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Managing the Fleet: Materials Degradation and its Effect on Aging Aircraft

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Introduction

Military aircraft are designed to operate under rigorous conditions that differ from their commercial counterparts. When fielded they typically employ technologies that provide us with strategic advantages over our adversaries. Consequently, the conditions that high-performance military aircraft experience during flight put tremendous stresses on their structural components. When coupled with the harsh environmental conditions to which these aircraft are subjected at various operating bases around the world, and given the number of years we now must fly them, aging aircraft issues have become paramount within the Air Force.

Heavy aircraft such as bombers, tankers, or transports (freighters) have their own aging issues. In the case of bombers, the last B-52H was delivered to the Air Force in 1962. The B-52 is now projected to fly until 2040. Never before in the history of aviation has anyone envisioned a fleet of aircraft flying for 80 years, but this is the reality the Air Force and the nation now face. Transport and tanker aircraft are confronted with similar challenges. Newer aircraft would undoubtedly prove more economical to fly, offering reduced maintenance and fuel costs, but budgetary constraints have minimized procurement of replacement aircraft, thus requiring us to maintain and upgrade the existing fleet.

During the early days of flight, technological advancements in aerodynamics, propulsion, and materials were rapid. Remaining on par with or ahead of our adversaries required the Air Force to continually develop and rapidly field new aircraft. Because such aircraft were retired before they wore out, aging was not a major consideration. As designs have become more complex, their development time and cost have risen tremendously. We're now at the point where it takes many years to achieve a revolutionary advance in technology. This means the aircraft that are flying during this development period are expected to do so for longer times. Unlike in the past, wear and aging problems are issues that we now routinely face.

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An Advanced Aircraft Coating Capability Requirement for Military Aircraft

By Stephen L. Szaruga, Air Force Research Laboratory, Wright-Patterson AFB, Ohio

Military aircraft require and employ exterior coating systems much different than automotive and architectural coatings. Coating systems for fighters, bombers, and transport aircraft serve multiple purposes: most importantly of these, coating systems must protect aircraft structures and associated fastening and joining mechanisms from corrosion. They must also provide survivability features that reduce an aircraft's chances of detection from visual and infrared (IR) threats. Lastly, they must be durable, abrasion- and chemically-resistant to protect the underlying structure.

To satisfy these requirements, military aircraft utilize a three layered coating system (Figure 1). The first layer, the aluminum surface treatment, provides an acceptable surface on the aluminum structure for subsequent overcoating. An anodizing process is utilized to deposit a thin (10-20 μm) aluminum oxide coating. Anodization deposits the coating through an electrolytic process involving sulfuric and chromic acid immersion[1]. The resulting coating, which is somewhat porous, is sealed and densified by boiling in water. The sealing process introduces chrome salts that dissolve within the oxide film. These chrome compounds will help protect aircraft structures from future corrosion attacks on the underlying aluminum by inhibiting oxidation and by modifying the local acidic/alkaline (pH) chemistry, which will further inhibit corrosion mechanisms. This surface treatment has been used for over 40 years in the protection of aluminum and is considered a mature and universally accepted process.

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Special Issue: Aging Aircraft

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Editorial: A Call to Arms

While at this year's Aircraft Structural Integrity Conference (ASIP) in Williamsburg, Virginia, I listened enrapt to Colonel Michael Carpenter's presentation on the charter, objectives, and future directions of the Aging Aircraft System Program Office (ASC/AA). More important than the content and delivery of his talk (both which were excellent, by the way), was his entreaty to us, the audience, to continue the good fight to keep our service aircraft flying for decades to come.

His talk reinforced several things I knew to be true: large procurement programs are things of the past. Military hardware of all types, with aircraft one of the more prominent among them, must now continue to function well beyond their anticipated service life. Getting more out of less has become one of the prevailing themes within the fleets of the Air Force, Army, Navy, Marines, and Coast Guard. As a result, the services, their contractors, and all technical specialists supporting their respective fleets have once again been subject to a major paradigm shift.

Those of us within the materials community have been right in the thick of these changes, brought on by fifteen years of acquisition reform. At one time in the not too distant past, performance was king – The imperative to develop and provide materials which could not only withstand, but thrive in the rigors experienced by high-performance combat aircraft drove the major design decisions. High strength and low weight were key. Cost and service life were secondary considerations, if at all. Through the initial stages of downsizing the military, cost became a prime consideration. Performance alone was no longer the only driver – new systems now had to be affordable to build, operate, and maintain. Ultimately, the new constraints on the defense budget had their effects on procurement, both in terms of reduced orders (B-2, F-117) and program cancellations (A-12). Since there was no corresponding reduction in need, it became necessary for aircraft scheduled for imminent retirement to continue to serve for years (or even decades) more. In a few short years, the average age of the Air Force's fleet will have doubled. The other services face similar trends. Aircraft designed for maximum service lives of twenty years must now remain in service for forty. Some of our larger aircraft, such as the B-52 and the C-141, will ultimately have service lives comparable in years to human lives. Most B-52 pilots are younger than the aircraft they fly and amazingly, will retire before their planes do. Not long ago, such ideas would have seemed inconceivable, but yet they now represent the world in which we live and work.

So, what can (or should) the U.S. defense community do to address the multitude of issues inherent to an increasingly aging air fleet? More specifically, what can those of us in the materials corner of the defense world do to keep our fleet flying? The short answer is: plenty. First of all, it is crucial to realize that the term 'aging aircraft' is merely a capstone for the myriad of technical, logistical, management, strategic, and even political issues which comprise this all-encompassing topic. It is within these areas, and possibly others, that the causes, effects, and most of the solutions lie to these vexing challenges. Materials degradation phenomena, such as fatigue, corrosion, creep, stress corrosion cracking, and others, represent only a fraction of the sum of technical problems facing these aircraft. Avionics, structures, propulsion, hydraulics, obsolescence of parts, maintenance and repairs, and fleet management represent equal or greater areas of concern.

To address these problems, an unprecedented collaboration of the services, government agencies, industry, and academia will be required. The need to blur institutional divisions and share information will be paramount to the ultimate success of this endeavor. Within the materials community, we must focus more of our energies into understanding and addressing the phenomena of materials degradation, so that our present fleet keeps flying, and so that future aircraft designs are more robust, allowing them to age more gracefully. Moreover, in support of this, many of the materials professionals who rise to this challenge will need to function less as specialists, and more as generalists, gaining an appreciation for the other major (non-material) aspects of aging aircraft phenomena. In this way, we will all gain broader insight into the overlying issues and how they relate to one another.

As one step towards developing such an understanding, AMPTIAC has dedicated this issue of the newsletter to the complex and increasingly important subject of aging aircraft. It is our sincere hope that the articles contained herein will enlighten the reader to both the major material issues, as well as many of the more programmatic ones now facing our aging fleet. Just as the U.S. military must adjust to meet the constantly changing threats facing the nation, we as technical professionals must adapt our activities and our perspective to meet the evolving expectations placed on our military hardware. The course of our actions in the years and decades to come will in great part determine the Nation's military readiness, and ultimately its security. Meeting the needs of aging aircraft is more than a plea for participation, it is in fact, a call to arms.

Chris Grethlein
Editor-in-Chief

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Managing the Fleet

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Program managers responsible for maintaining the existing Air Force fleet face two significant tasks: the first is to ensure that the structural integrity of the aircraft has not degraded. Understanding how these vehicles age with respect to material degradation phenomena is critically important to ensure flight readiness and safety. The second task deals with the issue of obsolete electronic parts. In today's defense environment, the DOD is a small consumer of highly specialized components, such as integrated circuits or visual displays. Companies that produce these parts also produce consumer electronics, which have become the overwhelming majority of their business. There is little incentive for these companies to continue producing limited runs of "military-only" equipment. This places a hardship on the DOD since a chronic shortage of replacement electronic parts can ultimately impose unplanned system upgrades.

The Air Force faces a tremendous challenge with respect to its aging fleet. Many of the systems we're flying today will still be flying 20 to 40 years from now. Addressing this problem requires a new focus and additional resources to concentrate on the problem. To provide this focus, the Air Force recently established the Aging Aircraft System Program Office (SPO) at Wright-Patterson AFB. This new emphasis and the paradigm change that it represents enable a "big picture" view of the fleet. Program management will now be more proactive, with less emphasis on "fighting fires" and more emphasis on working with the user commands to determine which issues must be addressed. The advantage of having a SPO dedicated to aging aircraft concerns is that technical solutions developed to support one aircraft type may be more easily recognized as having fleet-wide application, thus leveraging resources. Furthermore, the SPO will be able to impact ongoing and future acquisition programs, by incorporating the "lessons learned" from the fleet into the design, manufacturing, and sustainment strategies of these aircraft. Ultimately, these new aircraft will fly longer, be more robust, and above all else, they will age more gracefully.

Degradation of Materials

There is a myriad of different issues that Air Force program managers face when implementing strategies and programs to ensure the safe operation of our existing aircraft. Understanding and mitigating aging phenomena in them is preeminent among those issues impacting the long-term sustainment of the fleet. Consequently, any panoramic discussion of the major aspects of aging aircraft, such as avionics, reliability, maintainability, and material degradation mechanisms would fill a book. Since we lack the print space, the time, or the expertise to give each of these areas their due, we will prudently defer these discussions to others, and stick to those topics we can address ourselves. In this case, that would be the primary mechanisms affecting material degradation within the aging aircraft fleet. Most prevalent among these are fatigue, corrosion, stress-corrosion cracking, and aging of wiring.

Fatigue: Fatigue of metallic structural components plagues the entire Air Force fleet. Unlike other degradation phenomena, which in most instances can be controlled with proper design and maintenance, fatigue is unavoidable as long as the aircraft flies. In the simplest sense, fatigue is a process in which cracks initiate and grow. The process is induced when a structure is subjected to cyclic loading. Since cyclic loading always occurs in flight, crack growth is unavoidable. A critical issue for program managers to understand is how to monitor structural fatigue. With proper surveillance and care, aircraft with high numbers of flight hours can still be safely flown.

