

An Integrated Approach to Air Vehicle Health Management

Tobey Cordell

S&K Technologies, Inc.
3139 Research Blvd, Suite 101
Dayton, Ohio 45420

ABSTRACT

The Aeronautical Enterprise Program Office of the Air Force's Aeronautical Systems Center is aggressively working to reduce the ever-increasing costs of operating and maintaining the aging fleet by using an integrated approach to air vehicle health management. This approach is focused on technology transition efforts in four focus areas: fleet management / structural analysis, prevention, nondestructive inspection and health management, and repair and replacement. Each of the technology transition activities in these focus areas is closely tied with the MAJCOM warfighter customers' needs and those of the Air Force's Air Logistics Centers and the resident System Program Directors and is tied to demonstrated technologies coming out of the Air Force Research Laboratory, industry, or other development centers. The program is focused on rapid technology insertion with identifiable returns.

KEY WORDS

Aging Aircraft; fleet management; structural analysis; corrosion prevention, nondestructive inspection; NDI; air vehicle health management; component repair and replacement; materials substitution; corrosion; corrosion prevention compounds

INTRODUCTION

The US Air Force has adopted an integrated approach to structural damage management as one element of a comprehensive program for air vehicle health management. The average age of the fleet continues to increase, driven principally by the inability to buy significant numbers of replacement aircraft. It is anticipated that the average age of the fleet will be almost 30 years by 2017. The challenge of the aging fleet is that aging manifests itself in many areas: corrosion, fatigue cracking, lack of parts availability, aging wiring, and aging avionics. All of these factors results in an increase in repair operations and a resultant flow rate decrease in the depots. This then leads to several problems: reduced mission capability rates, decreases in aircraft availability, and maintenance cost increases. The cost increases result in fewer dollars being available for modernization, which results in fewer aircraft being purchased, leading to an older fleet.

Since 1991, the Air Force Aging Aircraft Program, led by the Aeronautical Systems Center, has been proactively sponsoring efforts to reduce the ever-increasing spiral of maintenance costs. The heart of the Air Force's effort has been a move from a maintenance policy of "Find and Fix" to a new approach focused on an "Anticipate and Manage" structural damage, including corrosion damage.

The Air Force Aging Aircraft Program has been clearly focused on the war fighter customer, conducting frequent assessments of critical needs in the field and at the Air Logistics Centers. The results of these surveys have been and are being used for program formulation. The identified needs include: establishing the economic service life of an aging weapon systems, with effective cost of ownership models; determining the onset of widespread fatigue damage; preventing, assessing, and controlling corrosion; reducing the inspection burden and improving inspection capabilities; and standardizing bonded repair.

An overarching approach to meeting these needs would be with a damage management toolkit that would include both analysis and decision software and would also include additional prevention, repair and replacement options.

For lack of a comprehensive damage management tool, corrosion today is identified but not quantified. This means that the structural impact of current corrosion damage is not a metric that can be used to make disposition decisions, for either maintenance or condemnation. An addition by-product is that time is wasted and structural life can actually be REDUCED by doing some corrosion repairs.

The structural impact of corrosion damage cannot be projected to a future date, or even the next Programmed Depot Maintenance (PDM) cycle to allow cost effective aircraft management. The consequence of this is the inability to anticipate and manage maintenance schedules and costs. There have even been cases where some aircraft have

been prematurely removed from service due to projected cost and schedule impact of managing structurally insignificant corrosion damage.

STRUCTURES STRATEGY



(Figure #1)

An Aging Aircraft Technologies Team (AATT) surveyed the Aircraft Structural Integrity Program (ASIP) managers of 30 weapon systems during each of the last three summers to determine the needs of the aging aircraft fleet. Results of the surveys indicate that the primary damage modes of AF aircraft structures are fatigue, corrosion, wear, and material degradation. Utilizing the AATT results, in combination with inputs from the Air Logistics Centers (ALCs), the Aging Aircraft Division of the Aeronautical Enterprise Program Office (AEPO), has developed a technical strategy addressing these damage mechanisms using an integrated approach to transition solutions to the users (ALCs, MAJCOMs, and field units). To make these solutions effective also requires an improvement to information management systems. Information management will allow these solutions to work together in achieving the following goals:

- Maintain safety
- Decrease sustainment costs
- Improve aircraft availability and mission capability rates

In addition, the traditional maintenance mindset of find and fix will have to evolve to one focused on anticipation and management. The preferred outcome will be the ability to defer maintenance without any loss in structural integrity.

