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A Probabilistic Assessment of Component Lead-to-Lead Tin Whisker Bridging

Presentation to the July 15, 2009 “Tin whisker telecon”

Link: http://nepp.nasa.gov/WHISKER/reference/tech_papers/2009-mccormack-whisker-bridging-assessment.pdf

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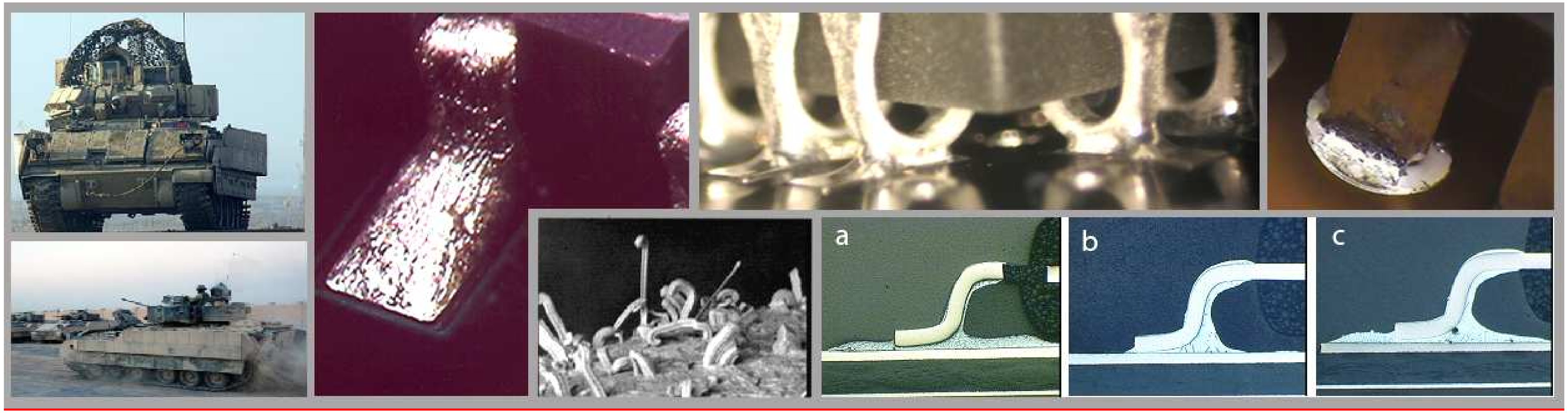

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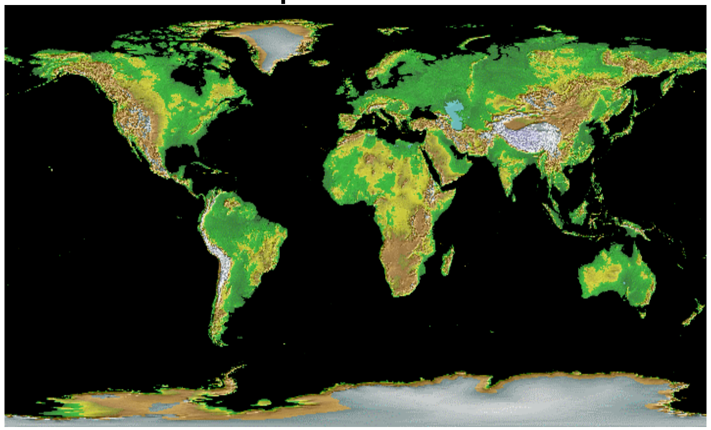
Background

- In 2006, the European Union mandated a somewhat controversial shift to Lead-free metallurgy to reduce environmental impact
  - Reduction of hazardous substances (RoHS) directive
  - Though the military/aerospace industry was not directly affected by the mandate —
    - Manufacturers shifted designs to address the market demand for Lead-free parts
    - Result was massive obsolescence of the Tin-lead parts
    - Multiple Lead-free solder alloys have replaced Tin-Lead alloys
    - Need to evaluate reliability and predictability over the broad spectrum of military/aerospace applications and platforms
  - Some manufacturers claim Tin platings with reduced whiskering
    - Little long-term data
    - Much conflicting data



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What is a whisker ?

- A hair-like metallic structure that sometimes erupt from a metal surface
- Coatings of Tin or Zinc are particularly able to develop whiskers
- Growth takes place over time (measured in days or years)
  - A no-growth/incubation period may take place
  - Growth rates may not be constant
  - Growth may start, stop and resume again spontaneously
- Lengths range from a few microns to over a mm, rarely over 10 mm
  - 18+ mm (18000+ microns) whiskers found on Space Shuttle PWB retainers
- Cross Sections: varied shapes, diameters < 1 micron to approx 13 microns
- Geometry may be straight, twisted or irregular

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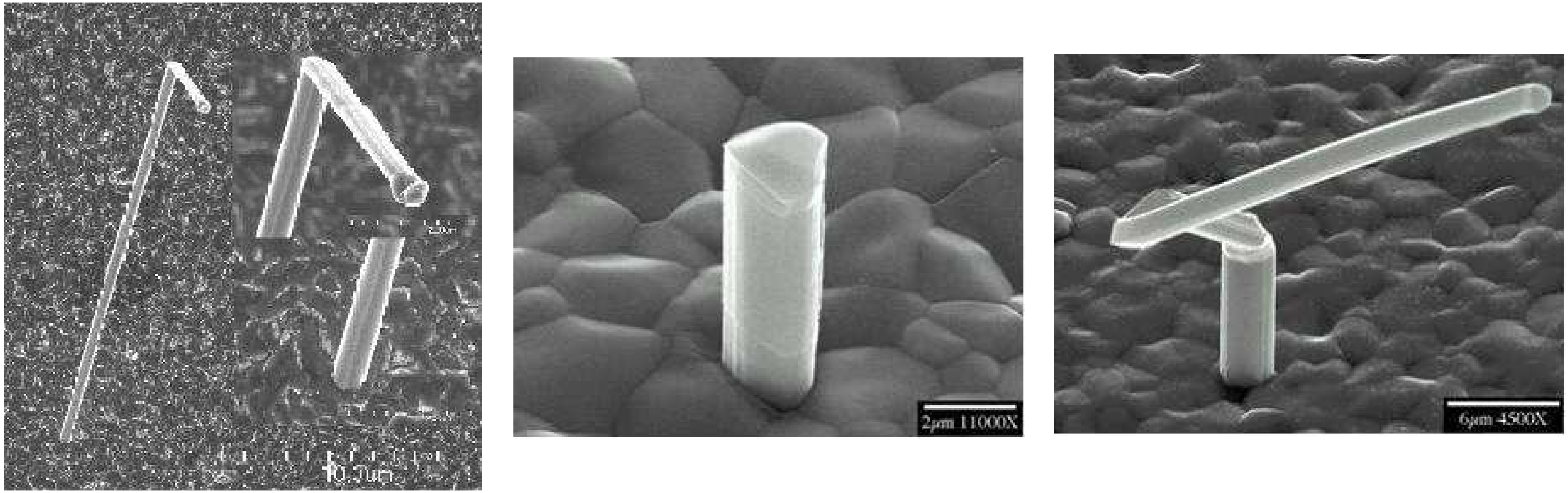
What is a whisker (cont.)?

