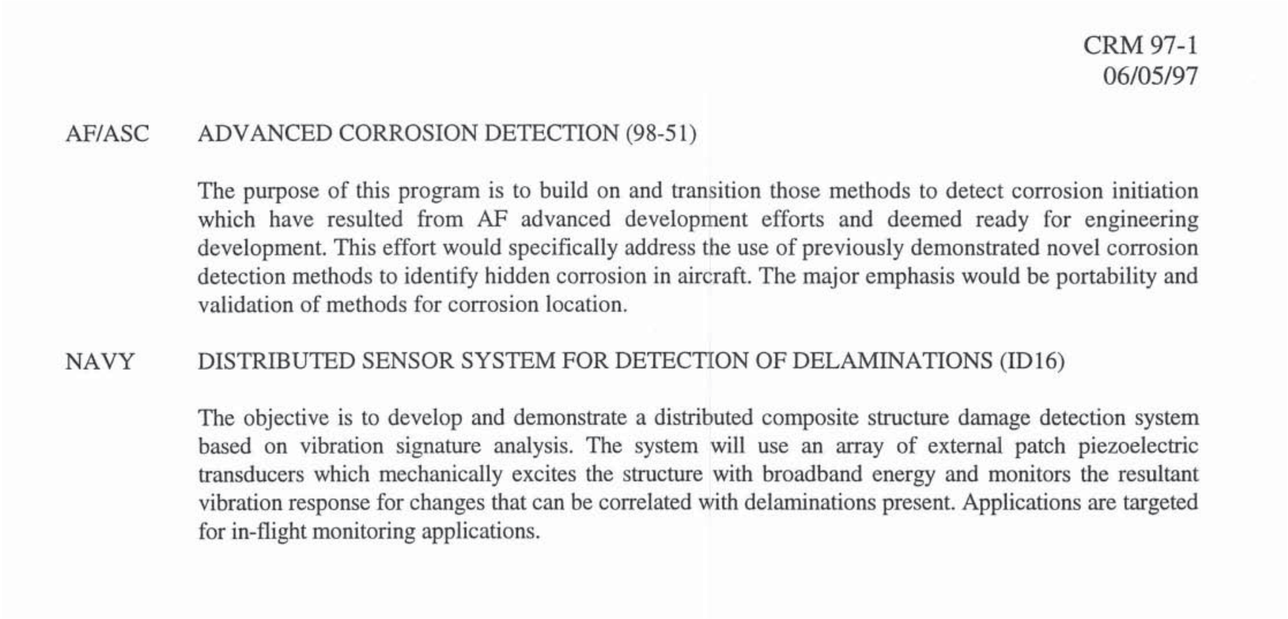
The object of this effort is to develop thermal wave IR NDE instrumentation for detecting hidden corrosion and formulate models of imaging process for optimizing the detection accuracy.

AF/OSR ELECTROCHEMICAL IMPEDENCE

Three approaches initiated with $1.1M of FY '96 funds to the development of an electrochemical impedance NDE instrument are being studied: (1) one based on a solid electrolyte sensor, (2) one based on a liquid sensor, and the data station was to use a neural net, and (3) one based on a solid state method of permanently mounting the sensors on the body on the aircraft. Data would be recorded with a portable instrument or an on-board instrument.

NAVY ADVANCED CORROSION DETECTION SYSTEM (ID2)

The objective of this project is to develop a compact and portable corrosion detection system that would allow the inspector to quickly detect and quantify the amount of corrosion present in an aircraft structural component. Corrosion under paint, between lap joints, under aircraft skins, under fasteners heads and in other hidden parts are some examples were corrosion needs to be detected.



CRM 97-1
06/05/97

AF/ASC ADVANCED CORROSION DETECTION (98-51)

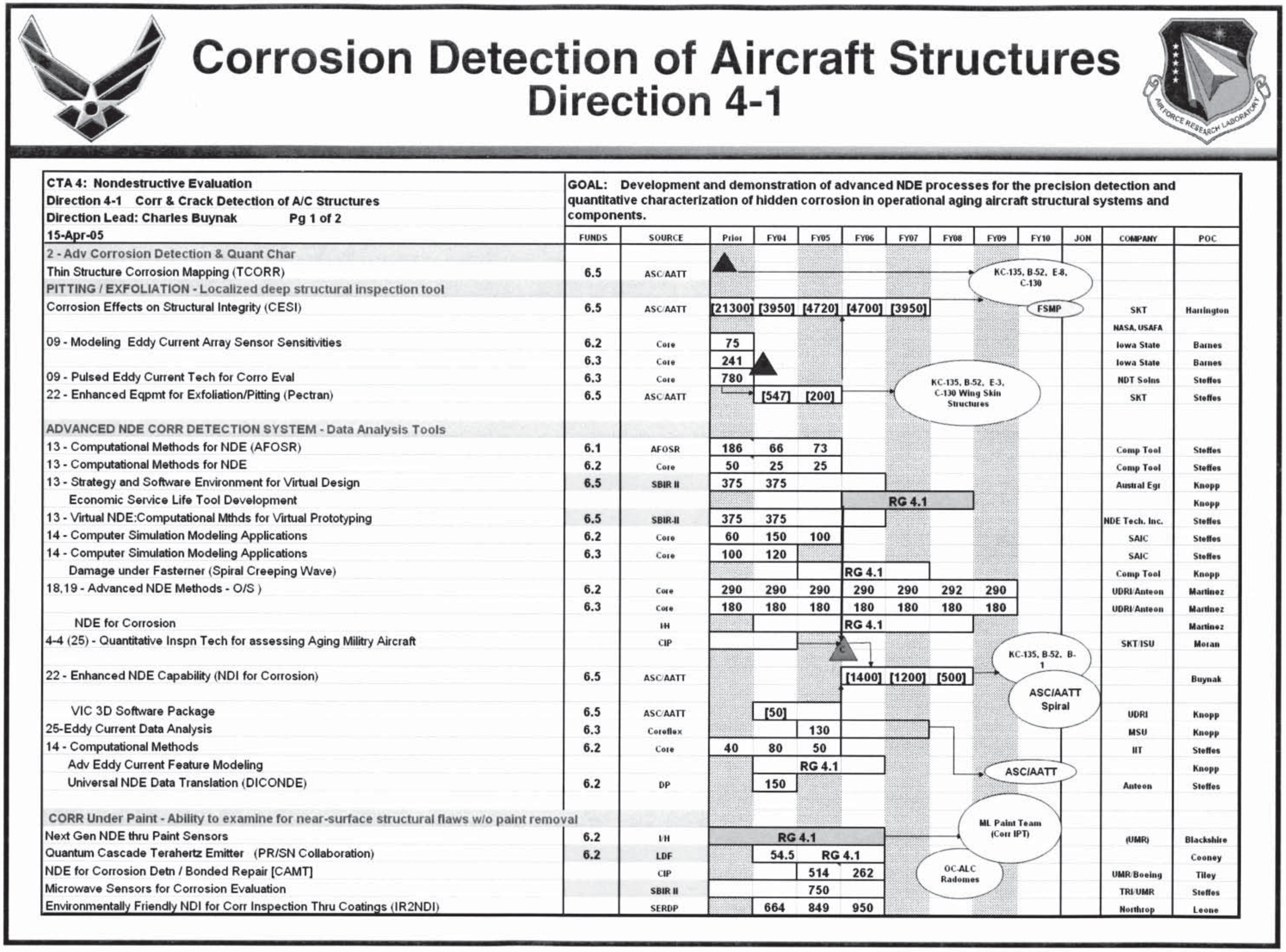
The purpose of this program is to build on and transition those methods to detect corrosion initiation which have resulted from AF advanced development efforts and deemed ready for engineering development. This effort would specifically address the use of previously demonstrated novel corrosion detection methods to identify hidden corrosion in aircraft. The major emphasis would be portability and validation of methods for corrosion location.

NAVY DISTRIBUTED SENSOR SYSTEM FOR DETECTION OF DELAMINATIONS (ID16)

The objective is to develop and demonstrate a distributed composite structure damage detection system based on vibration signature analysis. The system will use an array of external patch piezoelectric transducers which mechanically excites the structure with broadband energy and monitors the resultant vibration response for changes that can be correlated with delaminations present. Applications are targeted for in-flight monitoring applications.

APPENDIX F-8

Original ML Focal Area 4 NDE Program Roadmaps for the Planning Period of FY 04 - 10.

