AIRCRAFT DISASTERS – ROLES OF MATERIALS

T. B. Asafa[a*], M. O. Durowoju[a] and O. S. Ismail[b]

a. Mechanical Engineering Department, Ladoke Akintola University of Technology, P. M. B 4000, Ogbomoso, Nigeria.

b. Mechanical Engineering Department, University of Ibadan, P. M. B. 1, Ibadan.

Abstract

Aircraft disaster has been in existence since air was conquered by man as a means of transportation. 487.5 million and 874.4 millions of cumulative departures and flight hours respectively have been estimated since 1959. Analysis of aircraft failure based on 5,149 on-board fatalities recorded shows that 13% of total aircraft accident was caused by mechanical failure while loss of control was responsible for over 31% of onboard fatalities. Aircraft accident is known to be most fatal during take-off and landing phase contributing about 49% while onboard fatality during cruise is about 19%. In this work, reviews of aircraft disasters were made via Fractographic examination, SEM and finite element modeling. It must be stated that few of aircraft failures which are not material related are not considered in this review. The review focused on material related failure which have been analyzed, accepted and published in reputable journals.

Keywords: failure, fatigue, aircraft, disaster.

***Corresponding author (+2348034230964, teslimtunde@yahoo.com)**

1.0 INTRODUCTION

Aircraft disasters (or accident) can be thought of as 'an occurrence associated with the operation of an aircraft which takes place between the time any person boards the aircraft with the intension of flight and all such persons have disembarked and in which any person suffers death or serious injury or in which the aircraft receives substantial damage' [9]. The International Civil Aviation Organisation (ICAO) considers accident to have occured on an aircraft when a person is fatally or seriously injured, the aircraft substains damage or structural failure or the aircraft is missing or completely inaccessible [10]. Passenger aircraft flight hours have been on increase though without substantial increase in departures (Fig.1) [9]. This relationship could be attributed to decrease in accident rate ((Fig.2). Decrease in flight hours and departures observed in years 2002 and 2003 came as a result of the terrorist attack in US that sent fear to the hearts of regular 'flyers'. The observed increase however continued in 2004 after strick safety measures were adopted. 487.5 millions cummulative departures with 874.4 million cummulative flight hours since 1959 have been esimated.

Fig.1: Annual departures and flight hours between 1987 and 1996 [9]

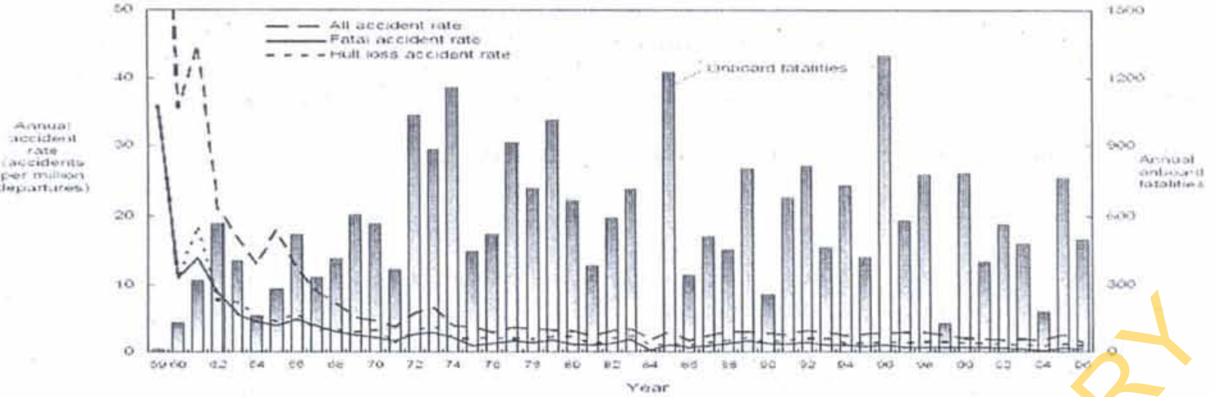

Fig. 2: Aircraft accident rate between 1959 and 2006 [9].

