



AEROSPACE RECOMMENDED PRACTICE

ARP7505™

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Risk Assessment after Tin Whisker Observation

RATIONALE

Aerospace, defense, and high-performance (ADHP) manufacturers may need to assess the risk of hardware failures attributed to tin whiskers. While GEIA-STD-0005-2 focuses on tin whisker mitigation and impact, it does not address assessment of risk posed by tin whiskers once they have been detected. This document provides recommendations on how to assess these risks by inspecting and measuring whiskers, documenting hardware history, modeling, and simulation. Informative case studies/lessons are provided to assist analysts in this process.

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1. SCOPE

This document contains information and guidance on assessment of the risk posed by observed tin whiskers for aerospace, defense, and high-performance (ADHP) products or other products that demand high reliability.

1.1 Purpose

This document provides direction on what steps to take once tin whiskers are identified on electronics. Accurate detection and measurement of whiskers requires careful inspection methods. This document also presents features that are often misidentified as tin whiskers without adequate materials analysis. It then provides a list of historical details from the assembly (including other potentially implicated hardware) that should be reviewed to isolate what caused the use of whisker-prone material(s) and bound the impact.

To assess the risk of the tin whiskers, the document covers modeling/simulation approaches involving the assembly geometry and magnitude of applied voltage. Common failure modes due to tin whiskers are provided for the community to understand the possible consequences of tin whiskers, which is frequently misunderstood/underestimated. The concept of how tin whisker populations pertain to Failure Modes, Effects, and Criticality Analysis (FMECA) is briefly covered. Several case studies and lessons learned from tin whiskers are also included. This combination of estimating the probability of various failure modes and the impact of the failure ultimately provides a qualitative method to assess risks to the mission, which is the purpose of this document.

1.2 Background

Since 2002, two European Union (EU) directives have prohibited the use of lead (Pb) in electronics, including the [Restriction of Hazardous Substances \(RoHS\)](#) and [Waste Electrical and Electronic Equipment \(WEEE\)](#). ADHP products historically used lead (Pb) to mitigate the formation of tin whiskers in component finishes and solder joints, but the likelihood of tin whisker formation in these high-reliability applications has risen due to the restriction of Pb in certain markets and applications and the rise in Pb-free materials without adequate mitigations. Additionally, the ADHP industry has been using more Pb-free commercial-off-the-shelf (COTS) electronics for their newer technologies due to the limited availability of leaded (Pb-containing) components.

While there are SAE standards summarizing tin whisker mitigation and impacts, there is limited available information on what to do if tin whiskers are found on electronic hardware and/or mechanical structures in close proximity to electronic hardware. The intent of this document is to bridge that gap and provide information on how to perform a thorough risk assessment once tin whiskers have been identified during electronics inspection.

Figure 1 illustrates the general flow of suggested actions once the presence of whiskers is verified, the initial step of which is to compile the unit/assembly history including the materials of the components and assembly processes/unit exposures. If no whisker-induced failures have been confirmed, the crucial steps are to:

- Characterize the whisker population (density or number of whiskers per area, lengths, diameters)
- Assess the unit geometry (i.e., with emphasis on spacing between exposed electrical conductors at different electrical potentials) and failure-prone areas
- Determine whether whiskers could break loose (or whether there are already loose whiskers) and could be redistributed to other regions
- Use modeling/simulation to estimate the likelihood of whiskers causing bridging or other failures at susceptible areas and document the consequences/worst-case scenarios based on the potential failure modes in the given application

The output of this compilation is the risk assessment that can be provided to leadership and the customer for informed decision making about what additional mitigations may be necessary and what (if any) equipment in the field is at risk of failure.

