COMBINATION OF CORROSION AND FATIGUE IN AIRCRAFT COMPONENTS

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The service failures in aging aircraft components due to corrosion and fatigue will be discussed using actual case histories. Of prime importance for avoidance or minimizing such failures is to establish the dominating mode of failure mechanism. This can be achieved through careful failure analysis involving different techniques such as metallography, fractography or microanalytical investigations.

INTRODUCTION

The average age of the world's fleet of commercial jet aircraft has risen steadily in the past decades and numerous airplanes now stand at 20 years (Fig. 1). Many accidents are attributable to the ravages of a lifetime of wear and tear and not to a mishap. This is the case even though operators are ordering new aircraft faster than manufacturers can build them, it is clear that aircrafts age will continue to rise, and that operators will continue to push their planes past the forseen operating age and amount of use that they were designed to withstand. Although the oldest planes often involve the greatest risk, chronological age alone is not the only criterion for a planes condition. The planes environment is also an importan factor. If planes are based near sea water, corrosion is more likely. Besides the age and use the quality and quantity of maintenance

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enormously influences the vulnerability to failure.
According to the experience in failure analysis in our institute, most of the aircrafts failures are caused by corrosion and fatigue. These factors can occur in different modes and combinations. Different types of corrosion shown up in different ways - such as cracks due to SCC, corrosion pitting, bubble in paint or flaking off the paint. Corrosion can also indirectly initiate or accelerate fatigue cracks.
The following case histories provide classic examples of aging aircrafts which failed due to corrosion combined with fatigue.

BROKEN HINGE BRACKET IN HORIZONTAL STABILIZER

A particular problem which has already caused some incidents, was investigated in the emergency landed aircraft. This aircraft was a twin-engined turbopropeller, six seats, low-wing with retractable landing gear. This plane was manufactured in 1970 and had 6000 flight hours when it went out of control during climbing after take-off for a cross-country flight. The failure occured suddenly and was accompanied by a loud report.
Inspection after the emergency landing revealed failure of the two outer elevator hinge brackets attaching the elevators to the horizontal stabilizers. The wall thickness of the broken angular profile, which is made of wrought Al-Alloy 2024, was approx. 0,8 mm. Both the hinge components and the elevator skin are covered with several layers of paint, which have peeled to a certain extent, above all in the vicinity of the rivet heads and fracture zones. The fractures are situated mainly in the rectangular corners of the hinge bracket (Fig. 1). With exception of one rivet, no rivet is missing from either hinges. In fact in some parts of the metal skin, intact rivets can still be seen which have only separated from the skin due to tearing out of a rivet hole. Traces of intensive corrosion and multiple cracks were revealed in several rivet holes in various sections of the skin (Fig. 2). Although all fractures were examined under the SEM, the fractographical findings were limited to sporadically intact fracture zones, because of heavy secondary damage due to the abrasion. Nevertheless it was established conclusively that incipient cracking in holes is partially intercrystalline. Clear indications of fatigue in the form of fatigue striations, were discovered in the rectangular longitudinal hinge edges. Moreover, these areas also exhibit zones with partially intercrystalline fracture

characteristics mixed with void structures. This type of fracture characteristic indicates corrosion effects at the crack initiation and during crack propagation. These findings could be confirmed by the subsequent metallographical examination. All the cracks discovered in the vicinity of the holes are slightly branched and partially intercrystalline, which is characteristic of corrosion cracking (Fig. 3). They originated under the rivet heads, where the Alclad layer is damaged. In order to determine whether aggressive media had any effect on crack formation and propagation, the bare surface of the hinge and the end of some cracks were thoroughly examined by the electron probe microanalysis. Chlorine enrichment up to several percent was detected.

It must thus be assumed that the corrosion occurring in the rivet holes was significant, at least indirectly, to the initiation of fatigue failure. The relatively high mechanical loading of the hinge brackets would also favour loosening of the rivets and the initiation of fatigue. Metallographical examination of the rivet holes showed that these holes were seriously damaged by corrosion pitting and stress corrosion cracking. Peeled-off paint over the rivets as well as abradded Alclad layer under the rivet heads allowed the corrosion to start. The role of the internal stresses caused by tightening the rivets may also be considered, but was not investigated.