- Electrically conductive, mechanically flexible, can cause shorting failures



Photos from JP002, JEDEC/IPC JOINT PUBLICATION, March 2006
Current Tin Whiskers Theory and Mitigation Practices Guideline

What is a whisker (cont.) ?

Tin Plating

Inter-metallic Layer

Base Material

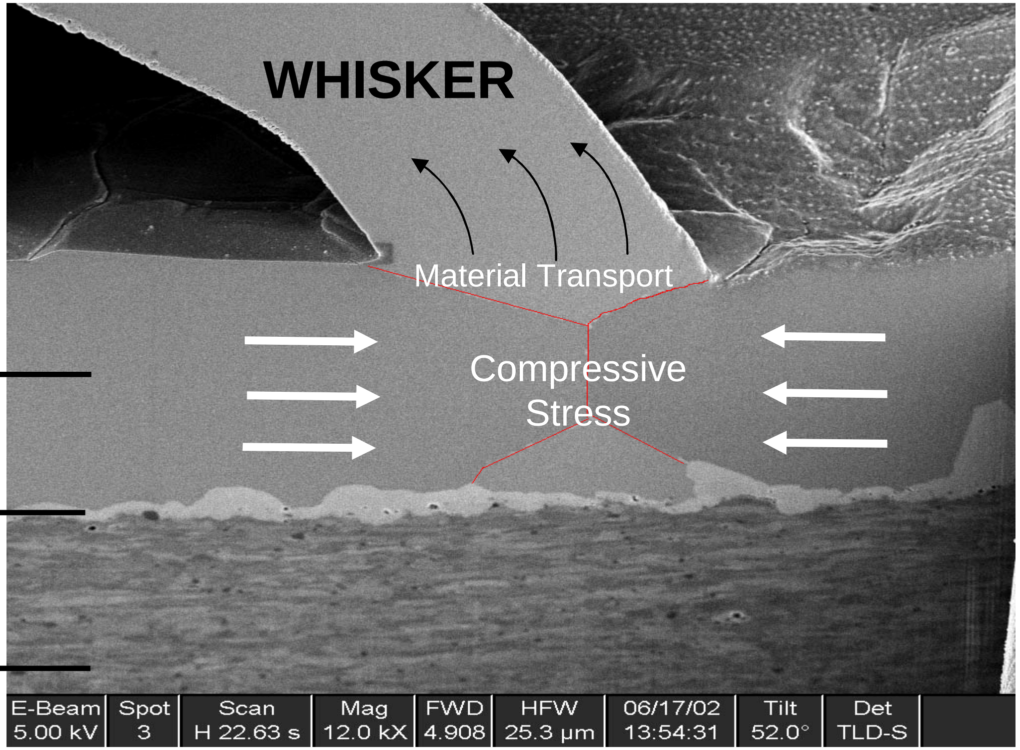


Image Courtesy of Motorola

Annotations by S. McCormack

One hypothesis is that whiskers are formed to relieve compressive stress.

Researchers are still trying to work-out a comprehensive growth theory

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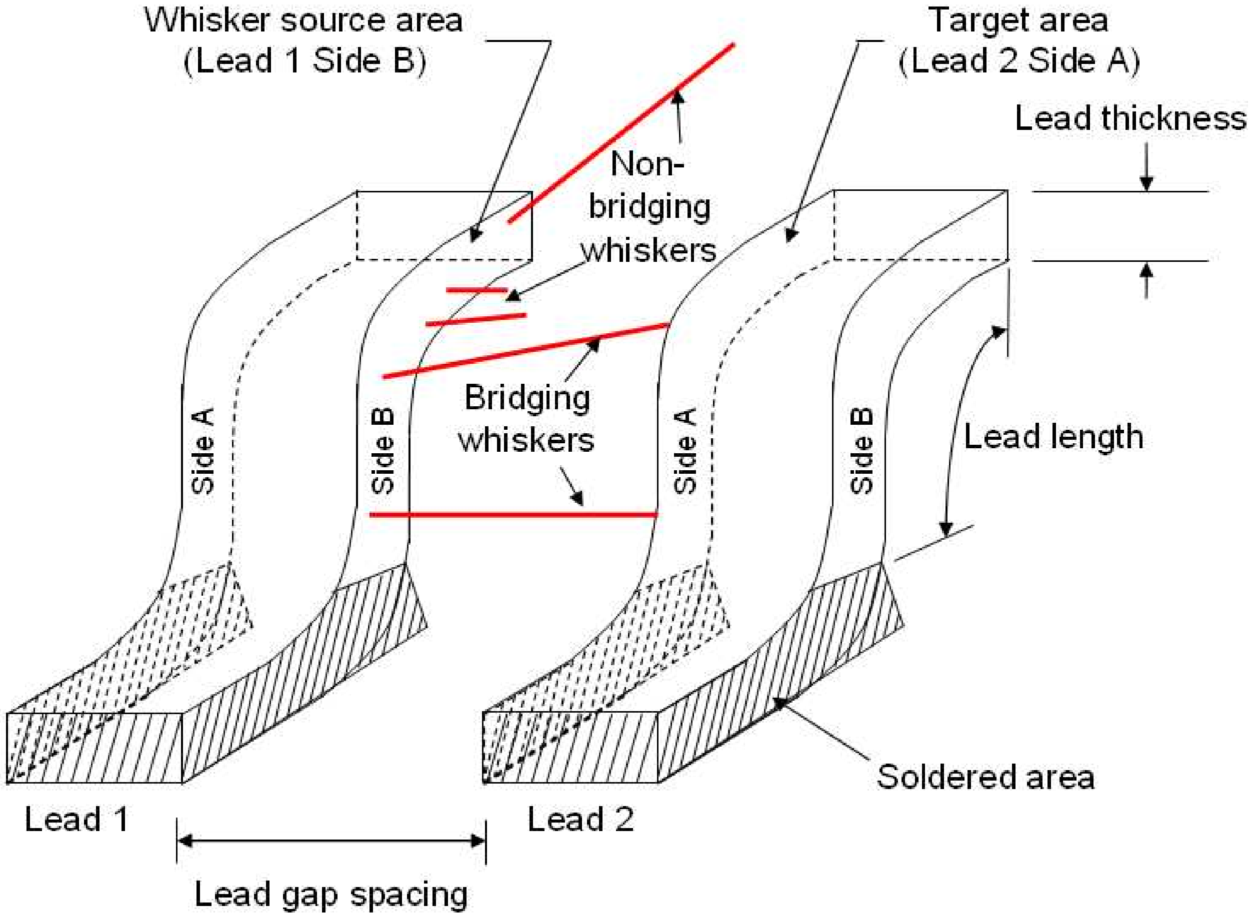
Overall Probabilistic Risk Assessment Approach

