PLATFORM SUSTAINMENT – LESSONS LEARNT ON AN AGEING AIRCRAFT

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Abstract

As our economic climate changes and our budgets are stretched to the limit, the need to extend the life of ones fleet of aircraft increases. This introduces a number of additional engineering challenges that if ignored, could lead to catastrophic results. This paper will reflect on two issues experienced during the sustainment of an ageing aircraft platform namely:

- *training and*
- *chemical ageing of sealant/compounds-leak detection.*

1 Introduction

Aircraft fleets around the world are typically remaining in service for longer than originally intended. This is because of the enormous cost in platform replacement, especially when the existing one is still capable of fulfilling its intending role. However, as the platform ages, failure rates increase as depicted by the typical bathtub curve in Figure 1.1 with an associated increase in operational and maintenance costs.

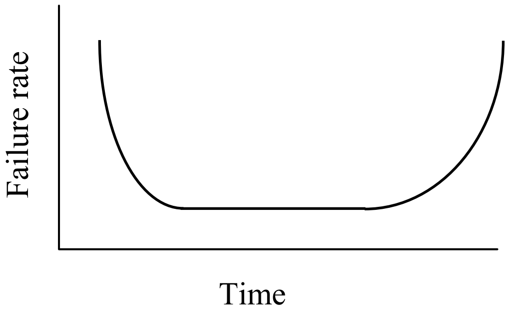


Figure 1.1 Typical Platform Life of Type Curve

The left hand edge of the “bath” represents early failures during development or early service life due to design or production discrepancies. The right hand side represents the wear-out phase where there is an increasing requirement for maintenance.

In order to improve the reliability and therefore the availability and supportability of an ageing platform, improvement programs are initiated under the umbrella of a sustainability plan. A typical sustainability plan would consider key generic systems that contain the highest risk to the safe operation and sustainability of the platform. Typical systems are:

- Oxygen Systems
- Explosive Ordinance (Emergency escape systems.)
- Hydraulic and Pneumatic
- Fuel and Lubrication
- Engine Bleed Air
- Structure
- Environmental Control
- Electrical, Avionics and Wiring
- Mechanical Systems and Components
- Hazardous Substances.

This paper will endeavor to show that ‘training’ as well as ‘sealant integrity or effectiveness’ should be considered as important issues to monitor during platform sustainment.

2 Training

2.1 The problem

Fatigue damage to structural, mechanical and electrical components are but a few mechanisms that drive failure rates up as an aircraft ages. These components are usually designed to a specification and the final product is expected to function, without deterioration, for a fixed period of time or design life. ‘Design life’ is usually fixed as a function of the item’s operational environment and operational requirements. Some components have no service life limit or are not shelf life limited at the time of manufacture.

So when an increased failure rate of a component on an ageing platform is experienced, the first and most common assumption is that the failure is due to ageing of the component. When maintaining an ageing platform, this assumption is correct in many instances but failure can also be totally unrelated to the ageing of the platform. To illustrate this we will consider an increase in mechanical failure of a military aircraft main wheel brake assembly. See Figure 2.1.1.

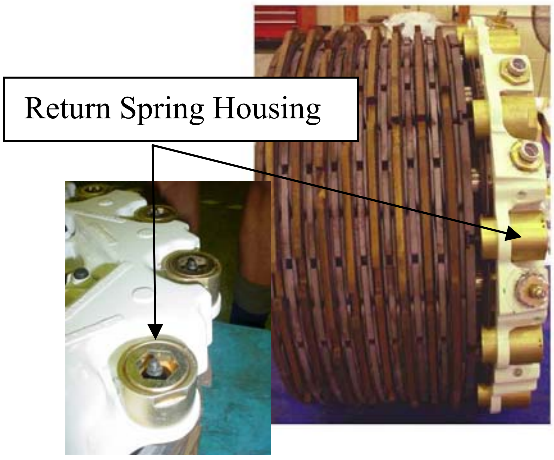


Figure 2.1.1 Main Wheel Brake Assembly

In 2006, two serious brake assembly failures occurred resulting in the associated main wheel deflating during the landing process. In 2007, six related failures occurred within eight months. This dictated an in-depth investigation into all brake system components from the cockpit through to the rubber compound of the main wheel tyres. Investigations into brake system design certification, any maintenance practice issues, aeronautical product conformance and operational practice issues were also investigated.