CRACKS IN GAS-TURBINE DIFFUSOR

This part stems from a gas-turbine of a jet engine which suffered a total power loss during a cross-country flight. The operator heard a dull "thump" as he tried (unsuccessfully) to restart the engine. Thus the aircraft flew gliding for 40 km and finally had to make an emergency landing. Taking into account the function and damage of each part of the turbine, the aircraft user suspected the main cause of failure to be the fracture of the bearing sitting on the compression shaft or the fractures within the diffusor (Fig. 4).

In this paper only the second possibility (damage in the diffusor) will be discussed. The high quantity of cracks can be divided into two groups, according to their location: 1. Cracks near to the welding seams and 2. Cracks in the bended areas.

Some cracks at different places were opened and investigated fractographically. The typical appearance of one free crack is shown in Fig. 5. The jagged edges of the cracks, together with the dark deposits on the surface, indicate older corrosion cracks, which started on the inner surfaces. The beach marks form half ellipses, with an origin at the dark corrosion cracks, exhibit evidence of fatigue.

The metallographical cross-sections revealed extensive damage due to SCC. As the micrograph Fig. 6 shows, the cracks are transgranular and branched. The martensite microstructure shows many finely dispersed carbides. The hardness is 330 ... 340 HV.

Although the diffusor revealed a high number of fatigue cracks initiated on multiple SCC sites, this damage was very probably not the main cause of the turbine failure. It could be shown that the rubbing of the blades on the peripheral ring already occurred at the service temperature. If the diffusor had been deformed due to a displacement of the cracks, than an increase of the axial play of the transmission shaft would have taken place. This would necessarily have caused a rubbing of the leading edges of the air turbine blades with the stator. However, no damage of this kind was observed on the stator blades.

CONCLUSIONS

Both case histories presented illustrate a well-known phenomenon of multiple-site damage in older airplanes. Corrosion and fatigue, the main dangers to an aircraft as it ages, tend to begin in a few, sometimes unexpected areas. These are often discovered by failure analysis of failed parts. The results of failure analysis are valuable not only for the designer - the manufacturing was already optimized over the years - but also for the user and institutions for working out safety maintenance and inspection programs.

Industry research establishment admit that progress is being made in advanced testing technologies, including different NDT like thermal imaging, CAT scanners, acoustic emission, laser interferometry and ultrasound testing. Nevertheless, a great part of the responsibility is beared by the National Transportation Safety Autorities which must assign the critical testing for the operating safety of the planes.

