Corrosion of Aircrafts - A Case Study in Mauritius

Kunal Boodhun, and B.Y.R. Surnam

***Abstract*—**Corrosion is actually one of the main problems in aircrafts. In Mauritius, the international airport at Plaisance is situated at 250m from the shoreline and has a relative humidity level frequently above 85%. These factors would inevitably increase the amount of corrosion in aircrafts.

This study was therefore performed to investigate the types of corrosion encountered and the cost of corrosion in one of the aircrafts of the Mauritian national fleet. The aircraft chosen was delivered in 1994. The required data were collected from three complete maintenance checks performed after 11393, 39465 and 63282 flying hours. Aluminium alloy 7075, which is used on the aircraft fuselage, was immersed in sea water to investigate its effect on the metal.

Various types of corrosion attacks were observed in various parts of the aircraft during the maintenance checks considered. During immersion in sea water, the aluminium 7075 sample suffered from serious pitting corrosion. Finally, the cost of corrosion peaked up to $217900 in the maintenance task performed after 39465 flying hours, indicating that better corrosion control is an important factor in decreasing maintenance costs.

***Keywords*—A**ircraft, atmospheric corrosion, galvanic corrosion, pitting, crevice corrosion, exfoliation, corrosion cost.

I. Introduction

MAURITIUS is a small tropical island of 1865 km^2 situated in the Indian Ocean. The corrosivity of its atmosphere, obtained through outdoor exposures of carbon steel, has been found to be in the range C3 to C4 according to ISO 9223 [1]. This shows that the Mauritian environment has moderate to severe corrosivity.

The airport, at Plaisance, is found within 250 m from the shoreline. It is found in the windward direction and relative humidity is frequently above 85%. Hence, it is expected that the corrosion rate at the airport, especially for sheltered areas, to be in the higher range of the expected corrosivity category. The atmosphere at Plaisance would therefore be corrosive which would adversely affect aircrafts flying to or from Mauritius. In addition, the aircrafts are normally bound to spend several hours or even days in the airport and this aggravates the situation even more with the expected deposition of airborne salinity on the aircraft body. Moreover, there are many aircrafts which are being used beyond their 20-year design life. The old aircrafts are even more prone to corrosion problems.

Corrosion, in general, has been found to be the second most important factor contributing to failures in aircrafts' components or structure, with fatigue being the most consequent one [2]. Corrosion occurrence is, in fact, omnipresent as well as unavoidable threat to the airworthiness and safety of airplanes. Apart from the external environmental conditions, it can be caused by trapped moisture which may enter the aircraft through rainstorm or may result due to rapid fluctuations of temperature, especially in tropical climates [3]. It may be caused by chemicals carried by the aircrafts. Uric acid near toilets can also damage metals rapidly [3]. Uniform corrosion, pitting, crevice corrosion, hydrogen embrittlement, galvanic corrosion, exfoliation corrosion and stress corrosion are, as a result, some of the corrosion modes commonly observed in aircrafts [2]. Erosion can also be caused by items such as stones and sand striking the blades of the engine during operation [3].

The corrosion problems encountered, due to a number of reasons, are often complex and interacting and they threaten the integrity of the aircraft [4]. They can affect the load carrying capability of the aircraft structure by reducing the cross sectional area of the structure and, also, increase the probability of crack formation [4]. To decrease the impact of corrosion problems on the aircraft, maintenance tasks take into consideration corrosion related checks. The corrosion cost, as a result, comprises of 10% of the total maintenance cost of the aircraft [4].

Taking into consideration the severe outdoor environmental conditions at Plaisance, a study was therefore performed so as to get a better insight into the corrosion problems encountered by the aircrafts of the Mauritian national airline fleet. Corrosion problems on one of its aircraft was considered as a case study and analysed. This is a first study which is expected to help the company in better organising its maintenance work and improve in the detection and repair of the corrosion related problems.

II. Methodology

In this study, one of the Mauritian national fleet's oldest, long-range four-engine commercial passenger jet airliner was used as a case study to determine the corrosion degradation

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effects of the outdoor and indoor environment affecting the aircraft.

