Feature article

Vulnerability, failure and protection of printed circuit boards in aircraft

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Abstract

This paper focuses on the importance of printed circuit boards (PCBs) as components in aircraft and how their failure, either by corrosion or in electronics, can result in catastrophic losses. Reviews some typical experiences and various failures with PCBs, and the attempts to protect them using conformal coatings, and also stresses that this is of increasing importance as these systems become smaller.

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It would be hard to claim that printed circuit boards (PCBs) are the single most important components of air and space craft, given the recent catastrophic losses because of insulation failures, but surely it can be agreed that they are high on the list. It can also be observed that corrosion or failures of electrical contacts are probably the single most common cause of failure in electronics in general. This paper reviews some typical experiences with PCBs and various failures and with the most common attempt to protect them from failures using conformal coatings.

It is well known that PCBs are becoming smaller and the components more densely packed on the boards with every generation of electronic devices. While that is a positive development in many ways, it also means that they are becoming more vulnerable to short circuits and contact failures. Control of operating conditions becomes more important, including temperature, moisture and atmospheric chemistry. For example, some years ago as I was standing on a rock jetty on the coast of North Carolina, an unexpected wave sprayed a couple of drops of salt water onto the junction between the removable lens and the lens mount on my single lens reflex camera. I was visiting a marine research station and one of the scientists advised me to immediately plunge the entire camera into a bucket of distilled water to wash away the salt water. I could not bring myself to do that, and the chloride ions in the water soon had destroyed the electronics in my camera.

The offending agent does not have to come as such an obvious liquid invader. Atmospheric moisture can cause similar problems. Here is a typical example. The growth of metallic whiskers on PCBs is becoming much more frequent, though still poorly understood phenomenon. In fact, it is so poorly understood that an informal international group of scientists if forming to pool knowledge on this subject, trying to develop a comprehensive catalogue of the conditions under which the whiskers occur. At this point the whiskers are known to be predominantly copper, zinc, tin or silver, which are the most important metallic components of PCBs. The problem is that these whiskers can bridge the insulating gap between the components in the PCBs and cause short circuits. One way in which the whiskers may form is under the influence of tiny galvanic currents in absorbed water on the PCB surfaces. The water provides a channel for the galvanic flow of electrons and the counter flow of metal ions between dissimilar metals. The metal ions build up and grow to form microscopic dendritic metal crystals. With the progressively smaller intervals between PCB components it takes very less time for this to cause serious problems. Two solutions
present themselves; keep atmospheric moisture down so that absorbed water is limited or protect the boards with conformal coatings.

In this example, from an integrated circuit (IC) on a PCB, each of the contacts along the IC has produced a “black rose” of corrosion products. The contacts on ICs are commonly flat copper strips coated with tin for improved solderability. In this case copper whiskers grew at the junction of the copper and tin. Then sulphur in the air reacted with the very high surface energy of the copper whisker to form what appears to be copper sulphide, the “black roses”. As time goes on and these roses become about twice as large, they will meet and short out the IC (Plates 1 and 2).

Plate 1 Low power color light micrograph of the contact strips along the edge of an integrated circuit. At the interface of the plastic case and the metal contacts are “black roses,” dendritic crystals of corrosion products

Conformal coatings are protective layers of various layers of various compositions intended to isolate the electronic circuits from the surrounding environment. Not all PCBs are going to spend a protected life in the cockpit of an aircraft. They might be in the wing of the aircraft where the atmosphere contains considerably higher concentrations of volatile organic compounds and possibly water, especially during maintenance or refuelling. They might be in the tail assembly where they would experience extremes of temperature fluctuation. For example, consider what happens when an aircraft comes down from cold high altitude conditions to land at a warm tropical airport. An unprotected PCB might suffer what would almost be immersion in condensed atmospheric water vapour. When such brutal changes are envisioned ahead of time, electronic components might actually be “potted” in epoxies to provide what is hoped to be a truly durable protective coating. However, sometimes the potting compounds themselves may fail; for example, they may crack from either residual stresses or from shrinkage during temperature excursions. A less expensive and more common form of protection is to spray or dip them in silicone elastomers or other organic compounds.

While the coatings extend the lives of the PCBs, they are not cure-alls. For example, many PCBs include a row of strip or pin contacts to which some form of plug is attached, the common form of connectors on home computers. These contacts necessarily penetrate through the conformal coatings to make electrical contact inside the connectors. This provides both a starting point and an avenue for entrance of corrosive materials. The bonding of the coating to the board materials, both board itself and electronic components, determines the rate of penetration of materials into the board.

An example of such a problem is shown in Plates 3 and 4 shows an undamaged PCB.

Plate 3 New PCB showing conformal coating covering the entire board except the ends of the contact. The contacts are orange at the upper ends, where they are coated, and silver at the bottom ends, where the metal is bare
Plate 4 Identical PCB to that in Plate 3, except for corrosion damage (the blue copper compounds around the contacts and on the board itself). The corrosion has penetrated under the conformal coating from the bare metal at the end of the contacts.

Plate 4 shows an identical PCB which had been hit by some fluid which corroded the connectors, penetrated under the coating and attacked the board components.

There is a potential, at least partial solution to this problem, likely to be especially helpful if the connections do not have to be made, broken and remade frequently. Coatings are available which could even entirely cover the exposed contacts. When the contact is made, it would penetrate the coating to the metal, and the coating would seal around the penetration. While this is unlikely to be a perfect solution, it would surely be an improvement over no protection at all.

It is commonly assumed that, once applied, the coatings will do their jobs well. But several problems may occur. In the first place the coatings may be uneven. Many of the coatings contain phosphors which fluoresce in UV radiation. Plates 5 and 6 show a PCB on which the coating is poorly distributed. As a quality control check this can help eliminate that problem. Some coatings are sprayed on and those coatings may suffer this unevenness problem. Dipping seems to ameliorate it. However, if a dipped coating is placed wet on a flat surface to dry, the coating may bond to the substrate and be torn when the part is removed.

Another interesting problem is that the coating viscosity may be too high and the coating may actually bridge over the components and not flow around them. Obviously, both original viscosity and rates of drying have to be carefully controlled. Plate 7 shows what happens in a corrosive environment when conformal coating do not protect the components on the PCB. In the PCB on the left, the coating covered the entire assembly. On the right the coating left gaps and corrosion in an identical area on a different board was relatively severe (Plate 8).

All this talk of corrosive environments may sound foreign to aircraft and aerospace manufacturers. One interesting job came in to us to determine why PCBs in a cockpit control module were corroding. It was suspected that,
perhaps the pilots were spilling coffee or soft drinks into the units! An elaborate sleuthing job led to the conclusion that the cockpit windows, just above the modules, were being left open during deicing, and that deicing fluid was running down into the openings around the slider switches, down the inside wall of the module, along the base and then being drawn up by capillary action onto the PCB, where severe corrosion took place. It was not coffee or soft drinks after all! Plate 9 shows the bottom of the module with the bottom cover pulled back, showing the three PCBs on which the corrosive damage took place.

**Conclusions**

The electronic components of an aircraft are vulnerable to all sorts of unexpected environmental stresses. As the systems get smaller, it is important to protect them from conditions that will promote corrosion, including atmospheric pollutants that may promote crystal growth in the metals of the systems. This metal crystal growth will become a larger concern as system design continues to shrink. It is also important not to assume that conformal coatings will necessarily solve corrosion problems, as the coatings may have their own defects.