Engineering Failure Analysis 65 (2016) 86–101

Contents lists available at ScienceDirect

Engineering Failure Analysis

journal homepage: www.elsevier.com/locate/engfailanal

An overview on how failure analysis contributes to flight safety in the Portuguese Air Force

Diogo Duarte [a,*], Bruno Marado [b], João Nogueira [c], Bruno Serrano [d], Virgínia Infante [e], Filipa Moleiro [f,g,h]

[a] Portuguese Air Force, Engineering and Programs Directorate, 2724-506 Amadora, Portugal
[b] Portuguese Air Force, Institute of Higher Military Studies, Lisbon, Rua de Pedrouços, 1449-027 Lisbon, Portugal
[c] Portuguese Air Force, General Staff — Resources Division, 2724-506 Amadora, Portugal
[d] Portuguese Air Force Academy, Granja do Marquês, 2715-021 Pêro Pinheiro, Sintra, Portugal
[e] ICEMS, Institute of Materials and Surfaces Science and Engineering, Instituto Superior Técnico, University of Lisbon, Av. Rovisco Pais, 1049-001 Lisbon, Portugal
[f] LAETA, IDMEC, Instituto Superior Técnico, University of Lisbon, Av. Rovisco Pais, 1049-001 Lisbon, Portugal
[g] Escola Superior Náutica Infante D. Henrique, Av. Engenheiro Bonneville Franco, 2770-058 Paço de Arcos, Portugal
[h] ISEL - Instituto Superior De Engenharia de Lisboa, Rua Conselheiro Emídio Navarro, 1959-007 Lisbon, Portugal

ARTICLE INFO

Article history:
Received 30 September 2014
Received in revised form 18 December 2015
Accepted 2 March 2016
Available online 31 March 2016

Keywords:
Aircraft failure analysis
Case studies
Sustainment engineering
Service life

ABSTRACT

Failure analysis has been, throughout the years, a fundamental tool used in the aerospace sector, supporting assessments performed by sustainment and design engineers mainly related to failure modes and material suitability.

The predicted service life of aircrafts often exceeds 40 years, and the design assured life rarely accounts for all in service loads and in service environmental menaces that aging aircrafts must deal with throughout their service lives.

From the most conservative safe-life conceptual design approaches to the most recent on-condition based design approaches, assessing the condition and predicting the failure modes of components and materials are essential for the development of adequate preventive and corrective maintenance actions as well as for the accomplishment and optimization of scheduled maintenance programs of aircrafts.

Moreover, as the operational conditions of aircrafts may vary significantly from operator to operator (especially in military aircraft), it is necessary to access if the defined maintenance programs are adequate to guarantee the continuous reliability and safe usage of the aircrafts, preventing catastrophic failures which bear significant maintenance and repair costs, and that may lead to the loss of human lives.

Thus being, failure analysis and material investigations performed as part of aircraft accidents and incidents investigations arise as powerful tools of the utmost importance for safety assurance and cost reduction within the aeronautical and aerospace sectors.

The Portuguese Air Force (PRTAF) has operated different aircrafts throughout its long existence, and in some cases, has operated a particular type of aircraft for more than 30 years, gathering a great amount of expertise in: assessing failure modes of the aircrafts materials; conducting aircrafts accidents and incidents investigations (sometimes with the participation of the aircraft manufacturers and/or other operators); and in the development of design and repair solutions for in-service related problems.

This paper addresses several studies to support the thesis that failure analysis plays a key role in flight safety improvement within the PRTAF. It presents a short summary of developed

* Corresponding author.
E-mail addresses: dxduarte@emfa.pt (D. Duarte), bsmarado@emfa.pt (B. Marado), jrnogueira@emfa.pt (J. Nogueira), baserrano@emfa.pt (B. Serrano), virginia@dem.ist.utl.pt (V. Infante), Filipa.moleiro@dem.ist.utl.pt (F. Moleiro).

http://dx.doi.org/10.1016/j.engfailanal.2016.03.003
1350-6307/

analysis and studies using optic and electronic (MEV) microscopy, material chemical composition analysis and Non Destructive Testing (NDT) to solve problems related to operation, maintenance and design issues.
Additionally, it presents the investment that has been made by the Portuguese Air Force in the last two decades, to increase the flight safety through the implementation of powerful aircraft configuration management tools, and structural condition assessment methodologies based on strain measurements, NDT evaluation programs and, more recently, on Structural Health Monitoring systems in their fleets.

