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Message from the Director: Advancing Aerospace Reliability, Maintainability and Safety

In its 2015 outlook for the aerospace industry, the international consulting firm Deloitte ("2015 Global aerospace and defense industry outlook," Deloitte Touche Tohmatsu, 2010.) heralded the "rising fortunes of the commercial aerospace sector," wherein robust growth will be driven by the replacement of obsolete aircraft with more fuel-efficient planes and the increasing demand for passenger travel in India, China, and the Middle East. In total, Deloitte forecasts that over the next 10 years the annual production of commercial aircraft will grow by 20 percent.

As the commercial aerospace sector continues grows, it is expected that Boeing's and Airbus' current duopoly in commercial aircraft manufacturing, will face the rise of China as a new competitor. This increased competition is expected to have a powerful impact on the technology innovations, supply chain value, sustainment strategies, and costs. Design for reliability and safety, supply chain creation, parts selection, qualification practices, reliability prediction, maintenance forecasting, obsolescence management, and counterfeit avoidance, will all be issues that must be addressed in an efficient and cost effective manner, to produce products that are less expensive to operate and sustain.

Since its inception in 1985, CALCE has had particularly strong ties to the global aerospace industry. Clients and partners have included Airbus (France), Bombardier (Canada), Boeing, BAE Systems (UK), AVIC (China), Crane, Curtiss Wright Controls, Embraer (Brazil), General Dynamics, General Electric, Goodrich, Harris, Honeywell, Lockheed Martin, L3, MIT Lincoln Labs, Moog, NASA, Northrup-Grumman, Orbital Sciences, Raytheon, Rolls-Royce (UK), Rockwell Collins, Smiths Industries (GE Aerospace), Textron, Unison Industries, United Technologies Aerospace Systems, the U.S. Air Force, U.S. Coast Guard, the U.S. Federal Aviation Administration, U.S. NAVAIR, and Westland Helicopters (UK). Each of these companies has looked to CALCE for help in developing state-of-the-art methods and technologies for next-generation systems.

By the use of machine learning techniques, CALCE has enabled the forecasting of maintenance, rather than relying on scheduled maintenance. Furthermore, because of our expertise in the actual failure mechanisms of electronics systems, we now have the tools to aid in design for reliability, as well as diagnostics and prognostics. With the anticipated growth in the commercial aerospace sector, CALCE is actively collaborating with companies internationally to achieve their design, operational, and sustainment goals.

Founder and Director

CALCE's Impact on Aerospace Industry Sectors

The total revenues for the global aerospace and defense industry were over $640 billion in 2014, with the US alone accounting for $272 billion of that total. These revenues are expected to increase, driven largely by high demand for passenger travel on the part of newly wealth residents of India, China, and the Middle East. The increased market size will present many challenges for the aerospace supply chain. More OEMs will enter the market, driving the need to detect counterfeits and ensure the reliability of new products from companies that don't have track records. Increased competition will mean shorter product qualifications times for new products. CALCE has been actively involved in creating solutions to all these challenges, and has been very active in educating leading industry members about the latest developments in avionics reliability and supply chain management.

Supply Chain

Design-related research has supported supply chain creation and management; component selection; rating, derating, and uprating; and reliability, safety, and obsolescence management. To this end, CALCE faculty have spearheaded the development of key supply chain and electronic component management (ECMP)-related standards, in particular, IEEE 1624 (*IEEE Standard for Organizational Reliability Capability*), which is a supply chain creation and assessment document that supports efficient supply chain creation, IEEE #1332 *Reliability Program Standard*, and IEEE #1413 *Standard Methodology for Reliability Prediction and Assessment for Electronic Systems and Equipment*. In the area of uprating, CALCE personnel developed the primary technical content for the Government Electronics and Information Technology Association (GEIA) and IEC standards on uprating. CALCE also produced a series of related books on parts selection and management and uprating.

Sustainment

CALCE is well known in the field of sustainment, having provided services to over 20 companies and governmental organizations including design refresh planning, forecasting, human obsolescence, and end-of-maintenance analyses. CALCE has also developed models and performed life cycle costing of aerospace systems that include prognostics and health monitoring (PHM) and return-on-investment analysis. Several cost-modeling efforts associated with the conversion to lead-free electronics have been completed. Specific examples of the cost modeling include end-of-maintenance analysis (Harris), throw-away analysis (Boeing), lead-free repair costing and sustainment stovepipes (NSWC Crane), open systems cost tradeoffs (General Dynamics/USAF), obsolescence management (Frontier Technologies), refresh planning model development (USAF), material risk index development (Westland Helicopters), cost manufacturing lead-free electronic (Honeywell), electronic part sourcing (Textron), obsolescence assessment (FPGAs for Rolls-Royce), and obsolescence management (U.S. Coast Guard).

