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THE Pb-FREE IN ELECTRONICS RISK MITIGATION (PERM) CONSORTIUM

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ABSTRACT
Since 2004, the defense/aerospace industry has looked to the AIA-sponsored Pb-free Electronics in Aerospace Project (LEAP) as its premier industry working group identifying and addressing risks and other challenges associated with the integration of Pb-free electronics in high performance/high reliability equipment. The working group was very successful in providing resources such as the publication of handbooks and standards as well as templates, guidelines, and other tools to support risk mitigation. However, the use of Pb-free materials has proliferated to the point where many components/parts are no longer available in tin-lead (either surface finishes or interconnection media).

Consequently, engineers are forced to use some Pb-free parts in their new designs or, in many cases, as part of retrofits and upgrades. Thus, the concern over performance and reliability is more widespread now than ever. With this rapidly "accelerating" effect of Pb-free, the existing LEAP structure did not provide an adequate approach to address the risks. Therefore, an ad hoc sub-committee of the LEAP team spent over a year "re-designing" or "upgrading" the present model to produce a more focused entity called the Pb-free Electronics Risk Mitigation (PERM) consortium. This new organization provides overarching executive leadership and coordination of Pb-free electronics risk management activities for the aerospace and defense community on both the government and industry side. The focus is on those activities that provide value-added results. This paper describes the organization, content, and expectations of the PERM and its stakeholders.

ACKNOWLEDGEMENTS
The impressive amount of work completed to date, in Pb-free risk identification and mitigation, is due to the efforts of many companies/organizations and people. There names and affiliations can be found on the PERM website (http://aiaaerospace.org/resource_center/affiliate_sites/perm/). However, the leadership of several people warrants recognition given the diverse nature of the membership of all teams mentioned in this paper. Those people are Lloyd Condra and Jerry Aschoff (Boeing), Ed Morris (Lockheed Martin), and Vance Anderson (Defense Microelectronics Activity). This effective collaborative working group model has transitioned into a powerful methodology for addressing an industry-wide challenge. The PERM White Paper [1] was used a the basis for this paper and the author would like to acknowledge the efforts of those previously mentioned, as well as Rusty Rentsch of the Aerospace Industries Association (AIA) for his support in the flawless operation of the LEAP Working Group and its transition to the Pb-free Electronics Risk Management Consortium.

BACKGROUND
For approximately fifteen years, the aerospace, defense, and other high performance (ADHP) electronics industries have been working to address the challenges resulting from the conception and subsequent enactment (July 2006) execution of the European Union's Restriction of Hazardous Substances regulation. While these companies are typically excluded from the restrictions on lead usage in electronics, the impact is still severe since the commercial supply chain has converted to Pb-free solder for the majority of their products. ADHP industry dependence on commercial-off-the-shelf (COTS) products has led to concerns as to how these products will perform under the harsh service, environmental, and storage conditions that many systems will experience throughout their life cycle. Prior to Pb-free solder, tin-lead (Sn-Pb) solders were the standard interconnection material for most electronics. A substantial database was generated to help predict performance behavior thus facilitating design and manufacture of ADHP products. Pb-free performance characteristics in ADHP applications are, to date, minimal or unknown thereby warranting generation and comprehension of a new performance database. Given the variety of Pb-free choices in the marketplace, generating this database is an overwhelming task. While some suppliers continue to provide tin-lead products, this "luxury" is viewed as a limited resource since consumer market demands may force reduction/termination of lead-based production lines. New products (as well as updates to traditional parts) are being introduced exclusively in Pb-free form. Figure 1 illustrates ADHP dependence upon the global supply chain. In general, ADHP companies must address two major concerns with the inception of Pb-free technology: 1. performance of the soldered interconnection and 2. potential deleterious effects of tin whisker formation from Pb-free finishes using pure tin. The first concern becomes more complex expanding into a long term issue that centers around the use of Pb-free and mixed Pb-free assemblies and the ability to sustain systems that use them. For example, when using mixed technology in repairing assemblies, remember that the Pb-free solder may require higher reflow temperatures. Thus, in addition to concern about Pb-free performance, one also needs to consider how much of the life time is impacted as a result of exposure to the higher

temperature [2]. Thus, the first concern results in a third concern of long term sustainment of Pb-free and mixed assemblies.