1. Define the component lead geometry
2. Define the required probability density functions
3. Establish the bridging failure definition
4. Execute a Monte-Carlo simulation
5. Compute and summarize the bridging metrics

Model Structure



A proximity based model.

Major Current Model Assumptions

1. Whiskers are mechanically robust, linear structures that do not exhibit curvature in three dimensional space.

2. No breakage of the whisker takes place prior to the whisker reaching its final length.

3. No credit is taken for advertent or inadvertent “whisker refreshing”.

4. No whisker fusing credit is taken.

5. No minimum threshold voltage is used for electrical conduction (current flow) to take place.

6. No whisker-to-whisker interaction is allowed.

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Major Assumptions (Cont.)

7. Detached whiskers posing a shorting risk are not taken into account.

8. Details associated with lead forming and specific lead micro-geometry were not included.

9. No participation of the front and back surfaces of the leads were allowed.

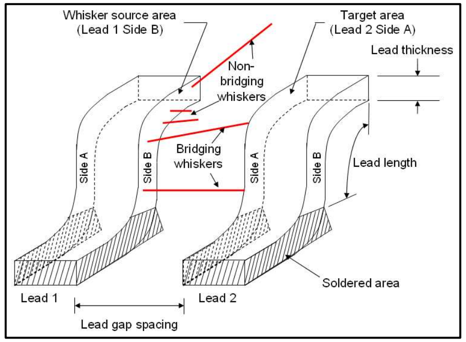
10. No whisker deflection due to external loads (air currents, acceleration, etc.).

11. No detailed chemistry or growth physics are explicitly included. These details are implicitly embodied in the experimental whisker results used to define the PDFs.

12. No direct environmental effects such as voltage, humidity, etc.

Geometry

A simplified representation of this



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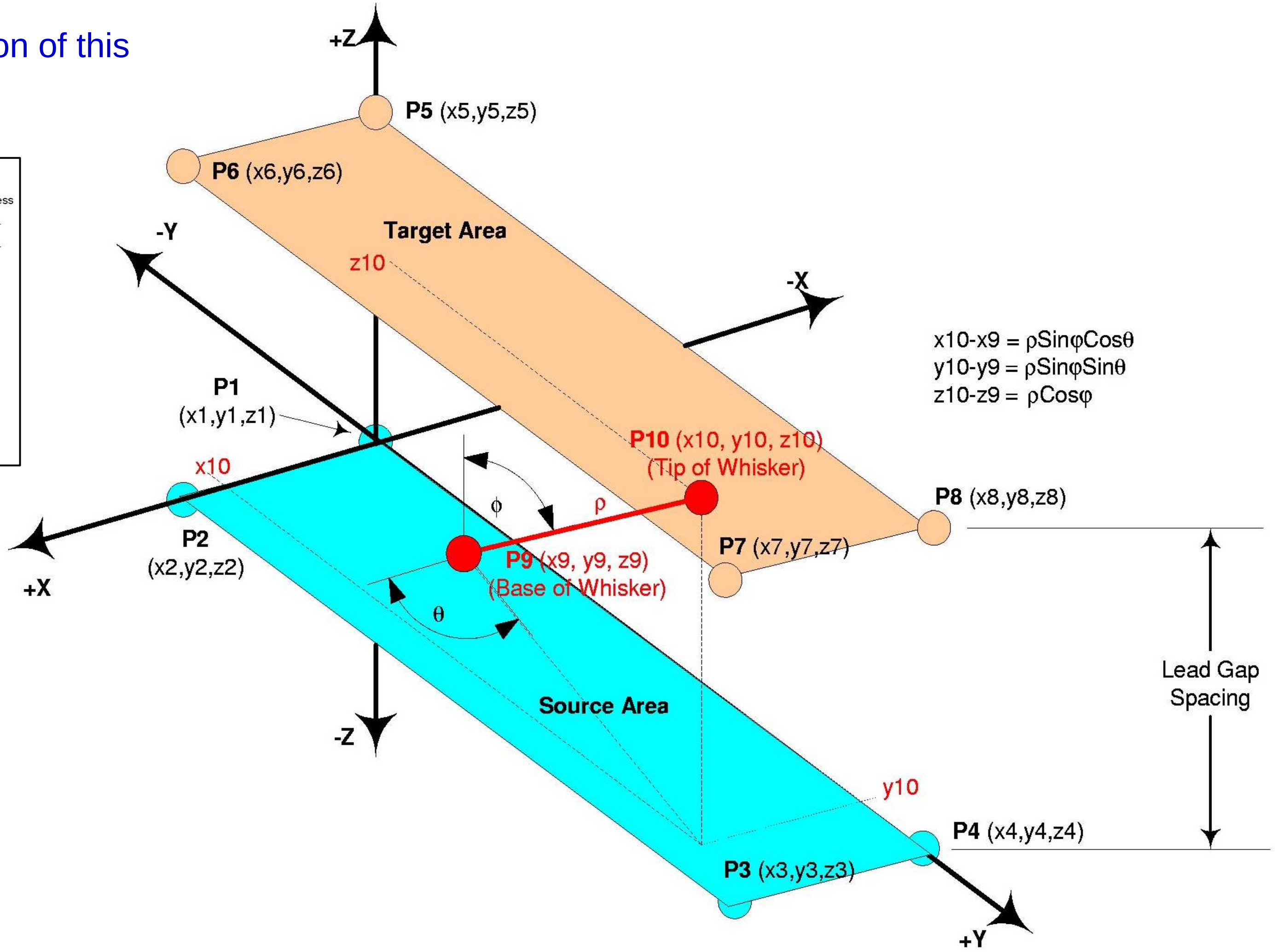

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Bridging Failure Definition

For a bridging failure to occur two requirements must be met.