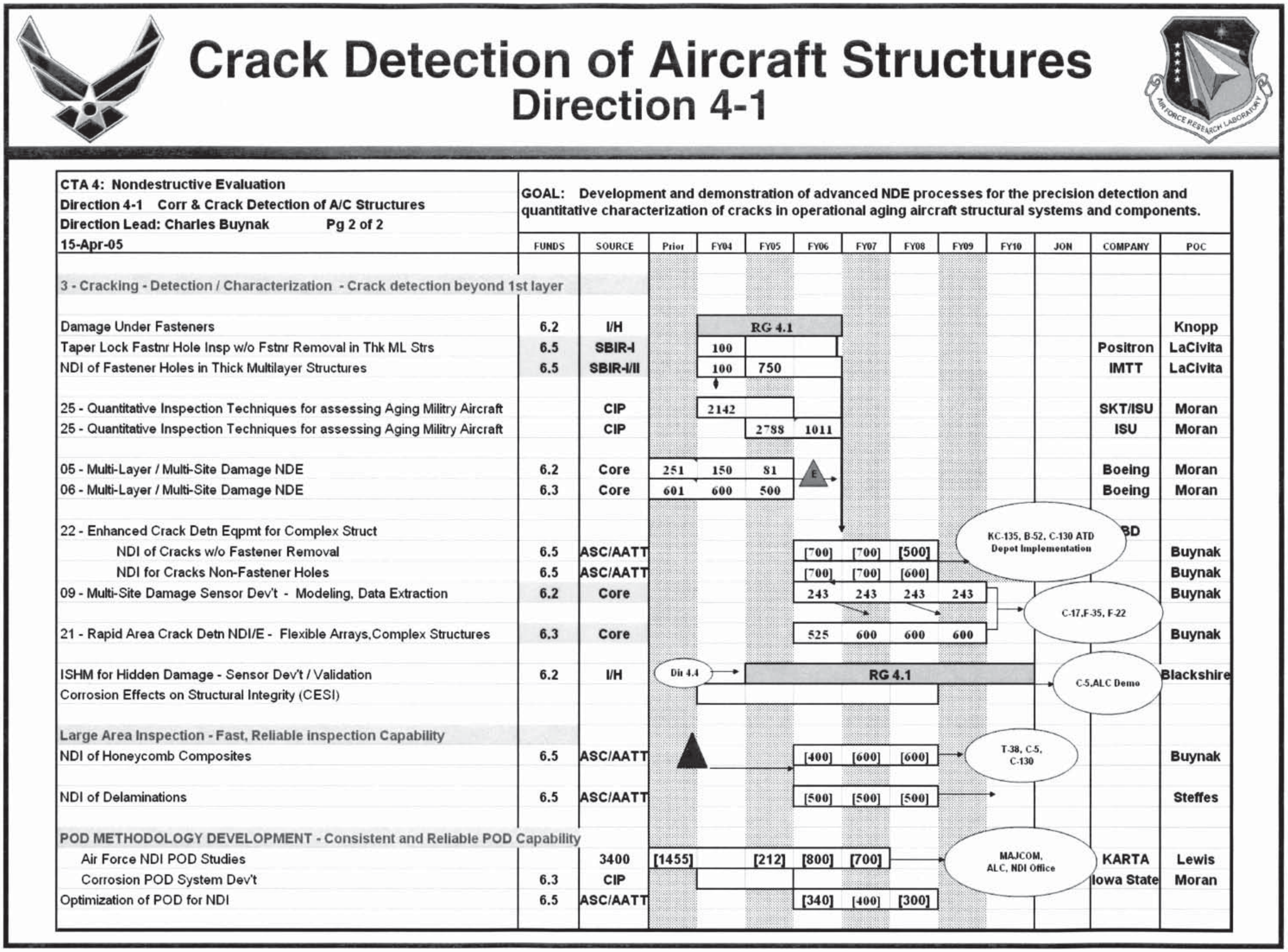


Corrosion Detection of Aircraft Structures
Direction 4-1

CTA 4: Nondestructive Evaluation
Direction 4-1 Corr & Crack Detection of A/C Structures
Direction Lead: Charles Buynak **Pg 1 of 2**
15-Apr-05

GOAL: Development and demonstration of advanced NDE processes for the precision detection and quantitative characterization of hidden corrosion in operational aging aircraft structural systems and components.

	FUNDS	SOURCE	Prior	FY04	FY05	FY06	FY07	FY08	FY09	FY10	JON	COMPANY	POC
2 - Adv Corrosion Detection & Quant Char													
Thin Structure Corrosion Mapping (TCORR)	6.5	ASC/AATT	▲							KC-135, B-52, E-8, C-130			
PITTING / EXFOLIATION - Localized deep structural inspection tool													
Corrosion Effects on Structural Integrity (CESI)	6.5	ASC/AATT	[21300]	[3950]	[4720]	[4700]	[3950]			FSMP		SKT	Harrington
												NASA, USAFA	
09 - Modeling Eddy Current Array Sensor Sensitivities	6.2	Core	75									Iowa State	Barnes
	6.3	Core	241	▲								Iowa State	Barnes
09 - Pulsed Eddy Current Tech for Corro Eval	6.3	Core	780									NDT Solns	Steffes
22 - Enhanced Eqpmt for Exfoliation/Pitting (Pectran)	6.5	ASC/AATT		[547]	[200]			KC-135, B-52, E-3, C-130 Wing Skin Structures				SKT	Steffes
ADVANCED NDE CORR DETECTION SYSTEM - Data Analysis Tools													
13 - Computational Methods for NDE (AFOSR)	6.1	AFOSR	186	66	73							Comp Tool	Steffes
13 - Computational Methods for NDE	6.2	Core	50	25	25							Comp Tool	Steffes
13 - Strategy and Software Environment for Virtual Design	6.5	SBIR II	375	375								Austral Egr	Knopp
Economic Service Life Tool Development							RG 4.1						Knopp
13 - Virtual NDE:Computational Mthds for Virtual Prototyping	6.5	SBIR-II	375	375								NDE Tech. Inc.	Steffes
14 - Computer Simulation Modeling Applications	6.2	Core	60	150	100							SAIC	Steffes
14 - Computer Simulation Modeling Applications	6.3	Core	100	120								SAIC	Steffes
Damage under Fastener (Spiral Creeping Wave)						RG 4.1						Comp Tool	Knopp
18,19 - Advanced NDE Methods - O/S)	6.2	Core	290	290	290	290	290	292	290			UDRI/Anteon	Martinez
	6.3	Core	180	180	180	180	180	180	180			UDRI/Anteon	Martinez
NDE for Corrosion		I/H				RG 4.1							Martinez
4-4 (25) - Quantitative Inspn Tech for assessing Aging Militry Aircraft		CIP				▲ C				KC-135, B-52, B-1		SKT/ISU	Moran
22 - Enhanced NDE Capability (NDI for Corrosion)	6.5	ASC/AATT				[1400]	[1200]	[500]		ASC/AATT Spiral			Buynak
VIC 3D Software Package	6.5	ASC/AATT		[50]								UDRI	Knopp
25-Eddy Current Data Analysis	6.3	Coreflex			130							MSU	Knopp
14 - Computational Methods	6.2	Core	40	80	50							IIT	Steffes
Adv Eddy Current Feature Modeling					RG 4.1					ASC/AATT			Knopp
Universal NDE Data Translation (DICONDE)	6.2	DP		150								Anteon	Steffes
CORR Under Paint - Ability to examine for near-surface structural flaws w/o paint removal													
Next Gen NDE thru Paint Sensors	6.2	I/H		RG 4.1					ML Paint Team (Corr IPT)			(UMR)	Blackshire
Quantum Cascade Terahertz Emitter (PR/SN Collaboration)	6.2	LDF		54.5	RG 4.1								Cooney
NDE for Corrosion Detn / Bonded Repair [CAMT]		CIP			514	262		OC-ALC Radomes				UMR/Boeing	Tiley
Microwave Sensors for Corrosion Evaluation		SBIR II			750							TRI/UMR	Steffes
Environmentally Friendly NDI for Corr Inspection Thru Coatings (IR2NDI)		SERDP		664	849	950						Northrop	Leone

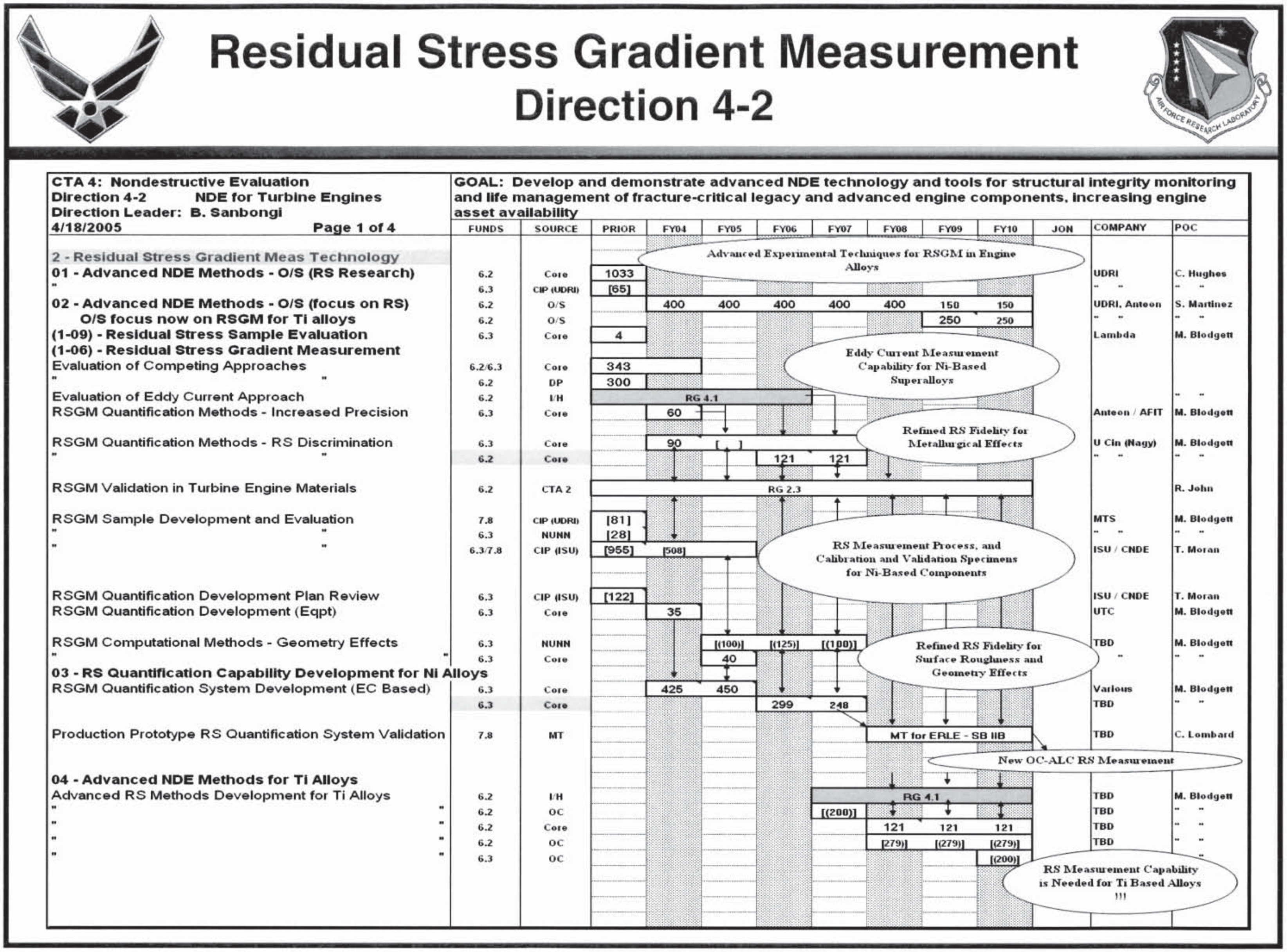


Crack Detection of Aircraft Structures
Direction 4-1

CTA 4: Nondestructive Evaluation
Direction 4-1 Corr & Crack Detection of A/C Structures
Direction Lead: Charles Buynak Pg 2 of 2
15-Apr-05

GOAL: Development and demonstration of advanced NDE processes for the precision detection and quantitative characterization of cracks in operational aging aircraft structural systems and components.