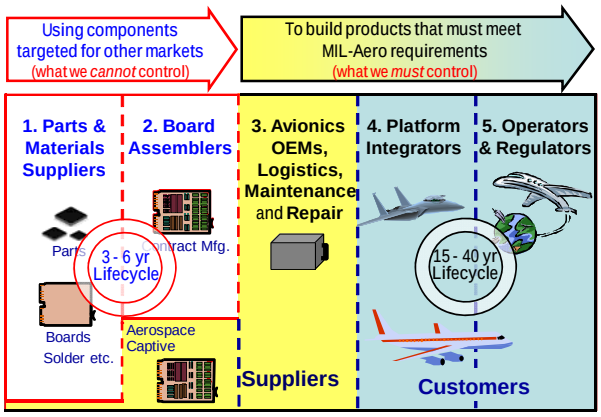

Figure 1. The Global Military and Aerospace Supply Chain [1]

History of the Organization

The electronics industry has been faced with conforming to the requirements of two prominent European Union industrial regulations, i.e. the Waste from Electrical and Electronics Equipment (WEEE) and the Restrictions of Hazardous Substances (RoHS) [1, 2]. The WEEE Directive focuses on awareness of recycling electrical and electronic equipment (EEE) and encourages designers to consider a product's entire life cycle with emphasis on recycling (either part or all) as its end-of-life state [3]. RoHS addresses the minimization, if not elimination, of six substances considered hazardous to the environment. WEEE took effect on 12 August 2005 while RoHS became effective on 1 July 2006. Recognizing the impact such regulations would have on the electronics industry, several initiatives commenced well before the infamous July 1 2006 date in which some aerospace and defense companies met informally to discuss the effects the restrictions would have on their products' design, development, producibility, supportability, and reliability. Given that their customer community was unaware of the regulations and/or the potential impact, these companies added a degree of formality to their collaborations through meetings, telecons, consultations with research groups, etc. As the discussions/collaborations continued, the company representatives approached the Aerospace Industries Association (AIA) to discuss a methodology to coordinate an industry working entity. Accordingly in a united, pro-active effort, an industry working group, with the support of the Aerospace Industries Association (AIA), the Government Electronics and Information Technology Association (GEIA), and the Avionics Maintenance Conference (AMC) was formed in 2004. Its objective was to address needs for guidance and standards for the integration of Pb-free technology into high reliability equipment. This working group was called the Pb-free Electronics in Aerospace Project (LEAP). The team started off with approximately twenty organizations that included active members from North America and Europe. Represented among the membership were most of the world's major aircraft manufacturers and defense contractors, many mid-tier suppliers, academia, and relevant government/customer organizations. As one can imagine, the first few meetings consisted of the group "finding itself" in deciding what it wanted to accomplish and how it could make an impact on this significant industry trend. Given the investment made by the members' companies, it was understood that a return on investment needed to be established and, with input and concurrence from the working group, a set of "actionable deliverables" was established with due dates. These deliverables were a set of documents (standards and handbooks) that would provide the ADHP industry with necessary direction to identify, understand, and mitigate the two high level risks associated with Pb-free electronics, i.e. interconnection reliability and effects of tin whiskers.

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Evolution of the PERM

In 2006, in response to reliability concerns with use of Pb-free products and their sustainment (e.g. COTS) in aerospace/defense equipment, the DoD commissioned the Executive Lead-free Integrated Process Team (ELF IPT) to advise DoD on critical issues regarding policy and implementation of Pb-free electronics, i.e. basically providing direction to LEAP regarding needs in terms of guidance (handbooks) and requirements (standards). The LEAP WG integrated efforts with the ELF IPT in order to access government leadership and address the needs of the government acquisition and logistics communities. The group worked from 2004 through 2009 to develop a set of documents (the previously mentioned actionable deliverables) to meet the challenges of Pb-free and are acceptable for use across our industry. (See Table 1.) These documents are being issued initially in the United States by the GEIA (now TechAmerica), and then submitted to the International Electrotechnical Commission (IEC) for adoption globally.