Fatigue has two major classifications: low-cycle and high-cycle. Low cycle fatigue and high-cycle fatigue are two different mechanisms, each causing crack growth, and ultimately failure in mechanical components subjected to cyclic loading. The main difference between the two is the amount of loading applied to the structure, and consequently, the number of loading cycles to failure. Low-cycle fatigue occurs in materials under cyclic loads where each loading increment induces a small degree of plastic (permanent) deformation, eventually forming a crack. Continued loading will cause the crack to propagate, accelerating until catastrophic failure occurs. Conversely, high-cycle fatigue occurs under less loading than low-cycle, where each loading cycle only deforms the material elastically (temporary and recoverable), thus requiring many more cycles to induce and propagate a crack. As one might expect, cracks propagate much more slowly under these lower loads.

Figure 1 displays generic fatigue (S-N) curves for ferrous and nonferrous alloys. These curves show the relationship between the alternating (maximum) stresses that can be applied to a material as a function of the number of stress cycles, and are typical of the alternating stress behavior of metal alloys. These are the types of performance curves used to design airframes and specify performance requirements. As long as the total service load experienced by a material stays below it's S-N curve, catastrophic failure should remain unlikely. Note as an aircraft sees more service time, it continues to be cyclically

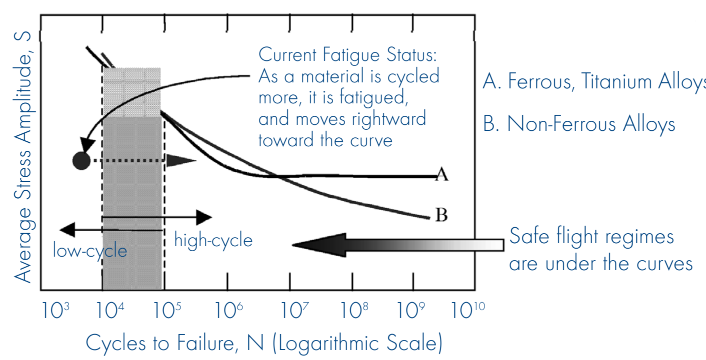

Figure 1: Representative Fatigue Curves

loaded, driving it's fatigue status rightward towards the curve, which represents its catastrophic limit. Low cycle fatigue is represented on the left side of the graph (as indicated) and is commonly defined as failure that occurs below 10^4 to 10^5 cycles. Failure above this range is attributed to high-cycle fatigue. Of particular note to designers is the S-N curve for titanium and ferrous alloys, which levels off at higher cycle regimes. This implies there is a threshold stress amplitude level, below which catastrophic failure will never occur.

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Understanding how an aircraft's performance affects its structural elements is crucial to ensuring its longevity. The type of fatigue that can ultimately affect a structure is dependent upon the type of loading to which it's subjected. Low cycle fatigue is induced by flight maneuvers and gust loads. Whenever an aircraft banks, climbs, descends, or encounters turbulence, the stresses induced into the structure can be of sufficient magnitude to induce the plastic deformation necessary for crack growth to progress. Cracks initiate and propagate from preexisting flaws, material defects, or design features (fastener holes or sharp corners). These are the types of loading simulated in fatigue testing. In contrast, high-cycle fatigue occurs when a structure is exposed to high frequency, low-amplitude cyclic loading induced by aerodynamic, mechanical, and acoustic sources. High-cycle fatigue failure has been observed on several military aircraft including the B-1, F-15, and F/A-18. It takes many more flight hours for high cycle fatigue to impact aircraft flightworthiness than low cycle. The aircraft community has yet to reach a consensus on the causes, mechanisms, and ramifications of high cycle fatigue. As the existing fleet will now be in service for many more years, the long-term effects of high-cycle fatigue are a growing concern, which needs to be better understood.

An essential point when considering fatigue of aircraft structures is the different design approaches that have been employed over the years. Commercial and large military aircraft such as our transports and bombers are designed using fail safe criteria. This approach employs multiple, redundant load paths as well as crack arrest features. As these aircraft age and cracks appear the built-in damage tolerance allows structures to degrade more "gracefully." The second approach is known as safe crack growth design. This methodology was used to design fighter, attack, trainer, and surveillance aircraft such as the F-16, A-10, T-38, and the U-2. Since excessive weight is extremely critical in these applications structures are often designed with no redundant load paths. The most important aspect to consider when designing single load path structures is the flaw size that could precipitate catastrophic failure. Continuing to safely fly these types of aircraft requires diligence on the part of program managers to ensure that proper diagnostic procedures and tools are used to identify troublesome structures before they reach the point of catastrophic failure.

Two basic methods are employed to predict and determine potential fatigue locations. The first is full-scale fatigue testing, which is performed during the development process. These tests are employed to ascertain the expected durability of the aircraft. Although the information obtained from these tests is extremely valuable, it often fails to fully characterize how fatigue affects actual aircraft structures. Experience has shown us that aircraft missions can change after the fleet has been deployed. Examples include changing the B-52 from a high altitude to low altitude bomber and the B-1 from a nuclear to conventional bombing platform. Since the initial full-scale fatigue testing did not consider the impact of these new mission requirements then the aircraft in question can experience fatigue damage that wasn't anticipated early on. In addition, fatigue tests do not consider interactions with environmental conditions, especially corrosive ones. The second method used to ascertain how structures age involves destructive inspections of aircraft with high numbers of flight hours. Data obtained from tear-downs are essential to develop a fundamental understanding of how actual aircraft structures degrade in service.

Another fatigue-related phenomenon that affects the aging fleet is widespread fatigue damage (WFD). The onset of WFD in a structure is defined as the simultaneous presence of many small cracks in multiple structural details. The discussion of fatigue to this point may have been somewhat misleading, as the reader might assume that fatigue induces a single crack in the material. In fact, most fatigue is widespread, as hundreds, or even thousands of cracks are manifested in cyclic loading. The net effect of numerous fatigue cracks located in the same general area is that they synergistically interact reducing the structure's residual strength. However, the single-crack concept is still important, because ultimately, catastrophic failure can occur when a single crack goes critical and in the process envelops other adjacent cracks in a zippering effect. Perhaps the best-known example of this type of failure occurred during the flight of an Aloha Airlines aircraft in 1988. During this unanticipated event, a large section of the upper fuselage skin just aft of the cockpit on a Boeing 737 (with a high number of flight hours) separated from the aircraft. Because of this incident, a considerable amount of work has gone into understanding WFD. Included in this work was the development of analytical models that can predict the residual strength of some structures. Much work remains to be accomplished in this important area.

One of the main challenges of managing an aging fleet is how to monitor the damage state in each aircraft so that a catastrophic failure doesn't occur. Using full-scale fatigue test results, inspection of aged structures, lessons learned, and information obtained from aircraft tear-downs provides us with a wealth of knowledge concerning what issues must be scrutinized. They also provide us with the data needed to help plan future maintenance activities, including refurbishment and outright structural replacements.

Corrosion: While not as severe a problem as experienced by the Navy's carrier-based aircraft, corrosion is an important factor that represents one of the Air Force's single largest maintenance cost drivers. Current estimates indicate the detection and repair of corroded aircraft structures costs the Air Force approximately $800M per year. In 1997, the National Materials Advisory Board's (NMAB) Committee on Aging of U.S. Air Force Aircraft released the results of their in-depth assessment of the Air Force's aging aircraft problem. Corrosion was one of the major concerns addressed by this report. The panel had two questions regarding the problem: what can be done about corrosion that currently afflicts the fleet, and how can future occurrences be prevented or reduced? The issues addressed in these two reports form the basis, in large part, for much of the activities conducted today to maintain and upgrade our existing aircraft.

There are multiple issues that must be addressed to properly maintain the existing fleet. The one certainty is that cor-

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rosion takes place and it must be minimized for us to safely continue to fly aging aircraft. Flight safety is improved when we can identify corrosion at an early stage and apply the necessary steps, including reapplication of coatings or corrosion prevention compounds. The aircraft industry has developed a mature system of materials, primarily cadmium or chromium compounds, that effectively eliminate or reduce the rate of corrosion. Regulatory pressures now require that alternative materials be developed to eliminate the need for heavy metals or volatile organic compounds (VOCs), both deemed environmental hazards. As a result, the issue of managing corrosion on existing aircraft becomes even more difficult, because we now must introduce new coating technologies that are neither widely available, nor whose actual long-term performance have yet been determined.

Corrosion is an insidious process, which in many cases occurs in locations that are not easily accessed. For instance, the regions between two structures that are bolted together, such as a lap joint, are difficult if not impossible to inspect without disassembling the structure. Localized corrosion, such as crevice corrosion, typically occurs in these regions. New nondestructive inspection methods are needed to enable surveillance of these difficult-to-reach places. Such tools would allow the Air Force to more effectively manage the fleet by establishing realistic maintenance and upgrade schedules.

Stress Corrosion Cracking (SCC): While SCC is a form of corrosion, it's an issue of sufficient singular importance that it should be discussed separately. The mechanisms that induce SCC are far different from the electrochemical reactions that consume metals. Stress corrosion cracking is a process in which a metal alloy under stress becomes brittle when exposed to a corrosive medium. In many cases, the environment is only slightly corrosive. An Air Force base located near the ocean is a perfect example of just such an environment.

Materials of concern to the aging aircraft community are aluminum alloys that contain copper, zinc, and magnesium as alloying elements. When coupled with certain heat treatments, these materials become sensitive to corrosive environments and SCC occurs. Examples of susceptible alloys include the high strength aluminums, such as 7075, 7079, and 7178; all with the T6 heat treatment, and 2024 T3 (naturally aged). The heat treatment or aging induces residual stresses into the alloy, which combine with operational loading (fit-up) stresses. When a structure fabricated from an SCC-sensitive alloy is subjected to these combined stresses and then exposed to a corrosive environment, SCC can result. What makes SCC difficult to manage is that failures occur along grain boundaries within the metal itself. Consequently, no corrosion products are visible, thus making this type of corrosion difficult to locate and mitigate on a fielded system.

In the early days of all-metal aircraft, skins were very thin and systems were rapidly replaced due to obsolescence, so SCC problems were rare. However, when aircraft structures became more complex and skin materials were designed as integral parts of the structure, SCC became more prevalent. Especially problematic were integrally stiffened structures machined from larger billets of material. The residual stresses induced by the heat treatment, in conjunction with those from the machining process made these materials sensitive to SCC. Unfortunately, this sensitivity was not fully understood until after the Air Force had procured a number of different aircraft models that now form the backbone of the fleet. The KC-135, B-52, E-3, E-8, C-130, and T-38 all contain significant quantities of SCC-sensitive aluminum alloys. SCC isn't restricted to aluminum alloys though - other materials, including the high strength steels used in landing gear assemblies, can also fail by SCC

SCC on existing aircraft can be reduced or delayed if appropriate maintenance procedures are developed and followed. For example, improved corrosion prevention compounds and coating systems can isolate the sensitive alloy from the environment. This coupled with improvements to repair procedures, whereby anti-corrosion coatings are refurbished, as necessary, will ensure adequate performance of a structure fashioned from an SCC sensitive alloy. The most costly, yet best method for eliminating SCC is to replace the material with an alloy specifically designed to resist this form of corrosion. The major classes of materials used to construct the C-17 were chosen with this in mind.