1. The length of the whisker must equal or exceed the spacing between the leads.

2. The (x, y) location of base of the whisker must combine unfavorably with the growth angles so that intersection of the whisker and target area will occur.

Risk Metrics

Two risk metrics were chosen

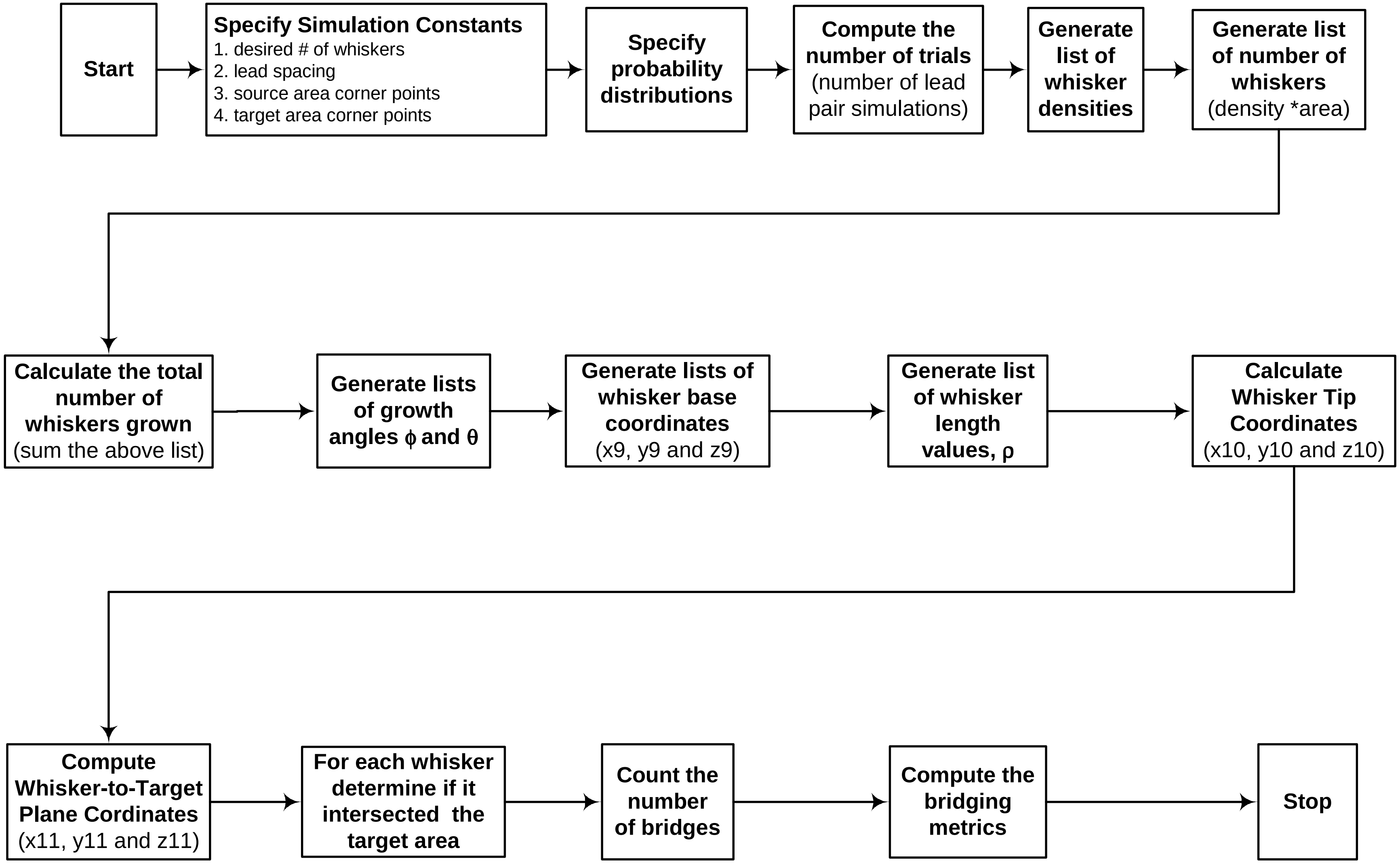
R_1 = Bridging risk per square millimeter

- Scales with the area that is contributing to the whisker bridging risk
- Helps determine when Tin area is the greatest contributor to bridging risk.

R_2 = Bridging risk per lead side

- Scales with the number of lead sides that are contributing to the whisker bridging risk

Simulation Strategy



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Probability Distributions

- 6 PDFs

Number	PDF	Type
1	PDF_x for *x* coord. of whisker base on source area	Uniform
2	PDF_y for *y* coord. of whisker base on source area	Uniform
3	PDF_θ for Whisker Rotation Angle, θ	Uniform
4	PDF_φ for Whisker Azimuth Angle, φ	Stepwise Continuous
5	PDF_{WD} for Whisker Area Density	Normal
6	PDF_{LW} for Whisker Length, ρ	Lognormal

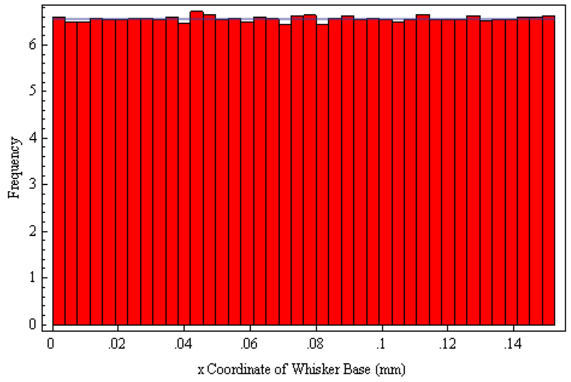
Fused two separate data sets:

1) Long term but statistically lean Dunn data
2) Short term but statistically rich Fang data

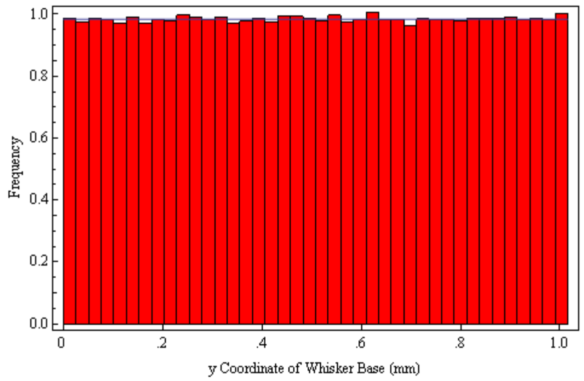
Example Probability Distributions (Cont.)