	FUNDS	SOURCE	Prior	FY04	FY05	FY06	FY07	FY08	FY09	FY10	JON	COMPANY	POC
3 - Cracking - Detection / Characterization - Crack detection beyond 1st layer													
Damage Under Fasteners	6.2	I/H		RG 4.1	RG 4.1	RG 4.1							Knopp
Taper Lock Fastnr Hole Insp w/o Fstnr Removal in Thk ML Strs	6.5	SBIR-I		100								Positron	LaCivita
NDI of Fastener Holes in Thick Multilayer Structures	6.5	SBIR-I/II		100	750							IMTT	LaCivita
25 - Quantitative Inspection Techniques for assessing Aging Militry Aircraft		CIP		2142								SKT/ISU	Moran
25 - Quantitative Inspection Techniques for assessing Aging Militry Aircraft		CIP			2788	1011						ISU	Moran
05 - Multi-Layer / Multi-Site Damage NDE	6.2	Core	251	150	81	E						Boeing	Moran
06 - Multi-Layer / Multi-Site Damage NDE	6.3	Core	601	600	500							Boeing	Moran
22 - Enhanced Crack Detn Eqpmt for Complex Struct												BD	
NDI of Cracks w/o Fastener Removal	6.5	ASC/AATT				[700]	[700]	[500]					Buynak
NDI for Cracks Non-Fastener Holes	6.5	ASC/AATT				[700]	[700]	[600]					Buynak
09 - Multi-Site Damage Sensor Dev't - Modeling, Data Extraction	6.2	Core				243	243	243	243				Buynak
21 - Rapid Area Crack Detn NDI/E - Flexible Arrays,Complex Structures	6.3	Core				525	600	600	600				Buynak
ISHM for Hidden Damage - Sensor Dev't / Validation	6.2	I/H	Dir 4.4		RG 4.1	RG 4.1	RG 4.1	RG 4.1	RG 4.1	RG 4.1			Blackshire
Corrosion Effects on Structural Integrity (CESI)													
Large Area Inspection - Fast, Reliable inspection Capability													
NDI of Honeycomb Composites	6.5	ASC/AATT				[400]	[600]	[600]					Buynak
NDI of Delaminations	6.5	ASC/AATT				[500]	[500]	[500]					Steffes
POD METHODOLOGY DEVELOPMENT - Consistent and Reliable POD Capability													
Air Force NDI POD Studies		3400	[1455]		[212]	[800]	[700]					KARTA	Lewis
Corrosion POD System Dev't	6.3	CIP										Iowa State	Moran
Optimization of POD for NDI	6.5	ASC/AATT				[340]	[400]	[300]					



Residual Stress Gradient Measurement

Direction 4-2

CTA 4: Nondestructive Evaluation
Direction 4-2 NDE for Turbine Engines
Direction Leader: B. Sanbongi
4/18/2005 Page 1 of 4

GOAL: Develop and demonstrate advanced NDE technology and tools for structural integrity monitoring and life management of fracture-critical legacy and advanced engine components, increasing engine asset availability

	FUNDS	SOURCE	PRIOR	FY04	FY05	FY06	FY07	FY08	FY09	FY10	JON	COMPANY	POC
2 - Residual Stress Gradient Meas Technology													
01 - Advanced NDE Methods - O/S (RS Research)	6.2	Core	1033									UDRI	C. Hughes
"	6.3	CIP (UDRI)	[65]									" "	" "
02 - Advanced NDE Methods - O/S (focus on RS)	6.2	O/S		400	400	400	400	400	150	150		UDRI, Anteon	S. Martinez
O/S focus now on RSGM for Ti alloys	6.2	O/S							250	250		" "	" "
(1-09) - Residual Stress Sample Evaluation	6.3	Core	4									Lambda	M. Blodgett
(1-06) - Residual Stress Gradient Measurement													
Evaluation of Competing Approaches	6.2/6.3	Core	343										
" "	6.2	DP	300										
Evaluation of Eddy Current Approach	6.2	I/H	RG 4.1										" "
RSGM Quantification Methods - Increased Precision	6.3	Core		60								Anteon / AFIT	M. Blodgett
RSGM Quantification Methods - RS Discrimination	6.3	Core		90	[ ]							U Cin (Nagy)	M. Blodgett
" "	6.2	Core				121	121					" "	" "
RSGM Validation in Turbine Engine Materials	6.2	CTA 2				RG 2.3							R. John
RSGM Sample Development and Evaluation	7.8	CIP (UDRI)	[81]									MTS	M. Blodgett
" "	6.3	NUNN	[28]									" "	" "
" "	6.3/7.8	CIP (ISU)	[955]	[508]								ISU / CNDE	T. Moran
RSGM Quantification Development Plan Review	6.3	CIP (ISU)	[122]									ISU / CNDE	T. Moran
RSGM Quantification Development (Eqpt)	6.3	Core		35								UTC	M. Blodgett
RSGM Computational Methods - Geometry Effects	6.3	NUNN			[(100)]	[(125)]	[(100)]					TBD	M. Blodgett
" "	6.3	Core			40							"	" "
03 - RS Quantification Capability Development for Ni Alloys													
RSGM Quantification System Development (EC Based)	6.3	Core		425	450							Various	M. Blodgett
	6.3	Core				299	248					TBD	" "
Production Prototype RS Quantification System Validation	7.8	MT						MT for ERLE - SB IIB				TBD	C. Lombard
04 - Advanced NDE Methods for Ti Alloys													
Advanced RS Methods Development for Ti Alloys	6.2	I/H						RG 4.1				TBD	M. Blodgett
" "	6.2	OC					[(200)]					TBD	" "
" "	6.2	Core						121	121	121		TBD	" "
" "	6.2	OC						[279)]	[(279)]	[(279)]		TBD	" "
" "	6.3	OC								[(200)]			"

Advanced Experimental Techniques for RSGM in Engine Alloys

Eddy Current Measurement Capability for Ni-Based Superalloys

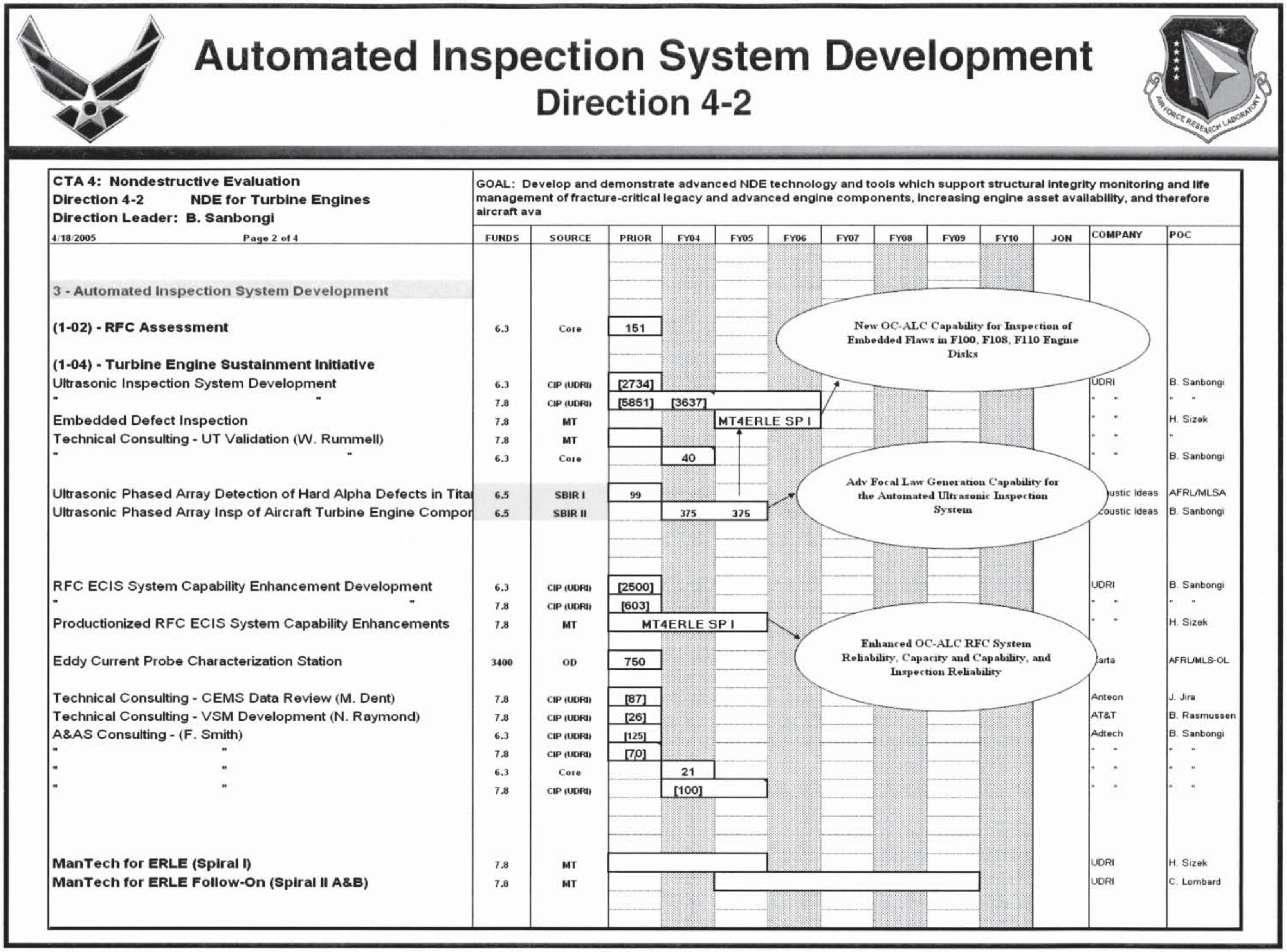
Refined RS Fidelity for Metallurgical Effects

RS Measurement Process, and Calibration and Validation Specimens for Ni-Based Components

Refined RS Fidelity for Surface Roughness and Geometry Effects

New OC-ALC RS Measurement

RS Measurement Capability is Needed for Ti Based Alloys !!!



