BOEING®
ENVIRONMENTAL TECHNOTES
August 2005 Volume 10, Number 3

Aerospace Industry Transition to Lead-Free Electronics

For several decades the solder used for the assembly of high-reliability electronics has been predominantly an alloy of Tin (Sn) and Lead (Pb). The performance characteristics of this alloy and associated manufacturing/repair processes are well understood. Reliability analysis and qualification tests have been developed that can adequately predict and verify system performance to ensure that required system reliability can be achieved.

Figure 1 – Tin is OK for the Tin Man, but not for aerospace electronics See Figure 2.

Boeing began tracking international initiatives to replace lead in solder in 2000. At that time R&D efforts were started to identify the performance impications (Figure. 1) that might be associated with lead-free electronics materials and assembly processes in aerospace applications. Over the past several years Boeing has expanded research efforts and shared data with other high reliability electronics producers and users through various industry consortia.

The technical issues are many and complex, and not the focus of this discussion. However, it should be noted that the aerospace industry faces some unique challenges for its electronics equipment, such as rugged operating environments, high consequences of failure, and the need to support our products for times that extend into decades. As the only major industry that repairs electronics at the circuit card level, aerospace also faces unique reparability and configuration control challenges. A major impact of the transition to lead-free electronics is that for the foreseeable future there won't be a single, preferred lead-free replacement for all products. As a relatively small user of electronics, the aerospace industry must utilize electronic components produced for a number of other markets, and therefore will be forced to use a variety of lead-free alloys. The reliability analysis and qualification testing methods established as valid for tin-lead solder assembly may not be appropriate for the new lead-free solders.

The performance risk situation for using lead-free technology in diverse, long life aerospace electronics is very poorly characterized. In addition, it has become clear that consumer electronics industry trends (http://www.stltoday.com/stltoday/emaf.nsf/Popup?ReadForm&db=stltoday\news\stories.nsf&docid=59891F180F48E70386257050001DF52C). will force aerospace to adapt to an evolving lead-free transition in the global supply chain prior to realizing the level of technology maturity that we expect in its various applications. In response to this situation, Boeing established an Enterprise wide Steering Team early in 2003 to develop a strategy that would recognize the imminent impact of lead-free electronics across its products.

The Steering Team very quickly came to the conclusion that supply chain dynamics was the forcing function for an aerospace transition, not the direct force of environmental directives and legislation. It was also clear that there were several business and technology factors that would prevent employment of a straightforward process of selecting and qualifying a lead-free electronics solution that would be timely with respect to the expected pace of the electronics industry transition. The Boeing Team decided that it would be most important to proactively seek a coordinated aerospace industry strategy and response, while it continued to fund internal research and participate in consortia based R&D to better define the technical risk issues in its applications.

Boeing approached the Aerospace Industries Association (AIA, **http://www.aia-aerospace.org)** in late 2003 as a potential sponsor for a lead-free electronics in aerospace working group. Subsequent to receiving AIA approval, the first face to face meeting of the working group occurred on 5/3/2004 (**http://www.calce.umd.edu/leadfree/other/Procarione_ACI.pdf**). The resulting discussions amongst the participating system integrators and electronics OEMs made it clear that to be effective the stakeholder representation had to be expanded to include the commercial airline operators, the regulators, and DoD. With the assistance of AIA we were able to quickly receive recognition and sponsorship from ARINC-AMC (Avionics Maintenance Conference, **http://www.arinc.com/amc/**) and GEIA (Government Electronics and Information Technology Association, **http://www.geia.org**). Expanding the US participation resulted in the realization that to be effective we needed to have international participation and recognition. In addition to allowing broader stakeholder participation, GEIA provided the path to publish standards and further enabled international recognition through its formal links to the International Electrotechnical Commission (IEC, **www.iec.ch/home-e.htm**). This in turn enabled the active participation of key European aerospace companies in the working group now constituted under the acronym LEAP (Lead-free Electronics in Aerospace Project **http://www.meecc.com/presentations/anderson.pdf** slide 11). Lloyd Condra, a Technical Fellow with Boeing Phantom Works, Seattle, WA, is leading the LEAP Working Group, sponsored jointly by AIA, AMC, and GEIA. He is also the chairman of IEC TC-107, Process Management for Avionics, and of the GEIA Avionics Process Management Committee.