Table 1. Actionable Deliverables from the Original LEAP Working Group

- GEIA-STD-0005-1 Performance Standard for Aerospace and High Performance Electronic Systems Containing Pb-free Solder
- GEIA-STD-0005-2 Standard for Mitigating the Effects of Tin in Aerospace and High Performance Electronic Systems
- GEIA-STD-0005-3 Performance Testing for Aerospace and High Performance Electronics Containing Pb-free Solder and Finishes
- GEIA-HB-0005-1 Program Management / Systems Engineering Guidelines for Managing the Transition to Pb-free Electronics
- GEIA-HB-0005-2 Technical Guidelines for Aerospace and High Performance Electronic Systems Containing Pb-free Solder
- GEIA-HB-0005-3 Rework and Repair Handbook To Address the Implications of Pb-free Electronics and Mixed Assemblies in Aerospace and High Performance Electronic Systems
- Pb-free Control Plan Template

In 2008, the ELF IPT. along with LEAP WG leadership, initiated a discussion to re-examine the ADHP needs and decide if a next phase of activity should be considered. Specifically, the focus was on 1) streamlining the collaboration model by combining LEAP and ELF into one group and 2) identifying the key elements in Pb-free risk mitigation and coordinate associated activities to maintain focus on goals and discourage redundancies. Furthermore, this new group would be the first "line of defense" in communications to DoD in reporting progress in these activities. Several discussions ensued followed by a strategy meeting in St. Louis, MO in September 2008. Within two months, the Pb-free Electronics Risk Management (PERM) Consortium was established (Figure 2).

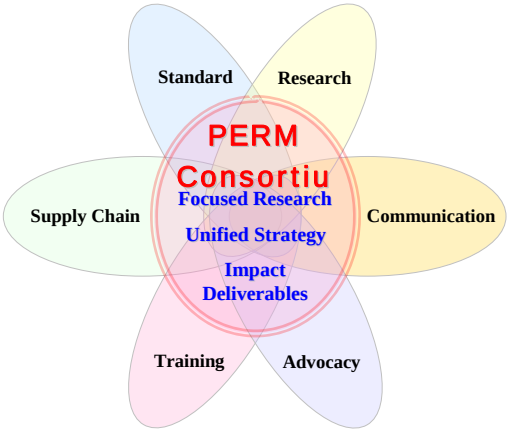

Figure 2. The Pb-free Electronics Risk Management Consortium

PERM AND THE NEXT LEVEL OF INDUSTRY RESPONSE

The purpose of the PERM Consortium is to provide overarching leadership and coordination of Pb-free electronics risk management activities for the aerospace, defense and high-performance (ADHP) communities. The goal is to respond better to the long-term challenges of Pb-free solders and finishes over a system's life cycle. The charter of the PERM is to provide guidance for the long-term overall aerospace and defense strategy, and tactics to deal effectively with the Pb-free electronics issues. A coordinated risk management approach for the transition to Pb-free electronics is needed in order to ensure the performance, reliability, maintainability, and safety characteristics required in aerospace and defense electronics.

The consortium is chartered by the Aerospace Industries Association (AIA) and includes support from DoD, DoE, Army, Air Force, Navy, FAA, NASA, industry, academia, and international members.

Structure of the PERM Consortium

PERM is organized to provide an executive leadership perspective and address communications, research coordination, standards, training, advocacy, supply chain, and international cooperation issues through dedicated task teams and advisory groups. A PERM Steering Committee has been established to ensure a focused and integrated approach in meeting the consortium goals. The organization's framework is shown in Figure 3.