Aging of Wiring: Another critical problem currently being addressed is the degradation of wiring systems. This issue has become extremely important over the past few years as we struggle to manage our aging aircraft assets. Aging wiring exists virtually everywhere, so the issue isn't one that only affects the aircraft community. For several years the Department of Defense has been a partner with NASA, the FAA, the Department of Commerce, the Consumer Products Safety Commission, the Department of Energy, the National Science Foundation, and many other government agencies in a joint program to understand the issues relevant to aging of wiring systems. This group is formally known as the Wire System Safety Interagency Working Group, and is responsible for devoting significant resources to address this important matter.

Wire systems connect the various electrical, electronic, and electro-mechanical systems found aboard all aircraft. Due to the harsh conditions in which aircraft operate, the induced wear from maintenance procedures, and the passage of time, all wiring system components are subject to aging. For our larger transport, bomber, and tanker aircraft, wiring components located inside the pressurized skin experience far gentler conditions than those exposed to the external environment. Therefore, severe aging issues don't plague them. However, just the opposite can be said for wiring components found on landing gear and areas adjacent to wheel wells, leading and trailing edge flaps, fuel cells, and other exposed locations. These areas see far greater temperature extremes, and are also subject to moisture, salt (when near marine areas), ultraviolet light, chemical exposure (cleaning solvents, fuel, hydraulic fluids), and extreme vibration. The organic materials used to insulate the wires are definitely known to degrade from long-term exposure to these adverse conditions.

Fighter aircraft present their own set of challenges. The wiring itself is subjected to a tremendous amount of bending, twisting, and other stresses. The handling required to maintain the aircraft, replace failed line-replaceable units, and upgrade capabilities, coupled with in-service vibration can lead to insulation damage, such as chafing. This type of damage can initiate

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dielectric breakdown, which subsequently can lead to arcing.

Maintenance and flight-induced damage are only part of the problem. Another aspect to consider is that many different types of insulating materials have been used over the years. Polyvinyl chloride (PVC), polyimides (Kapton), polytetrafluoroethylene (Teflon), and many other materials have all been tried. Many of these materials have been banned by the military because of the hazards associated with using them. Fires initiated by failure of Kapton are well documented. Although these materials are not incorporated in new aircraft, they still exist in significant quantities in our fielded systems.

Due to the large amounts of wiring found on all aircraft, including fighters, and the complexity entailed in replacing them, rewiring our older aircraft is clearly not an affordable solution. Continuing to safely fly these aircraft requires care on the part of their maintainers as well as diligence on the part of program managers and squadron commanders. The research community can help through the development of improved diagnostic tools to locate areas of concern.

Barriers to Implementation

While it is certain that many of the problems vexing the fleet are materials-related in nature, it is equally certain that innovative materials and processes will provide the solutions to keep the fleet in good health. However, recent changes in the regulatory environment have severely altered (and narrowed) the Air Force's repertoire of time-honored approaches to aging problems. In response to the environmental and occupational safety regulations enacted during the 1990's, there has been a flurry of activity to develop alternate materials and processes. Our challenge is to develop new "green" processes that provide us with effective substitutes for our mature, but banned processes.

While regulatory compliance itself is not an aging aircraft issue, it does directly impact our ability to implement solutions for the fleet. Thus, it deserves some discussion here. Table 1 provides a brief synopsis of some of major replacement efforts underway.

Conclusions:

Maintaining our aging aircraft assets, such that readiness is unaffected and flight safety is assured is a challenge that relies in large part on support from the materials community. Understanding and dealing with issues such as corrosion, fatigue, stress corrosion cracking, and wiring insulation degradation are severe enough alone. Added to these are the challenges of finding new effective materials and processes in a more restrictive regulatory environment. The materials community contributes in many areas, both from the standpoint of helping keep our existing fleet in the air, but also by learning from our present problems to develop better approaches for our new aircraft. A case in point is the newer aluminum alloys employed on the C-17. These materials were developed to minimize or eliminate the corrosion problems such as those found on our aging aircraft.

Learning from our past mistakes and preparing for the future led the Air Force to place more emphasis on our corporate treatment of the fleet. The new Aging Aircraft SPO, led by Brigadier General (select) Rosanne Bailey, is a major step in developing a fleet-wide management strategy. This SPO works with the user commands, the Air Logistic Centers, and the individual aircraft program managers to develop a proactive maintenance strategy, which maximizes opportunities for both technology transfer into and between different air platforms. As a natural consequence, this strategy minimizes the need for "fighting fires", saving our energies for big picture issues. This new strategy, with its dedicated resources, will enable our fleet to continue to age yet accomplish our mission in defense of the United States. ■

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Table 1: Examples of Service-Enabling Technologies Now Restricted

Material or Process	Application	Restrictions	Substitute Material or Process
Organic Solvents	Vehicle for Sprayed Polymer Coatings for corrosion protection of airframes and aerosurfaces.	High Volatile Organic Content (VOC) solvents heavily restricted (possible smog contributors) by Clean Air Act (1990)	Lower VOC solvents, alternate application methods
Chlorinated solvents	Cleaners, paint thinners, and strippers. These solvents are all non-flammable.	1996 EPA regulation banned new usage of chlorinated solvents, cited as "ozone-depleting substances."	Water-based and other low-VOC systems.
Chlorofluorocarbons (CFCs)	Cleaners, propellants, lubricants, aerosols, refrigerants.	1996 EPA regulation banned new usage of CFCs, cited as "ozone-depleting substances."	Hydrochlorofluorocarbons (HCFCs) a temporary fix, but they will remain legal for only another decade. Other alternatives are more expensive and not as effective.
Hexavalent Chromium	Used in metal plating process to prevent corrosion on structural parts. Heavily used on landing gear.	New groundwater and air pollution regulations are severely limiting the usage of this process.	Thermal Spray Coating, Flame Spraying.
Solvent stripping of aircraft paint	Methylene chloride and methyl ethyl ketone used to strip paint off aircraft prior to repainting.	Clean Air regulations have severely restricted usage of these solvents. Waste disposal becoming cost-prohibitive.	CO_2 pellet blasting. (See this issue's article on the FlashJet process)

Aircraft Coating Requirement

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An epoxy- or polyurethane-based primer overcoats the treated aluminum surface. The primer provides additional corrosion protection, and promotes adhesion to the subsequent topcoat. Many of these primers also contain chrome-based salts in a particulate form to further enhance corrosion protection. These salts are water-soluble and migrate to localized corrosion spots through the small amount of soluble water in the primer resin. The topcoat serves as the outermost barrier to the environment. The topcoat's most important feature is camouflage, such as proper color (typically gray shades) and low surface gloss (sheen). The low visual gloss feature requires that the topcoat contain a relatively high level of inorganic pigments to physically roughen the surface. This rough surface scatters reflected light, reducing any glint from the sun, thus avoiding detection by the eye.

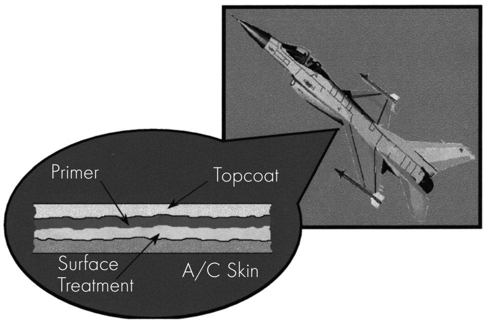

Figure 1: Military Aircraft Coating System

Complex and potentially hazardous processes are utilized when aircraft paint must be removed. To inspect the underlying metallic structure, the coating system must be completely removed for eddy current, ultrasonic, and visual inspection. There are two classes of coating removal: chemical and mechanical. Chemical paint removal uses aggressive solvents to soften the polymeric resins within the coating system so that the waste can be washed off or physically scraped off. These chemical systems contain extremely hazardous solvents, and the resulting waste stream (solvent and paint) must be disposed of in compliance with local and federal regulations. Mechanical paint removal systems utilize sanding, water jets, and plastic media to physically damage and remove the paint. In general, mechanical paint removal methods produce less hazardous waste but are more expensive and require more manpower and time to remove the coating. Mechanical removal systems can also damage thin aluminum skins as well as any composite structures.

Painting of military aircraft is accomplished in two types of operations: depot refurbishment or infield service. The most common is the depot refurbishment cycle. At regular intervals (8-12 years) military aircraft are returned to large depots for scheduled inspection, refurbishment, replacement, and updating of components. As mentioned before, the structural inspection methods currently utilized require full removal of the entire coating system. The paint is removed early in the depot cycle; the recoating process at the end of the cycle. Preparation, cleaning, and painting require up to three days of labor and drying time before the aircraft is mission ready. The repainting step in the depot process is among the longest in the maintenance cycle. Reducing or eliminating portions of the paint process within the depot would represent significant cost and time savings.

Some topcoat repainting is also performed in the field (at an operational Air Force base). This involves simple mechanical paint removal (typically sanding) and repainting of the topcoat. Repainting is required to replace faded, marred, or scratched paint defects. The camouflage topcoat has a high volumetric loading of inorganic pigments and consequently, is extremely sensitive to ultraviolet degradation from the sun. Since the polymeric resin content in camouflage coatings is significantly lower compared to typical automotive and architectural coatings, deterioration of the resin can expose inorganic pigment, which results in chalking (Figure 2). Chalking or discoloration are the primary reasons for repainting in the field.