Assumed uniform distributions

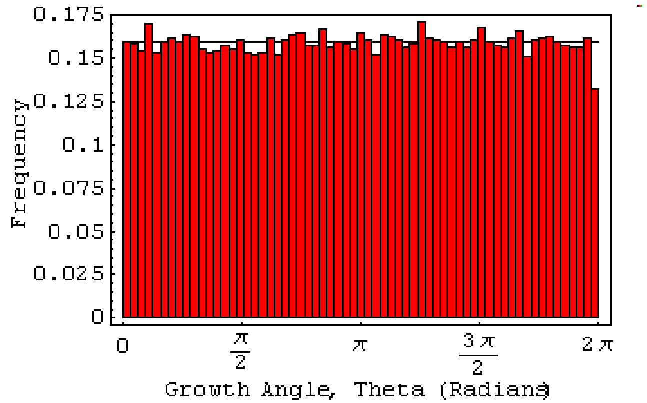
X Coordinate of Whisker Base



Y Coordinate of Whisker Base

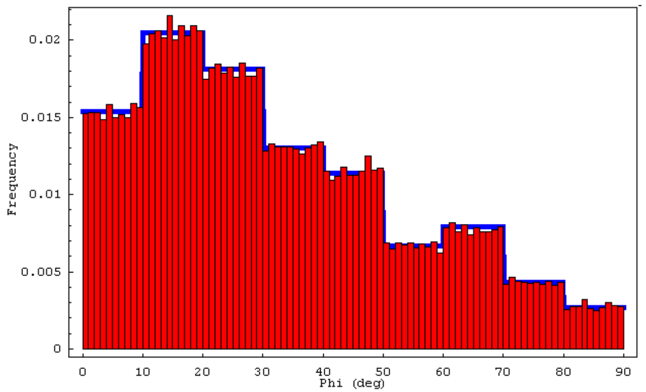


Whisker Growth or Rotational Angle

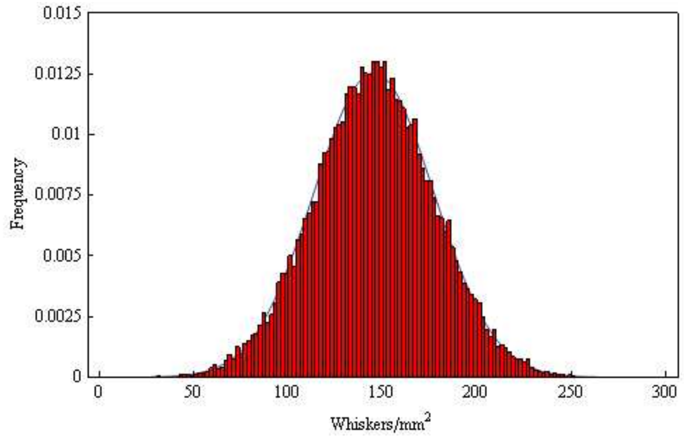


Fang, Osterman, and Pecht (2006)

Whisker Azimuth Angle



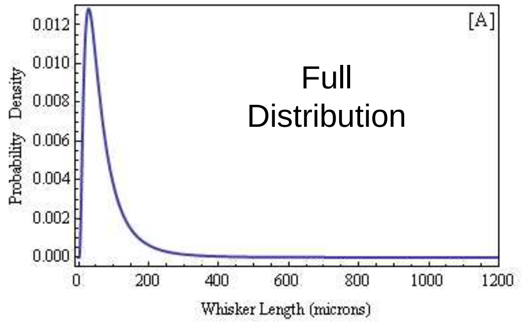
Whisker Area Density



Example Probability Distributions (Cont.)

- Whisker Length
- Tail-Controlled Lognormal Distribution

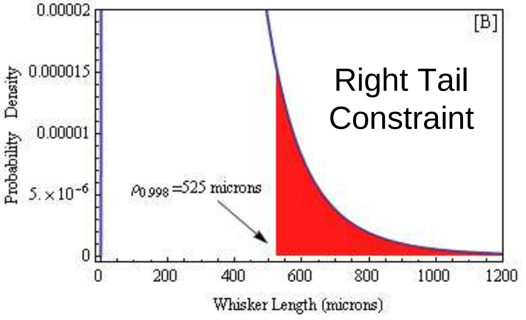
$$PDF_{LW} = \frac{e^{-\frac{(\ln[\rho]-m)^2}{2s^2}}}{s\rho\sqrt{2\pi}}$$