Automated Inspection System Development

Direction 4-2

CTA 4: Nondestructive Evaluation
Direction 4-2 **NDE for Turbine Engines**
Direction Leader: B. Sanbongi
4/18/2005 Page 2 of 4

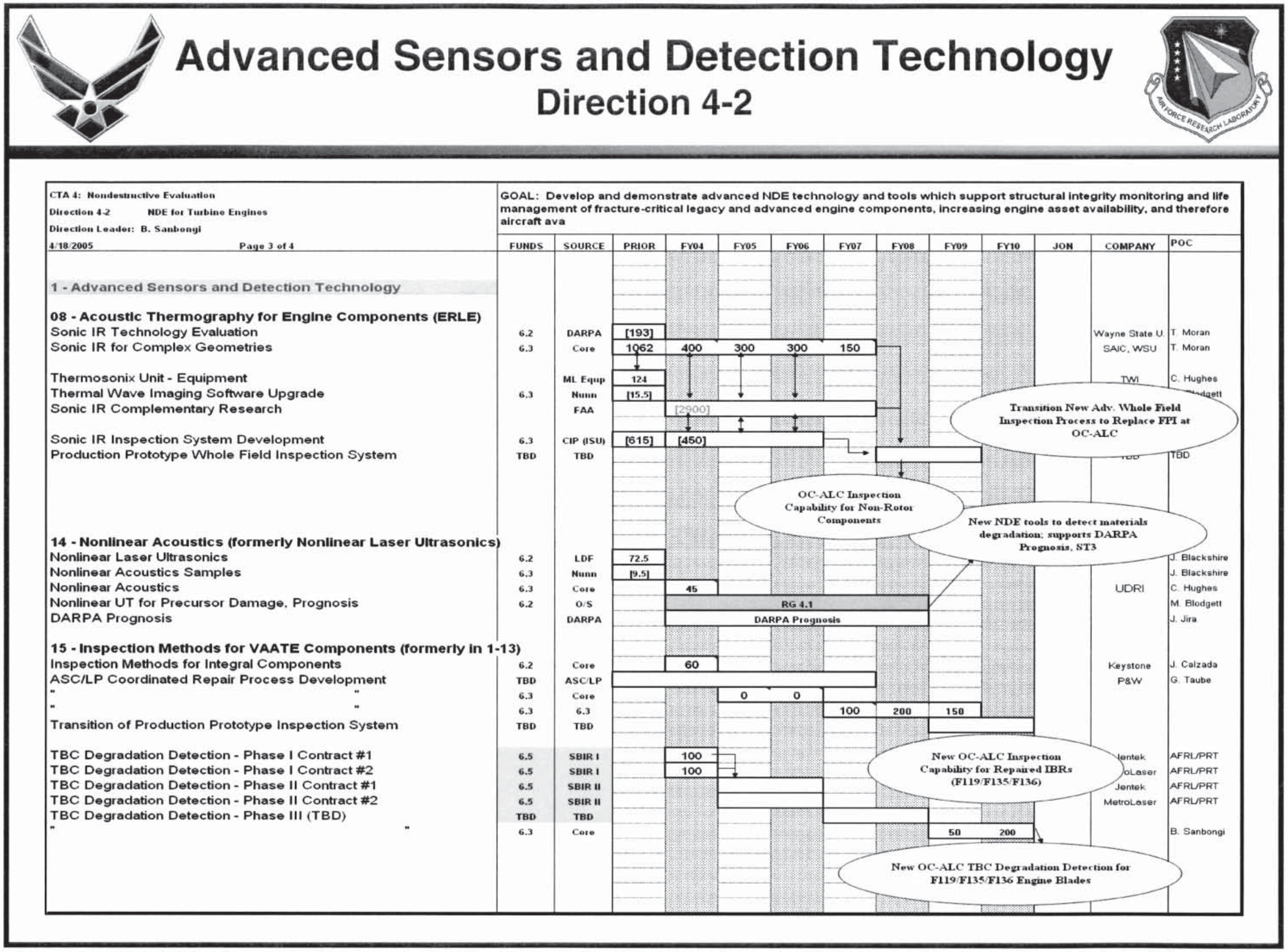
GOAL: Develop and demonstrate advanced NDE technology and tools which support structural integrity monitoring and life management of fracture-critical legacy and advanced engine components, increasing engine asset availability, and therefore aircraft ava

	FUNDS	SOURCE	PRIOR	FY04	FY05	FY06	FY07	FY08	FY09	FY10	JON	COMPANY	POC
3 - Automated Inspection System Development													
(1-02) - RFC Assessment	6.3	Core	151										
(1-04) - Turbine Engine Sustainment Initiative													
Ultrasonic Inspection System Development	6.3	CIP (UDRI)	[2734]									UDRI	B. Sanbongi
" "	7.8	CIP (UDRI)	[5851]	[3637]								" "	" "
Embedded Defect Inspection	7.8	MT			MT4ERLE SP I							" "	H. Sizek
Technical Consulting - UT Validation (W. Rummell)	7.8	MT										" "	"
" "	6.3	Core		40								" "	B. Sanbongi
Ultrasonic Phased Array Detection of Hard Alpha Defects in Tita	6.5	SBIR I	99									ustic Ideas	AFRL/MLSA
Ultrasonic Phased Array Insp of Aircraft Turbine Engine Compor	6.5	SBIR II		375	375							coustic Ideas	B. Sanbongi
RFC ECIS System Capability Enhancement Development	6.3	CIP (UDRI)	[2500]									UDRI	B. Sanbongi
" "	7.8	CIP (UDRI)	[603]									" "	" "
Productionized RFC ECIS System Capability Enhancements	7.8	MT	MT4ERLE SP I									" "	H. Sizek
Eddy Current Probe Characterization Station	3400	OD	750									arta	AFRL/MLS-OL
Technical Consulting - CEMS Data Review (M. Dent)	7.8	CIP (UDRI)	[87]									Anteon	J. Jira
Technical Consulting - VSM Development (N. Raymond)	7.8	CIP (UDRI)	[26]									AT&T	B. Rasmussen
A&AS Consulting - (F. Smith)	6.3	CIP (UDRI)	[125]									Adtech	B. Sanbongi
" "	7.8	CIP (UDRI)	[70]									" "	" "
" "	6.3	Core		21								" "	" "
" "	7.8	CIP (UDRI)		[100]								" "	" "
ManTech for ERLE (Spiral I)	7.8	MT										UDRI	H. Sizek
ManTech for ERLE Follow-On (Spiral II A&B)	7.8	MT										UDRI	C. Lombard

New OC-ALC Capability for Inspection of Embedded Flaws in F100, F108, F110 Engine Disks

Adv Focal Law Generation Capability for the Automated Ultrasonic Inspection System

Enhanced OC-ALC RFC System Reliability, Capacity and Capability, and Inspection Reliability



Advanced Sensors and Detection Technology

Direction 4-2

CTA 4: Nondestructive Evaluation
Direction 4-2 NDE for Turbine Engines
Direction Leader: B. Sanbongi
4/18/2005 Page 3 of 4

GOAL: Develop and demonstrate advanced NDE technology and tools which support structural integrity monitoring and life management of fracture-critical legacy and advanced engine components, increasing engine asset availability, and therefore aircraft ava

	FUNDS	SOURCE	PRIOR	FY04	FY05	FY06	FY07	FY08	FY09	FY10	JON	COMPANY	POC
1 - Advanced Sensors and Detection Technology													
08 - Acoustic Thermography for Engine Components (ERLE)													
Sonic IR Technology Evaluation	6.2	DARPA	[193]									Wayne State U.	T. Moran
Sonic IR for Complex Geometries	6.3	Core	1062	400	300	300	150					SAIC, WSU	T. Moran
Thermosonix Unit - Equipment		ML Equp	124									TWI	C. Hughes
Thermal Wave Imaging Software Upgrade	6.3	Nunn	[15.5]										[illegible]
Sonic IR Complementary Research		FAA		[2900]									
Sonic IR Inspection System Development	6.3	CIP (ISU)	[615]	[450]									
Production Prototype Whole Field Inspection System	TBD	TBD										TBD	TBD
14 - Nonlinear Acoustics (formerly Nonlinear Laser Ultrasonics)													
Nonlinear Laser Ultrasonics	6.2	LDF	72.5										J. Blackshire
Nonlinear Acoustics Samples	6.3	Nunn	[9.5]										J. Blackshire
Nonlinear Acoustics	6.3	Core		45								UDRI	C. Hughes
Nonlinear UT for Precursor Damage, Prognosis	6.2	O/S				RG 4.1							M. Blodgett
DARPA Prognosis		DARPA				DARPA Prognosis							J. Jira
15 - Inspection Methods for VAATE Components (formerly in 1-13)													
Inspection Methods for Integral Components	6.2	Core		60								Keystone	J. Calzada
ASC/LP Coordinated Repair Process Development	TBD	ASC/LP										P&W	G. Taube
" "	6.3	Core			0	0							
" "	6.3	6.3					100	200	150				
Transition of Production Prototype Inspection System	TBD	TBD											
TBC Degradation Detection - Phase I Contract #1	6.5	SBIR I		100								entek	AFRL/PRT
TBC Degradation Detection - Phase I Contract #2	6.5	SBIR I		100								oLaser	AFRL/PRT
TBC Degradation Detection - Phase II Contract #1	6.5	SBIR II										Jentek	AFRL/PRT
TBC Degradation Detection - Phase II Contract #2	6.5	SBIR II										MetroLaser	AFRL/PRT
TBC Degradation Detection - Phase III (TBD)	TBD	TBD											
" "	6.3	Core							50	200			B. Sanbongi