The aircraft was delivered in 1994 and all the corrosion problems detected during the scheduled checks were collected and analysed. The parameters considered were: the type of corrosion, the number of man hours involved in repair, the component which had sustained damage, the materials used during inhibition or repair and the cost of man hours and materials involved. The information was obtained from checks performed on the aircraft.

For the purpose of this study, the results of three complete maintenance checks on the aircraft were considered for investigation, namely two C checks and one IL (intermediate layover) check. The first C check considered was performed after 11 393 flying hours in 1997 (1C Check) and the second one was performed after 39 465 flying hours in 2004 (8C Check). The IL check considered was performed after 63 282 flying hours in 2010 (IL2 Check).

In order to get an insight into the effect of the nearness of the shoreline to the airport and the effect of the sea and hence, the airborne salinity, on the aircraft fuselage, an aluminum sheet sample of type 7075 and of size 100mm x 100mm was immersed in sea water up to 120 days and the pits formed on the metal surface were measured through micrometry using a metallurgical microscope.

The cost of corrosion in the aircraft was also determined and analyzed. Labor hours involved and cost of components repaired and replaced were taken into consideration.

III. Results and Discussion

A. 1C Check (C Check after 11393 flying hours, in 1997)

For the first major check, after 11393 flying hours, seven corrosion related tasks were performed. Three were preventive measures and the others were corrective ones. Fretting, atmospheric and galvanic corrosion were observed.

Fretting corrosion was observed at the wingtip/winglet joint pins on the right hand wing. The cadmium plated pins were replaced by chromium plated pins. Galvanic corrosion was observed on the main landing gear. However, the corrosion was superficial and the corroded region was cleaned. Atmospheric corrosion was observed on the electrical connectors for radio altimeter transceivers leading to a reduced reliability of these instruments.

B. 8C Check (C Check after 39465 flying hours, in 2004)

Fig. 1 shows the corrosion problems encountered during this check.

Galvanic corrosion was the most commonly observed modes of corrosion. Exfoliation corrosion was mostly noted at locations where aluminium alloys were used, with surface delamination as the most common visible damage indication. Fig. 2 shows an example of a seriously damaged part in a wing flap through exfoliation and which required replacement.

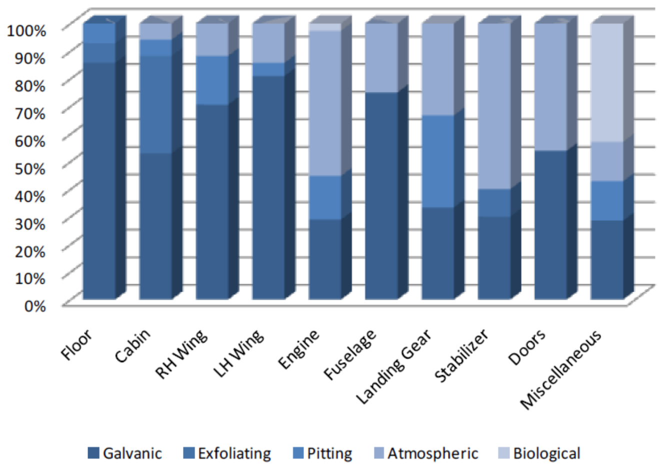

Fig. 1 Corrosion problems encountered during 8C Check


Fig. 2 Badly affected wing flap which resulted in the replacement of the part.

In addition to superficial atmospheric corrosion which could be seen at several spots, the fuselage of the airplane was also affected by galvanic corrosion, mostly around rivets and fasteners as shown in Fig. 3.