Baseline Right Tail Constraint

Max Whisker Length: 525 microns

Fraction of whisker lengths less than the max measured: 0.998



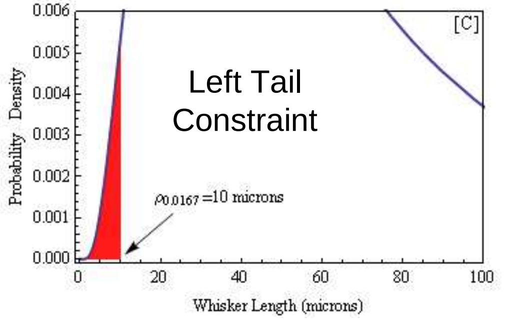
Baseline Left Tail Constraint

Whisker Length: 10 microns

Fraction of whisker lengths less than the 10 microns: 0.0167

Baseline Location Parameter, m = 3.9833

Baseline Shape Parameter, s = 0.792435



Dual Constraints allow m and s to be solved for

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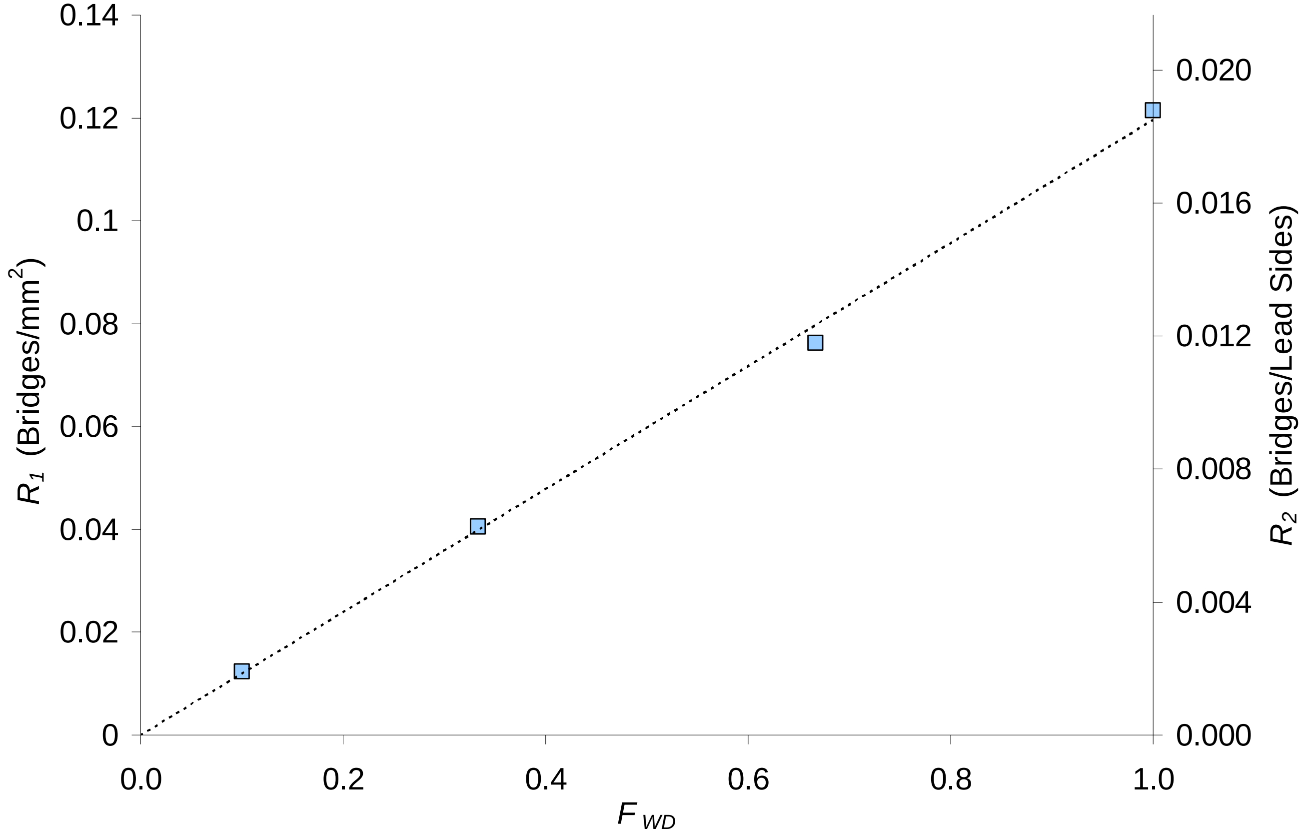
Whisker Density Results



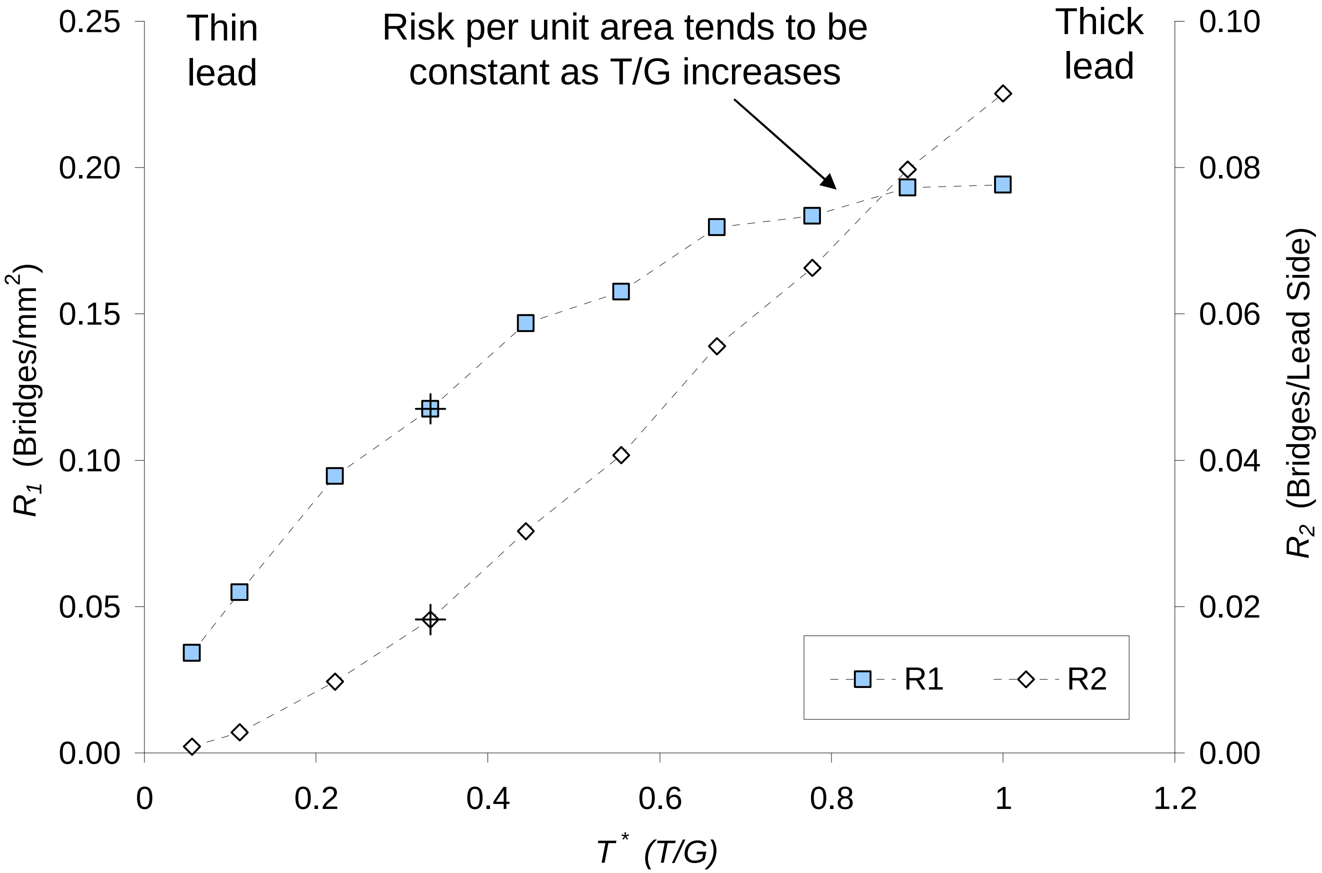
A whisker-density fraction $F_{WD} = 1$ corresponds to a mean-area density of 145.2 whiskers/mm² with a standard deviation of 31.8 whiskers/mm²

