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Brazilian Air Force aircraft structural integrity program: An overview

Abstract: *This paper presents an overview of the activities developed by the Structural Integrity Group at the Institute of Aeronautics and Space - IAE, Brazil, as well as the status of ongoing work related to the life extension program for aircraft operated by the Brazilian Air Force BAF. The first BAF-operated airplane to undergo a DTA-based life extension was the F-5 fighter, in the mid 1990s. From 1998 to 2001, BAF worked on a life extension project for the BAF AT-26 Xavante trainer. All analysis and tests were performed at IAE. The fatigue critical locations (FCLs) were presumed based upon structural design and maintenance data and also from exchange of technical information with other users of the airplane around the world. Following that work, BAF started in 2002 the extension of the operational life of the BAF T-25 "Universal". The T-25 is the basic training airplane used by AFA - The Brazilian Air Force Academy. This airplane was also designed under the "safe-life" concept. As the T-25 fleet approached its service life limit, the Brazilian Air Force was questioning whether it could be kept in flight safely. The answer came through an extensive Damage Tolerance Analysis (DTA) program, briefly described in this paper. The current work on aircraft structural integrity is being performed for the BAF F-5 E/F that underwent an avionics and weapons system upgrade. Along with the increase in weight, new configurations and mission profiles were established. Again, a DTA program was proposed to be carried out in order to establish the reliability of the upgraded F-5 fleet. As a result of all the work described, the BAF has not reported any accident due to structural failure on aircraft submitted to Damage Tolerance Analysis.*
Key words*: Fatigue, Damage tolerance, Structure, Service life.*

INTRODUCTION

The first Brazilian flight was reported on 23 October 1906, and was performed by Alberto Santos Dumont in an airplane named 14 bis. At that time, not much was known about other achievements, so that initially Santos was considered to be the first man to fly a fixed-wing craft, capable of taking off, flying and landing under its own power (Hoffman, 2003). Another important milestone in Brazilian aeronautics was the flight of the Demoiselle (Fig. 1). It was the first ultra-light airplane in history (Winter, 1998). Santos Dumont flew the Demoiselle for the first time in 1908.

Airplanes manufactured in the first half of the 20th century were primarily based on the static strength point of view. The aircraft industry's approach to achieving structural integrity was significantly modified as a result of failures that occurred in the 1940s and 1950s. The most significant were the fatigue failure of the wing of the Martin 202, in 1948, and the Comet fuselage failures that occurred in 1954. At that time, the concept known as safe life was introduced. According to this philosophy, an article needed to be tested to prove its fatigue strength.

The safe life approach is based on the life-to-failure test divided by a scatter factor, usually three or four, to account for uncertainties in material properties, manufacturing and assembly processes, and applied loads. When strictly enforced, the safe life approach imposed a severe penalty: if the service life was reached, then the fatigue life was deemed expended and the aircraft removed from service. However, if a flaw existed in the structure, the safe life did not ensure flight safety.

Figure 1: Demoiselle Santos Dumont's first ultra-light plane 1908 (Winter, 1998)

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Another significant change in the structural integrity program was due to the failure of an F-111, in 1969. This and other accidents initiated the era of damage tolerance for military aircraft. In this methodology, flaws are assumed to exist in a structure's most critical locations. The goal of the structure integrity program is to find and repair the damage before failure occurs. This new approach was also adopted by the FAA (Federal Aeronautics Administration) in 1978, due to fatigue concerns relating to a catastrophic Boeing 707 failure.

Ever since the first flight, Aeronautics in Brazil has developed with the aim of better and safer flying. Capability and confidence in structural tests and analysis were always the main goal in the Brazilian Air Force (BAF). Until 1990, the fatigue life philosophy adopted by BAF was the safe life. After in-depth studies and field experience, it was concluded that Damage Tolerance Analysis (DTA) was a much more reliable concept for determining the service life of aeronautical systems.

The main steps of a DTA Program can be summarized as follow:

- Flight data survey

This task is necessary in order to obtain the information on how the airplane is being used. Some data must be available for further analysis: load factors, altitude, speed, angular accelerations, etc. This body of information is called L/ESS (Load/Environment Spectra Survey)

- Stress-to-load Ratio

This is how the stress in each Fatigue Critical Location (FCL) relates to the L/ESS. The equations come from stress analysis and strain gauged aircraft.

- Stress Spectra

For each FCL the stress spectra are determined, based on the L/ESS and the stress-to-load ratio.

- Residual Strength

Based on the material properties, structure geometry and fracture mechanics parameters, how the structural strength decreases with crack size is determined. The minimum strength required defines the critical crack siz

- Crack growth curve

With all previous parameters and a valid code, the crack growth can be computed and inspection intervals may be assigned according to the capability of the maintenance depot.

The damage tolerance approach provides a framework for extending structural life. Because structural repairs and replacements are based on periodic inspections determined by analysis and testing, an aircraft is permitted to fly so long as inspections on it are properly performed.