The principal issue faced with military aircraft coatings has been the amount of hazardous materials produced during their application and removal. Aircraft painting, stripping, and repainting accounted for over 70% of all hazardous materials generated by the United States Air Force (USAF). The paint-related maintenance cost in 1995 was in excess of $700 million. Environmental restrictions reducing volatile organic content (VOCs) and hazardous air pollutant (HAP) emissions, as well as minimizing chrome compound emissions are placing an extreme strain on the current coatings technology base. In 1995, the USAF depots generated nearly 200,000 kg of VOCs and 220,000 kg of organic HAPs; the generation of these pollutants split between the paint application and removal processes[2]. Generation of VOCs and HAPs are generally attributed to solvents present in primer and camouflage topcoats as well as chemical paint stripping components. While field units are typically limited to topcoat painting, they account for 2/3rd of the VOCs generated by the USAF. This is due to repair and repainting of faded and damaged camouflage topcoat. Clearly, incorporation of more durable, environmentally compliant coatings technologies such as low VOC coatings and alternates to chromium for corrosion protection would significantly reduce the amount of hazardous wastes generated by the USAF. Improved durability, environmentally compliant topcoats would significantly reduce or eliminate field touch-up and repainting, also reducing total VOC emissions and related costs.

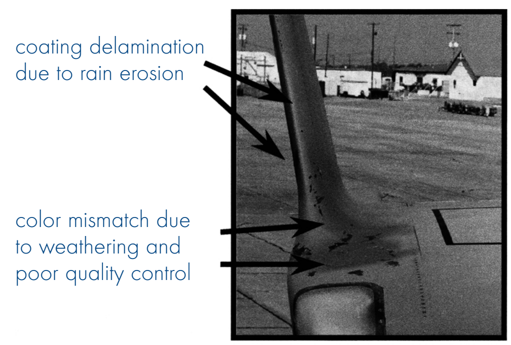

Figure 2: Coating Degradation

In 1993, the USAF developed the Air Force Coating System Strategy to address the environmental considerations and costs related to painting military aircraft. This strategy contained three critical elements:

A. Designate a single manager to implement the USAF Coatings Systems Strategy. The single manager is the single focal point for coating related issues within the USAF. This office coordinates all efforts across the USAF through direct customer (depot, field, and command) participation.

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B. Establish a Coatings Technology Integration Office (CTIO) to integrate paint and depaint products and processes. This single facility contains depot and field paint processing capabilities to support incorporation of new technologies into the depots and field units. The CTIO also assists in resolution of coating related problems in the field and identifies shortcomings with coating and stripping techniques. The CTIO is owned and operated by the Air Force Research Laboratory at Wright-Patterson AFB OH.

C. Initiate development of a research and development program to provide a fundamental understanding of coating systems performance and degradation mechanisms leading to alternative environmentally compliant approaches as well as improved coating life performance.

An important step in execution of the AF Coatings System Strategy was to document user requirements in an Operational Requirements Document (ORD). The ORD provides guidance and future funding to address the shortcomings of coating systems. The Advanced Aircraft Coating Capability (AACC) ORD identifies specific mission requirements and proposed approaches. The primary purpose of the AACC ORD is to develop a permanent corrosion protection system for military aircraft. This permanent component would serve the current functions as the surface treatment and primer. It would last the life of the aircraft (30-40) years and utilize an environmentally compliant corrosion protection technique (i.e. no chrome compounds). Non-permanent components (topcoat) must provide a service life of no less than eight years with a goal of fifteen years. The objective of topcoat performance is to eliminate topcoat replacement in the field, reducing costs and VOC generations.

The AACC ORD also requires a nondestructive inspection (NDI) compatibility with existing or projected equipment and techniques to perform NDI without removal of the permanent coating system. As mentioned, current NDI techniques require full coating removal to inspect the underlying metallic structure. Future NDI techniques will require technology development which will allow structure to be inspected through up to 500 µm of coating. This capability is key in making the AACC concept feasible, as structural integrity quantification is currently, and will continue to be, required for all military aircraft.

Another key technology required to enable the AACC concept is selective paint stripping. Present chemical and mechanical paint removal techniques remove all polymeric based coatings and in the case of mechanical media, also the surface treatment. A selective stripping technique would remove only the non-permanent topcoat without removing or damaging the permanent components in the AACC concept. There are currently two approaches under development. The most advanced is a hard coating (siloxane based) that is placed over the primer and subsequently overcoated with topcoat. This technique relies upon mechanical paint removal with the hard coating very resistant to removal. This interface coating is then touched up after topcoat removal and overcoated with a fresh coating. Polymeric based interface coatings that are sensitive to certain solvents are also under development. When exposed to a particular solvent, the interface coating and overcoat is softened and removed. After removal, this interface coating is replaced and overcoated with topcoat. Both of these approaches are well under development and represent the most mature of all of the future technologies required for the AACC concept.

Improved-durability camouflage topcoats have been developed that have significantly improved UV degradation resistance to standard polyurethane camouflage topcoats. Deft Incorporated (Irvine CA) has developed an extended-life topcoat that is a fluoro-modified, high-solids, polyurethane camouflage topcoat. Fluoropolymers have been used for years in exterior coating products, offering both excellent color stability and chemical and UV degradation resistance when compared to conventional hydrocarbon-based coatings. Recent breakthroughs in fluoropolymers have improved the workability of these materials, enabling spray application. This fluoropolymer topcoat has a fivefold improvement in color stability and threefold improvement in gloss retention over the standard polyurethane camouflage topcoat. Laboratory testing has identified improved cleanability over the current topcoat. This extended life topcoat meets all current environmental

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Aircraft Coating Requirement

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The FAA's Assurance Center Keeps Aging Aircraft Flying Safely

Economic considerations often dictate that aircraft have their service lives extended. As a result, at least 20% of all commercial jet airplanes flying today are considered to be aging aircraft[1]. To varying degrees, all of these older aircraft have encountered, or can be expected to encounter, aging problems such as fatigue cracking, stress corrosion cracking, corrosion, and wear. Over their service life, the numerous pressurization cycles experienced by aircraft can result in a phenomenon known as Widespread Fatigue Damage (WFD).

WFD refers to a type of multiple element cracking that degrades the damage tolerance characteristics of an aircraft structure. Left undetected, WFD can lead to a sudden and catastrophic failure of the aircraft. An example of this was the 1988 Aloha Airlines incident, in which a Boeing 737 experienced a nearly catastrophic midair structural failure in which it lost part of its upper fuselage. Subsequent inspection yielded WFD as the cause. The aircraft had been used for transporting passengers over short distances from island to island, and had consequently been subjected to an unusually high number of pressurization cycles for the low numbers of operating hours seen by the aircraft. Because of the low number of operating hours, the WFD had not yet been detected under typical inspection intervals. This incident served to raise awareness of the aging U.S. commercial aircraft fleet. The failure to detect this damage before the incident indicated the need for improved inspection techniques and characterization of the fatigue properties of aircraft structural materials. It also indicated the culminating problems within the Nation's aging aircraft fleet.

As a result of the Aloha incident, Congress passed the Aviation Safety Act of 1988. This act increased the FAA's scope to include research on improving maintenance technology and new methods for detecting the onset of cracking, delamination, and corrosion. With the Aviation Safety Act in place, the FAA developed the National Aging Aircraft Research Program (NAARP) and set forth to develop new methods of evaluating the airworthiness of high-time/high-cycle aircraft that have accumulated a large number of flight hours and pressurization cycles.

Broad ranges of research activities are managed by NAARP. Research areas include structural integrity, corrosion, inspection systems, aircraft engines, airborne data monitoring systems, maintenance and repair, and rotorcraft structural integrity. NAARP is also intended to meet FAA mission objectives, assess research quality, validate research effectiveness, predict success in operational environments, and develop methods for deploying research benefits to the user community. All of the FAA research contained in the NAARP falls into broad categories including Aging Aircraft Structural Integrity, Maintenance and Inspection, and Information Systems. The research contained in the NAARP supports maintenance, transport, commuter, and engine programs conducted by the FAA Aircraft Certification and Flight Standards Services.

During the 1990's, the FAA expanded its commitment to support long-term academic research crucial to the future of aviation via the establishment of a major new program known as the Air Transportation Centers of Excellence (COE). This program made it possible for the FAA to work in partnership with the academic community and industry to advance aviation technology. The Air Transportation Centers of Excellence have enabled the FAA to access academic and industry resources while expediting the application of research to benefit the aviation community and the flying public. Through long-term collaborative efforts, the government and its affiliates partner to build competence and leverage resources by sharing facilities and expertise. Through the aviation research centers throughout the country, the FAA takes a proactive part in creating a pool of technical professionals trained in aviation related research areas, by helping finance graduate education, and fostering cooperative FAA-university-industry research and development efforts; and, ultimately, improving the national airspace system.

The Airworthiness Assurance Center of Excellence (AACE), established in September 1997, is the most recent of the four centers created under this program. Other centers include Computational Modeling of Aircraft Structures, Airport Pavement, and Operations Research. The AACE consists of nine core members: Iowa State University, Ohio State University, Arizona State University, Northwestern University, University of Dayton, University of Maryland, University of California - Los Angeles, Wichita State University, and Sandia National Laboratories. The Ohio State University and Iowa State University serve as lead institutions. There are presently 68 industry partners, 31 university affiliates, and 12 other partners, which include other government laboratories, state organizations, etc. Each selected institution is awarded long-term cooperative agreements to conduct research in specific areas of aviation related technology. Through this partnership, the government, academic institutions, and industry leverage the resources available for aviation research. AACE research areas include:

- Advanced Materials
- Maintenance, Inspection, and Repair
- Crashworthiness
- Propulsions and Fuel Systems Safety Technologies

Sandia National Laboratory's main contribution to the AACE comes in the form of support from the Airworthiness Assurance Nondestructive Inspection Validation Center (AANC). The FAA established the AANC in 1991 under the NAARP. The AANC opened in 1993 and is operated by Sandia National Laboratories. It is located in a 24,000 sq-ft hangar at the West End of the Albuquerque International Airport. The center is dedicated to the study and validation of Nondestructive Inspection (NDI) techniques. It takes the technique from the R&D stage to an operational demonstration in real-life maintenance. It verifies new NDI techniques on actual aircraft under typical field maintenance conditions. By demonstrating and validating new techniques on actual aircraft and aircraft sections, the AANC serves as a catalyst for

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FAA's Assurance Center

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new technique development with subsequent technology transfer to the aircraft industry. The AANC is also dedicated to validating technologies for the repair of commercial aircraft.

To support research activities within the NAARP, the FAA Technical Center established a Sample Defect Library (SDL) at the AANC. The SDL functions as a clearinghouse and repository for specimens and samples used by all researchers in the NAARP for validation assessments and demonstrations. The SDL at AANC contains samples of the major types of damage encountered in aging aircraft with the complete records (type of defect and, where available, maintenance, load, etc.) for each article. The samples in the SDL are used to validate new and improved NDI processes. The SDL contains examples of aircraft repairs, panels, skin, frame sections, and other structural elements. The SDL contains representative examples of corrosion, disbonds, and fretting, as well as first and second layer fatigue cracks.