More than 30 US and international aerospace system integrators, electronics OEMs, regulators, and user organizations actively participate in the LEAP working group. The LEAP goal is to produce "actionable deliverables." Those deliverables are the following standards and guidelines:

1. Performance Standard for Aerospace and High Performance Electronic Systems Containing Lead-free Solder - Used by aerospace electronic system "customers" to communicate requirements to aerospace electronic system "suppliers"
2. Technical Guidelines for Aerospace and High Performance Electronic Systems Containing Lead-free Solder - Used by aerospace electronic system "suppliers" to select and use lead-free solder alloys, other materials, and processes.
3. Technical Standard for Mitigating the Deleterious Effects of Tin (Figure. 2) in Aerospace and High Performance Electronic Systems - Used by aerospace electronic system "customers" to communicate this concern to aerospace electronic system "suppliers"
4. Program Management/Systems Engineering Management Guidelines for Managing the Transition to Lead-free Electronics. - Used by program managers to address all issues related to lead-free electronics, e.g., logistics, warranty, design, production, contracts, procurement, etc.

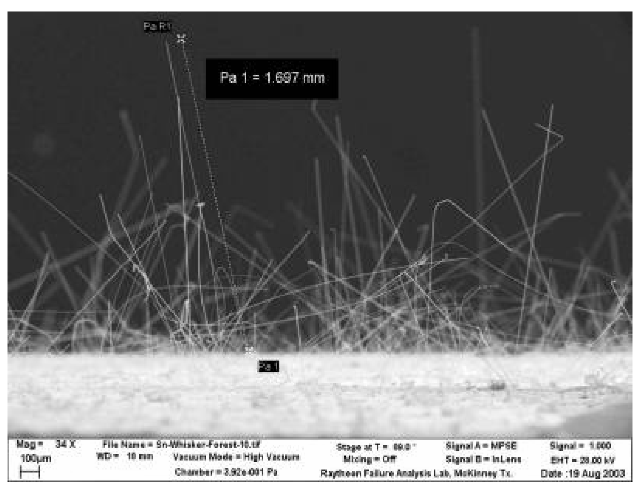


Figure 2 – Tin whiskers capable of causing system short circuits, i.e. system functional loss.

These four items will first be published as GEIA documents. They will subsequently be forwarded to the IEC via TC-107 for international recognition.

In an activity closely coordinated with the LEAP working group, ARINC-AMC is in the process of drafting Project Paper 671: Guidance for Lead-Free Soldering, Repair and Rework (**http://www.arinc.com/aeec/draft_documents/671_d1.pdf**). This activity is focused on the needs of the commercial transport aircraft operators, but the resulting guidance is expected to be applicable to most aerospace electronics repair situations.

With the transition to lead-free becoming more pervasive across the global electronics industry the aerospace challenge to maintain a robust configuration control processes becomes more daunting. A leading indicator of the transition, the use of pure tin plating on leaded components, is well upon us. This is particularly troublesome for space based electronics, where tin whisker induced events can result in total functional loss (**http://nepp.nasa.gov/whisker/index.html**).

As lead-free solders come into more common use, electronics repair in aerospace may become prohibitively expensive if we lose confidence in the fidelity and accuracy of configuration information systems. Boeing recently advised its electronic suppliers of the need for vigilance as this situation evolves.

Boeing intends to continue to work with its customers and suppliers to implement common strategies and processes consistent with the enormous diversity of requirements that span our many products.

For more information contact Bill Procarione, (314)233-9809 (william.l.procarione@boeing.com)

Update on Cadmium Plating Alternatives

The search for an alternative to cadmium plating is still going on and it looks like the aerospace industry might be getting closer to an answer. Other industries, such as automotive, have already found an alternative to cadmium plating but the aerospace industry is having a more difficult time because aerospace uses high strength steel parts. For example, the aerospace industry typically uses 4340 or 300M steel alloys that have been heat treated to an ultimate strength level of 260 to 300 ksi for landing gear parts (see Figure 1). Cadmium plating is the preferred corrosion resistant coating for these types of steels because the cadmium plating process is non-embrittling (does not cause hydrogen embrittlement) and does not reduce the fatigue life of the steel.

In addition, corrosion resistance, lubricity, electrical contact resistance and paint adhesion are other important factors to consider when looking at an alternative for cadmium plating. The Joint Cadmium Alternatives Team (JCAT) has created a document that lists all of the requirements for a cadmium alternative, and this can be found at the JG-PP web site (**http://www.jgpp.com/projects/projects_index.html**) under the project named "Joint Cadmium Alternative Team". JCAT is comprised of materials engineers from the Navy, Air Force and Army, and Boeing.

JCAT is currently looking at several cadmium alternatives to see which ones can pass a hydrogen embrittlement test to verify that the new plating/coating process is non-embrittling, and is also conducting tests to see which ones can pass a hydrogen re-embrittlement test with maintenance fluids. Some of the candidates being tested by JCAT are Alumiplate, IVD Aluminum, Sputter

Figure 1 – Large complex high strength steel landing gear part that requires cadmium plating on external and internal surfaces.