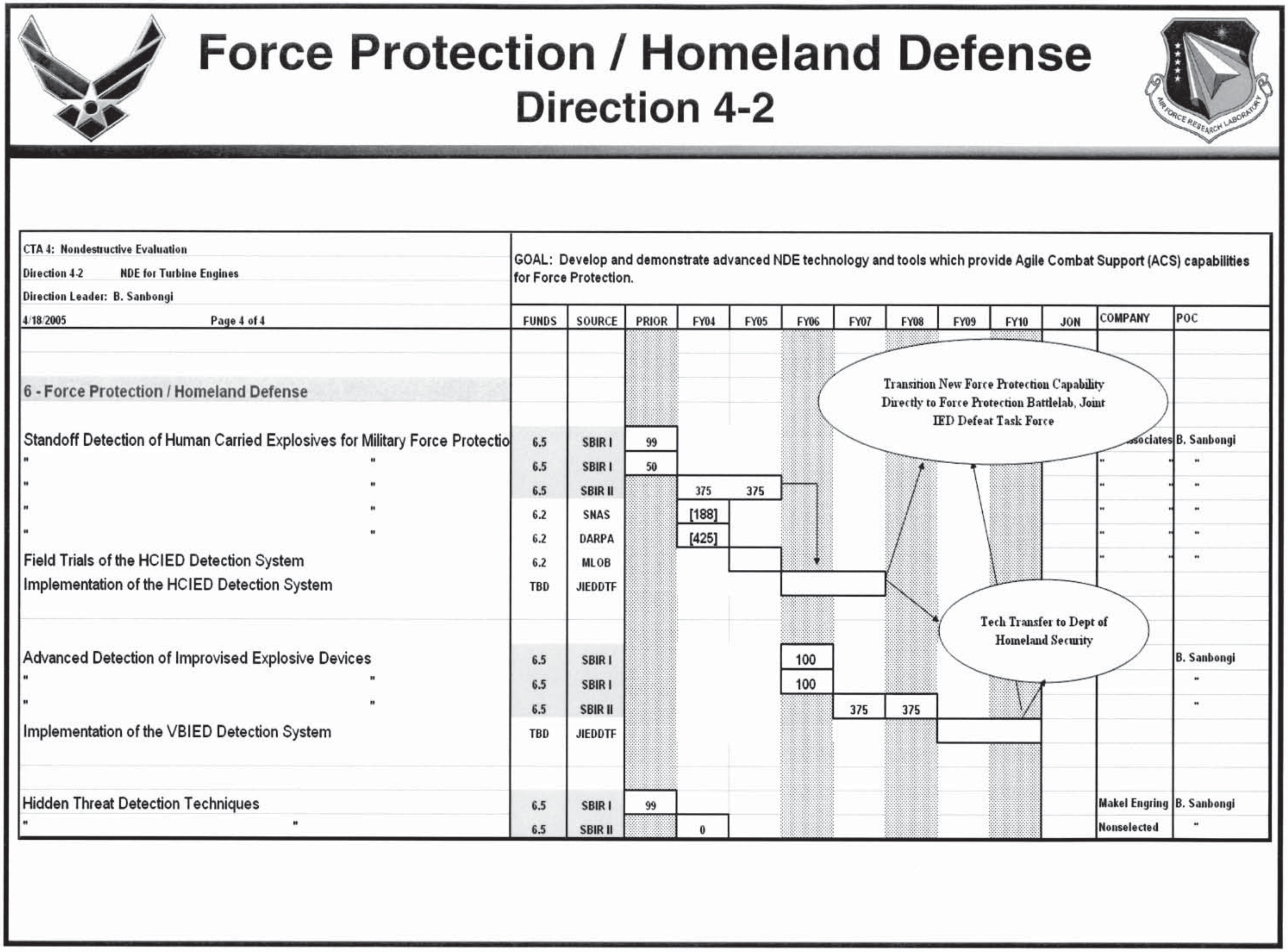
Transition New Adv. Whole Field Inspection Process to Replace FPI at OC-ALC

OC-ALC Inspection Capability for Non-Rotor Components

New NDE tools to detect materials degradation; supports DARPA Prognosis, ST3

New OC-ALC Inspection Capability for Repaired IBRs (F119/F135/F136)

New OC-ALC TBC Degradation Detection for F119/F135/F136 Engine Blades



Force Protection / Homeland Defense

Direction 4-2

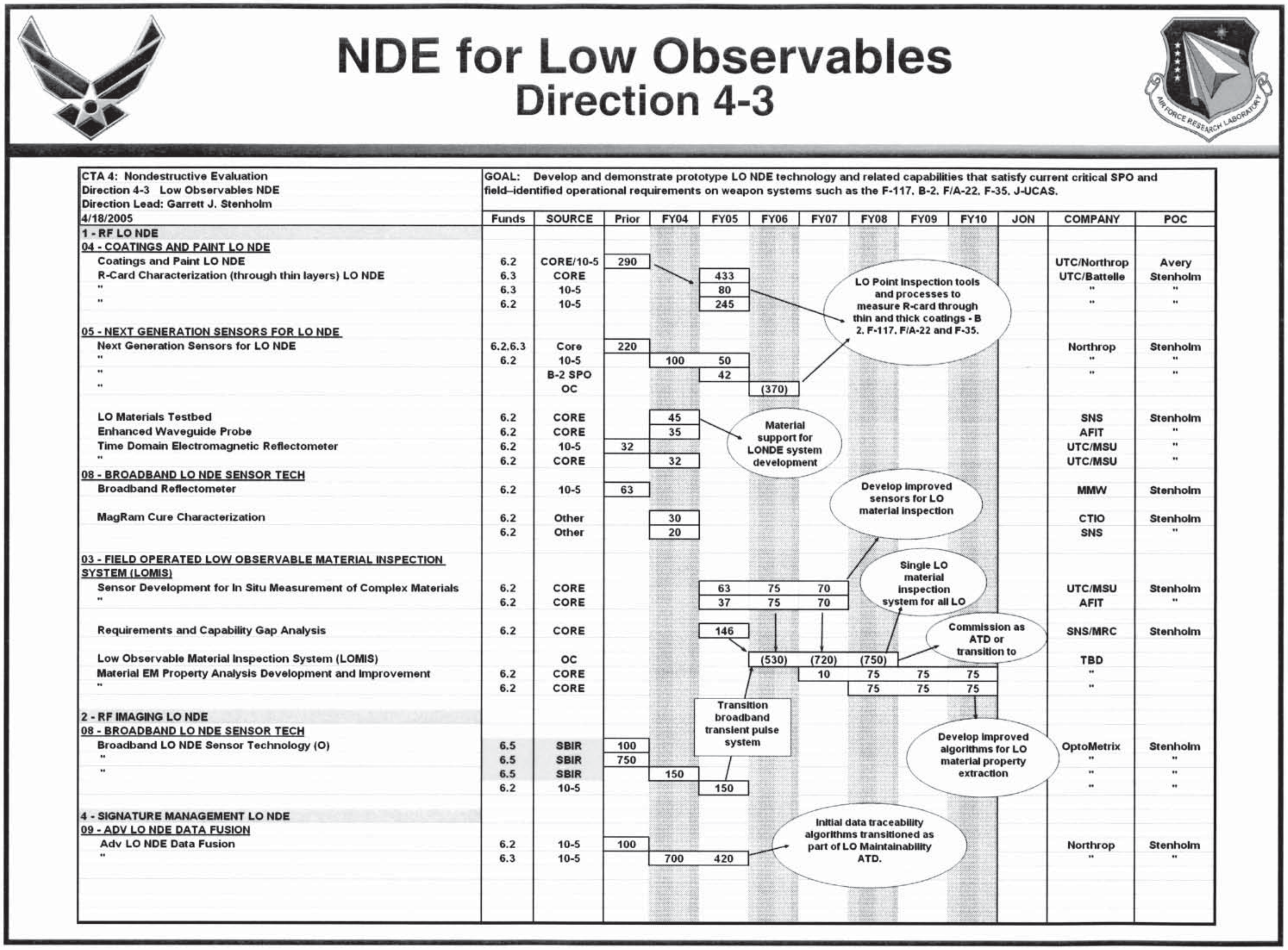
CTA 4: Nondestructive Evaluation
Direction 4-2 NDE for Turbine Engines
Direction Leader: B. Sanbongi
4/18/2005 Page 4 of 4

GOAL: Develop and demonstrate advanced NDE technology and tools which provide Agile Combat Support (ACS) capabilities for Force Protection.

	FUNDS	SOURCE	PRIOR	FY04	FY05	FY06	FY07	FY08	FY09	FY10	JON	COMPANY	POC
6 - Force Protection / Homeland Defense													
Standoff Detection of Human Carried Explosives for Military Force Protectio	6.5	SBIR I	99									ssociates	B. Sanbongi
" "	6.5	SBIR I	50									" "	"
" "	6.5	SBIR II		375	375							" "	"
" "	6.2	SNAS		[188]								" "	"
" "	6.2	DARPA		[425]								" "	"
Field Trials of the HCIED Detection System	6.2	MLOB										" "	"
Implementation of the HCIED Detection System	TBD	JIEDDTF											
Advanced Detection of Improvised Explosive Devices	6.5	SBIR I				100							B. Sanbongi
" "	6.5	SBIR I				100							"
" "	6.5	SBIR II					375	375					"
Implementation of the VBIED Detection System	TBD	JIEDDTF											
Hidden Threat Detection Techniques	6.5	SBIR I	99									Makel Engring	B. Sanbongi
" "	6.5	SBIR II		0								Nonselected	"

Transition New Force Protection Capability Directly to Force Protection Battlelab, Joint IED Defeat Task Force

Tech Transfer to Dept of Homeland Security



NDE for Low Observables
Direction 4-3

CTA 4: Nondestructive Evaluation
Direction 4-3 Low Observables NDE
Direction Lead: Garrett J. Stenholm

GOAL: Develop and demonstrate prototype LO NDE technology and related capabilities that satisfy current critical SPO and field–identified operational requirements on weapon systems such as the F-117, B-2, F/A-22, F-35, J-UCAS.