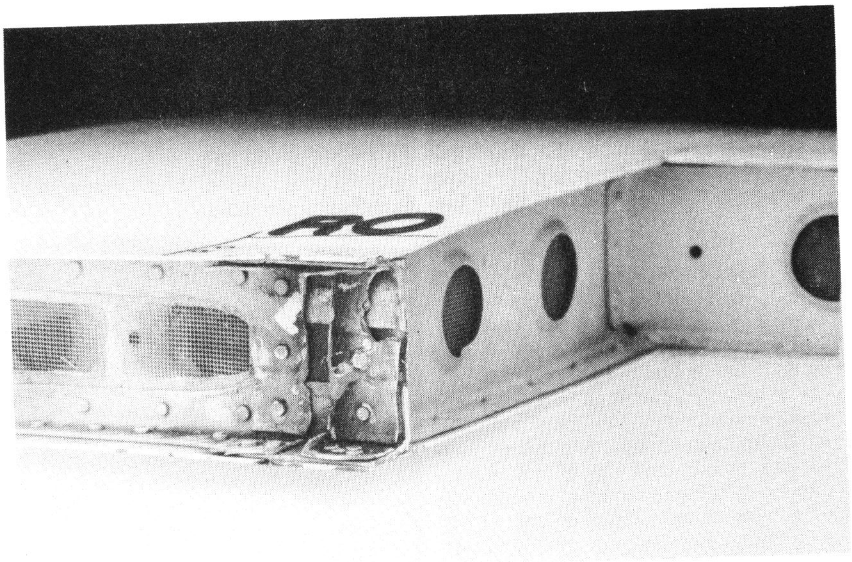

Fig 1 View of fractured outer hinge bracket

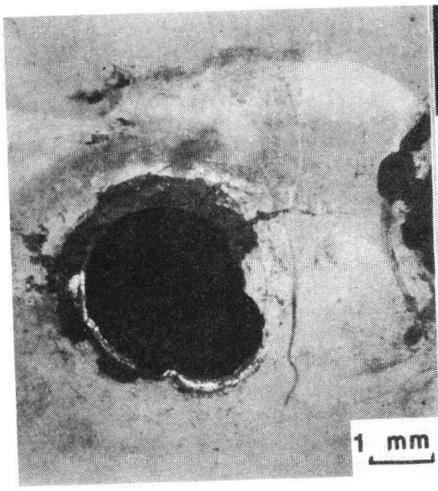

Fig 2 Corrosion underneath rivet heads

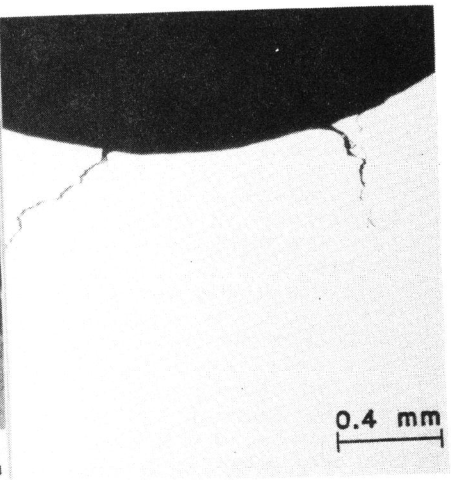

Fig 3 Microsection through rivet hole.

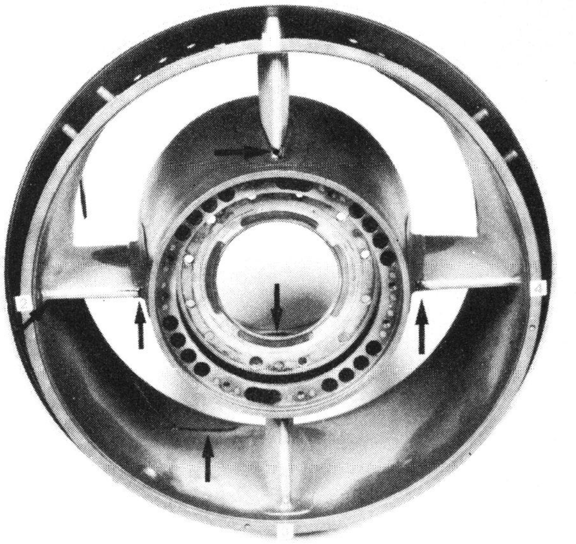

Fig 4 Gas-turbine diffusor with cracks (arrows)

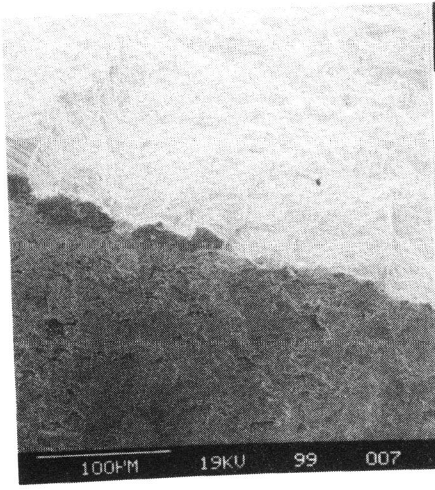

Fig 5 Free crack with jagged edge due to corrosion

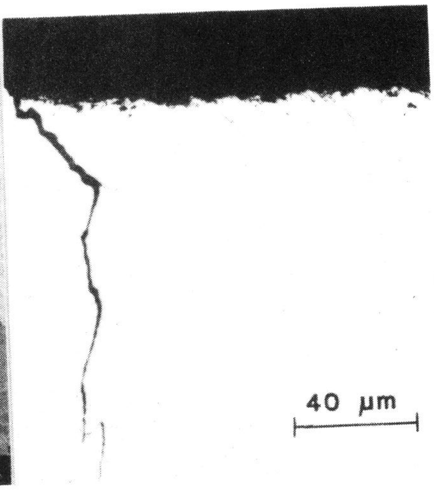

Fig 6 Transcrystalline, branched cracks