Aluminum, Acid Zinc-Nickel, Alkaline Zinc-Nickel, Aluminum-Manganese, SerMetel, and Tin- Zinc. Following completion of the hydrogen embrittlement tests – the successful candidates will move on to corrosion and fatigue testing. For typical Zn-Ni plating test specimens, see Figure 2.

Boeing is also conducting their own cadmium alternative tests and is spending a considerable amount of time and effort on evaluating the use of alkaline zinc-nickel plating on high-strength steels.

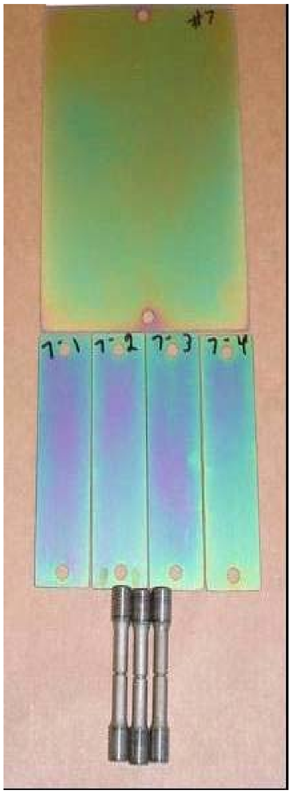
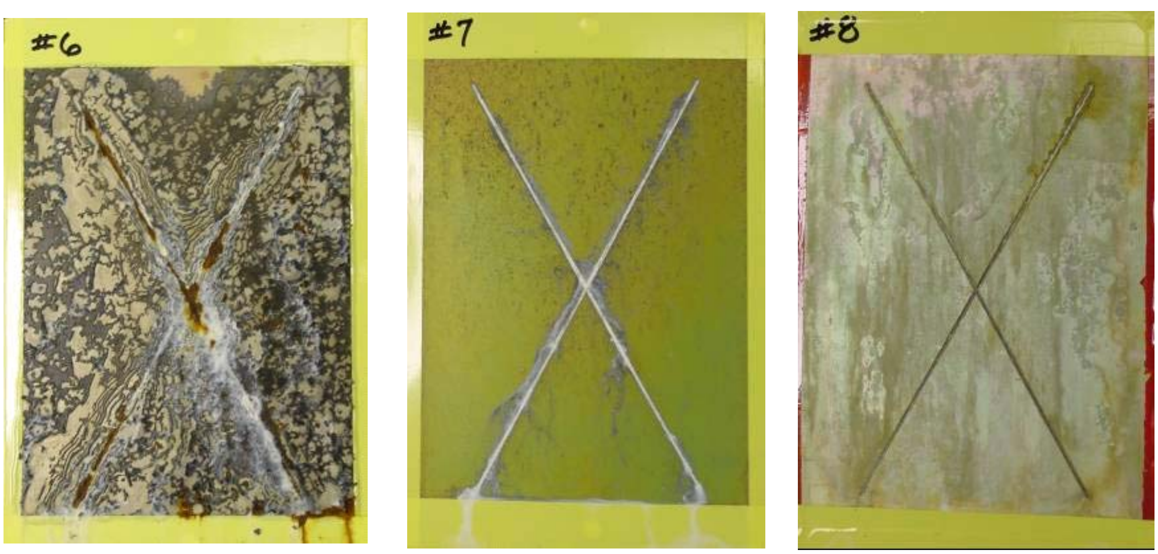


Figure 2 – Zn-Ni Test Specimens. 4 x 6" Corrosion Test Panel (Top), 1 x 4" Adhesion Test Strips (Middle), and ASTM F 519 Type 1a.1 Hydrogen Embrittlement Test Specimens (Bottom)

Previously, the alkaline zinc-nickel plating needed a nickel strike prior to the application of the alkaline zinc-nickel in order to pass the hydrogen embrittlement test, but now Boeing has found a way to apply alkaline zinc-nickel plating without a nickel strike and still be able to pass the hydrogen embrittlement test. Comparison of the corrosion test results between the different zinc-nickel platings and cadmium are shown in Figure 3. This is very encouraging, and testing continues to look at hydrogen embrittlement, corrosion resistance, and fatigue properties for this LHE (Low Hydrogen Embrittlement) version of alkaline zinc-nickel plating.

Currently, Boeing is allowing the use of zinc-nickel plating as a substitute for cadmium on some non-threaded low strength steel (< 180 ksi UTS) parts, and hopefully will be allowing the use of zinc-nickel for the remainder of their parts in the near future.

For more information contact Steve Gaydos, (314) 233 – 3451, (**stephen.p.gaydos@boeing.com**).



Zn-Ni with Ni Strike — Alkaline Zn-Ni — Cadmium

Figure 3 - Scribed corrosion test results on plated steel test panels after 816 hours in ASTM B 117 salt spray.