Advanced Tools for Thermographic Nondestructive Inspection

Developed under NAVAIR SBIR N97-030

By

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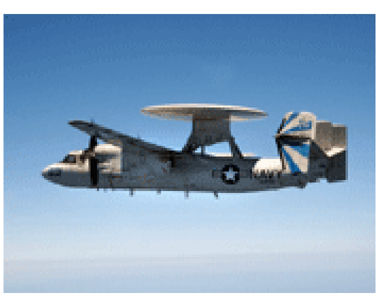


Problem Statement

Maintenance and life extension of the significant number of aging aircraft in the Navy Fleet is a growing concern that directly affects national security. The average age for Navy aircraft is close to 20 years. However, economic realities have forced the Navy to keep aircraft in operation far beyond their original design lifetimes. Comprehensive maintenance and nondestructive testing (NDT) is essential if the desired life extension is to be accomplished, and a corresponding increase in the costs of operations and maintenance is inevitable. Consequently, cost of aviation depot-level repairables—which is driving the cost of maintaining the aircraft—has risen an average of 13.8 percent per year.

The Navy is conducting a series of programs to assess and extend the aircraft operational service life of their fleet. These programs determine structural modifications, replacements, and redesigns to extend operational service life to meet inventory requirements. Both material condition and fatigue life are primary considerations related to achieving this goal.

Corrosion is the largest single cost driver ($1.4 billion in 2001) for aircraft repair and acts to reduce fatigue life/mission life. Impact damage, delaminations, adhesive bonding, and fluid ingress are examples of problems that work to reduce mission life of composite components. The use of composites in newer and future aircraft, such as the JSF and V-22 is greater and will increase the proportion of inspection cost and replacement for composites vs. metal.

Thermal Wave Imaging, Inc. has developed a portable, easy to use thermal inspection system that offers unprecedented capability for detection of subsurface flaws in metal and composite aircraft structures. A unique approach to processing infrared image data was developed to allow detection of features such as delamination, corrosion, or small amounts of fluid that were previously undetectable using thermal inspection methods. The smaller, lighter, more sensitive ThermoScope® DM system and MOSAIQ™ software developed under this project allow fast, noncontact inspection of large aircraft structures.

ThermoScope DM would have a positive impact on the following:

- **Mission availability & effectiveness**- Rapid inspection of both surface and subsurface defects in metals and composites without the need for disassembly or special facilities. Allowing for faster return to service for aircraft that are increasingly under high use and alert status in today's Navy.
- **Safety and manpower requirements**- Single operator inspection yields fast, accurate results with no exposure to harmful elements. Complete inspection of surface area provides quantifiable results to stay within inspection criteria. Or as in the case of the E-2C propellers, provide the only inspection methodology able to find cracks in the foam core under the composite outer layer. These cracks have led to disintegration of blade and loss of use.
- **Maintenance & repair costs**- Inspect on aircraft in the hangar or the runway, saving manpower and the cost of special facilities, or shipping the component off site. Fast, wide area inspection and immediate feedback provides inspector with important information to validate repairs and extend part life.

Systems are now available and in use within the DoD and commercial sector. The U.S. Navy, Air Force, Army, Coast Guard and Reserve forces are all experiencing increasing maintenance costs for their aging aerospace, sea and land based systems and share common goals of reducing these costs. Corrosion is the single largest cost driver for all DoD entities. Composite aerospace components are also facing difficulties due to life extension and age. In addition the DoD use of composites is growing in air, land, and sea applications that indicate a growing need for composite inspection. Originally sponsored by JSF, AIR (3.0) under SBIR N97-030.

Who Could Benefit?

The ThermoScope DM project is now in Phase III of the SBIR program, and an IDIQ contract is in place with NAVAIR that allows government agencies to quickly and easily purchase units. Allowing purchases by all DoD entities that are in need of fast quantifiable inspection of composites and metal for:

- Corrosion (under paint, between layers, front and back surface, measurement)
- Delamination (composite)
- Adhesive bonding (composite/composite, composite/metal, composite to honeycomb core, metal/metal)
- Wall thickness measurement (metal, composite, ceramic coatings)
- Water or oil detection in honeycomb
- Impact damage
- Porosity
- Validate repairs

Used for the following NAVAIR platforms: F-18, AV-8, V-22, P-3, E-2C, CH-46.
Also applicable for use by the: JSF, F-14, EA-8B, C-130, C-40A, HH/UH-1N, CH-53, H-3, MH-53, SH-60, TH-57, plus others.