4/18/2005	Funds	SOURCE	Prior	FY04	FY05	FY06	FY07	FY08	FY09	FY10	JON	COMPANY	POC
1 - RF LO NDE													
04 - COATINGS AND PAINT LO NDE													
Coatings and Paint LO NDE	6.2	CORE/10-5	290									UTC/Northrop	Avery
R-Card Characterization (through thin layers) LO NDE	6.3	CORE			433							UTC/Battelle	Stenholm
"	6.3	10-5			80							"	"
"	6.2	10-5			245							"	"
05 - NEXT GENERATION SENSORS FOR LO NDE													
Next Generation Sensors for LO NDE	6.2,6.3	Core	220									Northrop	Stenholm
"	6.2	10-5		100	50							"	"
"		B-2 SPO			42							"	"
"		OC				(370)							
LO Materials Testbed	6.2	CORE		45								SNS	Stenholm
Enhanced Waveguide Probe	6.2	CORE		35								AFIT	"
Time Domain Electromagnetic Reflectometer	6.2	10-5	32									UTC/MSU	"
"	6.2	CORE		32								UTC/MSU	"
08 - BROADBAND LO NDE SENSOR TECH													
Broadband Reflectometer	6.2	10-5	63									MMW	Stenholm
MagRam Cure Characterization	6.2	Other		30								CTIO	Stenholm
	6.2	Other		20								SNS	"
03 - FIELD OPERATED LOW OBSERVABLE MATERIAL INSPECTION SYSTEM (LOMIS)													
Sensor Development for In Situ Measurement of Complex Materials	6.2	CORE			63	75	70					UTC/MSU	Stenholm
"	6.2	CORE			37	75	70					AFIT	"
Requirements and Capability Gap Analysis	6.2	CORE			146							SNS/MRC	Stenholm
Low Observable Material Inspection System (LOMIS)		OC				(530)	(720)	(750)				TBD	
Material EM Property Analysis Development and Improvement	6.2	CORE					10	75	75	75		"	
"	6.2	CORE						75	75	75		"	
2 - RF IMAGING LO NDE													
08 - BROADBAND LO NDE SENSOR TECH													
Broadband LO NDE Sensor Technology (O)	6.5	SBIR	100									OptoMetrix	Stenholm
"	6.5	SBIR	750									"	"
"	6.5	SBIR		150								"	"
	6.2	10-5			150							"	"
4 - SIGNATURE MANAGEMENT LO NDE													
09 - ADV LO NDE DATA FUSION													
Adv LO NDE Data Fusion	6.2	10-5	100									Northrop	Stenholm
"	6.3	10-5		700	420							"	"

LO Point inspection tools and processes to measure R-card through thin and thick coatings - B 2, F-117, F/A-22 and F-35.

Material support for LONDE system development

Develop improved sensors for LO material inspection

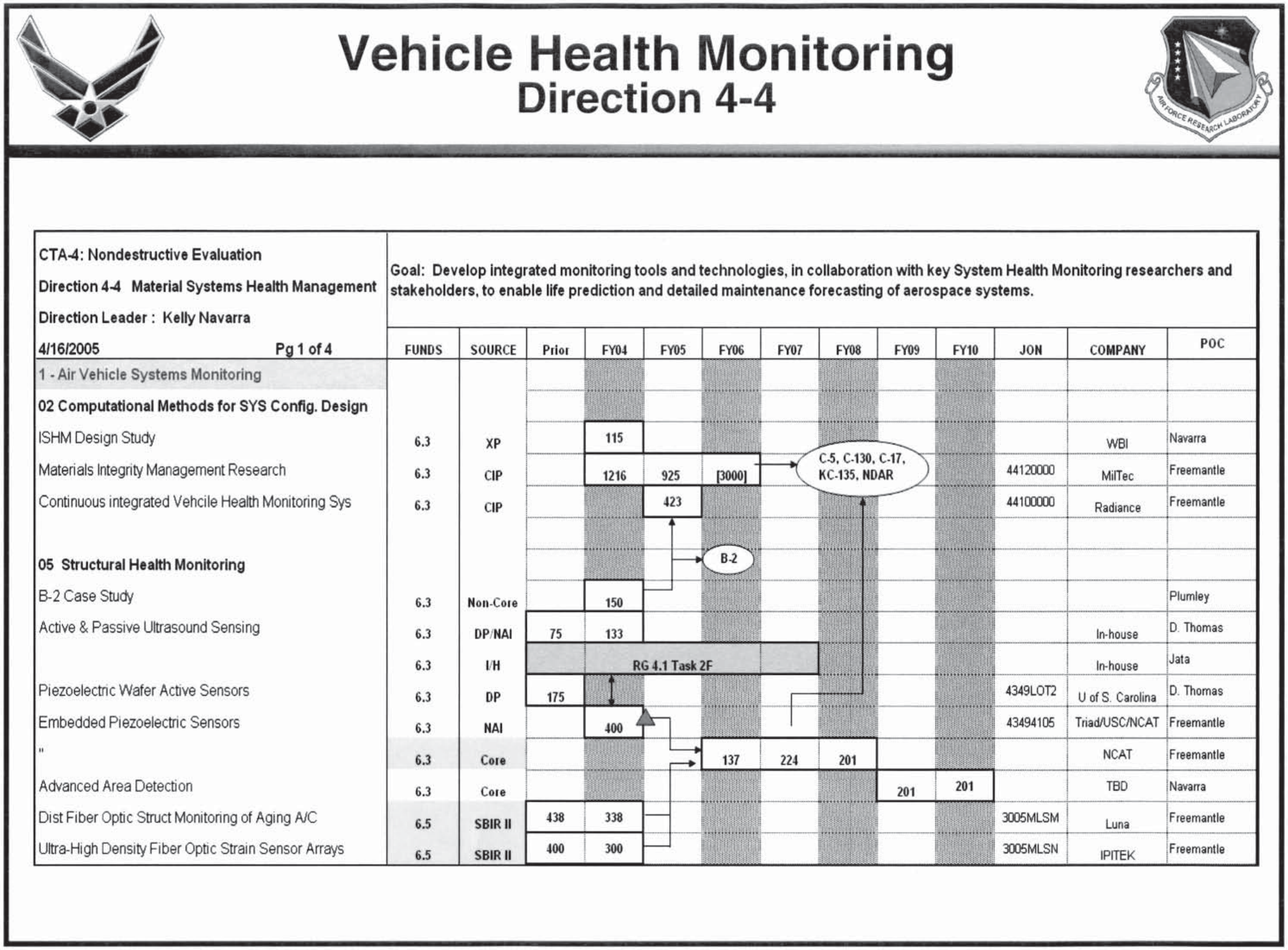
Single LO material inspection system for all LO

Commission as ATD or transition to

Transition broadband transient pulse system

Develop improved algorithms for LO material property extraction

Initial data traceability algorithms transitioned as part of LO Maintainability ATD.



Vehicle Health Monitoring

Direction 4-4

CTA-4: Nondestructive Evaluation

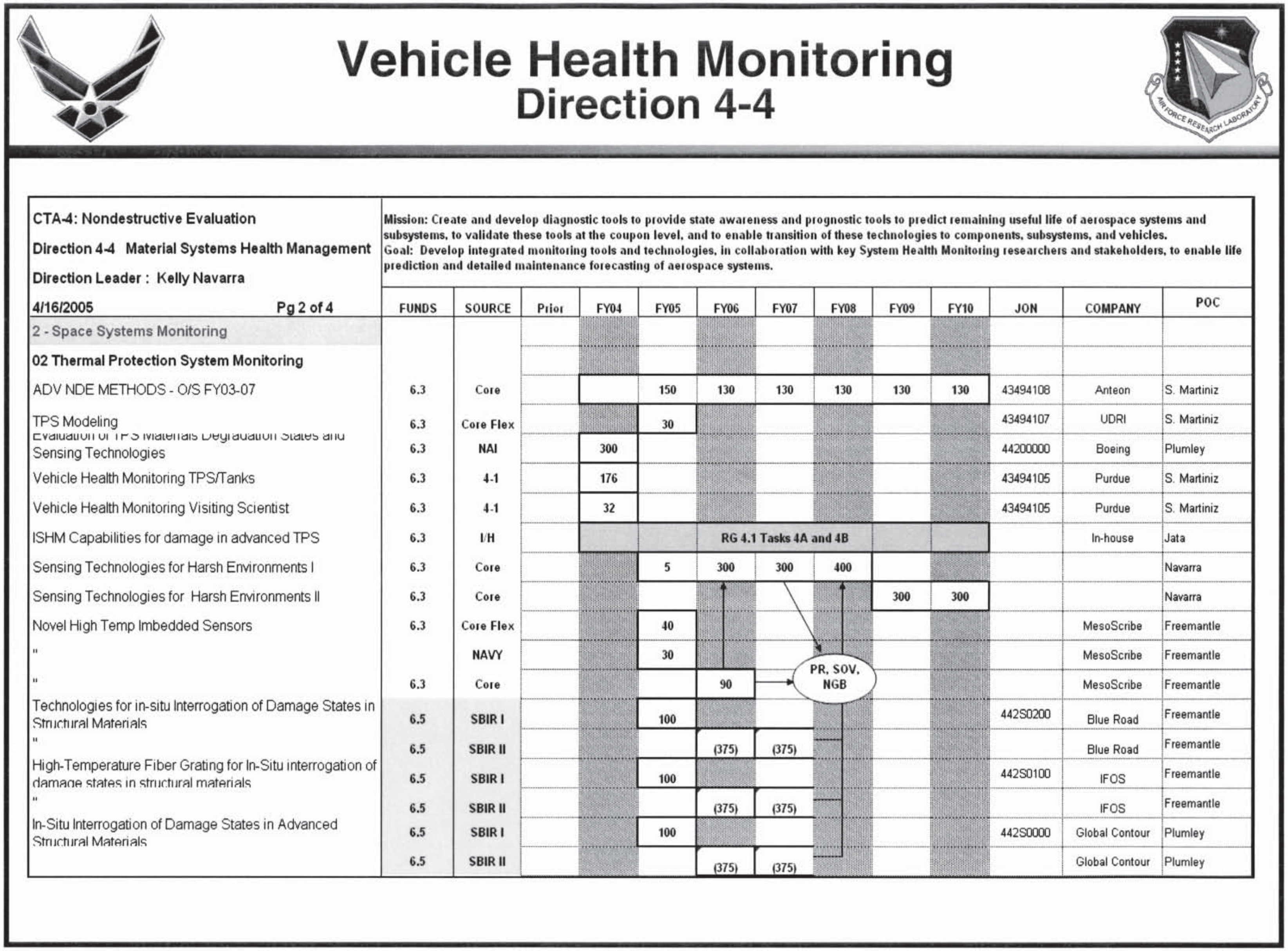
Direction 4-4 Material Systems Health Management

Direction Leader : Kelly Navarra

4/16/2005 **Pg 1 of 4**

Goal: Develop integrated monitoring tools and technologies, in collaboration with key System Health Monitoring researchers and stakeholders, to enable life prediction and detailed maintenance forecasting of aerospace systems.