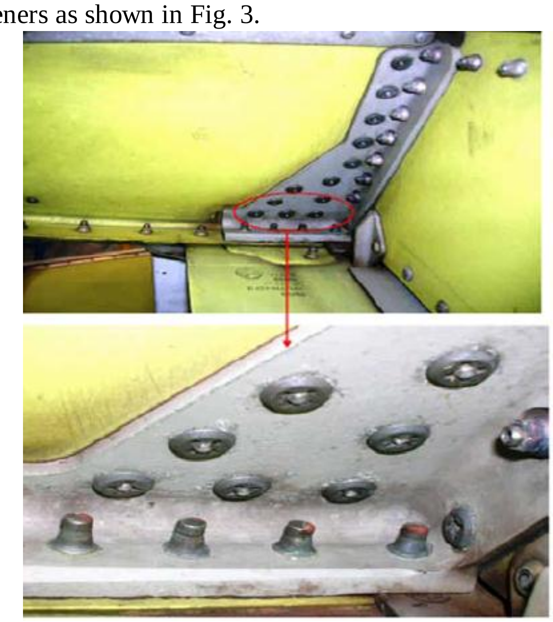
Fig. 3 Galvanic corrosion around rivets in the engine area

Both the left and right wings showed presence of three types of corrosion, namely galvanic, exfoliating and atmospheric, with galvanic corrosion as the most common one. Exfoliation corrosion was observed on the fuselage as shown in Fig. 4.

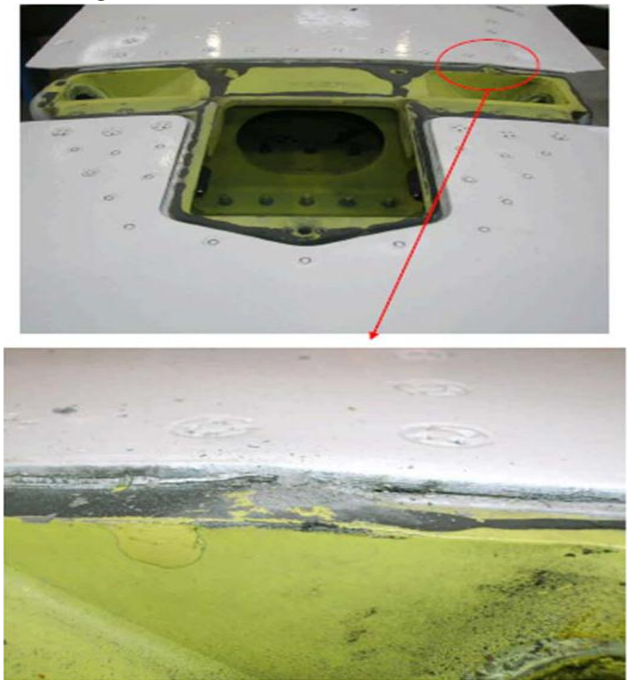

Fig. 4 Exfoliating corrosion on the fuselage

The delamination could be observed on the edge of the aircraft panel. If immediate repair was not undertaken, the corrosion would have propagated, resulting in extensive damage.

Atmospheric corrosion was observed in several parts. Fig. 5 shows the effect of atmospheric corrosion in the lower wing region. Constant exposure to rainwater, moisture, high humidity and sea breeze were, most probably, some of the factors that contributed to cause corrosion in this area. Although the situation may seem alarming at first sight, the damage caused was mostly superficial rusting and well within allowable limits to ensure the aircraft airworthiness.

Fig. 5 Atmospheric corrosion on lower wing

C. IL2 Check (IL Check after 63 282 hours, in 2010)

During the 2010 inspection, a significant number of cases involving galvanic corrosion were noted while atmospheric corrosion was the least common. Figure 6 shows the different types of corrosion observed in the airplane during the IL2 Check. The landing gear suffered essentially from galvanic and pitting corrosion whereas the engines were subjected to galvanic, pitting and atmospheric attacks. Fig. 7 shows pitting corrosion observed on the engine.