Large sections of various fuselage structures and complete aircraft are also housed at the AANC, such as a Boeing 737-200 transport, a Fairchild Metro II commuter, the forward and aft sections of a McDonnell Douglas DC-9, a Boeing 747, and a Coast Guard HU-25 (Falcon 20) executive jet. The AANC is also developing an electronic database containing information on the history, flaw type, size, type, location, and characterization of each sample within the library. This sample library of aircraft components or simulated components with their well-characterized flaws allows cross-linking of aircraft inspection results with well-understood flaws. The AANC's role in the AACE will include independently evaluating research for potential usefulness, providing samples of aircraft structural defects in support of Center research, assisting the FAA with effectiveness and reliability assessments for new technologies, evaluating effectiveness and reliability of new repair technologies, and transferring technologies from Center laboratories to the airline industry.

A Sample of AANC's Test Airframes

Research activities sponsored by the AACE included studies such as the damage of sandwich composites, damage tolerance and fatigue characteristics (fatigue crack growth) of cast aluminum and titanium alloys, and composite repairs. They also include investigations into areas such as the bonding of composites for construction of small aircraft; and creep, fatigue, and damage tolerance of adhesively bonded composite joints.

Researchers at Wichita State University are studying the damage tolerance of composite sandwich airframe structures as part of the AACE's advanced materials effort. Sandwich structures provide an efficient method to increase bending rigidity without a significant increase in structural weight. Their thin gage thicknesses are adequate to carry in-plane and out-of-plane loads and are stable under compression without a significant weight penalty. Damage tolerance of sandwich structures is significantly different from that of conventional laminated structures and typical damage concerns such as penetration, delamination, core crushing and facesheet debonding must be addressed. The damage tolerance of sandwich structures is critical to realizing their weight saving potential and to reduce the extent and frequency of repair. Researchers are seeking to clarify key issues pertaining to the damage tolerance of composite sandwich fuselage structures including residual strength and damage residual strength and damage propagation and to

develop methodologies to assess the adequacy of fuselage designs to meet FAA safety requirements. They intend to determine the effect of a wide variety of impact damage states on the damage tolerance characteristics of composite sandwich panels over a significant range of panel configurations. Through this research they will determine the Critical Damage Threshold (CDT) of the sandwich structures that can be reached for the aircraft to remain in safe flight under limited maneuvers.

Wichita State University researchers are also investigating the behavior of adhesively bonded composites used in the construction of small aircraft. Composite airframe components in small aircraft tend to make significant use of bonded construction for both improved structural efficiency and reduced manufacturing cost. However, many issues arise in this type of construction. For example, many manufacturers use unusually large adhesive bond layer thicknesses that are beyond the range for which structural performance data is currently available. Surface preparation methods for composite bonding often involve the use of removable peel plies that sometimes lead to poor structural reliability of the adhesive joint. Also, there is a general lack of agreement on design and test criteria of adhesive joints. Investigations are focusing on the evaluation of common test methods used for adhesives, the effect of bond thickness on adhesive joint strength, the design and optimization of adhesive-bonded joints, and the determination of the effect of surface preparation procedures in composite joints. The study is also exploring the creep, fatigue, and damage tolerance of adhesively bonded composite joints.

Researchers at Iowa State University, under grant from the AACE, are studying the design and quality assurance of premium quality airframe castings. The damage tolerance, design, and quality assurance of aircraft components manufactured from aluminum and titanium castings have been identified as major research issues. Advantages of cast air-

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Mark Your Calendar

Commercialization of Military and Space Electronics
2/11/02 - 2/14/02
Los Angeles, CA
Contact: Dale Stamps
CTI, Inc.
904 Bob Wallace Avenue, Suite 117
Huntsville, AL 35801 USA
Phone: (256) 536-1304
Fax: (256) 539-8477
Email: dale@cti-us.com
Web Link: www.cti-us.com

The 2002 TMS Annual Meeting
2/17/02 - 2/21/02
Seattle, WA
TMS
420 Commonwealth Drive
Warrendale, PA 15086 USA
Phone: (724) 776-9000 ext. 243
Fax: (724) 776-3770
Email: mtgserv@tms.org
Web Link: www.tms.org/cms

Molding 2002
3/4/02 - 3/4/02
New Orleans, LA
Executive Conference Management
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Email: ecm@executive-conference.com
Web Link: www.executive-conference.com

International Filament Winding / Fiber Placement Seminar
3/20/02 - 3/22/02
Salt Lake City, UT
Contact: John Green
The Green Sales Guy, Inc.
Phone: (801) 561-3584
Fax: (801) 561-3577
Email: John@theGREENsalesguy.com

Diminishing Manufacturing Sources and Material Shortages Conference 2002
3/25/02 - 3/28/02
New Orleans, LA
University of Alabama in Huntsville
Von Braun Research Hall, E-47
Huntsville, AL 35899 USA
Phone: (256) 876-0635
Web Link: smaplab.ri.uah.edu/dmsms02/

28th Environmental and Energy Symposium & Exhibition
3/25/02 - 3/28/02
Charleston, SC
Contact: Kira Migliore
National Defense Industrial Assoc. (NDIA)
2111 Wilson Blvd, Suite 400
Arlington, VA 22201 USA
Phone: (703) 247-2590
Fax: (703) 522-1885
Email: kmigliore@ndia.org
Web Link: www.ndia.org

2002 MRS Spring Meeting
4/1/02 - 4/5/02
San Francisco, CA
Exhibit: April 2-4
Materials Research Society
506 Keystone Drive
Warrendale, PA 15086-7573 USA
Phone: (724) 779-3003
Fax: (724) 779-8313
Email: info@mrs.org
Web Link: www.mrs.org/.MRS

Tri-Service Sponsored Symposium on Advancements in Heat Shield Technology
4/16/02 - 4/18/02
Redstone Arsenal, AL
Contact: Sherry Starling
University of Alabama in Huntsville
Von Braun Research Hall, E-47
Huntsville, AL 35899 USA
Phone: (256) 876-2628
Email: smaplab.ri.uah.edu/AHT02

104th Annual Meeting of the American Ceramic Soc (ACerS)
4/28/02 - 5/1/02
St. Louis, MO
American Ceramic Society
PO Box 6136
Westerville, OH 43086-6136 USA
Phone: (614) 794-5890
Fax: (614) 899-6109
Email: customersrvc@acers.org
Web Link: www.ceramics.org

9th DoD ElectroMagnetic Windows Symposium
5/13/02 - 5/16/02
Redstone Arsenal, AL
Contact: Sherry Starling
University of Alabama in Huntsville
Von Braun Research Hall, E-47
Huntsville, AL 35899 USA
Phone: (256) 876-2628
Email: smaplab.ri.uah.edu/

Friction Stir Welding Technology for Defense Applications
5/14/02 - 5/15/02
Columbus, OH
Contact: Nancy Porter
Edison Welding Institute
1250 Arthur E. Adams Drive
Columbus, OH 43221-3585
Phone: (614) 688-5194

2nd International Conference on Durability of Fiber Reinforced Polymer (FRP)
5/29/02 - 5/31/02
Contact: Brahim Benmokrane, P. Eng., Ph.D.
University of Sherbrooke
Department of Civil Engng.
Sherbrooke, Quebec, Canada, J1K 2R1
Phone: (819) 821-7758
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Email: bbenmokrane@andrew.sca.usherb.ca
Web Link: www.gci.usherb.ca/cdcc2

14th World Energy Conference (WHEC 2002)
6/9/02 - 6/14/02
Contact: 14th World Hydrogen Energy Conf
c/o O'Donoughue & Associates Event Mgmt
5486 Cote-Saint-Luc Road
Montreal, Quebec, Canada, H3X 2C7
Phone: (514) 481-7408
Fax: (514) 481-7379
Email: info@hydrogen2002.com
Web Link: www.hydrogen2002.com

3rd International Conference on Composites in Infrastructure ICCI'02
6/10/02 - 6/12/02
San Francisco, CA
Contact: Engineering Professional Dept.
University of Arizona
1224 N Vine Avenue
Tucson, AZ 85719-4552 USA
Phone: (520) 621-3054
Fax: (520) 621-1443
Email: epd@engr.arizona.edu
Web Link: www.az-icci.org

National Space & Missile Materials Symposium
6/24/02 - 6/27/02
Colorado Springs, CO
5100 Springfield Street, Ste. 509
Dayton, OH 45431 USA
Phone: (937) 254-7950
Fax: (937) 253-2296
Email: mkubal@anteon.com
Web Link: www.usasymposium.com

48th Annual Tri-Service Radar Symposium
6/25/02 - 6/27/02
Monterey, CA
Contact: 48th Annual Tri-Service
Radar Symposium
c/o Infrared Information Analysis
Veridian Systems Division, Inc.
PO Box 134008
Ann Arbor, MI 48113-4008 USA
Phone: (734) 994-1200 x2821
Fax: (734) 994-5550
Email: mss@veridian.com
Web Link: www.iriacenter.org

NTIAC Aids Effective Maintenance of Aging Aircraft

The Nondestructive Testing Information Analysis Center (NTIAC) provides technical expertise, authoritative analysis, engineering services, and laboratory research, development, and engineering support in responding to DOD, other Government agency, and industry requests and needs in areas related to nondestructive testing, inspection, and evaluation. Today's advanced technology requires materials, components, and structures of unprecedented efficiency, operating nearly at their ultimate capability. At the same time, approaches are being sought to cut costs by extending the life of many aging structures and operating systems. As a result, there are increasing requirements for capabilities to nondestructively test, inspect, and evaluate to ensure quality, reliability and safety.

NTIAC is operated by Texas Research Institute Austin, Inc. (TRI/Austin) which has the in-house nondestructive evaluation (NDE) laboratory capability and expertise to support a wide spectrum of activities. These activities can range from scientific research with universities, to laboratory determinations, to in-the-field demonstrations, and finally to commercialization and transfer-to-use. As a small business, TRI/Austin is very active in the Small Business Innovative Research (SBIR) program, which provides opportunities for NTIAC to leverage and extend its NDE-related technical services to the DOD and other Government agencies.