A comprehensive statistical analysis of aviation accident involving worldwide commercial Jet fleet from 1997 through 2006 is provided in Fig.3.The categorisation was based on Fatalities by CAST / ICAO Taxonomy Accident category. The figure indicates that loss of control is the highest cause of aviation accident followed by system component failure (which related to material failure). In a similar report, 13% of total aircraft accidents since 1950 was caused by mechanical failure while loss of control is attributed to over 31% with reference to on-board fatalities[11].

Further statistical analysis was conducted to categorise these accidents according to flight phase. Fig.4 (accident phase) clearly indicates that fatal accident happened most during landing phase while on-board fatality is zero during taxing [9]. Most of the accident and fatalities are associated with depature (take off/climb) and arrival (approach/landing) phases. 'During these phases, aircraft is close to the ground and in a more vulnerable configuration than in other phases of flight' as maneuvre margin is greatly reduced [12]. Take off and initial landing account for 29% of on-board fatalities while 20% is attributed to final approach and landing. These are higher in comparison to 19% observed during cruise stage.

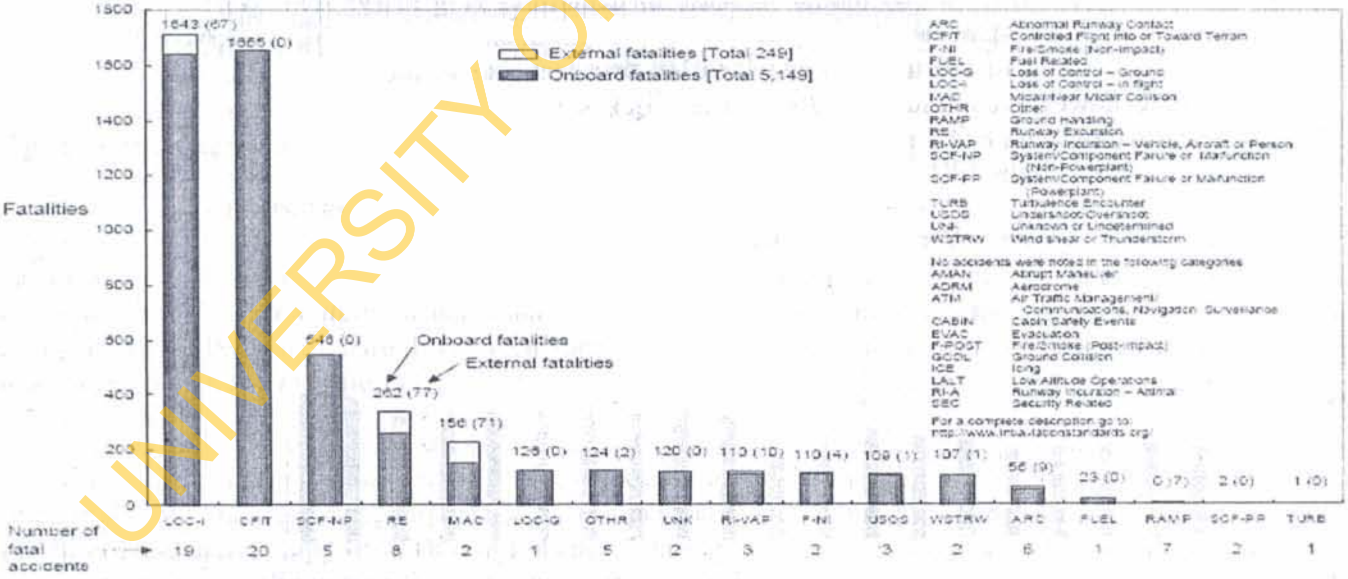

Fig.3: Fatalities by CAST/ICAO Taxonomy Accident Category [9]