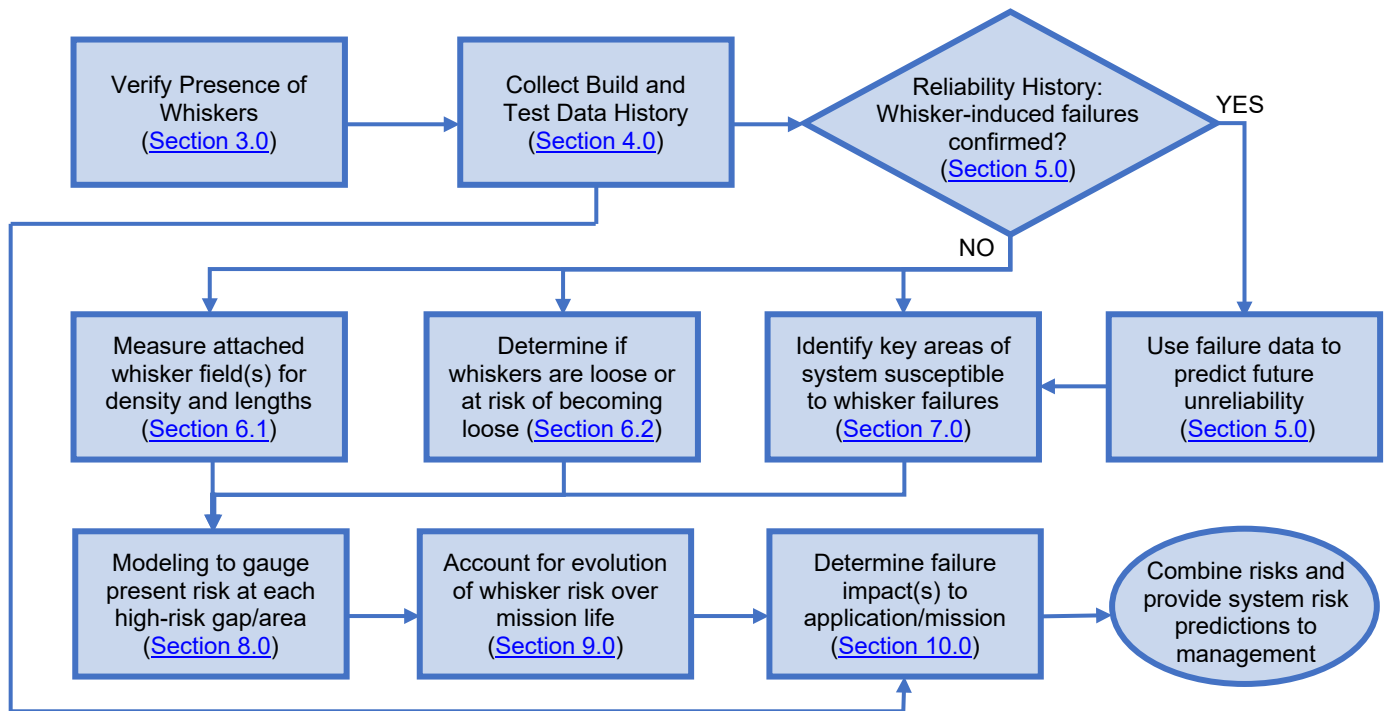


Figure 1 - Flow chart for tin whisker risk assessment activities

1.3 Misconceptions

This document does not provide methods to anticipate when whiskers will spontaneously form, nor does it provide absolute predictions on whisker density, diameter, lengths, and growth rates, which are dependent on a multitude of factors. Whenever possible, risk assessments should be based on actual findings on production (or relevant) hardware that has grown tin whiskers, as there are limitations in projecting growth. If not, estimations on similar parts or other reported statistics could be used.^[1] It also does not provide guidance on Pb-free control plans or mitigation which should be implemented early on during program planning and are covered in GEIA-STD-0005-1 and GEIA-STD-0005-2, respectively.

1.4 Intended Use

This document is intended for use as technical guidance by ADHP electronics system suppliers and their customers (i.e., aerospace and military vehicle integrators, operators, regulatory organizations, and their suppliers such as system original equipment manufacturers and system maintenance facilities). It is intended for guidance with the development and fielding of ADHP products; however, it may also be referenced for other products with similar characteristics (e.g., low volume, rugged use environments, high reliability, and long lifetime).

This document establishes guidelines as the aforementioned parties incorporate Pb-free materials into assemblies and find tin whiskers. It may also be used to assess implicated hardware in the field after finding tin whiskers on follow-on builds with the same components/materials or in hardware returned from or inspected in the field. The information contained herein is intended to make product teams aware of the risk of tin whiskers to their hardware/mission in order to make informed decisions on whether additional mitigations are necessary or whether the risk is manageable as is. This is achieved through:

- Implementing optimal inspection methods to detect tin whiskers
- Assessing unit/assembly history
- Modeling/simulating the whisker population, their potential changes over time, and the likelihood for whisker bridging and causing electrical shorting, metal vapor arcing, and/or failures caused by conductive debris
- Determining the likelihood and impact of potential failure modes based on assembly-specific parameters

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (U.S. and Canada only) or +1 724-776-4970 (outside U.S. and Canada), www.sae.org.

SAE J1739	Potential Failure Mode and Effects Analysis (FMEA) Including Design FMEA, Supplemental FMEA-MSR, and Process FMEA
GEIA-HB-0005-2	Technical Guidelines for Aerospace and High Performance Electronic Systems Containing Lead-free Solder and Finishes
GEIA-STD-0005-1	Standard for Developing a Lead-Free Control Plan to Manage the Risks of Lead-Free Solders and Finishes in Aerospace, Defense, and High-Performance Soldered Electronic Products
GEIA-STD-0005-2	Standard for Mitigating the Effects of Tin Whiskers in Aerospace, Defense, and High Performance Electronic Systems

2.1.2 IEC Publications

Available from IEC Secretariat, 3 rue de Varembe, PO Box 131, CH-1211 Geneva 20, Switzerland, Tel: +41 22 919 0211, www.iec.ch.