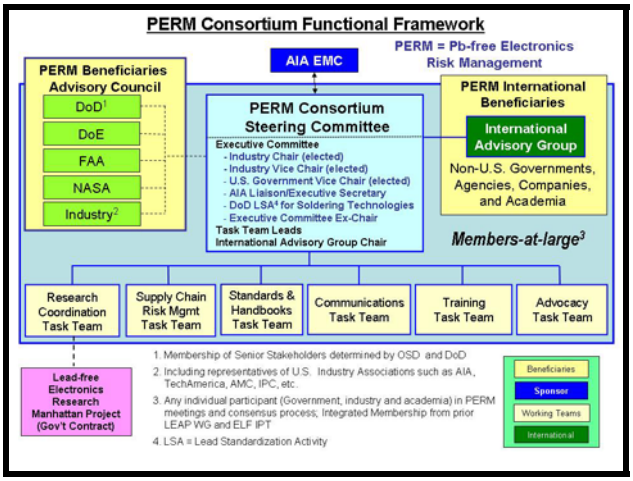

Figure 3. PERM Consortium Functional Framework

Research Coordination

The research coordination team is the top-level research facilitation activity for the ADHP community with respect to Pb-free electronics. It provides an open forum to define, develop, and support coordination of research across consortia members' activities that address the critical needs of the ADHP industry with regard to the global transition to Pb-free electronics. The task team also serves as the Technology Review Board for the PERM Consortium and will:

- Provide peer review and vetting of relevant research and inform members of that research
- Define research gaps and recommend projects to fill those gaps, including maintenance of a research roadmap and funding needs
- Encourage communication and collaboration between consortia members on current research to reduce duplication of effort and to allow corroboration of results
- Provide assessment of relevant research to ADHP applications and provide recommendations to the Standards & Handbooks and other PERM task teams as needed
- Provide coordination of the Lead Free Electronics Manhattan Project

The focus of the team is to provide "actionable deliverables"; however, it is recognized that some key technical questions exist for which the current knowledge is insufficient for implementation on ADHP programs. In such cases, it may be necessary to access in-work research knowledge, which can be used provisionally, in lieu of "final published results." It is also expected the team will provide a set of solutions and applicability considerations, rather than a specific single answer.

It is noted that the PERM Research Coordination Task Team does not fund or conduct research; rather it provides a coordinated ADHP view of the research currently being done, and identifies needed research.

Special mention should be made of the Lead-free Electronics Research Manhattan Project shown in Figure 3 under the Research Coordination team. The Lead-Free Manhattan Project (LFMP) was a high-energy focused working group comprised of fifteen nationally subject matter experts (SME) whose efforts were funded by Office of Naval Research and Joint Defense Manufacturing Technology Program. The project was divided into two phases. The object of Phase I was to define/document the key baseline practices regarding Pb-free risk reduction. Phase II, building upon the Phase I work, provided a technology roadmap which included a research gap analysis, statements-of-work, and cost estimates to facilitate execution of a major program. A Phase III (execution of the research agenda as identified by the Phase II gap analysis) is in the planning stages. Phase III is now known as the Pb-free Electronics Risk Reduction program. Key observations/"take-aways" from the overall project are as follows [3]:

1. Serious technical gaps exist for Pb-free electronics that have to be overcome for use in harsh ADHP environments over long service lifetimes, with high consequences of failure.
2. Quantification of degraded reliability and lifetimes is a significant gap.
3. The three-year Pb-Free Electronics Risk Reduction Program schedule is aggressive, but realistic.
4. Phase 3 execution will require and draw on the best available talent in the ADHP community.
5. Phase 3 will benefit any DoD or commercial product that relies on Pb-free COTS electronics and operates in extreme or harsh environments

Standards and Handbooks

Standards and Handbooks are the cornerstone of the PERM Consortium effort serving as the bridge from the science behind the technology to the execution of the technology in ADHP electronics. Through Standards and Handbooks, the customers and suppliers gain insight to the technology. These documents define what can and cannot be done with respect to the implementation of Pb-free in ADHP electronics—thus satisfying both sides of the contractual equation. Standards and Handbooks provide the basis for ensuring the end users continue to have electronic systems that are safe and reliable while meeting their performance objectives.

PERM will manage and/or participate in the development of national and international standards for Pb-free electronics in ADHP applications. PERM will provide peer review of documents to ensure their content and quality meet the needs of the Aerospace and Defense community. PERM will facilitate coordination of draft documents in

cooperation with standards bodies to ensure both government and private sector requirements are met.