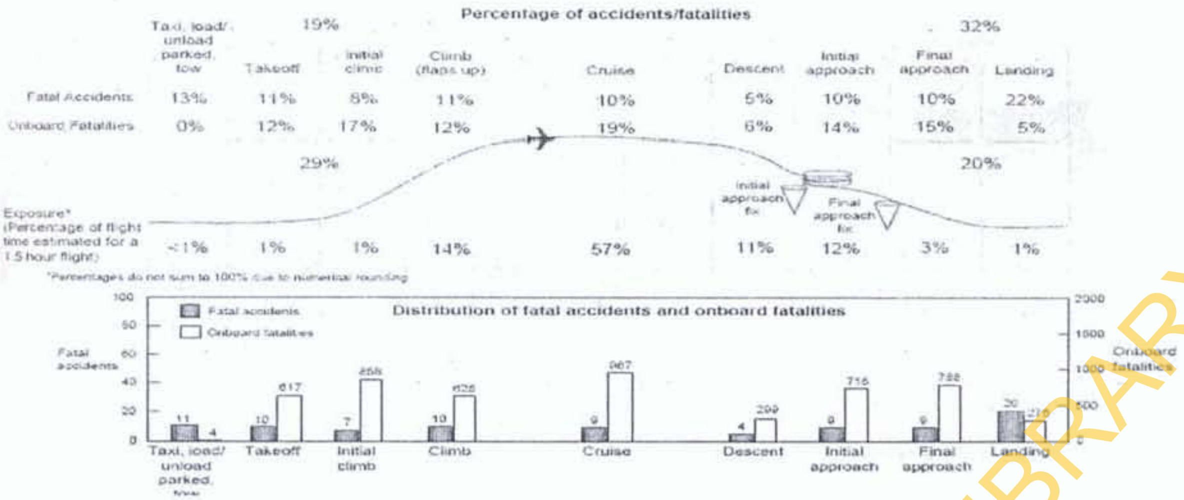

Fig.4: Fata accidents and onboard fatalities by phase of flight [9].

Aircraft disasters, with respect to material failure, may be due to fatigue, sudden impact, hidden defect, corrosion, creep and quick crack propagation. An investigation of failures in aircraft parts and structures indicates that fatigue is responsible for 55% of in-service failures followed by corrosion (16%) [1]. Fatigue often affects the components in power generation / transmission systems which are often subjected to most arduous conditions. Aircraft materials and their properties are hereby discusses for better understanding of what goes on in aircraft industries.

2.0 Materials for aerospace vehicles

Aerospace vehicles operate under severe internal and external conditions. The propulsion units operate at high temperature level while being chemically affected by fuels and propellants before, during and after combustion [7]. The stresses which aerospace vehicles must withstand are very complex, as a direct effect of severe operating conditions and varying environmental characteristics. Failures due to fracture, fatigue and creep have been reported [7, 8]. Basic materials for aerospace vehicles are high- and very-high strength steels, aluminum based light alloys, titanium alloys, nickel, iron-nickel, cobalt-based refractory superalloys, sintered materials, composites and polymers. Under high temperature operations, materials with satisfactory behaviour towards high stresses must be used. Titanium alloys are often used and mostly for aircraft flying above Mach number of 3 while composites may be used for subsonic aircraft due to their lower resistance at high temperature. Laminated materials obtaining by the reinforcement of glass threads with epoxy resins are becoming popular for manufacture of leading edges, doors, panels owing to their satisfactory resistance to corrosion [7]. Domes are now constructed of organic glasses because of their excellent optical performance and satisfactory mechanical properties. Superalloys are used for components operating at high temperature (above 540^{0}C) like casings, pipes, turbo blades, disks. Resistance to corrosion must also be satisfactory as these components are in contact with high-temperature and oxygen-rich combustion gases [7].

In the succeeding sections, aircraft disasters due to the failure of certain components are examined.

3.0 Samples of Material Failure Analyses

3.1 Failure of aircraft propeller

An investigation conducted on the failure of a Cessna-185 aircraft revealed that the disaster was brought about by fracture of its propeller [2]. One of the propeller blades (Fig.5) was broken up during flight. The propeller was made of high strength 2024 aluminum alloy commonly used in aerospace industry.

Fig.5: Broken propeller of the airplane [2].

Analysis of the failed blade revealed several deformed area resulted from impact effect. The crack surface (Fig. 6) was investigated with stereo and scanning electron microscope (SEM) with results shown in Figs 7, 8 & 9. It was eventually concluded that the failure of the aircraft was due to the fracture of its propeller blade where micro-cracks formed on the deformation zone led to stress concentration causing crack propagation and eventual rupture of the propeller [2].