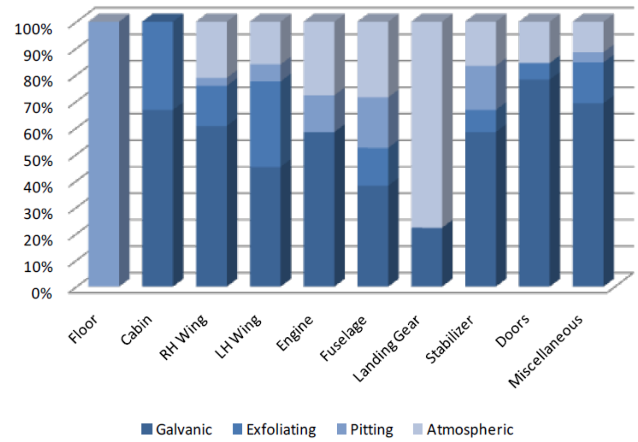

Fig. 6 Types of corrosion observed during the IL2 Check

Fig. 7 Pitting corrosion on the engine

The presence of very high temperatures and exhaust residues could be the prime causes for corrosion development on the engine. Although these pits were difficult to detect, their presence could have yielded in serious consequences over a long time period.

There were large number of issues concerning the cabin which involved replacement of screws, nuts and fittings damaged by galvanic corrosion. Fig. 8 shows the occurrence of this type of corrosion on seat frames which were subjected to exfoliating corrosion.

Fig. 8 Exfoliating corrosion at the base of a cabin attendant seat

Pitting corrosion was also detected on the floor structure of the aircraft.

Figures 9 and 10 summarise the corrosion issues encountered in during the 2004 and 2010 inspections.

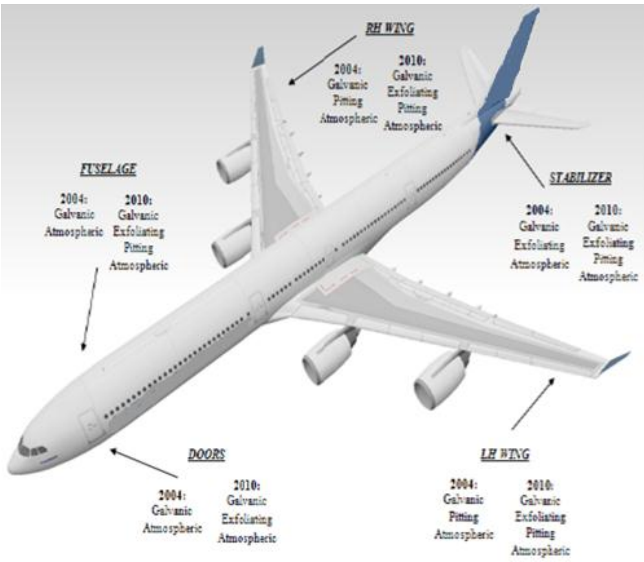

Fig. 9 Representative 3D image of the lower fuselage and the location of the types of corrosion modes observed in 2004 and 2010 inspections

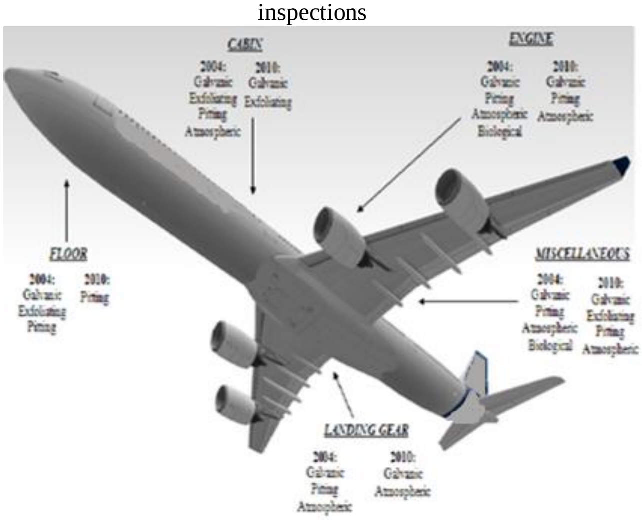

Fig. 10 Representative 3D image of the lower fuselage and the location of the types of corrosion modes observed in 2004 and 2010 Inspections

D. Cost of corrosion

For each of the three checks, the cost of corrosion was determined. For the 1C Check it was observed that 25% of the corrosion cost went to the labour cost and 75% of the cost went to replacement or reparation of the corroded materials. Figures 11 and 12 show the corrosion cost associated with the different aircraft parts for the inspections of 2004 (8C Check) and 2010 (IL2 Check) respectively.