As a result it was found that prior to 2006 a modification to the main wheel brake assembly was carried out to alleviate similar occurrences, but to no avail. Investigations were coming to a head to the extent that the operational crew was being questioned as to what brake pedal effort was being applied.

While conversing with the maintenance crew regarding the operation of twelve return spring assemblies (See Figure 2.1.1) on the brake unit, it was found that the maintenance crew were not fully conversant with the operation of a grip and tube assembly in the twelve return spring housings.

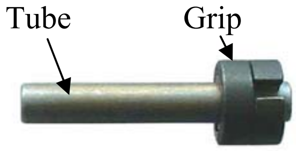


Figure 2.1.2 Grip and Tube Assembly

The grip is an interference fit with its tube. The grip is designed to only move along the tube, during the application of brake pressure, as the brake discs wear in the brake assembly to maintain constant brake pedal travel in the cockpit. With brake pedals released, there remains a residual 100 psi hydraulic pressure behind the twelve hydraulic pistons. This residual pressure removes any play in the brake system between the first pressure plate and the pistons but is not high enough to apply brake pressure. What acts against the 100 psi pressure force is the interference fit between grip and tube.

Degradation of this interference fit resulted in residual hydraulic pressure of 100 psi applying mild braking force on the wheels during taxing. This braking force was not felt during take-off but would generate enough heat to bind the brakes once the undercarriage was folded away and out of the cooling air stream.

Because the grip and tube assembly is downstream of the anti skid circuit, the anti skid system could not control the resultant wheel lockup and thus deflation on landing. Although maintenance publications dictate replacement of grip and tubes when the grip has travelled down the full length of the tube, maintenance personnel have become complacent through re-positioning the grip on the tube for re-use. Figure 2.1.3 illustrates why this practice would have gone unnoticed for many years until degradation of the interference fit, through re-use of the grip and tubes, would result in failure of a brake assembly.

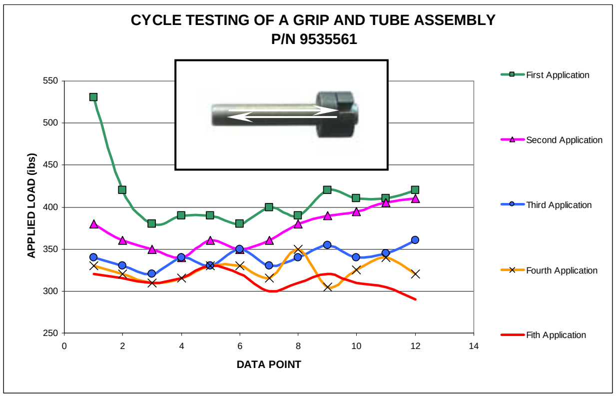


Figure 2.1.3 Grip and Tube Recycling Test

The 100 psi residual pressure would overcome the grip and tube interference fit when the applied force to move the grip fell below 300 lbs. (After the fifth application of the same grip and tube as illustrated in Figure 2.1.3.) A compounding factor is that the **form** and **fit** of a "used" grip and tube is identical to that of a "new" grip and tube. In addition, the **functionality** of a "used" item is not far removed from that of a "new" item where a new item can only be verified through certified testing.

2.2 The Solution

Appropriate training could have avoided the increase in failure rate. Training programs generally provide operational, removal, installation, inspection and system testing of various platform components, assemblies and sub-assemblies. Primary components, with respect to technical airworthiness and system safety should enjoy a more in-depth training regime that should include a fault tree analysis and failure mode identification as a test to confirm the maintainer has the required depth of knowledge to ensure airworthiness of the platform.

One can explain the working principles of the associated grip and tube in the brake assembly to the student, (the concept of interference fits is as well known as locking wire or a split pin) but nothing has triggered the student to think about the consequences of all its failure modes. This two-way approach should be mandatory for primary components.

3 Chemical ageing of sealant

3.1 The problem – Sealant reversion

Sealants of various types and manufacture are used extensively within the aerospace industry to form a gas/liquid tight seal between two surfaces. Leak testing is carried out at prescribed intervals to ensure/repair the integrity of the sealant interface. However, through ageing, one encounters sealant reversion, a term used when the cured sealant "reverts" to its uncured or original state.