INTEGRATED APPROACH

The above integrated approach to the structures strategy is focused in four areas: fleet management / structural analysis, prevention, Nondestructive Inspection (NDI) and health management, and repair and replacement.

FLEET MANAGEMENT / STRUCTURAL ANALYSIS

- **Corrosion Prediction software (“To Be”)**
- **Damage State Knowledge/Morphology**
- **Structural Integrity Analysis Software (ASIP)**
- **Cost of Corrosion Tools**

Figure 1

The fleet management / structural analysis focus area, Figure 1, cuts across several key areas for effective fleet management. At the heart of this portion of the overall effort is the incorporation of environmentally induced effects into structural integrity analysis software for use by ASIP managers throughout the active duty fleet. A lead-in to the analysis is the establishment of damage state and morphology. This is combined with other NDI results to provide an “As Is” state of the structure. To better understand the “To Be” state of the structure at some time in the future, given knowledge about the anticipated basing decisions for the aircraft, a set of Environmental Severity Indices have been established for the wide variety of Air Force, Navy, and Coast Guard air bases. Another portion of the overall effort is the establishment and validation of damage prediction software capable of predicting the state of damage in the future. An ancillary, but important, effort being supported in this focus area is the establishment and use of methods to determine the continuing costs to identify, analyze and repair corrosion-related damage, and to understand the related effects on aircraft mission capability rates.

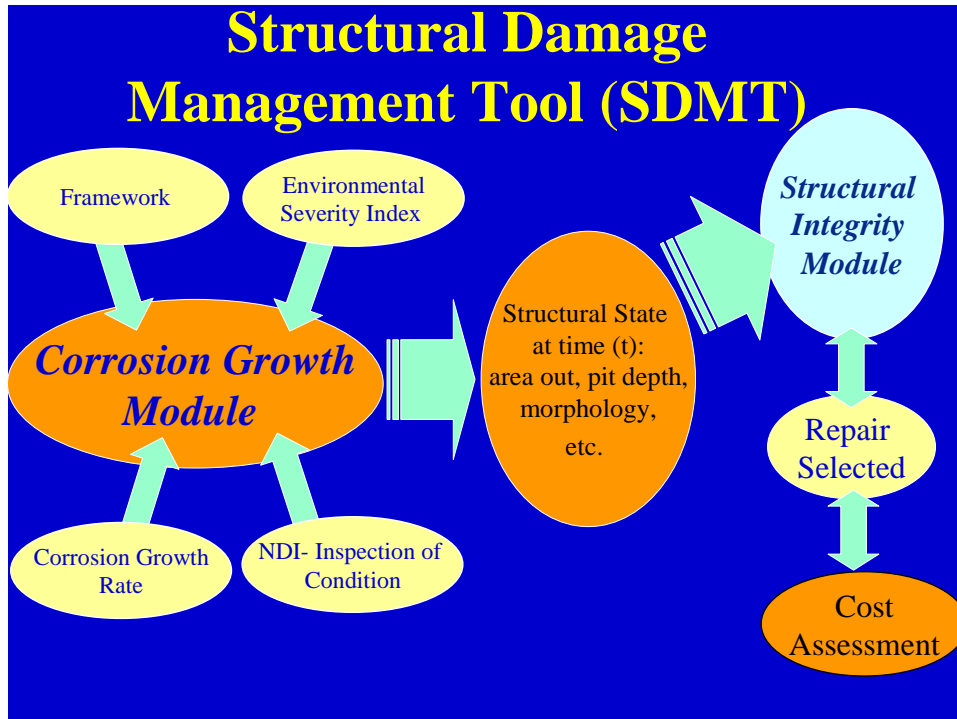


Figure 2

Figure 2 illustrates the overall relationships between the external inputs, the internal modules within the Structural Damage Management Tool (SDMT) and its output to structural integrity analysis software. The process of establishing, validating, and winning acceptance for the SDMT is very challenging. First, one must develop the corrosion growth module and the related algorithms. This module has a variety of inputs: the structural framework and the aircraft basing locations and times, the environmental severity indices for the bases involved, the corrosion growth rates for the various alloys to be evaluated and the NDI results that describe the “As Is” state of the structure. The corrosion growth module’s output is the “To Be” structural state at a given time in the future, with further output to a structural integrity module for determination of any repairs needed at the current time to allow safe operation until the next programmed depot maintenance cycle. A further refinement of the SDMT is the incorporation of a cost assessment capability to allow further refinement of the results of the repair selection.