IEC 60068-2-82	Environmental Testing - Part 2-82: Tests XW ₁ : Whisker Test Methods for Electronic and Electric Components
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2.1.3 Global Electronics Association Publications

Available from Global Electronics Association, 3000 Lakeside Drive, 105 N, Bannockburn, IL 60015, Tel: 847-615-7100, www.electronics.org.

JESD201	Environmental Acceptance Requirements for Tin Whisker Susceptibility of Tin and Tin Alloy Surface Finishes
JESD22-A121	Measuring Whisker Growth on Tin and Tin Alloy Surface Finishes

2.1.4 U.S. Government Publications

Copies of these documents are available online at <https://quicksearch.dla.mil>.

MIL-HDBK-502	Product Support Analysis
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2.1.5 Other Publications

- [1] Panashchenko, L. (2009). *Evaluation of Environmental Tests for Tin Whisker Assessment* (Figure 16). University of Maryland, College Park.
- [2] NASA Guidance for Optical Inspection for Metal Whiskers - a series of informational videos intended to improve the probability of detecting metal whiskers. Available at <https://nepp.nasa.gov/whisker/video/inspection/index.html>.
- [3] Hillman, D. (2009). *False Tin Whiskers: Masquerading Tin Copper Intermetallics*. Proceedings of SMTA International Conference.
- [4] Panashchenko, L. (2010). *Plating Dendrite Formations on Sn plating*. CALCE University of Maryland.
- [5] Carpentier, N. et. al. (2024). *Aerospace Report No. TOR-2024-01220: Tin Whiskers - Commercial-off-the-shelf (COTS) Parts Usage, Risk Assessment, and Mitigation Guidance*. The Aerospace Corporation.
- [6] GEIA-STD-0005-2. *Standard for Mitigating the Effects of Tin Whiskers in Aerospace, Defense, and High Performance Electronic Systems*. SAE International.
- [7] Panashchenko, L. (2012). *The Art of Metal Whisker Appreciation*. NASA Goddard Space Flight Center.
- [8] Schmidt T.E. et al. (2023). *Long-Term Tin Whisker Risk Mitigation Using a Conformal Coating*. National Aeronautics and Space Administration (NASA). Available at <https://ntrs.nasa.gov/citations/20230008802>.
- [9] Panashchenko, L., Brusse, J., and Leidecker, H. (2010). *Long-Term Investigation of Urethane Conformal Coating Against Tin Whisker Growth*. NASA Goddard Space Flight Center.
- [10] JSC-66491. *Standard for JSC Lead-Free Control Plans (LFCP)*. National Aeronautics and Space Administration (NASA).
- [11] Woodrow, T.A. (2005, April 18-20). *Evaluation of Conformal Coatings as a Tin Whisker Mitigation Strategy*. IPC/JEDEC 8th International Conference on Lead-Free Electronic Components and Assemblies, San Jose, CA.
- [12] Woodrow, T.A. (2006, September 24-26). *Evaluation of Conformal Coatings as a Tin Whisker Mitigation Strategy, Part 2*. Proceedings of SMTAI International Conference, Rosemont, IL.
- [13] Fox, W. and Woody, L. (2014). *Tin Whisker Risk Management by Conformal Coating*. Proceedings of IPC APEX EXPO, Las Vegas, NV.
- [14] Sivakumar, P. et al. (2021). Long-term Thermal Aging of Parylene Conformal Coating Under High Humidity and its Effects on Tin Whisker Mitigation. *Polymer Degradation and Stability*.
- [15] Wickham, M. *1500 days of testing Sn whiskering PCB assemblies to determine the suitability of conformal coatings to mitigate against shorting*. National Physical Laboratory.
- [16] Han, S. (2012). *Assessment of an Electrical Shorting and Metal Vapor Arcing Potential of Tin Whiskers* [Doctoral thesis]. University of Maryland.
- [17] Courey, K.J. et. al. (2008). Tin Whisker Electrical Short Circuit Characteristics, Part I. *IEEE Transactions on Electronics Packaging Manufacturing*, 31, 2-40.
- [18] Courey, K.J. et. al. (2009). Tin Whisker Electrical Short Circuit Characteristics Part II. *IEEE Transactions on Electronics Packaging Manufacturing*, 32, 41-48.
- [19] Van Westerhuyzen, D. et. al. (1992). *Tin Whisker Induced Failure in Vacuum*. Proceedings of International Symposium for Testing and Failure Analysis.