1. Introduction

Ever since the beginning of aviation, a major concern in the aircraft and aerospace industries is flight safety. Although great effort has been being put onto the materials and systems reliability, leading to an increase in the overall aircrafts reliability, the problem that arises is that fatal accidents due to materials and systems failures, although rare, still occur nowadays.

Failure analysis has been thoroughly used to investigate occurrences related to flight safety and aircraft accidents and incidents investigations throughout the years, allowing for a better understanding of the root cause of those mishaps and for the development of corrective actions that contribute for the construction and development of more reliable systems, as well as for the definition of safer operational and maintenance procedures.

Although the authors fully subscribe Arjen Romeyn [1], saying that from a Safety perspective, it is desirable that air transport systems are examined, tested and analyzed to define and assure the safe operation of those systems, rather than analyze the results of incidents and accidents, the aim of this review paper is to support the thesis that failure analysis plays a key role in the overall safety of aircraft systems.

Another purpose of this article is to highlight the high reluctance of the aircraft industry to change, which is intrinsically related to the reliability of the aircraft systems, and bears as a significant a challenge for aircraft sustainment engineers. Due to a relatively small number of aircraft produced and to their relatively small number of flight hours (when compared to the designed aircrafts' service life), unexpected failures related to design issues often occur far into the service life of the aircraft, whereas in other industries of similar complexity (e.g. automotive) they are bound to be corrected during the first commercial years of the products. Hence being, the desired low failure rates on aircrafts bearing new configurations or innovative systems are extremely difficult to achieve. In these new systems there is no data available from operational experience making it hard to identify design errors that derive from differences between the real service conditions and the manufacturer predicted service conditions included in the original design. For that reason, evolutions in the design and certification of aircrafts are rather slow processes, where innovative systems and features are difficult to include, and often result in drawbacks in the design due to rises of failure probability that reduce the systems reliability, bearing significant costs or even compromising safe operation and putting in risk a large number of human lives.

One other important issue that stands out in this article is the significant role of the human factor in aircraft systems failures. In the majority of the investigations performed on aircraft accidents, or other flight safety related investigations, the conclusions point out, directly or indirectly to human errors, to inadequate procedures, or organizational related issues as contributive causes for the failure, which usually comes as the result of innumerous factors, and that often outcome in material failures which lead to unsafe conditions.

2. Context and literature review

Men have always tried to travel increasingly larger distances, within the least possible periods of time. This need for movement has been the drive for the enhancement and spread of knowledge, communication and commerce across the world and throughout history, for which men have developed more and more complex and effective ways to achieve it. If the movement was initially made only by land, it rapidly embraced the sea and, more recently in the early twentieth century, the skies also became part of the common human travel system with the use of airplanes and helicopters. Although air lift assets are, in historical context, very recent when compared to land or sea transportation, they are at the beginning of 21st century one of the safest forms of travel across the world.

Table 1 (Roger Ford [2]) compares the number of people killed during travel by different means of transportation, showing that when considering the distance traveled, the rate of human fatalities per unit of distance traveled, by air is significantly lower than by any other means of travel.

Similar results were evidenced for the United States and for Australia, by Ian Savage [3] and by the Australian National Transport Safety Bureaus [4], which show that for either case, air transportation appears as the safest form of transport, within those countries.

Nevertheless, the current low fatality of commercial air transport was not always such an undisputable truth and has evolved over the years. And if airborne travel systems are today broadly accepted as one of the safest ways of transportation, a few decades ago, in the mid-20th century it was not so. In fact the rate of accidents per flight hour in civil aviation in the past 20 years has been reduced to approximately one third of the initial values. Fig. 1 shows the number and rate per 10 million flights