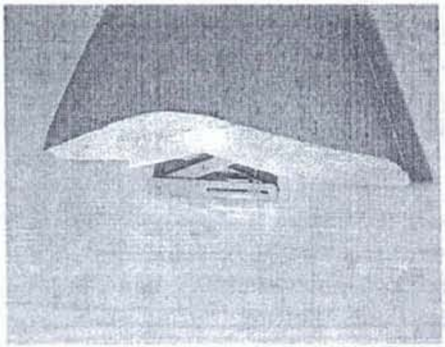

Fig.6: Crack surface of the failed blade [2].

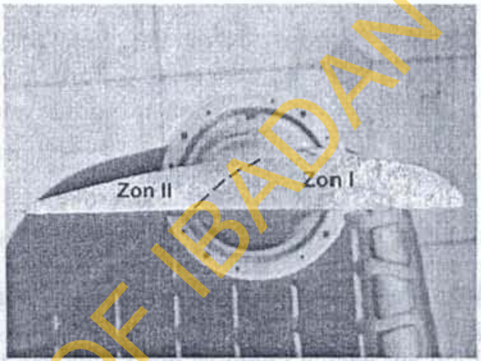

Fig.7: Zones I and II on the crack surface [2].

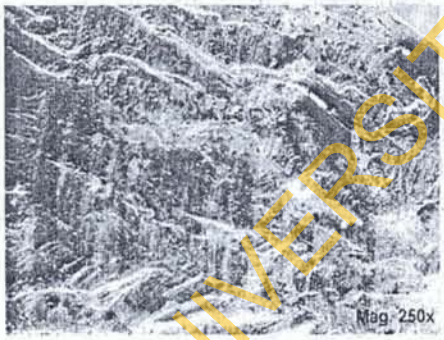

Fig.8: Zone I semi-elliptic striations [2].

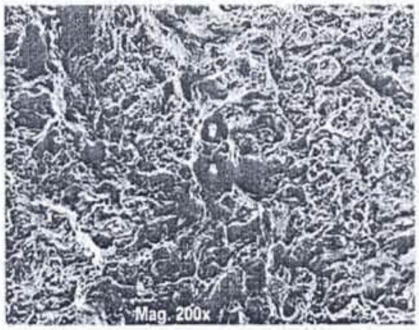

Fig.9: SEM image of zone II [2].

3.2 Failure of aircraft main landing gear

The disaster of Piaggio Avant P180 aircraft was caused by separation of flange fillet from the landing gear wheel during taxing [3]. Fig.10 provides the general view of the failed wheel where A denotes the piece of wheel flange fillet fractured and separated and B is the remainder of the wheel. The wheel is made of forged material made from 2014-T6 aluminum alloy and the history of the aircraft revealed that it has been in service for 22 years [3].

Fractographic examination was performed using LEO Supra 35 field emission scanning electron microscope (FESEM). The topography of fractured surface A and B (as identified) have three distinct regions. Region C is characterized by flat, smooth and bright surface containing beachmark, region D has flat and bright surface alternating between rough and dull ones while region E could be identified by rough, dull with coarse grains (Figs. 11 and 12). Region C indicates a fatigue crack growth while D indicates unstable crack propagation with E indicating a region of final unstable fracture [3].

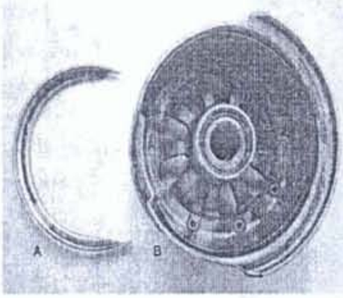

Fig.10: General view of the failed wheel [3].

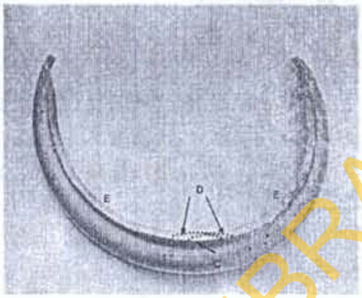

Fig.11: View of the fractured surface of the wheel flange showing regions C, D and E [3].

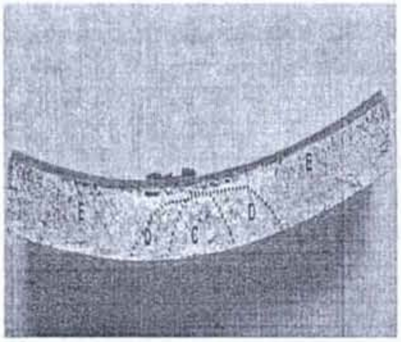

Fig.12: Sectioned fractured surface of the wheel flange.