Figure 3.1.1 Example of PR 1750 sealant reversion

In extreme cases, reverted sealant can flow from joints under the influence of pressure and gravity such as in the crew module of an ageing platform. Figure 3.1.2 depicts crew module pressurization leak rates registered in 2005 against a fleet of aircraft with all aircraft having excessive leak rates above the maximum allowable as a result of sealant reversion.

Three aircraft tail numbers were considered in a data collection exercise to determine if the cabin pressurisation leak rates have been increasing over time through the recording of Carried Forward Unserviceability (CFU). See Figure 3.1.3.

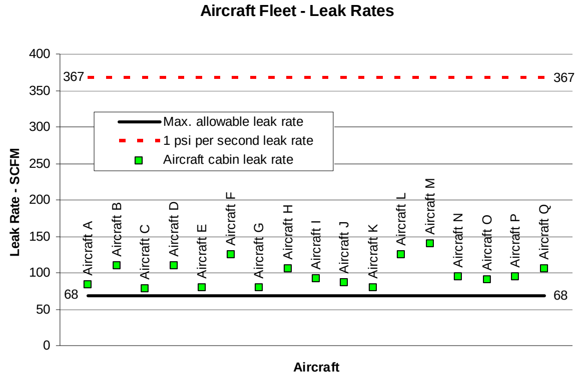


Figure 3.1.2 Snap Shot (2005) of Fleet Leak Rates

The leak rates given against the CFU's indicate increasing values over time. The CFU typically being terminated through the statement:

- Leak rate will not affect airworthiness or operational capability.
- Difficult to determine location of leaks without incurring significant costs and down time.

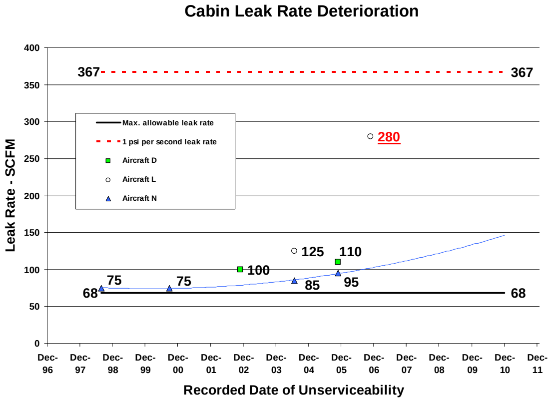


Figure 3.1.3 Leak Rate Deterioration

Typically, a high altitude military aircraft has a cabin pressurisation leak rate range between 38 standard cubic feet per minute (scfm) production leak rate and a maximum 68 scfm in-service leak rate. Figure 3.1.3 illustrates a range from 75 scfm to as high as 280 scfm. The 'worst case' condition.

The CFU therefore has never been rectified and the reasons have been carried over to later CFU's without considering the impact of the increasing cabin pressurisation leak rates. The consequences of having excessive cabin leak rates on airworthiness are:

1. In the event of a high altitude oxygen supply system failure, the effects of hypoxia could result in the loss of the aircraft.
2. In the event of a loss of pressure source, less time will be available for descent to a safe altitude. The rate of pressure loss will be greater with higher leak rates
3. By allowing cabin leak rates to increase, the airflow through the pressure-regulating valve is reduced and therefore the effectiveness of the pressure regulator to control cabin pressure is also reduced.
4. A cabin pressure-regulating valve is generally designed to fail in the closed position to retain cabin pressure. The effectiveness of this safety feature is reduced with increasing cabin leak rates.
5. Reduced mass flow to secondary circuits such as avionics cooling.

One of the causes for the increasing trend in leak rates is the inability to determine the location of possible leaks. Because of the structure of the crew module, certain areas have not enjoyed sufficient re-sealing as a result of the difficulty in identifying areas of leakage

One could predict, following the trends illustrated in Figure 3. 3 that the eventual leak rate by December 2010 would be well above the

367 scfm limit for some aircraft if the ageing effects and the crew module leak detection process is not improved. (Environmental criteria for military aircraft dictate that the rate of pressure decrease in the cabin may not exceed 1 psi/second [1] which at standard atmospheric conditions and fixed crew module volume, equates to 367 scfm.)