Training

The PERM Training Task Team will provide all stakeholders with accurate, up-to-date information about the nature of the risks associated with Pb-free electronics and how to manage those risks. Two general categories of training are necessary to accomplish this effectively: 1) awareness training and 2) detailed training on the handling, management, and implementation of Pb-free technology. All levels of organizations within DoD, industry and regulatory authorities, from management to shop technicians, are potential recipients of awareness training. Awareness training should be designed to highlight the nature of the problem and the potential repercussions of failure to act. Detailed training on the management and implementation of Pb-free technology is primarily designed for government and industry personnel who develop and support ADHP systems. This includes engineering, quality assurance, configuration management, supplier management, acquisition, program management, repair and maintenance personnel, and others as identified. The detailed information will also include techniques for determining the extent of the Pb-free exposure, methods for assessing the risks associated with that exposure, as well as options and strategies for mitigating those risks.

Existing training material will be identified to meet those needs and made available by establishing a comprehensive repository for all training and knowledge resources. In addition, the PERM Training Task Team will facilitate the development of new material where there are gaps as well as periodic updates of training materials and organized events.

Communications

The PERM Communications Task Team addresses the ADHP community's need for a comprehensive and efficient system to disseminate information concerning Pb-free electronics and to provide a Pb-free research data repository. The types of information communicated will include new issues/problems caused by Pb-free electronics (i.e. bad news), research findings and solutions (i.e. good news), Pb-free publications, funding opportunities, and international legislation activities. The PERM communication system includes the PERM website, email updates, teleconferences, face-to-face meetings and conferences.

The PERM communication system is a conduit for disseminating information from the PERM Management, Advisors, and Task Teams to the defense and aerospace electronic industries and critical cousins across the entire electronics industry. The result is an efficient, bi-directional, exchange of information regarding the use and risk management of Pb-free electronics in the ADHP industries. A major goal is to ensure the widest dissemination of information across the industry to ensure all related organizations and companies benefit from the efforts of the PERM.

The PERM website is be the key portal for information exchange providing up-to-date information on Pb-free issues, PERM activities, the Pb-free activities of other industry organizations and a research data repository. In addition, information is "pushed" to a comprehensive email database of stakeholders in the defense and aerospace electronics industry, related associations, critical cousins in other industries and government. The Communications Task Team publishes periodic reports (State of the industry, technical alerts, etc.) based on input from other PERM task teams.

The Communications Task Team will facilitate and coordinate the PERM's liaison with key industry organizations (AIA, TechAmerica, NDIA, IPC, and others).

Supply Chain Risk Management

Because the government and ADHP industries' supply chains are now heavily and increasingly dependent on the use of commercial electronic parts for nearly all of their systems. This increasing dependence is the greatest source of risk from Pb-free products. The objective of Pb-free supply chain risk management is to develop and provide actionable recommendations that can achieve more commonality in requirements and processes at the systems integrator/sustainment level to reduce the probability of unknowingly accepting non-compliant electronic components and subassemblies. Recommendations include optimizing the cost/reliability risk trade-offs across the product and requirement boundaries throughout the supply chain and developing approaches for conveying and promoting the needs of high reliability, long service life users to the materials and components end of the electronics supply chain.

The approach is to:

- Develop a representation of a generic aerospace and defense electronics supply chain that identifies the various (generic) interfaces across which requirements information and product conformance information flows
- Identify risks and best practices for risk mitigation at each interface
- Identify needs and opportunities for improvement
- Recommend actions to manage identified deficiencies and/or improve processes

Advocacy

The Advocacy Task Team tracks US legislation concerning Pb in electronics and works with the International Committee to identify relevant legislation, regulation, etc. Advocacy is chartered to reach consensus on the interests of the ADHP industries in these matters, through contact with

sister trade associations, PERM member companies, and government organizations. The Team is proactive in recommending voting positions on pending legislation.
The role of the Advocacy Committee is to:

- Coordinate with PERM Communications Team to best publicize the unified position PERM has taken.
- Generate positive action regarding the use of Pb in electronics for aerospace and defense, and attempt to resist proposed adverse action The result of this effort will reduce risk for ADHP electronics.
- Solicit input from:
    - Other PERM committees
    - AIA, TechAmerica, and other industry organizations
    - Government agencies
    - Interested individuals
- Generate quarterly reports and position papers on the identified legislation as needed.