	FUNDS	SOURCE	Prior	FY04	FY05	FY06	FY07	FY08	FY09	FY10	JON	COMPANY	POC
1 - Air Vehicle Systems Monitoring													
02 Computational Methods for SYS Config. Design													
ISHM Design Study	6.3	XP		115								WBI	Navarra
Materials Integrity Management Research	6.3	CIP		1216	925	[3000]					44120000	MilTec	Freemantle
Continuous integrated Vehcile Health Monitoring Sys	6.3	CIP			423						44100000	Radiance	Freemantle
05 Structural Health Monitoring													
B-2 Case Study	6.3	Non-Core		150									Plumley
Active & Passive Ultrasound Sensing	6.3	DP/NAI	75	133								In-house	D. Thomas
	6.3	I/H	RG 4.1 Task 2F									In-house	Jata
Piezoelectric Wafer Active Sensors	6.3	DP	175								4349LOT2	U of S. Carolina	D. Thomas
Embedded Piezoelectric Sensors	6.3	NAI		400							43494105	Triad/USC/NCAT	Freemantle
"	6.3	Core				137	224	201				NCAT	Freemantle
Advanced Area Detection	6.3	Core							201	201		TBD	Navarra
Dist Fiber Optic Struct Monitoring of Aging A/C	6.5	SBIR II	438	338							3005MLSM	Luna	Freemantle
Ultra-High Density Fiber Optic Strain Sensor Arrays	6.5	SBIR II	400	300							3005MLSN	IPITEK	Freemantle



Vehicle Health Monitoring
Direction 4-4

CTA-4: Nondestructive Evaluation

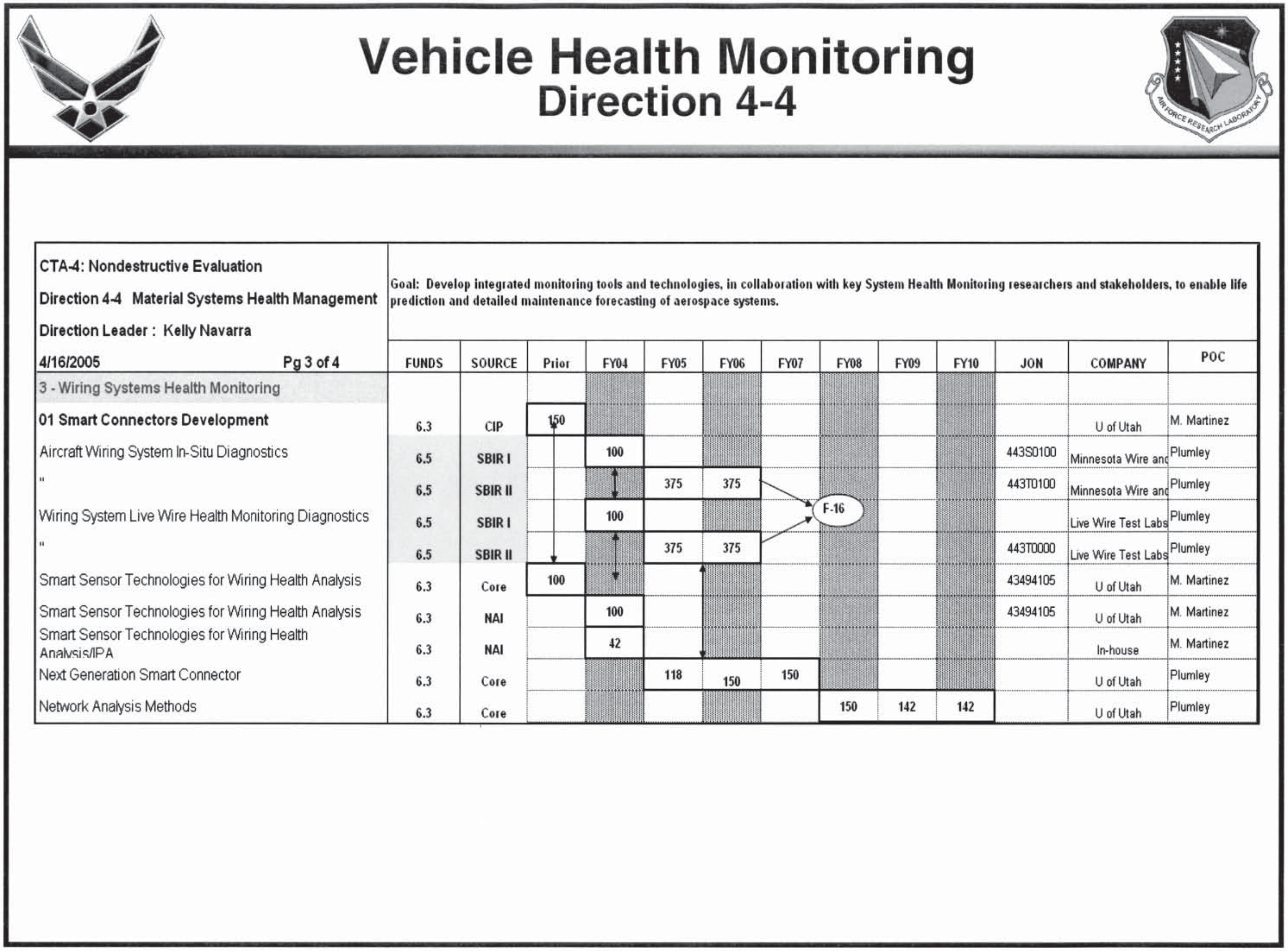
Direction 4-4 Material Systems Health Management

Direction Leader : Kelly Navarra

4/16/2005 **Pg 2 of 4**

Mission: Create and develop diagnostic tools to provide state awareness and prognostic tools to predict remaining useful life of aerospace systems and subsystems, to validate these tools at the coupon level, and to enable transition of these technologies to components, subsystems, and vehicles.
Goal: Develop integrated monitoring tools and technologies, in collaboration with key System Health Monitoring researchers and stakeholders, to enable life prediction and detailed maintenance forecasting of aerospace systems.

	FUNDS	SOURCE	Prior	FY04	FY05	FY06	FY07	FY08	FY09	FY10	JON	COMPANY	POC
2 - Space Systems Monitoring													
02 Thermal Protection System Monitoring													
ADV NDE METHODS - O/S FY03-07	6.3	Core			150	130	130	130	130	130	43494108	Anteon	S. Martiniz
TPS Modeling	6.3	Core Flex			30						43494107	UDRI	S. Martiniz
Evaluation of TPS Materials Degradation States and Sensing Technologies	6.3	NAI		300							44200000	Boeing	Plumley
Vehicle Health Monitoring TPS/Tanks	6.3	4-1		176							43494105	Purdue	S. Martiniz
Vehicle Health Monitoring Visiting Scientist	6.3	4-1		32							43494105	Purdue	S. Martiniz
ISHM Capabilities for damage in advanced TPS	6.3	I/H		RG 4.1 Tasks 4A and 4B								In-house	Jata
Sensing Technologies for Harsh Environments I	6.3	Core			5	300	300	400					Navarra
Sensing Technologies for Harsh Environments II	6.3	Core							300	300			Navarra
Novel High Temp Imbedded Sensors	6.3	Core Flex			40							MesoScribe	Freemantle
"		NAVY			30							MesoScribe	Freemantle
"	6.3	Core				90		PR, SOV, NGB				MesoScribe	Freemantle
Technologies for in-situ Interrogation of Damage States in Structural Materials	6.5	SBIR I			100						442S0200	Blue Road	Freemantle
"	6.5	SBIR II				(375)	(375)					Blue Road	Freemantle
High-Temperature Fiber Grating for In-Situ interrogation of damage states in structural materials	6.5	SBIR I			100						442S0100	IFOS	Freemantle
"	6.5	SBIR II				(375)	(375)					IFOS	Freemantle
In-Situ Interrogation of Damage States in Advanced Structural Materials	6.5	SBIR I			100						442S0000	Global Contour	Plumley
	6.5	SBIR II				(375)	(375)					Global Contour	Plumley