3.2 The Solution

In the case of the affected platform PR 1750 aerospace sealant is used to seal the pressurized crew module. For determining leaks during maintenance, the classical soapy water solution was utilised. However, PR 1750 material safety data sheets indicate removal of sealant can be achieved through the application of water or soap and water solution if skin contact occurs during the application stage. If the sealant has reverted, it would be susceptible to removal during subsequent soapy water leak testing. To prevent further degradation of sealant or complete removal of the crew module to facilitate the application of new sealant throughout the interface, numerous leak detection methods where considered namely:

- Ammonia-air + indicator
- Infrared
- Ultrasonic
- Helium detector
- Sulphur hexafluoride

Ultrasonic, helium-detector and sulphur hexafluoride methods are unsuitable due to the fact that these methods do not provide positive (visual) location of the leakage area. The Ammonia-air-indicator method was rejected on the grounds that it used a hazardous substance and the additional costs of developing a mixing apparatus to produce and control the ammonia-air mixture at varying flow rates during testing.

Infrared was utilised as it provided a visual indication of the leakage area. However, it was deemed to have the following perceived limitations:

1. Thermal conductivity of materials such as sealant, aluminium fasteners adjacent to leakage areas could conduct enough heat to mask leak indication.
2. The minimum leak path size that an infrared system could detect would be limited by the resolution of the infrared detector. Therefore the process may not accommodate the minimum size requirement for a leak and thus produce unreliable results.
3. The low pressurization limits of fuel tanks in general (approximately 5 psi) during testing might not provide a sufficient temperature drop at the leakage area for detection purposes.

Given the fact that the crew module is tested at a maximum of 11 psig and that a certain amount of leakage is required through the crew module as specified from manufacture, infrared was deemed suitable as a leak detection process and provided the following results as illustrated in Figures 3.2.1, 3.2.2 and 3.2.3.

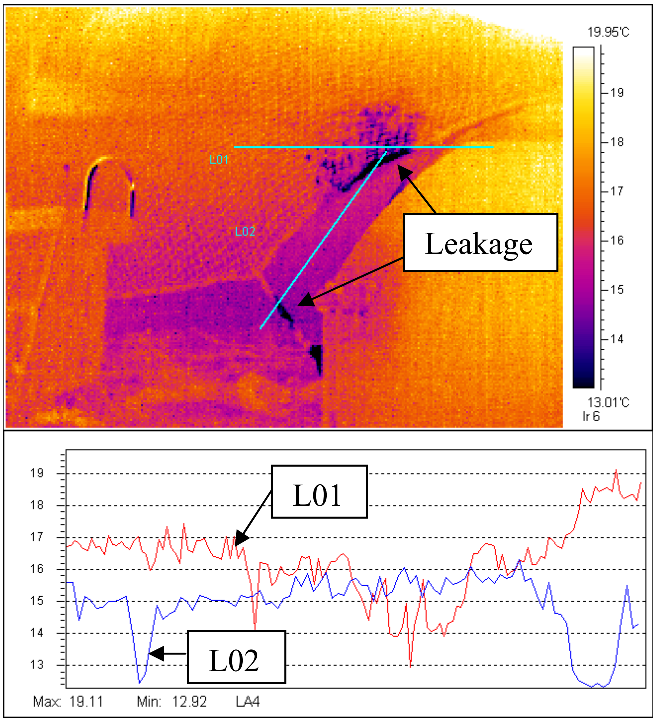


Figure 3.2.1 Infrared image of crew module leakage with temperature plots.

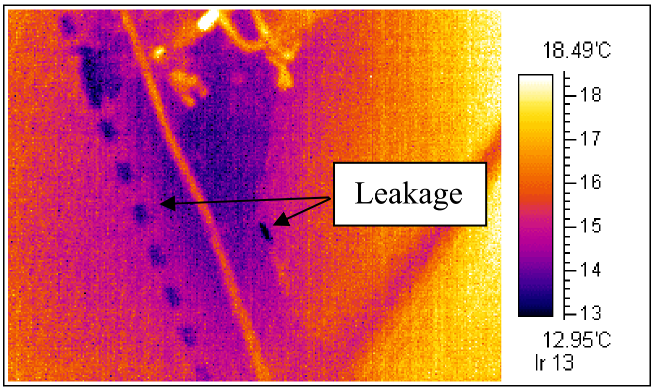


Figure 3.2.2 Infrared image of crew module bulkhead with leakage at fasteners.

Figure 3.2.3 Photograph of bulkhead fastener leakage area.