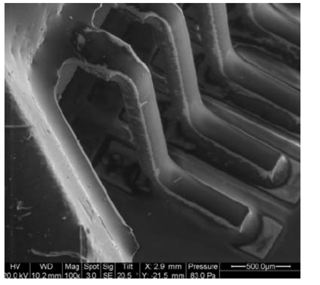
F_{WD} is a whisker density scaling ratio

Risk scales linearly with whisker density

Can use to compare high whisker density bright tin to low whisker density matte tin

Lead Thickness Results



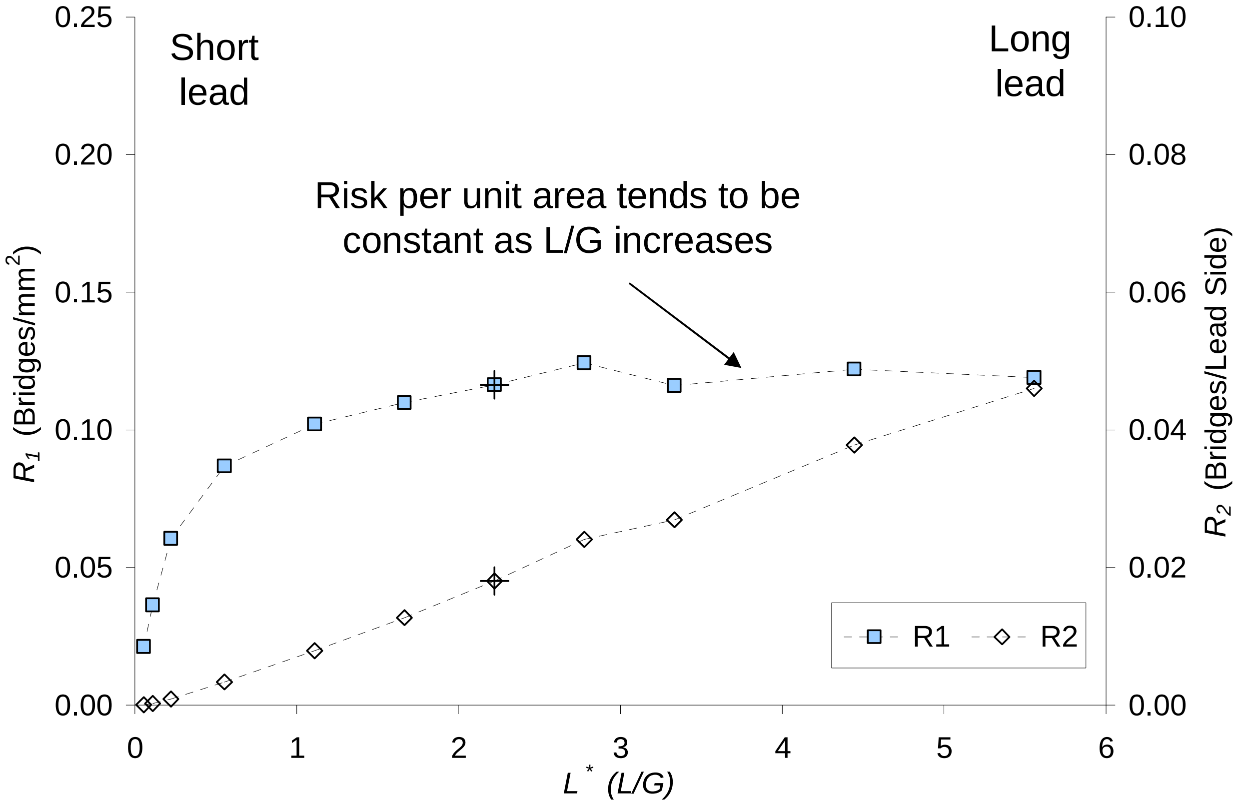


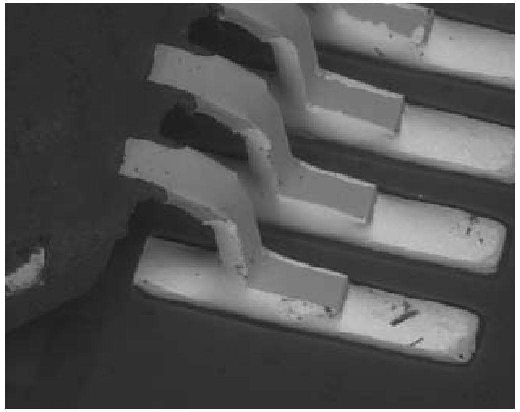
T = Lead thickness,
G = Lead gap spacing
(graph is for a fixed lead length)

Thinner leads yield reduced whisker risk due to smaller source and target areas and fewer growth angles resulting in bridging.

Could be used to evaluate increased risk due to poorly conformal coated lead edges.

Lead Length Results





L = Lead length,

G = Lead gap spacing

(graph is for a fixed lead length)

Shorter leads yield reduced whisker risk due to smaller source and target areas and fewer growth angles resulting in bridging.

Could be used to evaluate risk reduction for partial tin-lead solder coverage.