Predict “To Be” Condition

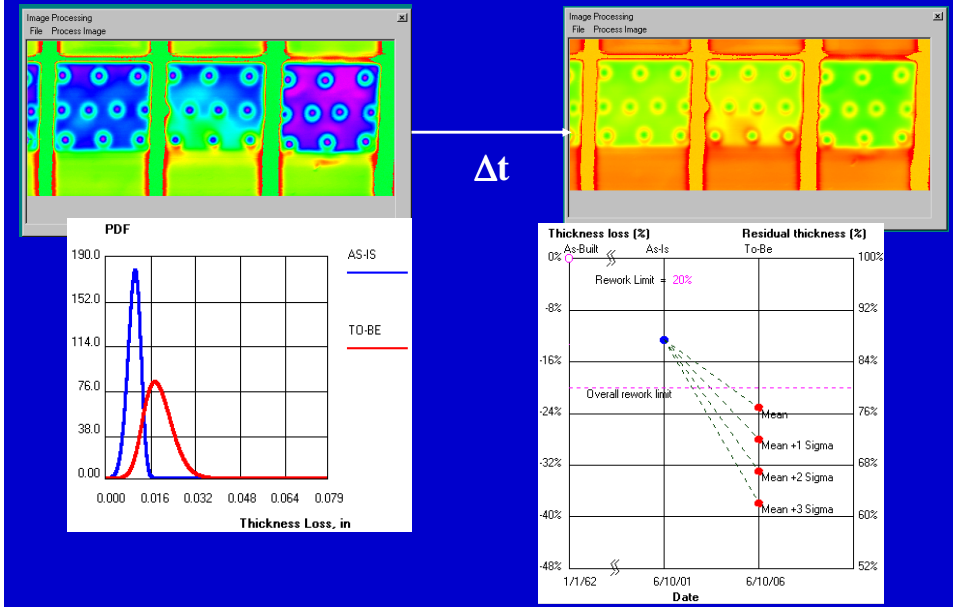


Figure 3 is a depiction of how a hypothetical “As Is” fuselage lap joint would corrode over time. The Probability Density Function (PDF) for the “As Is” damage state is depicted by the left-hand image and is shown by the blue line on the left chart. The Probability Density Function (PDF) for the “To Be” damage state is depicted by the right-hand image and is shown by the red line on the left chart. The right chart depicts the expected thickness loss over time and the probability of various outcomes possible with the passing of five years, the PDM cycle. In this case, it can be seen that the rework limit would be exceeded before the aircraft came back to the depot for maintenance, necessitating the repair of the damage during the current PDM cycle. It is possible to use the SDMT to look at alternate basing strategies to reduce the predicted thickness loss to prevent exceeding the rework limit before the next PDM cycle, with the result that the identified damage would not have to be repaired during the current PDM actions.