International Advisory Group
The problems and challenges associated with the successful implementation of Pb-free technology in ADHP applications are worldwide in scope. In addition, the original drive for the evolution toward Pb-free included legislation introduced within Europe, but regulations are now increasingly more international in origin.
The purpose of the International Advisory Group (IAG) is to work with the PERM Steering Committee to define and agree on clear and realistic goals that will promote ongoing international cooperation on risk mitigation issues related to Pb-free transition and use.

There are many independent research activities across the world, both within industry and academia that address aspects of Pb-free technology. However, there is still a lack of knowledge of the true impact of Pb-free in many key areas. There is therefore an obvious need to coordinate, or at least take cognizance of, these activities, and to disseminate realistic status information as is available. The Pb-free Electronics Risk Management (PERM) consortium offers an effective platform to achieve these goals.

To this end, the IAG will interface directly with the PERM Steering Committee, the Communications Task Team and the Advocacy Task Team. The IAG works to:

- Extend the active membership of the IAG to include as many relevant areas of academia, industry, government and regulatory authority as appropriate
- Develop a list of international contacts who would benefit from research outputs
- Provide details relevant to the PERM Steering Committee of those research activities being undertaken worldwide
- Support PERM consortium activities worldwide

THE PERM STAKEHOLDERS
The term “stakeholder” may have multiple meanings, including:

1. One who has a share or an interest in an enterprise. [4]
2. One that has a stake in an enterprise [5]
3. One who is involved in or affected by a course of action [5]

In the commercial sector, there are various levels of stakeholders. The customer is the ultimate stakeholder, whose expectations and satisfaction are of the highest concerns. The product manufacturer has an immense stake in the product because, if the customer’s expectations are not met, loss of market share and reputation damage will soon follow. All tiers of the supply chain will suffer if the manufacturer’s customer is displeased. In ADHP, a similar approach is used but an additional level is added above the customer. Usual DoD practice is for an agency (Navy, Air Force, Army) to implement a program management entity (program executive office) to specify and purchase the system or equipment for service personnel. However, ADHP now recognizes that the end user (the warfighter) is the critical stakeholder which is a level above the customer.

Pb-free technology, as previously mentioned, presents key risk areas: interconnection reliability , effects of tin whiskers and lifetime sustainment fo Pb-free and mixed assemblies. The harsh service and environmental conditions, that our warfighters experience, result in a challenge to ensure reliable equipment. ADHP systems and equipment need the ability to withstand large magnitudes of thermal cycle, vibration, and shock. The conditions are prevalent in such situations as super-quick altitude changes by fighter jets, rugged terrain negotiation by ground vehicles (e.g. HUMM-Vs), and depth charges or torpedo hits on our submarines and surface ships. See Figures 4a-c show examples of these conditions as well as others.

(a) Fighter jets experience sudden altitude changes resulting in extreme temperature and shock transitions (Raytheon Company photo).

(b) Ground-based vehicles can be subjected to high temperature and extreme vibration and shock loads (Raytheon Company photo).

(c) Surface ship service conditions can include exposure to high shock loads [7].

Figures 4 a, b, c. At high strain levels (temperature extremes), tin-lead solder outperforms Pb-free (SAC). A & D equipment must be able to withstand such extreme environments and service conditions.

Given the service conditions portrayed in Figure 4, one can appreciate how equipment failures can occur. Figure 5 shows a surface-mount solder joint crack as a result of mechanical shock. Figure 6 shows one example of a tin whisker and, as such, graphically illustrates the propensity for an electrical short occurrence which could lead to catastrophic consequences during battle (or peacetime) operations. Obviously, the greatest impact of A & D system performance (here defined as operational and reliability expectations) is with the end user.