One area of particular interest to NTIAC and of recognized importance to the Department of Defense is aging aircraft. It was pointed out at the Defense Science and Technology Seminar on Nondestructive Evaluation of Aging Aircraft held in June 2000 that "as fleet aircraft or any platforms age, the importance of effective and efficient inspection for damage and deterioration becomes increasingly important to ensure safety and affordable maintenance and sustainability." As aircraft get older, the primary threats are widespread fatigue damage and hidden corrosion, which degrade the structural integrity of the aircraft. Specific inspection needs for aging aircraft include the detection of fatigue cracks under fasteners; small cracks associated with widespread fatigue damage; hidden corrosion; cracks and corrosion in multi-layer structures; and stress corrosion cracking in thick sections.

NTIAC offers valuable expertise and resources in the campaign to extend the service life of aging aircraft. Two recent NTIAC state-of-the-art reports relevant to aging aircraft are *NDE of Hidden Corrosion* (NTIAC-SR-98-03, $75.00) and *NDE of Cracks in Aircraft* (NTIAC-SR-98-04, $75.00). The hidden corrosion report presents a survey of the status of development of NDE techniques for detecting corrosion, in particular hidden or inaccessible corrosion. For the sake of completeness, a discussion is presented on the characteristics of corrosion in terms of corrosion mechanisms, corrosion damage, and corrosion detection and measurement. A summary of results from a recent survey of NDE for corrosion in military systems is also presented. The report on the NDE of cracks presents a survey of the status of development of NDE techniques for detecting cracks, with emphasis on detecting cracks in aircraft structures. A discussion is presented on general considerations regarding how cracks are taken into account in aircraft structural integrity. A brief synopsis is given on damage tolerance considerations and the importance of widespread fatigue damage is also discussed.

An NTIAC-published Critical Review entitled *Nondestructive Evaluation for Condition-Based Maintenance* (NTIAC-CR-00-01, $55.00) presents a definition of condition-based maintenance, along with the elements of a successful condition-based maintenance program. Various types of condition monitoring are described and NDE methods used in condition monitoring are discussed, including case studies for various techniques.

Another valuable NTIAC resource relevant to NDE of Aging Aircraft is the *NDE Capabilities Data Book, 3rd Edition* (NTIAC-DB-97-02, $125.00 hard copy or CD; $175.00 for both). This data book provides a condensation of available reference data for demonstrated NDE performance capabilities in terms of probability of detection (POD). Various aspects of NDE capabilities quantification are discussed and over 400 reference POD curves are presented covering all major NDE methods. Results are provided for varying test object, test artifact, and data collection conditions; guidelines for selecting options for using NDE; and demonstrated specific NDE process capabilities. Original reference source information is provided for each data set.

Recognizing the importance of probability of detection and probability of false alarm (PFA) information for quantifying NDE of aging aircraft, as well as other inspection applications, NTIAC has developed a plan, under U.S. Air Force sponsorship, to establish a Computational NDE and POD Modeling Consortium. When implemented, Consortium activities will provide physical models of a variety of NDE techniques, statistical/empirical models for calculating POD/PFA using physical NDE models along with experimental laboratory and field NDE data, an online POD/PFA database, POD/PFA for NDE data fusion methods, and training materials for users. This Consortium will provide the basis for developing physical based models for probability of detection of various NDE techniques and applications resulting in optimized NDE capabilities for aircraft.

To order any of the publications cited above or for further information on other NTIAC products and services, contact NTIAC, Texas Research Institute Austin, Inc., 415 Crystal Creek Drive, Austin, TX 78746; phone: (512) 263-2106 or (800) NTIAC 39; fax: (512) 263-3530; email: info@ntiac.com; website at www.ntiac.com. ■

An Aging Navy Aircraft Fleet Requires Team-Based Solutions

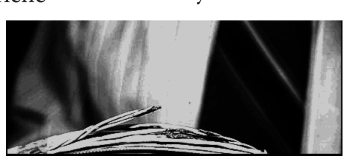
The Navy faces many of the same issues in aging aircraft as do the other services and even civil aviation. To a certain extent, all aircraft are "aging," some faster than others. The "Age" of an aircraft is a product of significantly more inputs than just chronological age.

Navy and Marine Corps aircraft operate in rugged and harsh environments and are subjected to the punishment of aircraft carrier landings and catapulted takeoffs, as well as regular operations in temperature extremes and salt water. Because of this, aircraft, as well as their component systems, age differently. The Navy's primary measure of aircraft age is "fatigue life," or the cumulative stress placed on an aircraft, and its systems, throughout its use.

The age of aircraft that operate from carriers is also measured through the number of arrested landings and catapulted takeoffs it has performed. Aircraft launchings from carriers are routinely subjected to forces many times that of gravity to get airborne within the short distance of the carrier flight deck. Likewise, when landing aboard a carrier, these aircraft are again subjected to multi-g loads as they land and are brought to a sudden stop by the arresting gear. While carrier aircraft are designed to handle the stresses and shocks of essentially being "slammed" onto a carrier and then shot back off, over the lifetime of the aircraft, these forces exact a toll on the structure of the aircraft, as well as on the avionics, powerplants and other systems. Thus an aircraft built in 1995 but subjected to more stress may be "older" than a less-stressed aircraft built in 1985. But fatigue life is only one aspect. Vibration and shock from normal flight, as well as from combat maneuvering also contribute. These issues are being carefully studied to better understand how all these forces interact to degrade aviation systems with the ultimate aim that these lessons will then be incorporated into the newest production aircraft.

In Fiscal Year 2000, the average Navy or Marine Corps aircraft was 18 years old. Helicopters averaged 20 years and fixed-wing aircraft averaged 17 years old. Specific models, like the P-3 *Orion*, S-3 *Viking* and CH-46 Sea Knight helicopters are significantly older. If procurement trends remain constant, the average age of all aircraft will stabilize at about 20 years. Projected replacement aircraft, such as the F/A-18 E/F Super Hornet and the Joint Strike Fighter will actually be replacing some of the Navy's newer aircraft (the F/A-18 C/D Hornet, F-14 Tomcat and the AV-8B Harrier). No replacements are scheduled for older aircraft, except the CH-46 and the CH-53D which will be replaced by the V-22 Osprey.

Because the fleet is aging, and current funding (dollars per flight hour) is flat, the Navy and Marine Corps are experiencing increases in repair costs and aircraft system failure rates, while readiness and reliability rates are dropping. In short, the Navy is spending more time and funding on maintenance for older systems and is not as mission capable as in the past. Indirectly, this has resulted in a drop in morale among the sailors and marines, who maintain these aircraft, as they are spending more time repairing these aging systems.



The Department of the Navy recognizes the problem of aging aircraft and is proactively engaged in addressing the issues of maintaining an aging fleet. There are currently two Navy programs specifically investigating age-related problems and strategies to overcome them. Aging aircraft wiring is one of the many safety issues under investigation by the Secretary of the Navy's Office of Safety and Survivability (OSS). In March, 1999, the Naval Air Systems Command (NAVAIR) stood up the Aging Aircraft Integrated Product Team (AAIPT) to spearhead efforts to improve readiness and reduce lifecycle costs for the Navy and Marine Corps by aggressively developing solutions to age issues. Because this is not simply a matter of procuring more spare parts or replacement systems, the AAIPT is pursuing a systems engineering approach to manage obsolescence and develop a spectrum of solutions.

In the relatively short time the AAIPT has been engaged, it has identified several strategies, new technologies and cost models. Chief among them is the development, in conjunction with the Office of Naval Research (ONR) and the Federal Aviation Administration (FAA), of an arc fault [1]circuit breaker (AFCB) to reduce the hazards in aircraft posed by aging wiring – a significant issue for both the military and civilian fleets. The AAIPT is also working with industry and Utah State University to develop "Smart Wire" technology. In other areas, the AAIPT is working with NAVAIR materials engineers to field a new phosphoric acid anodization process to prevent corrosion in aluminum honeycomb cores used in flight control surfaces, engine intakes and other critical areas, and with avionics engineers to develop obsolescence management tools. Additionally, NAVAIR engineers are utilizing a Russian titanium nitride coating technology to reduce erosion and increase life of titanium compressor blades in turbine engines serving in dusty environments.

Aircraft Wiring and the Need for Arc Fault Circuit Breakers (AFCB)

Arc tracking occurs primarily in aromatic polyimide-insulated wiring. When a defect occurs in the insulation that exposes the conductor and allows the current to arc, the energy discharge can cause the surrounding insulation to carbonize. As carbon is an excellent conductor itself, the defect then self-propagates, or "tracks" along the wire until the current finds a new "short" or open circuit and arcs to it.

As aircraft have become more complex over the years, the amount of wire in an aircraft has greatly increased. With more wire used, there is more need to conserve both weight and space. A typical aircraft in the fleet, such as the F-14 Tomcat, has thousands of feet of wire weighing thousands of pounds. Thus, engineers and manufacturers have developed new wire over the years with thinner insulation to reduce the total aircraft wiring weight, and the space it occupies. Decreasing the thickness of wire insulation from 5 mils (similar to the wiring in a car) to 2 or 3 mils (or the same as 2 or 3 human hairs) in an F-14 can result in a weight savings of 300 pounds. In a larger, or more complex aircraft such as an E-2C *Hawkeye*, or C-141 *Starlifter* with as much as 200 miles of wire, the weight saving is dramatically more.

Although these wires and insulation are very durable and capable, the reduced thickness of the insulation, and some

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properties of the polyimide insulation, make it susceptible in certain conditions to more rapid aging. Aircraft wiring is subjected to accumulated environmental stresses (temperature extremes, moisture, salt water, etc), exposure to liquids and gasses (fuel, hydraulic fluid, coolants, exhaust vapors, etc), and the wear and stress associated with the normal operation and routine maintenance of the aircraft. Wire and insulation defects occur because of the wire bundles vibrating, bending and rubbing against each other, or chafing against parts of the aircraft's structure over time. Merely pushing a wire bundle out of the way to access another bundle or part applies stress and can contribute to failure.

After repeated or continual stress, cracks, breaks, and open areas can occur in a wire's insulation. The wire can even break all the way through. Once the conductor (actual "wire" itself) is exposed, the current traveling through that conductor has a new, and usually "shorter," path to ground. The current may either "short" to ground in a bolted (or direct) fault, arc to another exposed conductor in an arc fault, or merely stop in an "open" circuit. If the current "shorts" to a flammable source, such as a fuel line, pooled hydraulic fluid, etc, a fire can result.