Used for the following Air Force platforms: F-22, F-16, KC-135, B-2, F-15, C-141, B-52.
Also applicable for use by the: F-16, F-117, JSF, HH-60, MH-53, Mi-17, Mi-24, A-10, UH-1N, E-3, E-8, U-2, RC-135, KC-10, B-1, C-130, C-22, C-5, plus others.

Possible use by Army Aviation: UH-60, RAH-66, CH-47, AH-1G, AH-64, plus fixed wing fleet.

NASA/Goodrich Aerospace: Used for Shuttle and X-33 applications.

Recent participation in Army corrosion study for land based vehicles and recent successful inspection of entire Coast Guard ship hull (110ft x 29ft) by a Cherry Point inspector for corrosion indicates that the applications can be far-reaching and not limited to DoD aerospace applications.

Baseline Technologies

Several different NDT technologies are required to perform the range of inspections that the ThermoScope DM is capable of doing. The following technologies are considered the baseline.

Ultrasound is used to detect subsurface defects, and to measure the thickness of materials. In this basic technique, a transducer transmits a sound pulse into a part and the same transducer receives returning echoes.

Disadvantages:

- Requires the use of a liquid or gel couplant on the part.
- Data sets can be large and require complex interpretation.
- Not effective on porous or multilayered materials, or those with complex internal structure.
- The point nature of the technique requires mechanical scanning to acquire C-scan images.
    - Increasing inspection time
    - Adding expense
    - Adding mechanical complexity
    - Limiting portability

Radiography uses a source to emit x-rays that travel through a part and are recorded by film or electronic sensor. The resulting image is more exposed where more photons passed through the part, which may be caused by void, thinner material or material difference.

Disadvantages:

- The “shadow nature” of the resulting image does not provide information about the depth at which features/defects occur.
- Interpretation and flaw discrimination are very difficult for complex geometry part.
- Limited in capability for detecting cracks and disbonds in most orientations.
- Requires two-sided access that is not available in many applications.
- X-ray film is expensive and cannot be reused.
- Film processing creates chemical waste.
- High cost to purchase and maintain facility because of health and safety guidelines.

Eddy Current is widely used to detect cracks, measure thickness and detect material variations. In the eddy current technique a probe coil (or coils) generates a localized ac electromagnetic field in a part and detects the part’s response due to the induced eddy currents.

Disadvantages:

- Limited to electrically conductive materials and practically limited to isotropic nonmagnetic materials.
- Inspection data can be difficult to interpret on complex geometry parts.

- Surface artifacts such as paint thickness variations, surface roughness and scratches can have large influences on the signals.
- Point nature of the technique requires scanning to acquire images.
    - Increasing inspection time
    - Adding expense
    - Adding mechanical complexity, and limiting portability
    - Data sets can be large and require complex interpretation.

Dye penetrant inspection requires coating the part with a dye that wicks into surface cracks. The surface is wiped or washed and often coated with a developer coating. Cracks are detected by visually observing the dye wicking out of the cracks.

Disadvantages:

- Limited to detection of surface breaking cracks of certain geometries.
- Dye will not wick into very tight cracks and washes out very open cracks.
- Surface artifacts such as surface roughness and scratches can have large influences on the detectability of flaws.
- The inspection is very difficult to automate and is highly inspector dependent.

Costs for technologies with wide area capabilities run in the range of a quarter million dollars without taking into account environmental or special housing needs. The range of cost of the ThermoScope DM is 100 to 170 thousand dollars.