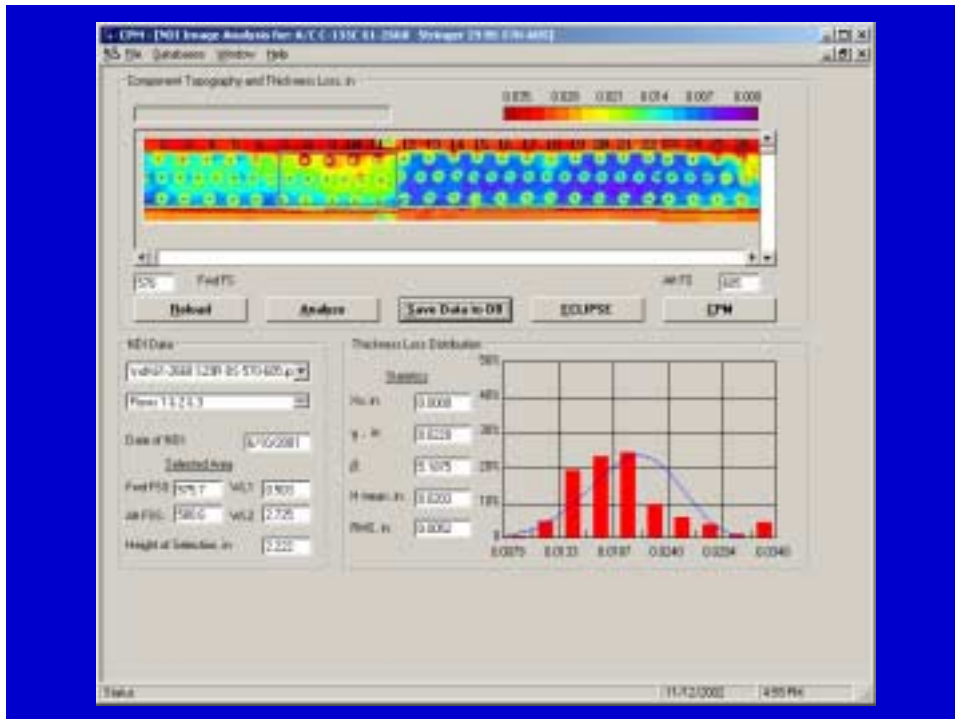


Figure 4

Figure 4 illustrates how the SDMT can also serve to interrogate specific areas of interest in a larger NDI damage scan. This individual “As Is” area can then be used as the basis for the “To Be” projection, with the output being interfaced with a structural integrity analysis tool for technical decision making. An ancillary benefit from the use of the SDMT is the ability to use the NDI scan as a means of refining the location of structural elements of the structure that may not have been located exactly as specified in the drawings. This feature can also be used to catalog and establish a reference for grindout locations on upper wing skins, something that today is relatively subjective in nature.

PREVENTION

- **Exposure Racks**
- **ESI – Basing Strategies**
- **Enhanced CPCs and Processes**
- **Web-Based Enhanced Materials Selection**

Figure 5

Prevention is being aggressively pursued on several fronts, as shown in Figure 5. Over the last several years, the Air Force has installed environmental exposure racks at virtually every Air Force base worldwide. These racks have been used for a continuing assessment of environmental effects on a wide range of materials and combinations of materials. The specimens from these racks continue to be periodically removed and evaluated for any changes. The results of these evaluations has been the development of a accurate set of Environmental Severity Indices (ESI) that can be used to quantitatively compare the effects of differing basing strategies for weapons systems. It should be pointed out, however, that the local environment near the runway, however accurately measured, does not necessarily mean that the same environment is found on or inside an aircraft located nearby. Further work is being done to more accurately measure the actual environment in various areas of different aircraft. Another key area of the prevention focus area is on Corrosion Prevention Compounds (CPCs). Efforts to better understand the mechanisms by which CPCs provide protection are being conducted, as well as the establishment of a web-based CPC database that provides all the key information in one place about every commercial CPC being used by the DoD. Another area important to prevention is the development of a new, web-based materials selection tools that allows the user to more easily and more confidently select materials that are more damage resistant, whether it be for a legacy materials replacement action or for the selection of materials for an all-new system.

New Specimen Racks: Basing Environment

Typical field installation

- Runway environment
- Base personnel install and remove
- 4 Test Cards per Sample Package
- Quarterly sample removals
- 1 Year Kinetic Data



- Ag (Chloride Sensor)
- Cu
- 7075 Al
- 6061 Al
- 1010 Steel



*Air Force Corrosion
Prevention and Control Office* →

Figure 6

In addition to the traditional racks, sets of new specimen racks, Figure 6, have been added to verify earlier measurements made with specimens on the traditional racks. These racks are in the typical runway environment as well and are providing independent confirmation of damage rates resulting from environmental exposure. The specimens are carefully weighed before exposure and then are weighed after any corrosion byproducts are removed after exposure. To gain a better understanding of the relationship between ground exposure specimens and the environment seen by actual aircraft materials, some specimens are now being exposed on racks that are mounted directly inside various areas of flying aircraft. Air National Guard C-141s and Coast Guard C-130s are providing new data for correlation with the earlier ground-based exposure specimens.