The first Brazilian aircraft to undergo a DTA-based life extension was the F-5, in the mid-1990s. Southwest Research Institute (SwRI) was contracted through the USAF (United States Air Force) to perform the analysis (Wieland et al., 1996). Their work included hands-on job training for BAF personnel. The load spectrum was obtained from 5 F5-Es operating at the Santa Cruz Air Force Base, Brazil.

In the late 1990s, a group was formed at the Institute of Aeronautics and Space (IAE) with the objective of developing human resources and technical expertise for in-house damage tolerance analysis. This group is now part of the Structural Integrity Subdivision (ASA-I) at the Aeronautical System Division (ASA) at the IAE.

The first in-house DTA work was with the BAF AT-26 “Xavante”. This aircraft was originally designed under a safe-life structural concept. It is a light ground-attack, reconnaissance and training subsonic jet aircraft. It was produced by EMBRAER under license from the Italian manufacturer Aermacchi SpA. The first plane flew in 1971. More recently, in the mid-90s, 4 accidents were reported two with BAF airplanes and 2 others worldwide involving this type of aircraft. All of them were related to structural failure in the wing spar (Fig. 2). Subsequent analysis showed that the failure was due to manufacturing quality problems caused by improperly drilled holes in a critical area (Mello Jr, 1999).

Figure 2: AT-26 wing main spar failure (Mello Jr., 1999).

Following this work, the BAF Structural Integrity Group was also responsible for performing the DTA for the T-25 “Universal” trainer, finished in 2005. Currently, the focus is on the upgraded F-5EM/FM, as discussed in the following sections.

THE MOST RECENT STRUCTURAL INTEGRITY PROGRAM

- **AT-26 (EMB 326) DTA**

In 1998, at the request of the Brazilian Air Command, the

Structural Integrity Subdivision began DTA assessment on the AT-26. The main requirements were to have a more reliable structure as well as to keep the flying status beyond the original, and proven unsafe, service life. The main tasks for the AT-26 DTA were: data review, flight data recording, processing and evaluation, strain gauged airplane for flight test campaign, coupon tests, structural FEM (Finite Element Modeling) and fracture mechanics analysis, and non-destructive inspection development. Figure 3 shows several pictures representing tasks accomplished during the AT-26 DTA.

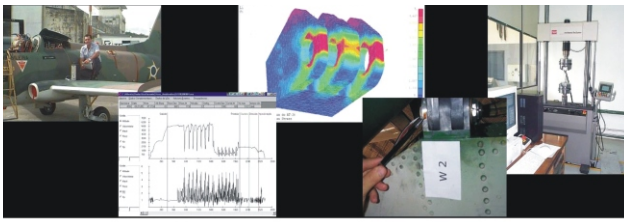

Figure 3: Pictures of the tasks relating to the AT-26 DTA.

The operational data and maintenance feedback were obtained from the Air Squadrons and PAMARF (BAF Depot responsible for this fleet), respectively. The fatigue critical locations (FCLs) were presumed based upon structural design and maintenance data and also from exchange of technical information with other users of the airplane around the world. The operational usage was obtained from actual missions of five fighters flying at the 1º/4º Grupo de Aviação de Caça in Fortaleza over a period of one year. The load/environment spectra survey (L/ESS) was used to determine the external forces acting on the aircraft components.

Finite element models of selected FCLs were constructed in order to obtain the stress levels at the locations most likely to develop fatigue cracks (Mello Jr., 1999). These local stress levels were experimentally confirmed and adjusted through an extensive flight test program. Strain gauges were installed at the main aircraft FCLs for stress-to-load ratio validation. Retardation parameters from coupon tests were then used as input for the crack growth analysis to obtain the crack growth curves (Mello Jr., 1998) and to define the adequate intervals for the non-destructive inspection method (NDI) applicable for each FCL.

A total of 15 fatigue critical locations were analyzed and for each one a proper NDI was scheduled. For the wing spar, considered the most critical spot, a new NDI procedure had to be implemented. The critical region and surroundings are inspected by eddy current technique with the help of video pack equipment (Fig. 4). This inspection is backed up by X-Ray of the entire region.

The main achievement of this project was to give the Brazilian Air Force the necessary time to transition from this aircraft to its replacement and increase the structural reliability of the AT-26.

Figure 4: Development in laboratory (a) and in the field (b) of the eddy current inspection guided by a video probe (Garcia et al., 2001).

- **T-25 "Universal" life extension**

The T-25 is the basic training airplane made by the Brazilian Aviation Company NEIVA, and used by AFA - the Brazilian Air Force Academy. This airplane was also designed under the safe-life concept. As the T-25 fleet approached its service life limit, the Brazilian Air Force began to question whether it could be kept flying safely. The answer was provided by an extensive Damage Tolerance Analysis. This airplane entered service at the beginning of the 70s. Unlike the previous project, no catastrophic structural accident was reported during its service life. Additionally, the safe-life full scale test was stopped after 7,000 effective flight hours without any reported major damage.