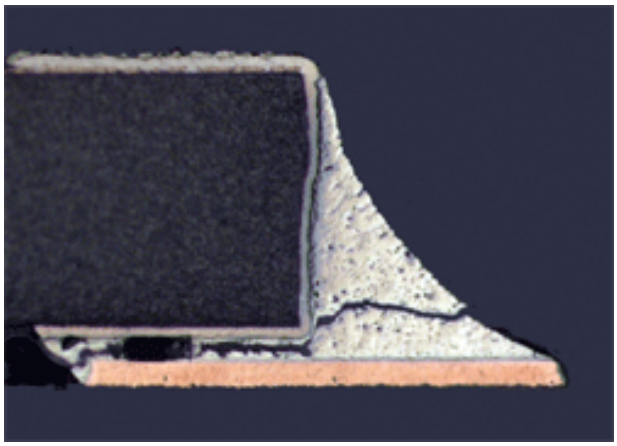

Figure 5. A Pb-free solder joint can fail earlier than an SnPb solder joint when subjected to mechanical vibration or shock in the field (courtesy University of Maryland-CALCE).

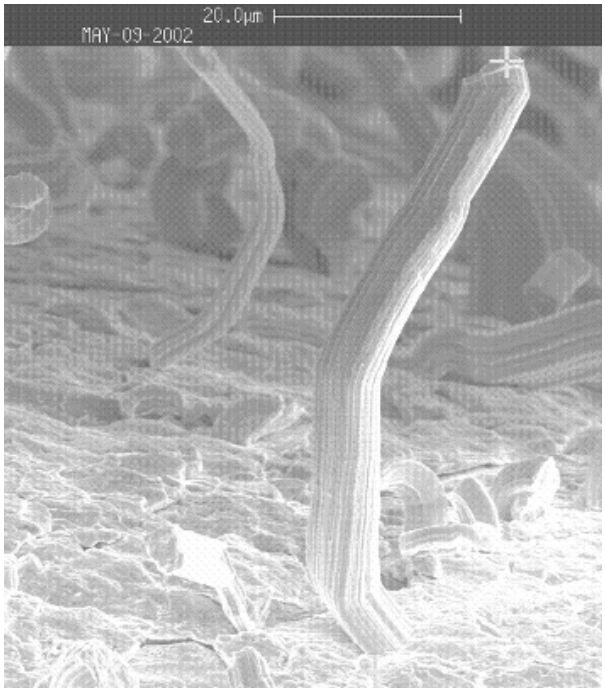

Figure 6. Tin Whiskers on a Tin-Plated Ceramic Chip Capacitor [8].

SUMMARY

With the goal of responding to the long-term challenge of Pb-free solders and finishes, the Pb-Free Electronics Risk Management (PERM) Consortium provides overarching leadership and coordination of Pb-free electronics risk management activities for the aerospace, defense and high-performance (ADHP) communities. Evolving out of previous government and industry efforts, the PERM Consortium provides a forum for leadership, communications, research coordination, standards and handbooks, training, advocacy, supply chain, and international cooperation through dedicated task teams and advisory groups. The PERM Consortium is chartered by the Aerospace Industries Association (AIA) and includes support from DoD, DoE, FAA, NASA, industry, academia, and international members.

Combining the talents and resources of many interrelated stakeholders will result in a disciplined approach to developing strategies to mitigate the performance risks from the integration of a multitude of new and uncharacterized materials. Throughout this entire effort, the PERM consortium continues to maintain its focus on the most critical of all stakeholders, - the warfighter.

ADDITIONAL ACKNOWLEDGMENTS

The past successes of the LEAP WG and the current progress of the PERM is attributed to many, many professionals who are also people caring very much about our warfighters. Included are those who served as the first leads for the original PERM committees. They are Lloyd Condra (Research Coordination), Bill Procarione (Supply Chain Risk Management), Gary Latta (Standards and Handbooks), Communications (Vance Anderson), Tim Kalt (Training), Dave Humphrey (Advocacy), and Bob Gregory (International Advisory). Others have since taken over these positions and their names can be found at the PERM website http://aia- aerospace.org/resource_center/affiliate_ sites/perm/members/.

I also wish to acknowledge my family: my wife Karen and my two sons John and Matthew for their patience and support .

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