An obvious solution that comes to mind is to replace all the wiring in the airplane, but most aircraft have portions of the wiring harness that are not accessible without complete disassembly. On larger aircraft, such as Navy P-3 Orions, there are literally hundreds of miles of wiring installed. It is simply not economically feasible in most cases, or even physically possible in others, to replace all of the wiring in every aircraft.

An arcing fault is characterized by an intermittent, high-impedance short circuit. It draws far less current then an equivalent bolted short circuit[2] and typically lacks the duration of a continuously overloaded circuit. Thus, an arcing fault will not trip a thermal circuit breaker. This demands a different type of circuit breaker, one specifically designed to trip under this condition.

By 1991, maintenance costs associated with polyimide (Kapton)-insulated wire were increasing. Because of that burden and the superior wire types subsequently available, a directive against using Kapton[3] and all polyamide insulations was extended to include all aircraft production and retrofit kits. However, approximately half of the aircraft fleet still has polyimide-insulated wiring installed. Some of these aircraft will have that wiring removed during depot-level repair, while others will retain their wiring throughout their entire lifecycle because of the impracticality of replacing it. While polyimide gets considerable negative attention, it is by no means the only problematic insulating material. Polyvinyl chloride insulation for example, is flammable and produces a highly toxic gas when it burns. In CY1996 alone, Navy maintainers conducted 1,274 power wire replacements due to damaged wire at an approximate cost of $2,000 each. There were 64 documented "wire fires" during a 30-month period between July, 1995 and December, 1997. Of those 64 fires, 80-90 percent of them might have been prevented by arc fault circuit breakers.

Presently, visual inspection is the primary means of detecting wire problems. Because aircraft wiring is typically run in bundles, much of which is inaccessible without dismantling the aircraft, there are inherent limitations in visual inspection techniques. Even though alternative inspection methods are being developed, the fact remains that new inspection technologies are not inexpensive nor foolproof. As such inspection will never offer the complete answer to the problem.

Aging Navy Aircraft

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Electrical engineers assigned to the NAVAIR's Electrical Power Systems Division are teaming with ONR and the FAA to develop an aircraft arc fault detecting circuit breaker that will be used in military and commercial aircraft. Also contributing significantly to this effort is the OSS. Through the creation of its Aircraft Wiring and Inert Gas Generator Working Group, the OSS has created a teaming environment that is critical to AFCB development. Other government agencies, several airlines, the Airline Pilots Association and industry are also assisting in this effort.

The first challenge of building an AFCB is packaging. AFCBs already on the market for residential use must be reduced in size by at least 50 percent to fit into aircraft applications. In some aircraft, such as fighters and smaller helicopters, the reduction in size is even greater. Miniaturizing the electronics is difficult, but the second and even greater challenge is miniaturizing the mechanical part of the breaker. Once the electronics sense an arc fault, bolted short or continuous overload, the breaker must then be able to mechanically "open" the circuit and stop the current flow. Making the mechanical device small enough to fit in the package, but still capable of overcoming the electromagnetic force keeping the circuit "closed" is the engineering challenge facing NAVAIR and its collaborators.

A third challenge is programming the electronic sensing elements to tell the difference between a true arc fault and a transient or spurious signal that poses no threat to the system. In aircraft with extensive electronics, such as the EA-6B Prowler electronic jammer, there are many power surges, transient signals and other electronic "signatures" the AFCB could erroneously interpret as an arc fault. If not properly developed such that the breaker trips on too many "false alarms," the AFCB would be considered a nuisance by frustrated technicians and might be removed from service.

Key benefits of the AFCB are safety, reliability, and cost savings. Safety is the number one concern – the safety and well being of Navy aircrews and fleet maintainers. Current inspection techniques cannot possibly detect all wire defects before they cause a problem, but the arc fault circuit breaker can catch wire defects possibly before they get the opportunity to cause serious mishaps. Additionally, significant cost savings may be realized because the AFCB will detect and stop arcing events before they can cause appreciable damage, thus reducing troubleshooting and repair. Lastly, the creation of a competitive technology base will keep costs down and spur further innovation in arc fault detection.

Residential arc fault circuit breakers are now in use and the National Electric Code will require arc fault circuit breakers in all new home construction starting in 2002. The aviation AFCB is currently in development by a joint NAVAIR/FAA team, and went through ground tests in a Navy C-9 aircraft in October, 2001.

Smart Wires

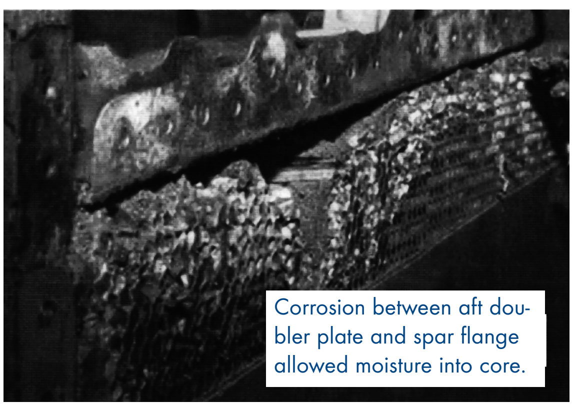
There is no single solution for the very complex issues of aging aircraft and their systems, (of which, wiring is one). Navy engineers are working on a spectrum of long-term production issues and short-term applications that can be retrofitted into the fleet. One of the new technologies being investigated is "smart wire."

Wiring diagnostics and prognostics, or "smart wiring," is the embedding of intelligence and sensors in the wiring system to manage the health of the wiring. Incorporating smart wiring reduces the time required to isolate broken wires, allows for proactive replacement of aged wiring systems prior to catastrophic failure, and provides a substantial increase in safety by eliminating wiring fires. The Navy is teaming with Management Sciences Inc. and Utah State University to develop this technology.

Corrosion Resistant Aluminum Honeycombs Reduce Support Costs and Increase Readiness

In addition to wiring, NAVAIR considers the top age-related cost drivers to be avionics obsolescence, corrosion control and total ownership cost. An example where corrosion in aging systems reduces readiness and increases cost is the aluminum honeycomb core materials used in flight control surfaces, engine intakes, access panels and doors.

Rudders, ailerons, flaps and many other structures on Navy aircraft are constructed using an aluminum honeycomb cores which, while structurally efficient and inexpensive to make, are prone to several corrosion-related types of failure. The harsh environment Navy and Marine Corps aircraft experience in maritime operations exacerbates the process. The most common failures include core material corrosion, corrosion-assisted fatigue of the hinge, and buffeting fatigue of the skin. These failures can be so extensive, that the parts have to be scrapped rather than repaired. Moreover, if a failure occurs in flight, the result may be loss of control.



Corrosion between aft doubler plate and spar flange allowed moisture into core.

To combat this problem, NAVAIR engineers are working with industry to implement a new process where the aluminum honeycomb cores are anodized with phosphoric acid to improve corrosion resistance. This process is expected to yield a cost avoidance over the next 10 years of more than $34 million.

In addition, follow-on technology will help eliminate problems associated with or caused by corrosion altogether. These new technologies include creating new honeycomb material, making control surface hinges out of titanium, and fabricating control surfaces and hinges from composite materials. All three of these new technologies are currently in development.

Russian Technology Employed to Increase Engine Life in Dusty Service Environments

A Soviet-era technology under evaluation by engineers at Naval Air Station – Patuxent River, MD is promising impressive life span and power improvements for aging aircraft engines. The program, evaluating a Russian titanium nitride coating for jet engine compressor blades, is proving so successful, its IPT members were awarded the Office of the Secretary of Defense Foreign Comparative Test Manager of the Year award in a ceremony on 9 Nov 2001 at Ft. Meyer, VA. The award was presented to the team, comprised of NAVAIR engineers as well as American, Canadian and Russian industry representatives.

The program itself involved evaluating a Russian process that coats turbine engine compressor blades with a thin coating of titanium nitride. These compressor blades, especially those used in the CH-53E *Super Stallion's* T-64 engine, were experiencing dramatically shortened life spans due to erosion.

"We had a problem with sand erosion taking the compressor in the T-64 engine down to 1/20th of its design life," explained Greg Kilchenstein, a NAVAIR Propulsion and Power Systems engineer and member of the integrated product team evaluating the new coating process. "That trickled down to other problems like compressor stalls."

Ultimately, eroding compressor blades affected performance to the point that Marines operating the *Super Stallion* in Southwest Asia during Operations Desert Shield and Desert Storm were having difficulty making heavy lifts. "They had to call on Army CH-47 *Chinooks* to make heavy lifts," said Kilchenstein. The CH-53E is fitted with a particle separator to filter out larger particles (>10 microns) before they are ingested by the engine. What remains is equivalent to a very fine dust getting "blown" through the engine at very hot temperatures and high speeds, and scouring engine components in its path like a sand blaster. "In the T-64 engine compressor, the blades in the first 10 stages are titanium," said Kilchenstein. "Titanium is lightweight, strong and a good candidate for building rotating components, but it's not good at handling hard-particle erosion."

Under the Component Improvement Program (CIP,) Kilchenstein's engine team received funding to fix the T-64's problem. "The CIP funded us to scour the world to find anything that could help the T-64," he said. The search led them ultimately to technology used in the Soviet-era Mi-24 *Hind* attack helicopter. "The Russians had the same experience in Afghanistan that we did in Southwest Asia with engines," Kilchenstein said. "They were scrapping about 80 percent of their rotor blades. This coating technology helped them reduce that rate to about three percent."

The coating process had been developed by the Ural Works of Civil Aviation (or PRAD by it's Russian initials) in Ekaterinburg, Russia, according to Chris Georgiou, a NAVAIR aerospace engineer responsible for advanced propulsion programs. It has been successfully protecting Russian TV2 and TV3 engines used in the Mi-24 and Mi-48 helicopters, as well as most of the Russian military fleet.

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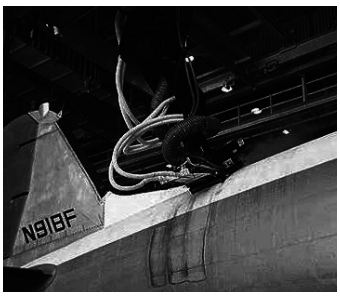
Revolutionary New Paint Removal Process for Aircraft is Both Environmentally-Friendly and Cost Effective

As the fleets of the Air Force, Navy, Army, Marines, and the Coast Guard continue to operate for longer periods, preventative maintenance becomes a much larger portion of life cycle costs. Aircraft painting represents one of the best defenses against the ravages of hostile service environments. It is also one of the most expensive aspects of maintenance. As such, it seemed appropriate to bring this significant advance in the state of the art to your attention.