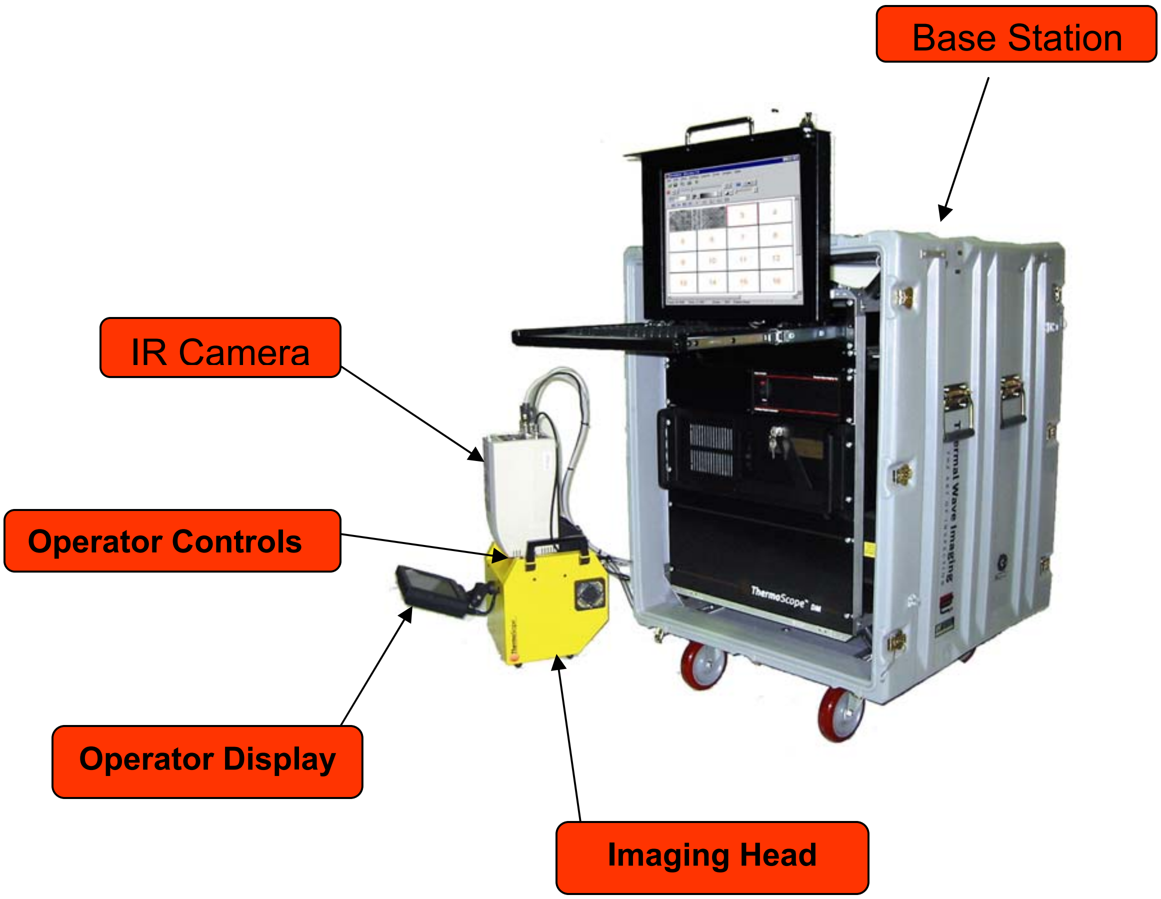
Technology Description and Comparison with Baseline

The portable Nondestructive Inspection (NDI) system we have developed under this program will directly impact numerous Government initiatives aimed at extension of the service lifetime of DOD aircraft.

- Inspect in-service aircraft without extensive disassembly or special facilities (unlike ultrasonic C-scan or x-ray inspection).
- Periodic inspection can be performed without removing the aircraft from service for extended periods of time.
- Inspection is non-contact and does not require immersion of the part, so that structures containing electronics or communication equipment can be readily inspected.
- Unlike single point inspection techniques, our technology is an imaging method, which allows complete inspection of an entire area.
- Designed for use by a single technician in either a field or manufacturing environment.
- Operator does not interact directly with a computer, but instead, uses an interactive display screen with push buttons as he is guided through the process.
- Lower maintenance costs as a result of reduced man-hour requirements.
- Increased service lifetime due to early diagnosis of problems including corrosion, delamination, water entrapment and impact damage.
- Can be automated and used to replace highly labor-intensive visual or coin tap inspections.
- Image results are easily archived for traceability and quality auditing purposes.

- No special facilities (e.g. immersion tanks, isolated room) are required for implementation. No ionizing radiation is involved.
- Extremely fast inspection of large areas.

ThermoScope™ DM



The basic concept of thermographic NDT is simple – the flow of heat from the surface of a solid is affected by internal flaws such as disbonds, voids or inclusions. In ***pulsed thermography***, light is used to heat the surface of the sample, and an infrared camera to detect changes in the surface temperature as the sample cools. A dedicated computer system analyzes the cooling behavior of each point on the sample and creates an image of the subsurface structure. Large, near-surface flaws may be detectable using a simple system (e.g. heat gun and IR camera), without computer enhancement. However, repeatable, quantifiable detection of deeper, subtler features requires the additional sensitivity that pulsed thermography provides. The sensitivity of the process is enhanced even further using the Thermographic Signal Reconstruction technique.