Vehicle Health Monitoring
Direction 4-4

CTA-4: Nondestructive Evaluation

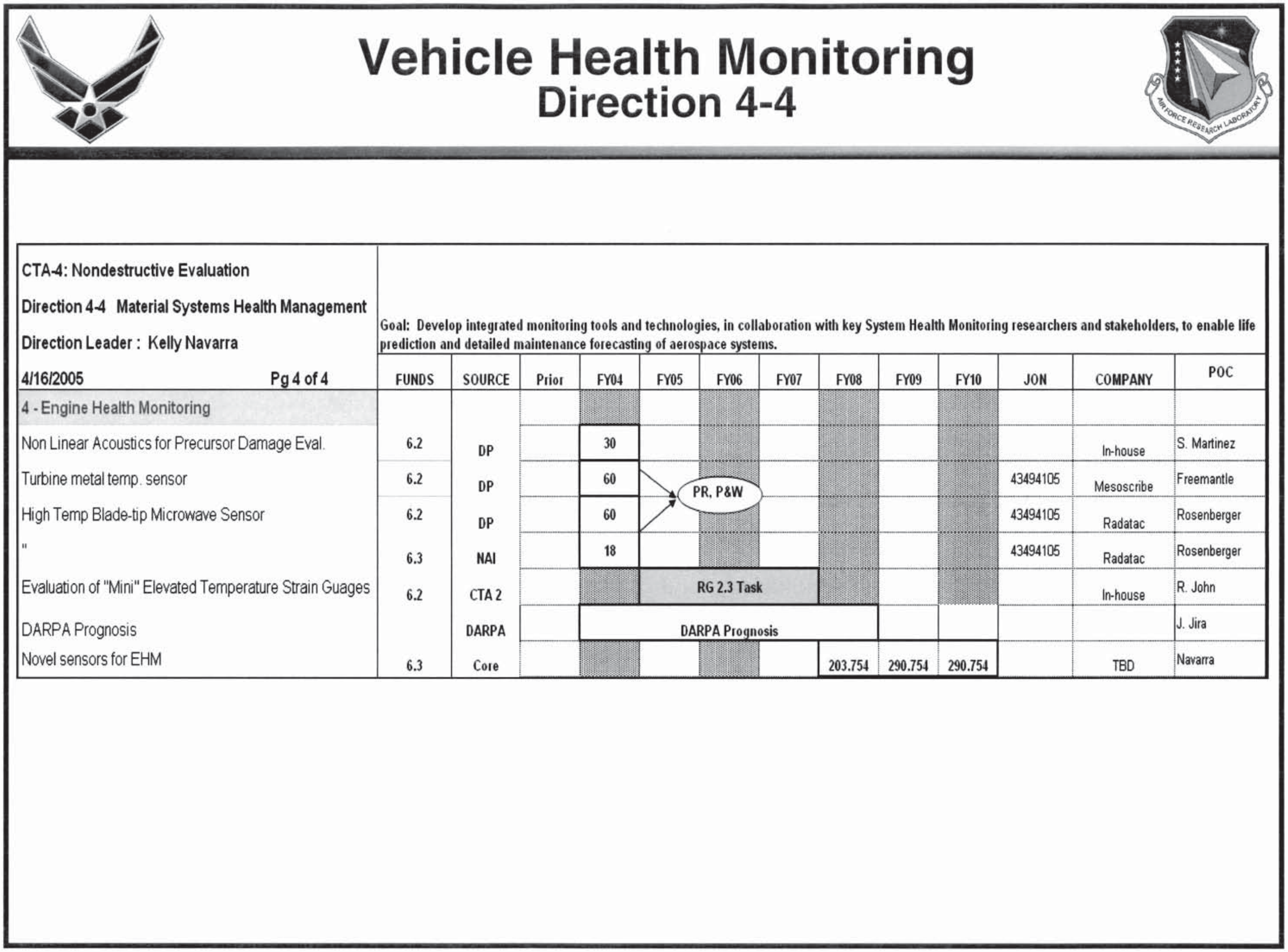
Direction 4-4 Material Systems Health Management

Direction Leader : Kelly Navarra

4/16/2005 **Pg 3 of 4**

Goal: Develop integrated monitoring tools and technologies, in collaboration with key System Health Monitoring researchers and stakeholders, to enable life prediction and detailed maintenance forecasting of aerospace systems.

	FUNDS	SOURCE	Prior	FY04	FY05	FY06	FY07	FY08	FY09	FY10	JON	COMPANY	POC
3 - Wiring Systems Health Monitoring													
01 Smart Connectors Development	6.3	CIP	150									U of Utah	M. Martinez
Aircraft Wiring System In-Situ Diagnostics	6.5	SBIR I		100							443S0100	Minnesota Wire an	Plumley
"	6.5	SBIR II			375	375					443T0100	Minnesota Wire an	Plumley
Wiring System Live Wire Health Monitoring Diagnostics	6.5	SBIR I		100				F-16				Live Wire Test Labs	Plumley
"	6.5	SBIR II			375	375					443T0000	Live Wire Test Labs	Plumley
Smart Sensor Technologies for Wiring Health Analysis	6.3	Core	100								43494105	U of Utah	M. Martinez
Smart Sensor Technologies for Wiring Health Analysis	6.3	NAI		100							43494105	U of Utah	M. Martinez
Smart Sensor Technologies for Wiring Health Analysis/IPA	6.3	NAI		42								In-house	M. Martinez
Next Generation Smart Connector	6.3	Core			118	150	150					U of Utah	Plumley
Network Analysis Methods	6.3	Core						150	142	142		U of Utah	Plumley



Vehicle Health Monitoring
Direction 4-4

CTA-4: Nondestructive Evaluation

Direction 4-4 Material Systems Health Management

Direction Leader : Kelly Navarra

Goal: Develop integrated monitoring tools and technologies, in collaboration with key System Health Monitoring researchers and stakeholders, to enable life prediction and detailed maintenance forecasting of aerospace systems.

4/16/2005 Pg 4 of 4	FUNDS	SOURCE	Prior	FY04	FY05	FY06	FY07	FY08	FY09	FY10	JON	COMPANY	POC
4 - Engine Health Monitoring													
Non Linear Acoustics for Precursor Damage Eval.	6.2	DP		30								In-house	S. Martinez
Turbine metal temp. sensor	6.2	DP		60		PR, P&W					43494105	Mesoscribe	Freemantle
High Temp Blade-tip Microwave Sensor	6.2	DP		60							43494105	Radatac	Rosenberger
"	6.3	NAI		18							43494105	Radatac	Rosenberger
Evaluation of "Mini" Elevated Temperature Strain Guages	6.2	CTA 2			RG 2.3 Task							In-house	R. John
DARPA Prognosis		DARPA		DARPA Prognosis									J. Jira
Novel sensors for EHM	6.3	Core						203.754	290.754	290.754		TBD	Navarra

Acronyms

AAF	Army Air Force
AEPO	Aeronautical Enterprise Program Office
AFACTS-I	Air Force Advanced Computed Tomography System I
AFACTS-II	Air Force Advanced Computed Tomography System II
AFALD	Air Force Acquisition Logistics Division
AFCUE	Air Force Computerized Ultrasonic Evaluation
AFCUE	Air Force Computerized Ultrasonic Evaluation System
AFLC	Air Force Logistics Command
AFML	Air Force Materials Laboratory
AFOSR	Air Force Office of Scientific Research
AFRL	Air Force Research Laboratory
AFSC	Air Force Systems Command
AFWAL	Air Force Wright Aeronautical Laboratory
AGARD	Advisory Group for Aerospace Research and Development
ALC	Air Logistics Center
AMC	Aeronautical Materiel Command
AMRAAM	Advanced Medium Range Air to Air Missile
ARDC	Air Research and Development Command
ARIS	Advanced Real-time Inspection System
ARPA	Advanced Research Projects Agency
ASC	Aeronautical Systems Center
ASD	Aeronautical Systems Division
ASIP	Aircraft Structural Integrity Program
ASNT	American Society for Nondestructive Testing
AUSS	Automated Ultrasonic Surface Scanner
BMO	Ballistic Missile Office
CAUSIS	Computer Aided Ultrasonic Inspection System
CBM	Condition Based Maintenance
CC	Commander in Chief
C-C	Carbon-Carbon
CCD	Charged Couple Device
CNDE	Center for Nondestructive Evaluation
CT	Computed Tomography
CTA	Core Technology Area
CUFS	Cracks Under Fasteners
DADTA	Durability and Damage Tolerance Assessment
DARPA	Defense Advanced Research Projects Agency
DDR&E	Department of Defense Research and Engineering
DOD	Department of Defense
DOE	Department of Energy

Acronyms (Cont'd)

DR	Digital Radiography
DRIP	Digital Radiography Insertion Program
EC	Eddy Current
ECIS	Eddy Current Inspection System
ENSIP	Engine Structural Integrity Program
ERLE	Engine Rotor Life Extension
FPI	Fluorescent Penetrant Inspection
FPIM	Fluorescent Penetrant Inspection Module
GDFW	General Dynamics Corporation – Ft. Worth
GE-AEG	General Electric – Aircraft Engine Group
GWP	Government Work Package
HFC	High Cycle Fatigue
HiPSAM	High Precision Scanning Acoustic Microscope
HR3DCT	High Resolution 3-Dimensional Computed Tomography
HRRTR	High Resolution Real-Time Radiography
IBIS	Integrated Blade Inspection System
ICBM	Intercontinental Ballistic Missile
IPT	Integrated Product Team
IRAD	Independent Research and Development
IRIM	Infrared Inspection Module
ISHM	Integrated System Health Management
ISIS	In-Service Inspection System
JLC	Joint Logistics Commanders
JTCG	Joint Technical Coordinating Group
JTCG	Joint Technology Coordinating Group
LAMDE	Laninography/Dual Energy
LCF	Low Cycle Fatigue
LFEC	Low Frequency Eddy Current
LFECA	Low Frequency Eddy Current Array
LGU	Laser Generated Ultrasonics
LMA	Lockheed Martin Aeronautics
LN	Logistics Need
LO	Low Observable
LONDE	Low Observable Nondestructive Evaluation
LTTP	Long Term Technology Program
LU	Laser Ultrasonics
LUIS	Laser Ultrasonics Inspection System
MAB	Materials Advisory Board
MAUS, MAUS-I, Early MAUS-II	Mobile Automated Ultrasonic Scanner
MAUS-II advanced, -III, -IV, -V	Mobile Automated Scanner

Acronyms *(Cont'd)*

MAX	Multi-Axis X-ray
ML	Materials Laboratory
MPI	Magnetic Particle Inspection
MR	Magnetoresistive
NASA	National Aeronautics and Space Agency
NASP	National Aero-Space Plane
NDE	Nondestructive Evaluation
NDI	Nondestructive Inspection
NDT	Nondestructive Testing
NIST	National Institute of Standards and Technology
OC-ALC	Oklahoma City Air Logistics Center
OO-ALC	Ogden Air Logistics Center
PDP	Program Definition Package
PLUS	Picosecond Laser Ultrasonic System
POD	Probability of Detection
POM	Program Objective Memorandum
PREE	Project REorientation for the Eighties
QNDE	Quantitative Nondestructive Evaluation
R&D	Research and Development
RAMTIP	Reliability and Maintainability Technology Insertion Prog.
RFC	Retirement for Cause
SA-ALC	San Antonio Air Logistics Center
SAB	Scientific Advisory Board
SBIR	Small Business Independent Research
SLV	Space Launch Vehicle
SM-ALC	Sacramento Air Logistics Center
SPO	Systems Program Office
SRB	Solid Rocket Booster
TAP	Technical Area Plan
TDL	Technical Direction Leader
TESI	Turbine Engine Sustainment Initiative
TPS	Thermal Protection System
TTCP	The Technical Cooperation Program
TTP	Technology Transition Plan
USAF	United States Air Force
UT	Ultrasonic Test
VIM	Visual Inspection Module
WADD	Wright Air Development Division
WFD	Widespread Fatigue Damage
WR-ALC	Warner-Robins Air Logistics Center
XIM	X-ray Inspection Module

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