- [20] Mason, M. and Eng, G. (2007). *Understanding Tin Plasmas: A New Approach to Tin Whisker Risk Assessment*. Proceedings of 45th Annual Reliability Physics Symposium, IEEE International.
- [21] Slade, P.G. (1999). *Electrical Contacts: Principles and Applications*. Dekker.
- [22] Atalla, M.M. (1955). Arcing of Electrical Contacts in Telephone Switching Circuits: Part V - Mechanism of the Short Arc and Erosion of Contacts. *Bell System Technical Journal*, 34, 1081-1102.
- [23] Corliss, C.H. (1962). Temperature of Copper Arc. *United States Bureau of Standards - Journal of Research - Physics and Chemistry*, 66A, 5-12.
- [24] Richardson, B.L.J. (1992). *Tin Whisker Initiated Vacuum Metal Arcing in Spacecraft Electronics*. Proceedings of 1992 Government Microcircuit Applications Conference.
- [25] Qualitative Application-Specific Risk Assessment Tool Hyperlink: [Pinsky Tin Whisker Risk Algorithm](#)
- [26] Touw, A. (2007). *Tin Whisker Interactions: A Monte Carlo Analysis*. CALCE Intl. Symposium on Tin Whiskers.
- [27] McCormack, S. and Meschter, S. (2009). *Probabilistic Assessment of Component Lead-to-Lead Tin Whisker Bridging*. International Conference on Soldering and Reliability.
- [28] <https://web.calce.umd.edu/tin-whiskers/spreadsheet/>
- [29] Hilty, R.D. and Corman, N. (2005). *Tin Whisker Reliability Assessment by Monte Carlo Simulation*. IPC/JEDEC Lead-Free Symposium.
- [30] Closed-form Risk Assessment Tool for attached whiskers developed under SERDP Contract: [Tin Whisker Spreadsheet](#)
- [31] Closed-form Risk Assessment Tool for detached whiskers (accessible by PERM only): [8-80 Lead Free Electronics Risk Management \(PERM\) Council - IPC WORKS](#)
- [32] Panashchenko, L., Brusse, J., and Leidecker, H. (2010). *Long Term Investigation of Urethane Conformal Coating Against Tin Whisker Growth*. IPC Tin Whisker Conference.
- [33] MIL-HDBK-502. *Product Support Analysis*. Department of Defense.
- [34] SAE1025. *Failure Mode and Effects Analysis (FMEA), Includes Criticality Analysis and Design, Supportability, Software, and Process FMEA*. SAE International.
- [35] Nagel, L.W. and Pederson, D.O. (1973). *SPICE (Simulation Program with Integrated Circuit Emphasis)*. University of California, Berkeley. Available at <http://www.eecs.berkeley.edu/Pubs/TechRpts/1973/22871.html>.
- [36] Courey, K. et al. (2009). Tin Whisker Electrical Short Circuit Characteristics - Part II. *IEEE Transactions on Electronics Packaging Manufacturing*, 32(1).
- [37] Han, S., et al. (2010). Electrical Shorting Propensity of Tin Whiskers. *IEEE Transactions on Electronics Packaging Manufacturing*, 33(3), 205-211.
- [38] Courey, K.J. et al. (2008). Tin Whisker Electrical Short Circuit Characteristics - Part I. *IEEE Transactions on Electronics Packaging Manufacturing*, 31(1).
- [39] Dunn, B. (1988). Mechanical and Electrical Characteristics of Tin Whiskers with Special Reference to Spacecraft Systems. *European Space Agency (ESA) Journal*, 12, 1-17.
- [40] Hada, Y. et al. (1978, April 25-26). *Study of Tin Whiskers on Electromagnetic Relay Parts*. 26th Annual National Relay Conference.

- [41] Slade, P.G. (1999). *Electrical Contacts*. Marcel Dekker.
- [42] Mason, M. S. and Eng, G. (2007). Understanding tin plasmas in vacuum: A new approach to tin whisker risk assessment. *Journal of Vacuum Science and Technology A: Vacuum, Surfaces and Films*, 25, 1562-1566.
- [43] Han, S. et. al. (2011). *Likelihood of Metal Vapor Arc by Tin Whiskers*. IMAPS Advanced Technology Workshop on High Reliability Microelectronics for Military Applications.
- [44] Anecdote: Tin Whiskers on Bus Bars
- [45] Leidecker, H., Panashchenko, L., and Brusse, J. (2011). *Electrical Failure of an Accelerator Pedal Position Sensor Caused by a Tin Whisker and Investigative Techniques Used for Whisker Detection*. 5th International Tin Whisker Symposium.
- [46] Lesniewski, T. (2009). *Assessment of Whisker Growth from Tin Coated Wire and Cable*. 2009 SMTAI Conference.
- [47] Metal Whiskers: A Discussion for CALCE Symposium. Available at <http://nepp.nasa.gov/WHISKER/experiment/exp2/index.html#current>.
- [48] IPC/PERM-WP-022 (2018). *Mitigation of Pure Tin Risk by Tin-Lead SMT Reflow - Results of an Industry Round-Robin*. White Paper Report Developed by IPC.