One of the vexing problems faced during the maintenance of legacy aircraft is the difficulty in selecting modern replacement alloys that have virtually identical mechanical properties but also are significantly more damage resistant than the original materials. A concomitant part of this problem is the twofold issue of supplier production of a limited use alloy and the willingness of the Defense Logistics Agency to stock such a material when there is very little demand. To assist in all the above, a new web-based materials selection tool has been developed and demonstrated. There has been strong interest in the use of this tool not only for replacement of components on legacy aircraft but also for initial materials selection for new weapons systems such as the Joint Strike Fighter

Proven Newer Materials already flying

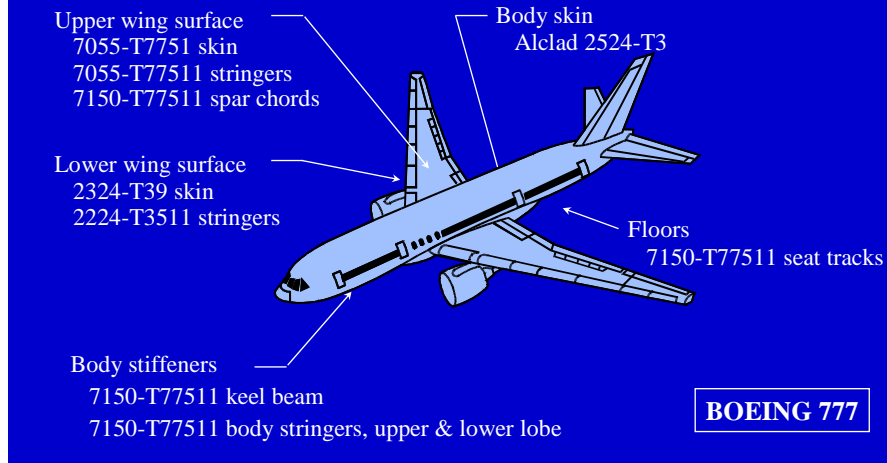


Figure 7

A key fact to remember is that many newer 2XXX and 7XXX alloys are already flying on commercial jetliners, Figure 7. Examples would be 7055-T7751, 7150-T77511, 2224-T3511, 2324-T39 and 2525-T3. However, in a legacy aircraft application, it is crucial that mechanical properties be virtually an exact match. Otherwise, there is the distinct possibility of increasing the stress levels on abutting structures. This is where the new Air Force Aeronautical Enterprise Office sponsored Materials Selection Tool can be of great assistance.

The SKT corrosion database, WACIS, is sponsored by the Aging Aircraft Division of the Aeronautical Enterprise Program Office, by the Air Force Research Laboratory, and by the Air Force Corrosion Prevention and Control Office. It makes available, to qualified users, environmental degradation, NDI, metallographic, mechanical testing and part geometry data in on convenient web-based tool. Each specimen in the database is carefully catalogued for completeness of data and ease of use.

NDI and Health Monitoring

- **Enhancing NDI Methods (“As Is”)**
- **Corrosion Sensors**
- **Tracking Methods**
- **Data Management (Map by Platform)**

Figure 8

Another key ingredient in the Air Force’s integrated approach is the use of Nondestructive Inspection (NDI) and Health Monitoring to better manage damage in the aging fleet, Figure 8. Finding various types of structural degradation is a critical element of the very successful USAF Airframe Structural Integrity Program (ASIP), with a strong emphasis on crack detection. Increasing attention on the effects of corrosion on structural integrity means more attention to the complex problem of quantifying both the extent and level of corrosion. Another approach being pursued is the use of corrosion sensors strategically located near what are anticipated to be areas that are susceptible to corrosion. Other approaches are looking at improved methods of tracking damage and repairs that are used to correct various types of damage. This tracking data would be incorporated into a data management system to allow time dependent mapping by platform for enhanced planning when maintenance would be anticipated.