Figure 3.2.1 shows leakage at the windshield and crew module panels with a temperature drop of approximately 2 degrees Celsius (See L02 of Figure 3.2.1). Figure 3.2.2 illustrates the capability of infrared to determine leakage at fasteners interfaced with sealant.

3.3 Summary

The infrared exercise was carried out on Aircraft L as depicted in Figure 3.1.3 and after repair and testing the leak rate was reduced from 280 scfm to below the maximum allowable and measured at 67 scfm. This process is now formulated into the appropriate maintenance publication as approved practice for leak detection of the crew module.

Any signs of sealant reversion in pressurized vessels should terminate the use of soapy water solution (if used) for leak detection and an alternative method sought.

4. Further developments

The perceived shortcomings of infrared leak detection have been further investigated with respect to thermal conductivity, minimum leak path size and low pressurization limits.

Through 'amplification' (without the use of hazardous substances) of the infrared signal, the performance of infrared leak detection has been significantly increased as shown in Figures 4.1, 4.2 and 4.3 below.

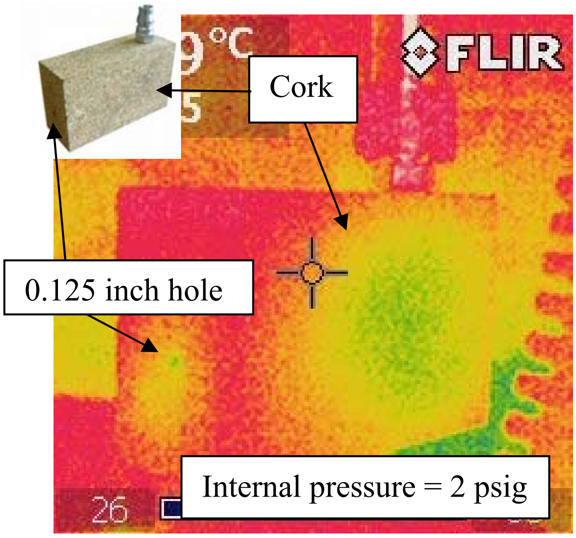


Figure 4.1 Thermal Conductivity

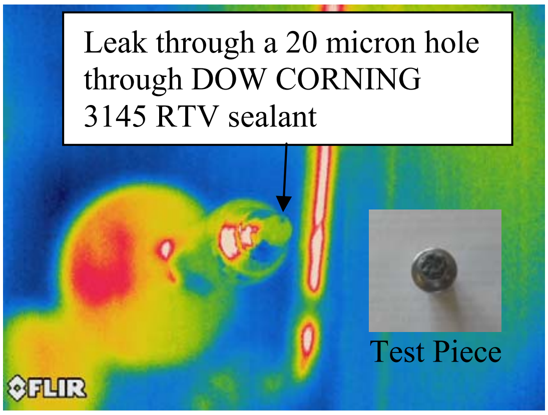
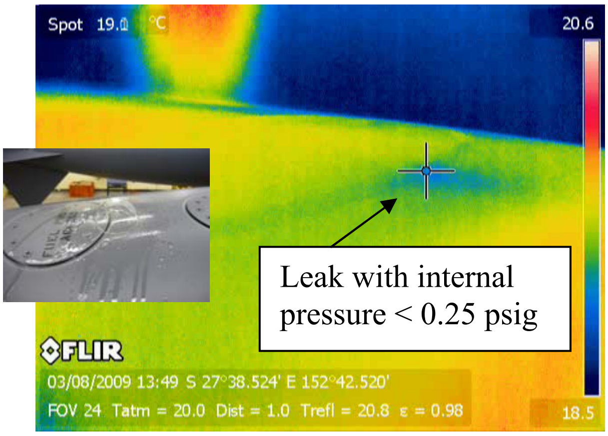


Figure 4.2 Leak Path Size



Leak with internal pressure < 0.25 psig

Figure 4.3 Pressure Limitations

5. Conclusions

Ageing platforms present many in-service management issues:

- fatigue in aircraft structures,
- components/spares that need alternative procurement,
- items that had no shelf life during initial manufacture are now failing and many more.

But it is rewarding to work on an ageing platform when it provides insight into shortcomings (training) that can improve the safety of future platforms. It is particularly rewarding when the challenges of maintenance results in new technologies such as infrared leak detection and forces one to push the technology further.

References

[1] MIL-E-18927E**.** *General Requirements For Aircraft Environmental Control Systems*. 18 August 1983.

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