2.2 Acronyms

ADHP	Aerospace, Defense, and High Performance
APP	Accelerator Pedal Position
BSE	Backscatter Electron
COTS	Commercial-off-the-Shelf
CTE	Coefficient of Thermal Expansion
DoT	Department of Transportation
DTC	Diagnostic Trouble Code
ECM	Electrochemical Migration
EDS	Energy-Dispersive X-ray Spectroscopy
ESD	Electrostatic Discharge
EU	European Union
FOD	Foreign Object Debris
FMECA	Failure Modes, Effects, and Criticality Analysis
GSFC	Goddard Space Flight Center (NASA)
IMC	Intermetallic Compound
LED	Light Emitting Diode
MEMS	Microelectromechanical System

MVA	Metal Vapor Arcing
NEPP	NASA Electronic Parts and Packaging
NESC	NASA Engineering and Safety Center
OEM	Original Equipment Manufacturer
PERM	Pb-Free Electronics Risk Management (Working Group)
PCB	Printed Circuit Board
PWB	Printed Wiring Board
RF	Radio Frequency
RH	Relative Humidity
RoHS	Restriction of Hazardous Substances
SAE	SAE International
SE	Secondary Electron
SEM	Scanning Electron Microscopy
SERDP	Strategic Environmental Research and Development Program
SMT	Surface Mount Technology
TO	Transistor Outline (referring to package type)
Vrms	Voltage Root Mean Square
WEEE	Waste Electrical and Electronic Equipment
XRF	X-ray Fluorescence

3. VERIFICATION OF WHISKERS

3.1 Optical Inspection of Tin Whiskers

To properly identify the presence of tin whiskers during inspection of hardware, appropriate lighting and equipment needs to be utilized. It is also important to note that some tin whiskers are too subtle for optical detection, and scanning electron microscopy (SEM) analysis may be necessary. As a starting point, the following website contains several video demonstrations by the NASA Electronic Parts and Packaging (NEPP) Program^[2] with useful guidance for the optical inspection of metal whiskers: <https://nepp.nasa.gov/whisker/video/inspection/>.

The videos highlight the importance of the combination of angle and type of illumination in conjunction with angle of inspection. They provide examples of both sparse and dense populations of whiskers as well as attached versus detached whiskers.

Limitations:

The material herein is presented “for guidance only.” The optical inspection techniques described are not guaranteed to detect all metal whiskers. Recommended equipment is shown in Table 1. Optical detection of metal whiskers can be hindered by many factors including, but not limited to:

- Insufficient operator experience inspecting actual metal whiskers.
- Operator fatigue from excessive inspection times.
- Use of improper light sources (e.g., ring lamps), angle of inspection versus angle of illumination, insufficient magnification.
- Very narrow thicknesses (on the order of 1 micron, which is less than 1/10th diameter of a human hair) and irregular, faceted edges of metal whiskers make illumination critical.
- Excessive glare from reflective surfaces can obfuscate whiskers.
- Conformal coatings can produce reflections or haloing that obfuscate whiskers.
- Objects adjacent to whiskers may block line of sight, illumination, or combination thereof necessary to see specific metal whiskers.
- Whiskers may be growing inside of packaged devices, requiring destructive analysis that may disturb, dislodge, or relocate metal whiskers.

Table 1 - Recommended equipment for whisker inspection

Equipment	Preferred	Not Preferred
Light Source	One or more narrow beam LED light sources with widely adjustable angle of illumination (e.g., goose neck) and variable brightness control. Reduced background/ambient lighting to remove stray illumination of region of interest.	Avoid ring light and/or bright field illumination that may over-illuminate the background, leading to glare/reflections that obfuscate whiskers in the foreground. Avoid filament or halogen light sources that may produce distracting shadows.
Stage	Multi-axis translation and rotation stage to vary orientation and stabilize the sample/region of interest relative to light source. (Optional) Hand-held orientation.	Stage setup or part fixturing that is unstable and puts the hardware at risk of falling over, potentially damaging or losing the whisker(s).
Optical Microscope	Magnification: ~3x to 100x (Optional) Digital (Optional) Binocular eye pieces may enhance 3D depth of field.	Insufficient resolution or artifacts/features created by digital software for digital microscopes that obscure the whisker or complicate the evidence.
Naked Eye	Possible to detect relatively long and/or dense populations of whiskers without magnification aid assuming proper illumination.	Due to the possibility of human error, it's suggested to also proceed with optical microscopy at higher magnification.