Transition to Lead-free Electronics

While aerospace equipment is exempt from lead-free regulations such as the Restriction of Hazardous Substances (RoHS) 2011/65/EU, the global economy and the dominance of consumer-based electronics has resulted in the elimination of lead-based electronic devices in the supply chain. As a result, electronic equipment manufacturers have looked to CALCE for mitigation approaches and lead-free solutions. To this end, CALCE has developed approaches to assess the reliability of reprocessed parts that have had their terminal finishes converted from a lead-free material to tin-lead. In addition, CALCE has developed life models for tin-based solders such as SAC305, SnAg, SN100C, and other low-silver tin-based alloys, and benchmarked these materials against eutectic tin-lead solder under harsh operating conditions. To mitigate the shock loading risk of some lead-free material systems, CALCE has investigated underfill and staking mitigation approaches and has developed life assessment models. As new materials continue to be developed, CALCE is continuing to test solder alloys, such as SACBi-based quaternary alloys, to develop life assessment models. In addition to solder interconnects, CALCE is examining the impact of process temperature and material changes on printed wiring board reliability. Printed wiring boards provide electronic connectivity and isolation of electric circuits formed to provide desired functions. Property changes, conductive anodic filament formation, and creep corrosion of lead-free finished copper pads for printed wiring boards present failure risks for automotive electronics.

In addition to the change in solder material, the removal of lead in electronics has raised concerns about failure risk due to tin whiskers. Conductive filament structures that spontaneously form on tin-finished surfaces, tin whiskers are a reliability concern for aerospace electronics. Because tin whiskers are conductive, their formation can create unintended electrical failures such as short circuits. Since 2007, CALCE has hosted eight international symposia on the topic of tin whiskers, with significant attendance by most of the aerospace community. To assess the potential for tin whisker-induced metal vapor arc formation, CALCE has developed models that can be used by electronic equipment designers. Further, CALCE has identified conformal coating quality issues that need to be considered when employing coating as a tin whisker risk mitigation strategy and is currently examining novel thin coating systems, such as atomic layer deposited (ALD) aluminum oxide and vapor deposited fluorocarbons. CALCE has also developed a tin whisker risk assessment model with Simulation Assisted Reliability Assessment (calceSARA®) software. calceSARA® provides simulation modules to assess the life expectancy of electronic hardware under anticipated life cycle loading conditions, as well as under accelerated stress test conditions. calceSARA® has been used to assess designs by EADS, Goodrich, Honeywell, NASA, Northrup-Grumman, Orbital Sciences, and Rockwell.

Product Qualification

With regard to establishing product qualification, CALCE has developed physics-of-failure (POF)-based simulation-assisted (virtual qualification) approaches to avionics. The application of POF, based on fundamental models for expected failure mechanisms, is a key approach for establishing test conditions and acceleration factors for assuring expected life. Furthermore, CALCE has been developing data-driven prognostics-based qualification methods to significantly reduce test times by analyzing the onset of degradation using machine learning techniques that CALCE developed for NASA. CALCE has developed experimental and mathematical techniques for the detection of anomalies and prognostics for a number of aerospace organizations. CALCE developed a method to exploit the behavior of high-frequency signals to detect and characterize early stages of degradation in electronic interconnects. A project that was conducted in partnership with MIT Lincoln Laboratories enabled the demonstration for the first time of a reliability monitoring technique using time domain reflectometry (TDR) for multichannel assessment of a highly complex area array package containing over 7,000 separable interconnects, which was intended for satellite applications. CALCE has also provided support to NAVAIR and Lockheed Martin to identify and develop mathematical algorithms for anomaly detection and prognostics for both rotary and fixed-wing aircraft.

CALCE is currently working with aerospace partners Embraer, Moog, United Technologies, and Unison to assess the use of highly accelerated stress screens (HASS) compared to environmental stress screens (ESS) for electronic systems. CALCE has been working with these partners to develop accelerated testing methods for life assurance under combined stress conditions (combined vibration and temperature cycling) and under simultaneous multi-axial vibration loading. This research has enabled companies to model the nonlinear interactions between different load (stress) sources, so that damage accumulation rates can be quantified and the corresponding acceleration factors determined.