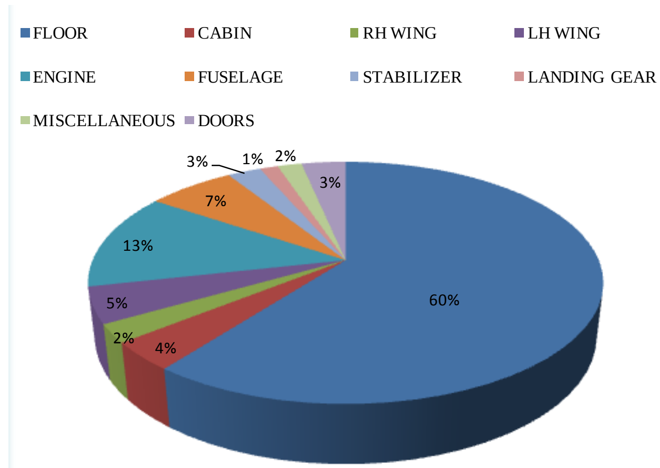

Fig. 11 Cost of corrosion for 8C Checks

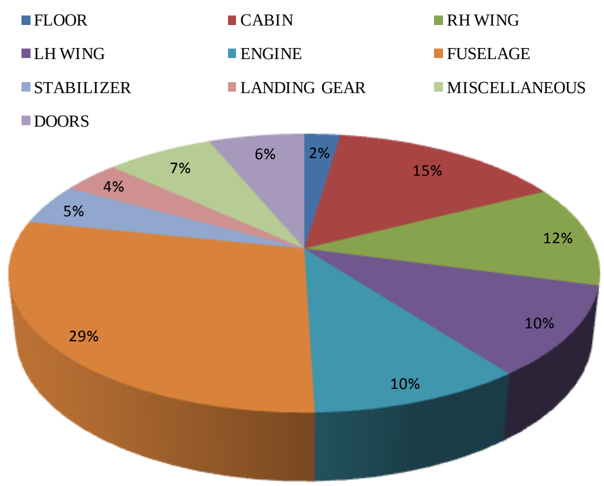

Fig. 12 Cost of corrosion for IL2 Check

For the 2004 check, the largest cost was associated to the floor zone due to the large number of corroded beams which had to be replaced. On the other hand the landing gear required the smallest part of the budget.

The cost of man hours for this maintenance check made up for around 40.1 % of the total cost.

As for the 2010 check, the largest sum of money was spent on the fuselage while the floor was allocated the smallest part of the corrosion budget. The cost of labour accounted for about 52.9 % of the corrosion-related budget in 2010. The small budget for the floor section is logically due to the thorough maintenance on this section in the 2004 check. The corrosive environment in Plaisance and in other airports would logically have an effect on the fuselage and on the other exposed parts and this shows out in Fig. 12.

Taking into consideration of the inflation rate, the present value of the maintenance costs were calculated. The results are shown in Table 1.

TABLE I
MAINTENANCE COST FOR THE THREE MAINTENANCE CHECKS CONSIDERED

Year of maintenance check	*Cost ($)*
1997	32, 200
2004	217,900
2010	87,500

The main reason for a decrease in the corrosion cost in 2010 is due to the fact that much work had already been performed on the flooring in 2004 and this decreased considerably the related cost in 2010. The cost of corrosion had increased considerably during the 2004 maintenance check due to flooring. This shows that there is a need for better corrosion prevention for eliminating these types of costs.

However, nowadays, more appropriate materials are being developed to decrease these types of costs. The use of composites in aircraft structures is the undeniable trend. Composites enable reductions in weight, extends operating life cycle and reduces repair and maintenance costs. They account for 16% of the Airbus A380 airframes and more than 50% of the Boeing 787 and Airbus 350 XWB primary structures [5]. Other materials are also increasingly being used, namely metal matrix composites, ceramics and ceramic composites and other light alloys such as aluminium lithium alloys.

E. Immersion of Aluminium 7075 Sheet in Sea Water

Aluminium 7075 sheet was immersed in sea water for 120 days to observe the effects of sea water on the aluminium alloy and hence the corrosive dangers to which the fuselage faces.