Procedure:

The following section provides guidance to improve the probability of detecting metal whiskers on hardware when optical inspection techniques are used. Emphasis has been placed on the importance of the type of lighting source used in combination with variable lighting angles and inspection angles. Metal whiskers are much smaller than a human hair and thus may be incredibly difficult to detect (see Figures 2 and 3).

**Figures 2 and 3 - Optical and SEM images comparing the thickness of a metal whisker to a human hair**

1. Handling:

- a. Follow electrical and other safety guidelines appropriate for the hardware to be inspected, including electrostatic discharge (ESD) mitigation practices.
- b. Avoid direct physical contact, forced air, or fluid cleaning of surfaces to be inspected. Such activities may detach whiskers and/or remove or relocate loose whisker debris.
- c. When available, handle object of interest using a stage with multi-axis translation and rotation. Hand-held positioning of hardware is optional.

2. Illumination and Angle of Inspection:

- a. The combination/variation of lighting angle and inspection angle are critical to increasing the probability of detection of metal whiskers via optical microscopy (see Figure 4).
- b. (Optional) Reduce ambient lighting (e.g., use dimly lit room) to eliminate stray light sources that may introduce glare or other unwanted illumination that can impact detection of whiskers.
- c. Avoid using “ring lamps,” which tend to inhibit proper illumination of extremely thin objects such as metal whiskers (see Figures 5 and 6).
 - i. Although ring lamps are desirable in circumstances requiring “shadowless” illumination, they also tend to produce excessive illumination of background or adjacent objects, resulting in glare that may inhibit detection of metal whiskers.
- d. Use a narrow beam light source (LED type is preferred) whose direction can be varied significantly through all axes (see Figures 7 through 12)
 - i. Multiple light sources from different angles may also be used
- e. Begin by shining light almost parallel to surface/region of interest.
- f. While inspecting, vary the angle of illumination slowly through as many angles as practical.
- g. Try also shining the light perpendicular to the surface of interest

3. Angle of Inspection:

- a. Look at the surface from a low angle almost parallel to the surface (e.g., lining up a putt).
- b. If possible, place a dark-colored, low reflection material behind the field of view/inspection to provide a contrasting dark screen for the illuminated whisker.

4. Magnification:

- a. Whiskers may be detected by naked eye inspection in cases where the whiskers lengths and/or the density of the population (number per area) are relatively large.
- b. When using magnification (e.g., microscope), it is preferable to begin with low magnifications (e.g., 3X to 10X) with larger fields of view so that a broader area can be inspected for evidence of whisker presence.
- c. Increase the magnification (e.g., 10X to 100X) gradually using results of low power inspections to guide toward regions of interest.

5. Airflow (Optional):

- a. If retaining the present position of whiskers is not important, then gentle airflow (e.g., lightly blowing) across the surface to make the whiskers move without detachment can result in whiskers glinting/sparkling as the angle of illumination and inspection are varied by the whisker motion. However, the use of compressed air or a dust can cause the whisker to detach and become lost.