Aircraft paint removal is an expensive process, representing a significant portion of its total maintenance costs. Not only are conventional processes very labor intensive, but also produce substantial quantities of chemical wastes which require costly disposal. Traditionally, chemical strippers such as methylene chloride have been used to soften the paint, followed by an additional paint removal step such as sandblasting, wire brushing or some other mechanical removal method. Chemical stripping requires extensive surface preparation to mask areas of the aircraft that could be damaged from chemical exposure. In addition, maintenance personnel must be protected from exposure to hazardous chemicals. To comply with environmental regulations, the waste, which consists of paint chips, expended solvent and blasting media, must be disposed of properly. Often times, the cost of this disposal exceeds the original cost of the labor and materials needed to remove the paint.



Alternative removal systems have been evaluated, including sandblasting; laser ablation; cryogenic removal, either with liquid nitrogen or dry ice; and wheat starch. Sandblasting is a good, all purpose removal technique, but can potentially cause mechanical damage to the structure's surface. This is particularly true in the case of aerospace structures, which are increasingly fabricated from organic matrix composites. Significant waste disposal costs are also a limitation of this technique.

The use of laser ablation alone can effectively remove paint, but it is difficult to control the intensity of the beam such that the coating is removed, but the underlying surface remains undamaged by heat buildup. The energy density, duration and frequency of the laser pulse all contribute to heat buildup in the substrate. The thermal conductivity of the substrate material, and its inherent ability to dissipate heat also regulate heat accumulation.

The U.S. Navy has experimented with paint removal systems employing a stream of liquid nitrogen. In this process, the sudden cooling brought about by the liquid nitrogen induces a thermal expansion mismatch (thermal shock) between the coating and the substrate, leading to cracking and spalling of the coating. The coating can then be brushed off or easily scraped away. The National Park Service successfully used this method to remove interior coatings from the Statue of Liberty during its most recent refurbishment. Preliminary tests indicated the thin copper sheets making up the statue would not be harmed by this removal method. In the Navy experiment, analysis indicated the change in temperature was insufficient to lift a thin coat of paint from the surface. Thicker coatings were more easily removed because of the greater difference in temperature between the coating and substrate.

In terms of waste disposal, both laser ablation and cryogenic removal produce more benign waste in less quantities than chemical stripping or sandblasting. When coatings are removed by laser, the waste products are CO_2, water, and the ash remaining after the paint is pyrolyzed. In cryogenic removal, the waste products consist only of the removed paint chips.

In the 1990's, engineers at the Boeing Company developed a coating removal system that combines the energy pulse of light with the thermal shock and abrasive properties of cryogenic cleaning. When these two methods are combined, the waste products are minimized. Marketed under the trade name Flashjet® Coating Removal System, this de-painting method is currently in use at the Corpus Christi Army Depot, Warner Robins Air Logistics Center and the Naval Air Station in Kingsville, Texas.

Flashjet was developed by a team of engineers from the McDonnell Douglas Corporation (now part of Boeing), Maxwell Laboratories Inc. and ColdJet Inc. It uses a xenon lamp to first vaporize the painted surface. A low pressure stream of dry ice particles cools the surface almost instantaneously and knocks the remaining ash away from the substrate. A vacuum system is used to collect the particulate waste. The Flashjet system has been proven effective for metal as well as composite surfaces, including fiberglass, kevlar and boron/graphite, epoxy-based components. Flashjet is capable of removing up to four square feet of paint per minute at a cost of less than $4.00 per square foot.

An analysis of life cycle costs comparing Plastic Media Blasting (PMB) and chemical processes to Flashjet for depainting the U.S. Navy's T-45 fleet demonstrates that Flashjet will result in significant life cycle savings over the projected 20 year service for the fleet.[1] Table 1 shows the

Table 1: Life Cycle Depainting Cost Comparison for T-45 Aircraft

Depainting Process	Waste Disposal Costs	Turn Around Time	Disposed Media	Process Cost Total	Total Life Cycle Savings
Chemical	$3,404,010.78	375 MH*	3,855,123 lbs	$16,877,646.87	$15,030,501.09
PMB	$863,490.63	220 MH	575,664 lbs	$9,547,129.68	$7,699,983.90
FLASHJET	$16,040.19	28 MH	1342.5 lbs	$1,847,145.78	

*MH – Manhours

cost comparison between the three processes. In terms of environmental impact, the PMB process has the potential to emit cadmium from aircraft fasteners and chromium compounds from the paint. The effluent capture system of Flashjet prevents the introduction of cadmium and chromium compounds into the work environment.

The FLASHJET gantry system at Warner Robins will be used to depaint composite radomes, flight control surfaces, fairings and other surfaces from the U.S. Air Force F-15 Eagle, C-130 Hercules, C-141 Starlifter and C-5 Galaxy aircraft.

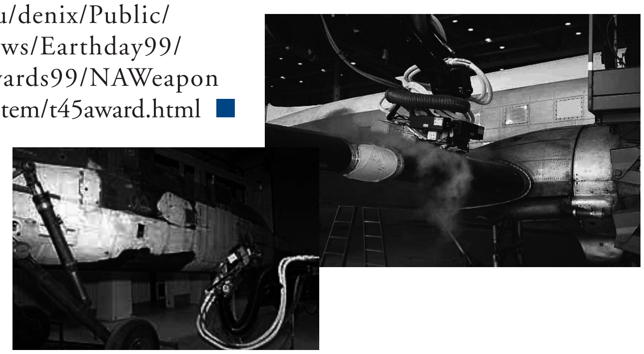
A seven-axis robot gantry system for the Corpus Christi Army Depot will accommodate the largest U.S. Army helicopter, the CH-47 Chinook. The FLASHJET system will be used to remove paint from AH-64 Apache, UH-60 Blackhawk, AH-1 Cobra, UH-1 Huey, SH-60 Seahawk and OH-58 Kiowa helicopters.

The FlashJet system offers significant savings in terms of waste disposal, turnaround time and the amount of solid waste produced. As program budgets continue their shift from procurement to maintenance, these significant savings will put more funds in the hands of the program offices to address the more urgent aspects of the aging aircraft fleet.

Chris Grethlein, AMPTIAC

All photos courtesy of ColdJet, Inc.

[1] Award Category Pollution Prevention – Weapon System Acquisition Team http://osiris.cso.uiuc.edu/denix/Public/News/Earthday99/Awards99/NAWeapon System/t45award.html ■



FAA's Assurance Center continued from page 10 ➤

frame structures include reduced part count, dimensional consistency, structural reliability, improved serviceability, and lower costs. A critical level of understanding not yet achieved is the determination of how effectively castings with discrete damage can carry design loads. Iowa researchers are therefore assessing the structural integrity of the cast components at the earliest stages of product definition from the point of view of casting process defect formation, damage tolerance (fatigue crack growth), residual strength and NDE.

In support of the AACE, AANC researchers are validating the effectiveness of composite repairs on metallic aircraft structures. Use of bonded composite repairs present a potentially cost-effective technique to safely extend the lives of aircraft. Instead of using riveted multiple steel or aluminum plates to repair damaged aircraft areas, a single Boron-Epoxy composite can be bonded to the damaged structure. The validation project being conducted by the AANC is intended to introduce and properly control the use of this composite repair technique on commercial aircraft. The project's goal is to identify the necessary FAA guidance to assure the continued airworthiness of this type of composite repair. The successful use of the boron/epoxy composite repair has already been demonstrated on an L-1011 doorframe.

David Brumbaugh
AMPTIAC

Reference

[i] NTIAC, May 2000 Newsletter, Volume 25, No. 3 ■

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regulations with less than 420 gm/l VOC level as applied and contains no hazardous materials[3]. This was a significant breakthrough in camouflage topcoat technology and will find its way into the USAF military aircraft inventory in the near future.

Alternates to chromium-based compounds for aluminum corrosion protection have been evaluated for over twenty years. One promising technology for an environmentally compliant surface treatment is based upon cerium oxide[4]. This method utilizes an electrochemically driven process to deposit a thin layer of cerium oxide on the surface of aluminum alloys. Experimental results have demonstrated that this chromium-free, corrosion protective surface treatment passes the 336-hour salt fog test, a critical corrosion resistance evaluation test required in military specifications. Electrochemical evaluations utilizing impedance spectrography have shown that accelerated corrosion testing in the laboratory can be correlated to performance in environmental screening (salt fog). While these results are promising, this technology is far from finding its way into the USAF depot system. Non-electrochemically driven surface treatment processes must be developed to provide protective coatings for entire aircraft surfaces. Compatibility with non-chromium containing primers and topcoats must also be demonstrated.

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[3] Deft Product Information Data Sheet, Extended Life Topcoat (Irvine CA: Deft Inc., 1997)

[4] Stoffer, J.O., O'Keefe, T.J., O'Keefe, M., Morris, E., Hayes, S, Yu, P, and Lin, X., Environmentally Safe Aircraft Coatings, Proceedings of the 32nd International SAMPE Technical Conference (Covina, CA: SAMPE Int., 2000)

Aircraft Coating Requirement

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Notes

[1] An arc fault is an intermittent, high-impedance short circuit which typically lasts a few milliseconds. During an arcing fault, the volltage will drop but the amperage will increase by a factor of 10 or more resulting in a localized discharge of a great amount of heat and energy. Because a typical arcing fault doesn't draw as much current, or last as long as a continuously overloaded circuit, it will not trip a conventional thermal circuit breaker.

[2] A bolted short circuit is a "zero impedance" fault that causes current to flow in a non-normal circuit or path. (i.e., wire to wire, wire to ground). Bolted shorts occur when defects (caused by age or damage) in the electrical system allow conductors to solidly touch each other or connect directly with ground. They can also occur if wire is improperly handled, maintained of installed.

[3] The Navy ceased use of Kapton wiring in new combat aircraft production in 1986 due to its poor arc tracking characteristics during ballistic tests, where bullets are fired into wire bundles.

Compiled by
Wade Babcock, AMPTIAC

This article was compiled from various materials supplied by Naval Air Systems Command, Patuxent River, Maryland. For more information on specific programs, please contact NAVAIR's John Milliman at (301) 342-2221 or millimanjc@navair.navy.mil.

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