The Thermographic Signal Reconstruction® (patent pending) approach developed by TWI addresses these limitations, and allows an unprecedented degree of sensitivity, depth range and resolution of subsurface defects. In the TSR approach, the time dependent temperature response of each pixel to thermal excitation is expressed as an equation that represents the degree to which that point on the sample conforms to "ideal" behavior. In effect, an entire image sequence is reduced to a set of equations in which time varying noise from the camera or the immediate environment has been eliminated. The sequence, which may comprise hundreds, or even thousands, of discrete frames can be reduced to a set of noise-free equations, allowing rapid mathematical manipulation of the sequence and advanced analysis capabilities.

Until now, thermographic inspection of large structures has been a time consuming, labor-intensive process that required processing and analysis of multiple image sequences. MOSAIQ™ offers an entirely new parallel processing approach to large area inspection that allows all acquired sequences to be processed an analyzed simultaneously, significantly decreasing inspection time. MOSAIQ is based on our proprietary Thermographic Signal Reconstruction (TSR) technology, which eliminates temporal noise from the IR camera signal and allows an astonishing improvement in high-resolution imaging of deep and low contrast subsurface features. MOSAIQ can be used with the EchoTherm® or ThermoScope® DM inspection systems to reduce the total inspection time for a large structure (e.g. aircraft fuselage or control surface) from several hours to a few minutes.

Benefits:

- Flat or curved parts
- Immediate feedback
- On aircraft inspection
- Single inspector procedure
- Quick set-up/breakdown
- Portable/ships in two flight cases
- No disassembly
- Single sided inspection
- Fast, wide area inspection

The Technology is Ready for Use

Systems have been delivered and are currently in use by the Navy at NADEP Cherry Point and Pax River. Other systems are in place at Warner Robins AFB, WPAFB, NSWC, Northrop Grumman, Boeing, Cessna, Nordam, NASA, General Electric, Rolls Royce, Siemens Westinghouse, Goodrich Aerospace, Lockheed Martin, General Motors, Ford and Visteon.

Thermal Wave Imaging is the owner of the proprietary technology developed under this project and currently has an IDIQ contract in place. The Navy and DoD can buy ThermoScope DM on a sole source basis as specified by the SBA.

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About the Company

Our Company: Since 1992, Thermal Wave Imaging, Inc. (TWI) has been dedicated exclusively to the advancement of Infrared Nondestructive Testing (NDT). We are the world leader in the development and commercialization of thermographic NDT products and services for the aerospace industry, automotive, and power generation industries. Our products have become the worldwide standard of excellence in thermography, and are used in the most demanding manufacturing, in-service and research applications.

Our Customers: Our relationship with our customers begins with an active involvement in defining and understanding their problems. We work closely with our customers to developing focused, cost effective solutions. We act as partners in the NDT process and try to anticipate changing application requirements before they evolve. We have developed strong relationships with the world's leading industrial, military and research organizations including:

- Boeing: Inspection procedure for AL-AL Doubler disbonds for all 7x7 aircraft, F-15 components, composite and metal on commercial aircraft.
- Lockheed Martin: P-3 component inspection, water in radomes, F-22 composite inspection.
- NASA: Multiple systems in place for R&D work and Shuttle applications.
- General Electric: Aerospace and Power turbine blades.
- Siemens Westinghouse: Power turbine blade, vane and transition inspection for cooling channel blockage and TBC coating thickness measurement.
- Sikorsky: Testing ceramic matrix components.
- Nordam: Composite aerospace components in manufacturing and service facilities.
- TRW: Inspection of solar panels.
- Proctor & Gamble: Thermal pads.
- Rolls Royce: Power turbine blade, vane and transition inspection.
- Cessna: Composite cowling inspection.
- Chrysler: Contract testing.
- Aston Martin: Composite automotive components.
- Mitsubishi: Power turbine component inspection.
- Stolper: Power turbine transition inspection.
- Intel: Inspection of IC's.
- Jaguar: Composite automotive components.
- Hughes: Solar panel inspection.
- Ford Motor Company: Composite and metal automotive components.
- Saudi Aramco: Pipeline inspection.
- Nissan: Composite and metal automotive components.
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- Visteon: Inspection of axles under dynamic load.