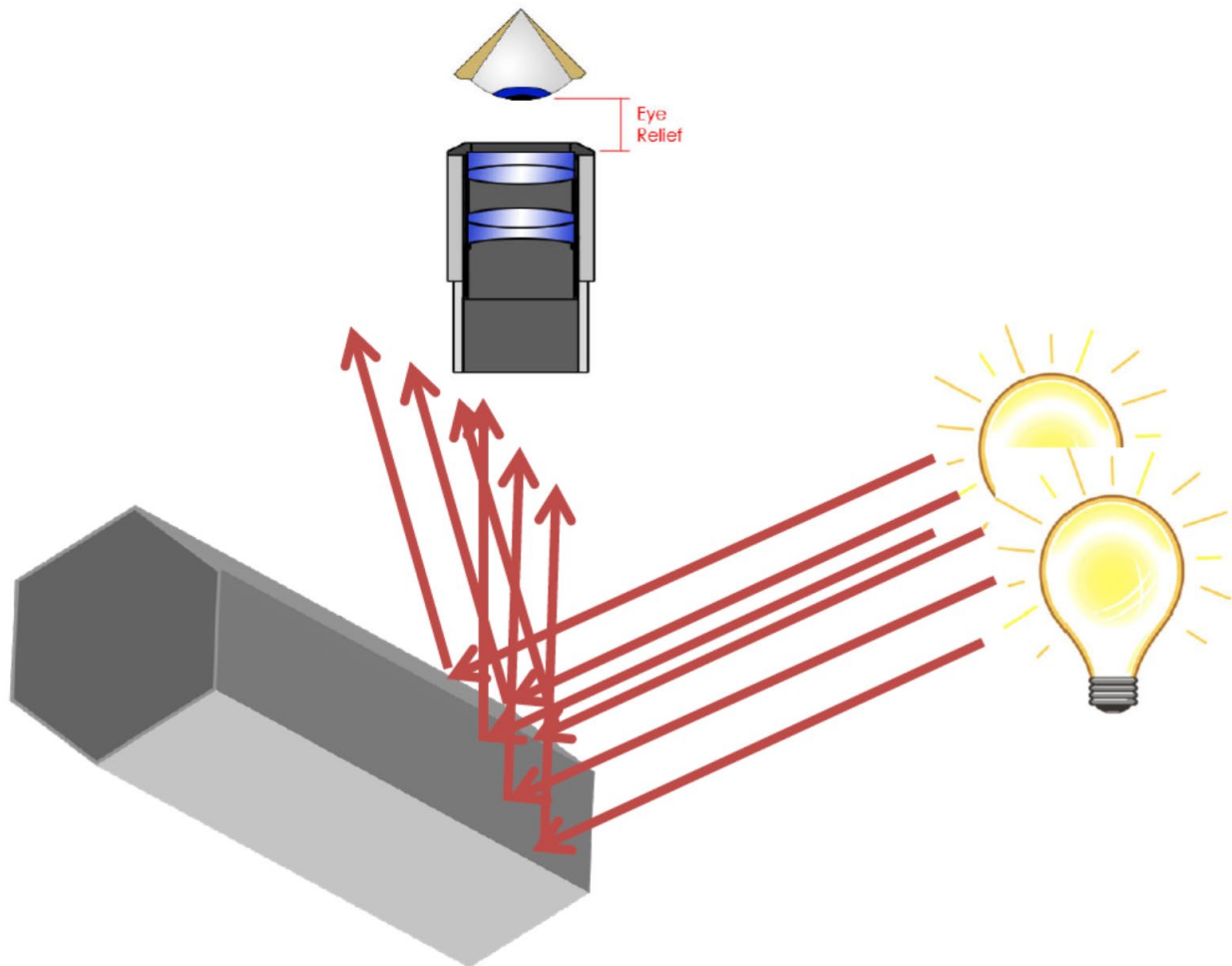


Figure 4 - The combination of the angles of illumination and inspection are critical to the probability of detecting metal whiskers via optical inspection. Due to the extremely narrow and faceted edges of metal whiskers, the range of angles necessary to have light reflect off the whisker in the direction of the inspection can be extremely narrow.

NOT PREFERRED

Figure 5 - Ring lamps tend to inhibit whisker detection due to excessive glare from background or adjacent surfaces

PREFERRED

Figure 6 - Directional LED lighting with narrow beams increases probability of whisker detection due to control of the angle of illumination



Figure 7 - Ring lamp illumination of tin-plated connector shell results in excessive glare compared to whisker illumination (compare with illumination on right)

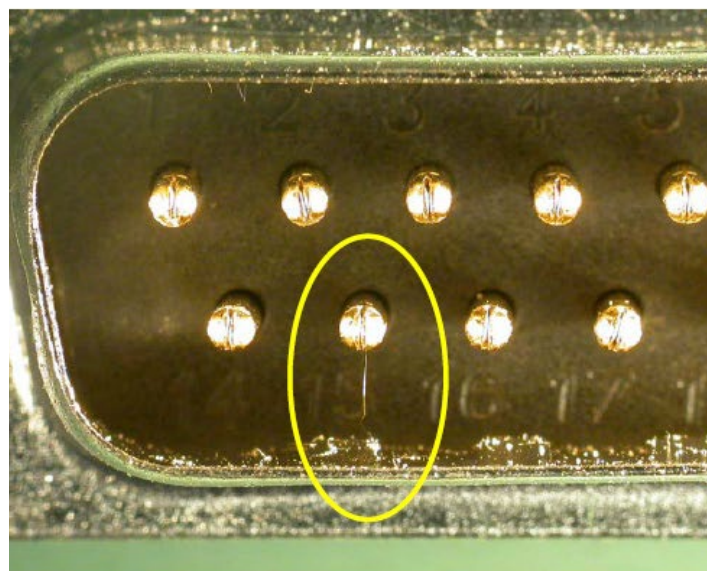


Figure 8 - Low-angle, directional LED lighting over a narrow range of angles results in proper illumination of whisker (compare with ring lamp illumination on left)

And There are Actually TWO Different Tin Whiskers
Bridging From Shell to Pin 15 and Pin 19