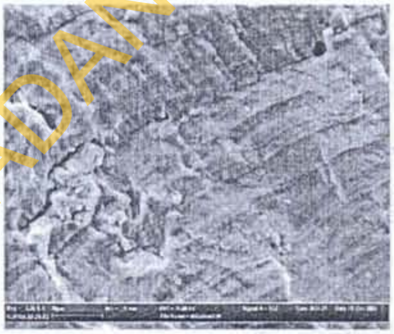

Fig.13: SEM micrograph far from initiation site [3].

Crack initiation was found to be along the inner surface of the flange close to the fillet. Defect resembling corrosion pit were also fund suggesting multiple initiation sites. The spacing of striation (which was found to increase with distance from initiation site) suggested the fact that fatigue crack growth occurred under constant amplitude loading (Fig.13) [3].

Morphological evidence indicated that failure occurs due to the fatigue crack propagation. The crack growth which reached 8mm in length and 5mm in depth before the final disaster. The crack was attributed to corrosion pit as a result of superficial /fretting from tyre bead and tube well [3]. Eliaz et al. [4] carried out a similar analysis on cargo aircraft main landing gear and found that the failure was by stress corrosion cracking mechanism. The cracks initiated around corrosion pit while the corrosion was accelerated by high cathode to anode surface ratio. The eventual fracture occurred as the crack reached a critical size too weak to sustain the load [4].

3.3 Fracture of a wing-fuselage connector

One of the most critical parts of an aircraft is wing-fuselage connector. Aerodynamics, inertial and gravity are transmitted from the wing to the fuselage via the connector. In a research conducted by Witek [5], failure of an agricultural aircraft occurred as a result of undetected fatigue crack growth in the lug of the connector. The failure occurred after 5000 – 6000hours of operation. The connector failure location (Fig 14) shows that the wing lug (which is the main component of connector) was fractured in 2 zones. Visual examination shows that crack initiated in bottom zone of lug (region I) where typical fatigue breach marks are obvious (Fig.15). Plastic bending and rupture of the top lug zone (region II) then followed. The curvature of the beachmarks shows that crack growth had taken place from zone A (Fig. 16(b)) and accelerated by corrosion [5].

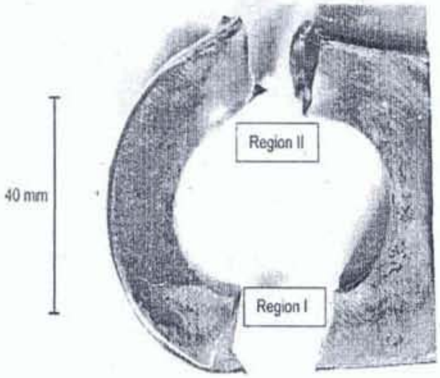

Fig.15: View of the lower wing lug after damage [5].

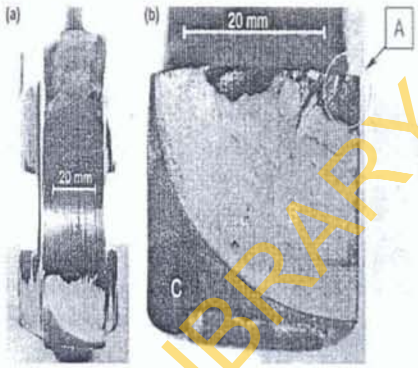

Fig. 16 (a) Cracked lug surfaces and (b) magnified view of lower fracture surface [5].

Finite element analysis of the connector model confirmed that von Misses stress distribution is maximum at the left-top part of the hole (Fig.17) which is the same with analyzed point of failure [5].

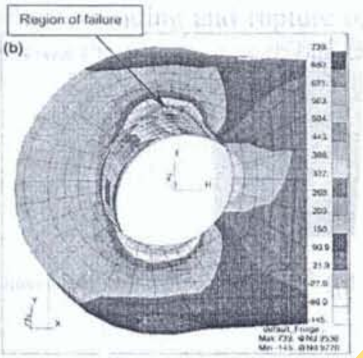

Fig.17: Von Misses stress distribution in the lug [5].