Counterfeit Part Detection

For products with long development and deployment cycles, counterfeit materials have become an increasing concern, particularly with the globalization of the electronics supply chain. CALCE was the first organization to help develop a technical bulletin (GEIA-TB-0003) based on concerns regarding counterfeit parts with GEIA. The ability to detect and avoid procuring counterfeit materials is critical to product integrity. To this end, CALCE has organized 12 conferences with the Surface Mount Technology Association (SMTA) for experts and organizations to share information on counterfeit detection and avoidance strategies. CALCE was the first to demonstrate the feasibility of tagging of parts with Prime Nanotech and Raytheon. CALCE has also conducted evaluations on the durability of tagging materials used in electronic devices to provide product authentication in partnership with DLA, Applied DNA Sciences, DataDot, and InfraTrac. CALCE efforts have resulted in commercially available tagged components for Cardinal Components. CALCE has also examined the use of material- and geometry-related markers for product authentication. Finally, CALCE is working with the SAE to develop standards for counterfeit detection and avoidance. Mr. Bhanu Sood, Dr. Diganta Das, and Dr. Michael Azarian are co-chairs, respectively, of the SAE G-19A subcommittees on Radiology, X-ray Fluorescence, and Miscellaneous Techniques (analytical chemical, physical, and thermal techniques) for the AS6171 Test Methods Standard on Detection of Counterfeit Electronic Parts. CALCE has provided training on counterfeit part detection and avoidance to many commercial and military avionics companies. CALCE has also provided consulting to the Department of Commerce and GAO on assessing the extent and impact of counterfeit parts, which led to major policy changes in defense and commercial aviation.

Avionic Batteries

CALCE has been developing approaches to improve the safety, reliability, and performance of avionic batteries. Collectively, CALCE researchers have authored over 35 internationally acclaimed textbooks and more than 150 publications on battery software development, lithium-ion battery testing, failure analysis, state of charge (SOC) model development, state of health (SOH) model development, POF/reliability and safety model development, implementation of prognostic methods to predict battery failure, novel battery material development, and material testing and characterization. The developed battery techniques and models can be incorporated into battery management systems (BMSs).

CALCE received an $80,000 grant from the Naval Air Warfare Center–Aircraft Division (NAWCAD) to develop advanced prognostics technologies for lithium-ion batteries that can assure high reliability and performance with minimum maintenance. On April 4, 2013, CALCE presented a web seminar on Boeing 787 Dreamliner fleet battery issues to over 200 engineers and scientists from government organizations, industry, and academia. CALCE has also developed a short-course on battery performance modeling and safety that has been presented to personnel from Aero Design, Harris RF Communication, HEICO, NASA, and Naval Surface Warfare Center (NSWC). CALCE was also a member of the technical consulting team to a major NASA effort looking at low-voltage failures of ceramic capacitors, whose 98-page report provided guidance on the use and screening of ceramic capacitors. CALCE is gradually shifting the research to analysis and modeling on battery failure mechanisms based on the previous experience. In-situ observation tests on the morphology and quantification of battery dendrite growth have been conducted for improving battery safety and material design at CALCE.

Education

CALCE has also supported the industry through professional development courses for the avionics industry (see table below). In addition, Prof. Pecht has organized full-length courses for NASA, given by CALCE experts. Prof. Pecht has also given numerous specialized presentations for senior Boeing and Airbus executives.

Course	Participants
Design refresh planning	Argon ST, ARINC, Army CECOM, DHS, ESSM, , Harris, Honeywell, Lockheed, NavAir, NIWA, NSWC Crane, Northrop, Raytheon, The U.S. Navy, and UK MOD
Obsolescence and cost modeling	ARINC, ASSETT, DRS Technologies, Frontier Technologies, Harris, Honeywell, Kollmorgen, Lockheed, Morey Corporation, NASA, Raydon, Trimble Navigation, UK MOD, United Defense, United Technologies, and Willcor
Electronic part obsolescence forecasting mitigation and management	BAE Systems, Canada Marshall Aerospace, Honeywell, Naval Air Warfare Center Weapons Division (NAWCWD), Sikorsky Aircraft, TCS Space & Component Technology, Tubitak-Uzay (Turkey Space Technology Research Institute), and UK Smiths Industries
Counterfeit detection and avoidance for electronics	Aerospace Corporation, Airbus Group, Boeing, CMC Electronics , Lockheed Martin, NASA Johnson Space Center, Northrop Grumman Aerospace Systems, and The U.S. Air Force
Uprating electronic devices	Allied Signal, Honeywell, Moog Space and Defense Group, Raytheon, Saab, and The U.S. Department of Energy
Electronic parts selection and management	Connecticut Hamilton-Sundstrand, NASA Johnson Space Center, The U.S. Department of Energy, and Technobit
Failure analysis of electronics	BAE Systems, Boeing, Celestica International, Channel One International, Crane Aerospace and Electronics, Honeywell Aerospace, Lockheed Martin Aeronautics, Lockheed Martin Space Systems, NASA Goddard Space Flight Center, Northrop Grumman Aerospace Systems, Rockwell Collins NASA Ames Research Center, and UTC Aerospace Systems
Lead-free readiness	CERPEI China, Embraer, Emerson Divisions & Electronics, Halliburton, Lockheed Martin, L3 Electronic Systems, and Schlumberger
Virtual qualification of electronics	BAE, Embraer, Honeywell, L3 Electronic Systems, Moog, NASA, and Tubitak-Uzay (Turkey Space Technology Research Institute)
Physics-of-failure and reliability	Honeywell, Indian Space Research Organization, NASA, and Tubitak-Uzay (Turkey Space Technology Research Institute).

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