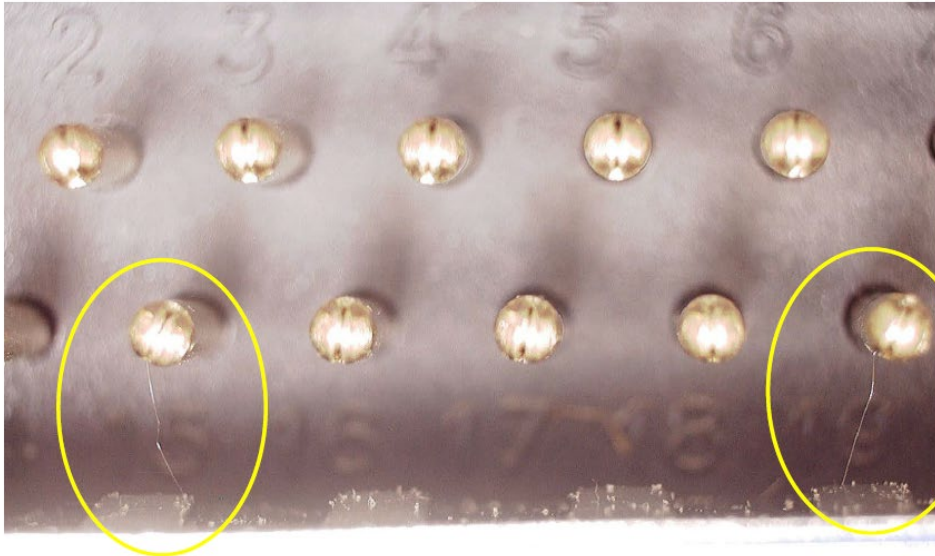


Figure 9 - Optical image of two whiskers bridging from two pins to the connector shell

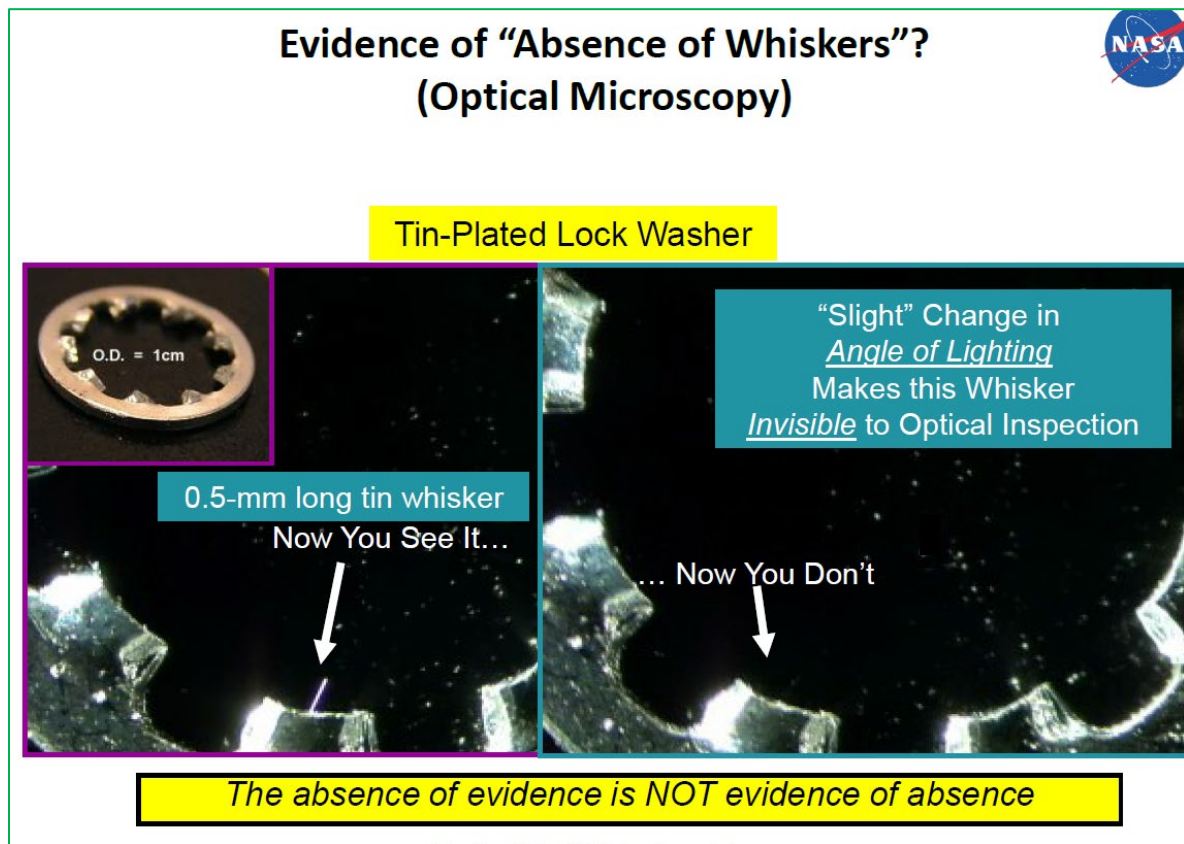


Figure 10 - Optical images showing the “disappearance” of a tin whisker on a lock washer with a slight change in the lighting angle, demonstrating the perceptibility of whiskers under variable lighting