3.4 Other material related failures

Aircraft failure can also be attributed to errors at various stages in aircraft life viz, design, manufacturing, assembly, inspection, operation and maintenance [8]. Failure of Tail Gear Box of helicopter was related to poor design of the gear box lug. The poor design eventually led to premature crack initiation and failure.

Defects introduce during manufacturing stage can produce serious weakening effects on the affected components. Crack can be nucleated and eventually led to failure. Example is a failure of compressor rotor of an aircraft that was due to improper contact between the rivets and rivet holes joining the components of the rotor drum together [8].

Assembly / inspection error can be as a result of inaccurate, incomplete or ambiguous assembly specification or in some cases as a consequence of human error or negligence. Such errors are often not detected during inspection. Failure of actuator bracket assembly of an aircraft was attributed to negligence of fasteners. Critical examination of the failure mode revealed that the fasteners holding one side of the plate in position within the actuator were not fixed in place. This led to excessive load on the other side of the plate leading to fatigue-crack initiation and its progressive propagation [1]. Failure of a high-pressure turbine rotor disc of an aircraft is also similar. Investigation shows that the detachment of the labyrinth ring from the disc was the first in the chain of events that cumulated into the aircraft accident. Analysis revealed that the axial movement of the labyrinth ring resulted in deformation of the pins at the ring/disc interface leading to fatigue failure and eventual fracture [8]. Improper maintenance is also a causative agent in aircraft failure. Example is the failure of wheel hub of an aircraft. Accident occurred as a result of premature failure of the hub due to fatigue, which was found to be originated from stress corrosion sites resulting from corrosion [8].

Conclusion

Indeed, majority of failures in aircraft do not just happened, they are caused. They may happen due to introduction of defects, which are often inadvertent, at various stages of service life of aircraft components. Fatigue is however known to cause very high percentage of failure with reference to materials. Failures in aircraft are often fatal leading to loss of life, damages of aircraft or even complete loss. Forensic engineering now becomes a sine-qua-non for proper investigation of in-service failure with a view to arresting its causative agents. Good design, proper manufacturing, right assembly, complete inspection and routine maintenance will go a long way in reducing aircraft accidents.

REFERENCES

[1] Findly, S.J. and Harrison, N.D. (2002). "Why aircraft fails?" Material Today. 11:18 – 25.

[2] Kushan, M.C. Diltemiz, S.F. and Sackesen, I. (2007). "Failure analysis of an aircraft propeller". Engineering Failure Analysis. 14: 1693 – 1700.

[3] Bagnoli, F. and Bernabei, M. (2007). "Fatigue analysis of a P180 aircraft main landing gear". Engineering Failure Analysis. doi: 10.1016/ j.engfailanal.2007.10.003.

[4] Eliaz, N., Sheinkopf, H. Shemesh, G., Artzi. H. (2005). "Cracking in cargo aircraft main landing gear truck beams due to abusive grinding following chromium plating". Engineering Failure Analysis. 12: 337 – 347.

[5] Witek, L. 2006. Failure analysis of wing-fuselage connector of an agricultural aircraft. Engineering Failure Analysis. 13: 572 – 581.

[6] Lourence, N.J., VonDollinger, C.F.A., Ciraca, M.L.A. deCampos, P.P. (2005). "Failure analysis of the main rotor grip of a civil helicopter". Engineering Failure Analysis. 12: 43 –47.

[7] Nica, A. (1978). "Mechanics of Aerospace Materials". Elsevier, Amsterdam.

[8] Bhaumik, S.K., Sujata, M. and Venkataswamy, M.A. (2007). "Fatigue failure of aircraft components". Engineering Failure Analysis. doi: 10.1016/ j.engfailanal.2007.10.001.

[9] www.boeing.com. Retrieved on December 21, 2007.

[10] www.intlaviationstandards.org. Retrieved on December 21, 2007.

[11] www.planecrash.com. Retrieved on January 5, 2008.

[12] www.101crash.com. Retrieved on January 10, 2008.

[13] http://www.nuc.berkeley.edu. Retrieved on December 15, 2007.