Aluminium 7075 is a copper containing high strength alloy with high zinc content. It is commonly used for the upper wing, spars and ribs. However, it resists poorly to exfoliation and stress corrosion [6].

After 60 days of exposure

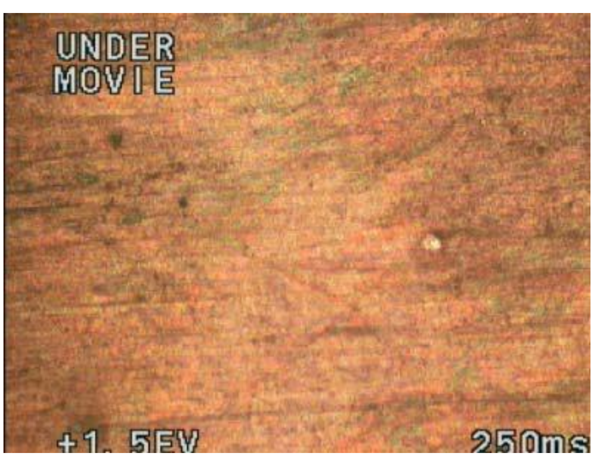

Fig. 13 Aluminium surface after 60 days immersion in sea water.

Pits were formed on the metal surface as shown in Fig. 13.

After 120 days of exposure

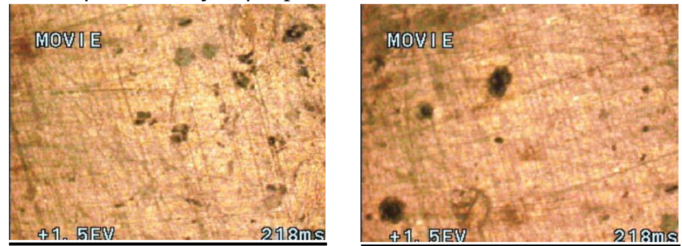

Fig. 14 Aluminium surface after 120 days of exposure in sea water.

Large number of pits appeared on the metal surface and their average diameter was found to be 15 μm, with the maximum diameter being 30 μm. The average depth was found to be 22 μm.

Although the size of the pits was very small and difficult to categorize according to ASTM G 46 [1], it gives a very good insight into the corrosive characteristics of the environment near the airport. Although this is an accelerated test to determine the corrosive effects of the environment at the Plaisance airport, the results show that the effects of airborne salinity and high relative humidity can be detrimental to the aircraft body. Pits can be formed which can lead to serious structural problems in the aircratft body.

Moreover, the presence of water or water vapour on the surface of aluminium converts the aluminium oxide layer into a hydrous form which is often highly porous. The corrosion then proceeds principally at flaws or grain boundaries [7]. At Plaisance, the relative humidity is frequently above 85% and therefore the time of wetness of the metal surface is expected to be very high. Also, the airborne salinity would be higher than in inland regions since the airport is situated only 250m from the coast and is situated in the windward direction. So, there is an increased probability of corrosion damage on the aluminium fuselage of the airplane. Sheltered parts of the aircraft are even more susceptible to corrosion attacks.

IV. CONCLUSIONS

The diverse amount of corrosion problems encountered during the maintenance checks and the cost of corrosion associated with the fuselage and other parts in the 8C and the IL2 Checks show that indeed corrosion is a serious problem in aircrafts. Galvanic corrosion, exfoliation and atmospheric corrosion are very common types of corrosion problems encountered during the checks and these can be eliminated to some extent through better selection of materials, as it is presently being adopted by airplane manufacturers. Frequent cleaning of the aircraft can also lead to a decreased atmospheric corrosion attack.

The cost of corrosion has peaked as high as $ 217,900 in 2004, showing that much can be done to reduce maintenance costs and improve profitability. Better selection of corrosion prevention methods can decrease these costs. It can also be concluded that there is room for better corrosion control. In addition, the corrosive Plaisance atmosphere requires for more preventive measures to make sure that the fuselage and the aircraft structure is safe for use.

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