The main goal was to extend the T-25 service life by 5,000 flight hours, retaining the integrity of the structure. For the complete analysis, the same steps presented for the AT-26 were followed. A total of 25 fatigue critical locations were considered: 11 in the wing, 10 in the fuselage, 3 in the horizontal stabilizer and 1 in the vertical stabilizer (Mello Jr. et al., 2004). Over 700 flight hours were collected from the BAF Academy planes, covering all the missions and typical idiosyncrasies of a variety of trainee pilots. For proper calibration of the stress-to-load ratio equations, 16 FCLs were strain gauged and a test flight campaign was conducted.

The DTA included an interactive phase with the Maintenance Depot and End User. This was considered a key step for the final result, since all the changes and recommendations must be maintainable and operational. Among the suggested changes in maintenance procedure were the new inspections in the center box wing spar and in the attachment lug region of the external/internal wing. Strap reinforcement at the root wing lower spar cap was also proposed to be carried out during a major Depot overhaul (Mello Jr. et al., 2005).

F-5M STRUCTURAL INTEGRITY PROGRAM

The BAF F-5, versions E and F, are being modernized. The upgrade includes new avionics and weapons system. It is clear that the operational effort will be changed considering the new system in a more capable aircraft. Also, the weight and its distribution have been modified. All of this made a new structural analysis mandatory to ensure a reliable service life. A complete proposal for a 2-year DTA program was submitted to the Brazilian Air Command. The program started on August 2007.

The fleet is now referred to as F-5EM/FM. Among the various changes that affect the structural life is the cutting of the forward fuselage at station 103 (60.5 for F-5F) to include a bigger radar antenna and the removal of one gun. This was necessary to make room for the new avionics. After all the modifications during the upgrade process, the "new" aircraft increased in weight, leading to changes in the structural load distribution. Also, new configurations and mission profiles were established.

One example of this configuration/profile change is the new airplane's capability to perform ripple, having the CCRP (Continuous Computer Release Point). An extensive g-jump in flight campaign was carried out to certify this type of mission as safe for the F-5. Strain gauges and accelerometers were installed to measure the instant load at critical spots.

With the new avionics, all airplanes are eligible for L/ESS (Load/Environment Spectra Survey). At the end, the DTA will determine what will be the impact of the upgrade on the maintenance schedule and workforce to support the F-5EM/FM fleet.

Also, it will show how new avionics and weapons systems affect the usage of the same platform in a specific Squadron. Due to changes in weight and balance, comparisons are being made between stress spectrum profiles for some of the aircraft fatigue critical locations. Finally, a maintenance schedule will be proposed based on what the analysis predicts. So far, more than 700 flight hours have been collected from the BAF F-5 Squadrons. Several computer codes and pre-analyses have been written, in order to substantiate the upcoming F-5EM/FM DTA Final Report.

PROSPECTIVE WORK

The Brazilian Air Force is already anticipating the need for a life extension of the A-1 "AMX". The AMX is an attack jet that provides the required performance to acquaint pilots with the demands of modern combat scenarios. The complete structural reassessment will be performed after a mid-life avionics upgrade to be carried out over the next few years.

The A-29 "Super-Tucano" (Fig. 5) is a combination of a turboprop with fourth-generation avionics and armament systems. The Super-Tucano has an outstanding human-machine interface, fully compatible NVG Gen III cockpit lighting innovation. It can operate in the most hostile environments and from unprepared runways, by day or night. Its first flight for the BAF was on August 2004.

The BAF requirements included a comprehensive fatigue life evaluation, following all the structural integrity and reliability certifications. EMBRAER has contracted the IAE's Structures Laboratory to perform the durability and damage tolerance full scale fatigue test for this aircraft. A three service life time has been simulated, and now cracks will be induced in the most critical areas.

Another two service lives will be tested with monitoring of the induced cracks. The damage tolerance analysis is being performed by EMBRAER.

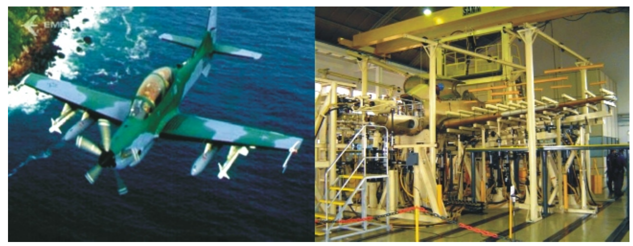

Figure 5: A-29 Super-Tucano Flying over the coast (a), assembled for fatigue full scale test (b).

There are several other projects that may be implemented over the next few years by the IAE Structural Integrity Group. Among them are C-130 DTA update, T-27 "Tucano" DTA and A-4 (Brazilian NAVY) DTA assessment.

CONCLUSION

Brazilian aviation has a history that is deeply involved in the history of manned flight. Since 1906, Brazil has been very active in the efforts to make flying better and safer. The new concepts of DTA to assure structure integrity were adopted by the BAF in the 1990s and since then there has been a significant improvement in safety for the projects that adopted that philosophy, with no reported accident due to structural failures on aircraft subjected to DTA. The IAE has proven that it has the necessary tools and technical personnel needed to analyze, propose changes and perform the follow-up for any structural problem faced by the Brazilian Air Force.

New operational requirements from the BAF will provide a long-term demand for human resources involved in structural analysis and design from the IAE Aeronautical Systems Division, Structural Integrity Group.

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