A better understanding of various NDI methods is being accomplished by using depot level techniques to evaluate environmental exposure specimens. The results are then correlated with inspection records from depot inspection of the legacy fleet.

SKT Dayton is continuing to build and use a structural component inventory



Figure 9

Another key ingredient in the establishment of an enhanced understanding of the effects of structural damage and its detection is the acquisition of actual structural components or sections of structural components. The Air Force Corrosion Prevention and Control Office has been instrumental in both acquiring both wing, fuselage and empennage sections of legacy aircraft and allowing the “harvesting” of selected sections of a variety of aircraft being scrapped, Figure 9. These sections have become the heart of a structural component library that is being put to many uses by S&K Technologies’ Dayton Office. The primary activity related to these sections has been to allow NDI methods in current Air Force use, and potential newer NDI methods, to be applied to actual structures which are then carefully disassembled and measured to validate the NDI findings

Multi-Component Inventory



- Added:
- C-130 526 parts
 - Warner Robins storage site parts
 - Misc. parts from C-5, C-141 and C-130 A/C
 - 61-2668 fuselage panels
 - Cherry Point C-130 wing

<http://missioncontrolonline.com/Wacis/main.cfm>

See Reports: aircraftpartlist.xls

Figure 10

The listing of the components in the structures library is available to qualified companies on a website sponsored by the Air Force, Figure 10.

Another aspect of the focus area is aircraft “health” management. Since 2002, corrosion sensors have been flying on C-141 and F-15 aircraft. Extensive lab and field analysis of various structural “health” sensors is also underway, with flight testing to follow. It is important to note that it is only through inference that the overall “health” of a structure can be ascertained from sensors. This is because the sensors are point-location dependent. They can only sense the local environment and the structural response in a very limited area in essentially direct contact with the sensor. One encouraging result coming from these early efforts has been a confirmation of the ability to locate sensors in predetermined “hot spots” that are likely to see environmental exposure before other parts of the structure. This could lead to sensors that would give early warnings about conditions that could be deleterious in key structural locations.

Repair and Replacement

- Materials Substitution
- Retrogression and Reaging
- Composite Patches

Figure 11

The final ingredient in the Air Force's integrated approach to air vehicle health management is the focus area of repair and replacement to mitigate damage in the aging fleet, Figure 11. Efforts in this focus area include the establishment of materials substitution approaches for legacy alloys, the use of retrogression and re-aging methods to alter components already in use, and the expanded use of fiber-reinforced composite patches on a broader range of aircraft structures.

The Air Force sponsored Materials Substitution program is establishing key data for a limited number of promising new alloys that have recently been made available by industry. Initial consideration for system customers are the C-130 and C-5. In addition to the System Program Director's teams for legacy aircraft, the Defense Logistics Agency has been involved in the Materials Substitution program to ensure that these new alloys are available in a timely manner and in sufficient quantities to anticipate the growing demand. Retrogression and re-aging is a promising process that has been demonstrated on components that are on or off the aircraft, with reservations. The thermal kinetics are understood, can be easily managed and carefully monitored. The progress has been demonstrated on full-scale components. Beyond these repair options, there are additional methods coming from both the Air Logistics Centers, from industry and from academia. Some of these include the use of composite patches for thick structures and the use of mechanical suppression techniques such as low plasticity burnishing to extend the fatigue life of current components.

CONCLUSIONS

An overview of the status of Air Vehicle Health Management would clearly point to the management of aging aircraft as a expensive, long term problem. This must be coupled with a recognition that current 'young' fleets and new point design aircraft will see extended operation over their lifetimes in the fleet, driven by the continuing inability to replace them. A second point to be carefully considered is that environmental (time-dependent) degradation under cyclic and /or sustained stress has a high potential to degrade flight safety. This degradation will have a significant impact on life cycle costs and availability and is now required to be addressed in managing the structural integrity of the fleet..

The result is a clear recognition that components can become critical to both airworthiness and life cycle cost due to environmental degradation. These components and their related weapons systems must be managed in the same robust manner as structurally significant fatigue critical components are being managed so successfully today. The validated capability to anticipate and manage damage for the PDM cycle will be a very significant step toward reducing the ever-increasing cost of repairs and reduced readiness of our aging fleet.

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