Dimensionless Gap Spacing Parameter

$$G^* = \frac{G}{\rho_{0.998}}$$

G = lead gap spacing (microns)

$\rho_{0.998}$ = upper whisker length fractile (microns)

= the whisker length value greater than or equal to 99.8% of all values

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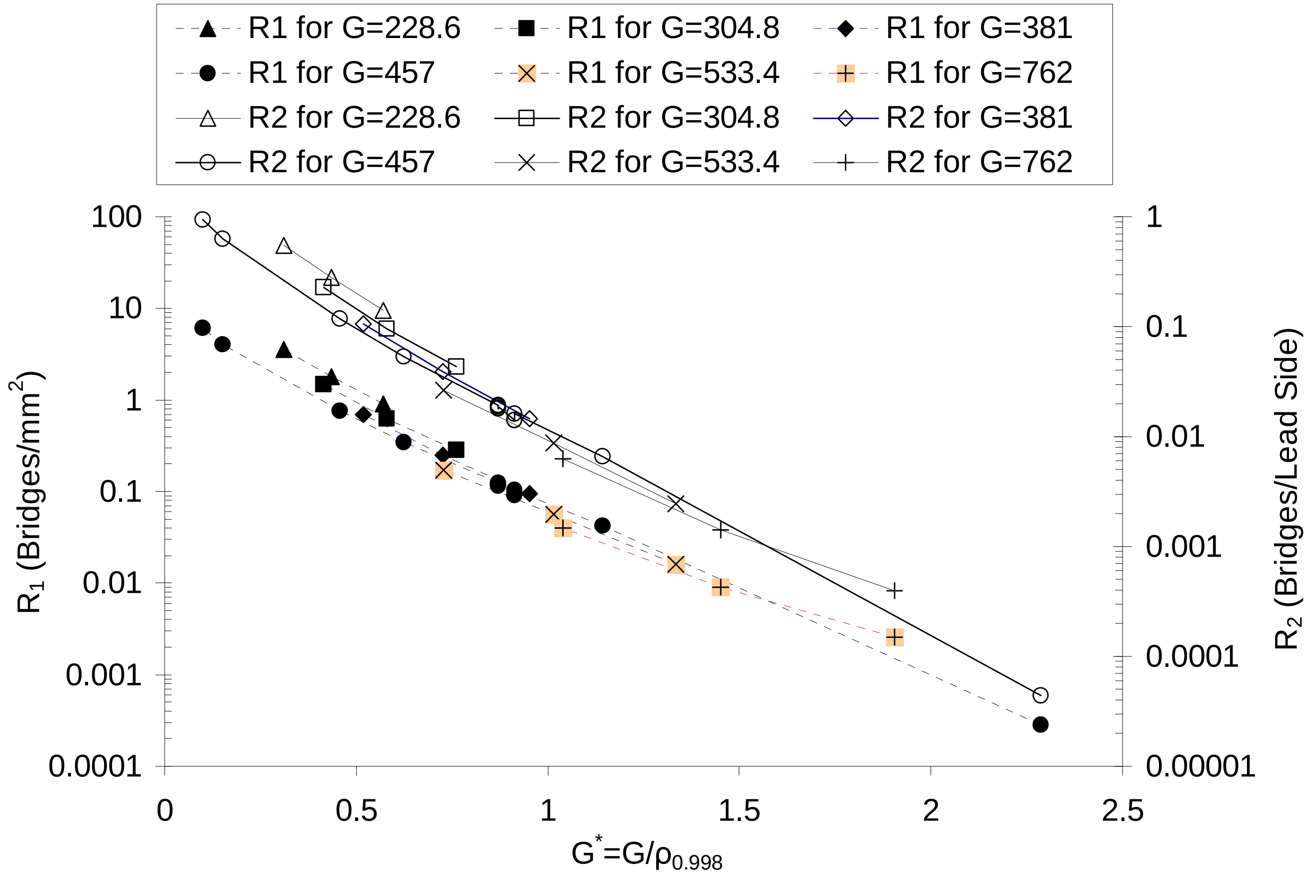
Gap Spacing Results



G = Lead gap spacing, $\rho_{0.998}$ = upper whisker length fractile

Not until G* approaches 2 or 3 does the whisker bridging risk decrease significantly for a system with 1000s of leads

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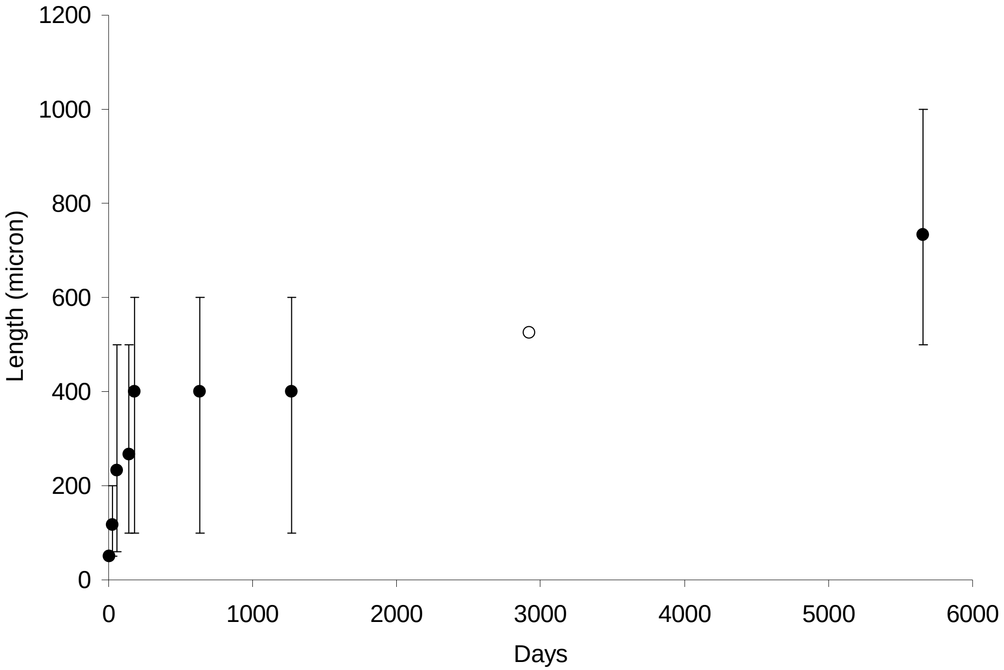
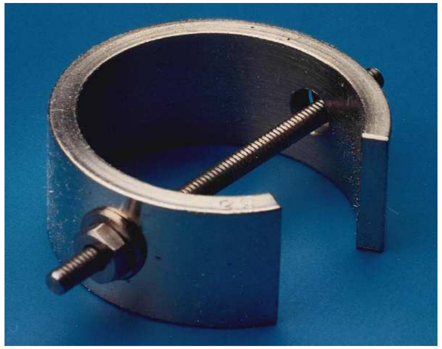
Long term growth data - Dunn specimen 11



The error bars indicate the maximum whisker length variation reported from the **three** C-Ring test specimen **locations** used to obtain the average value.

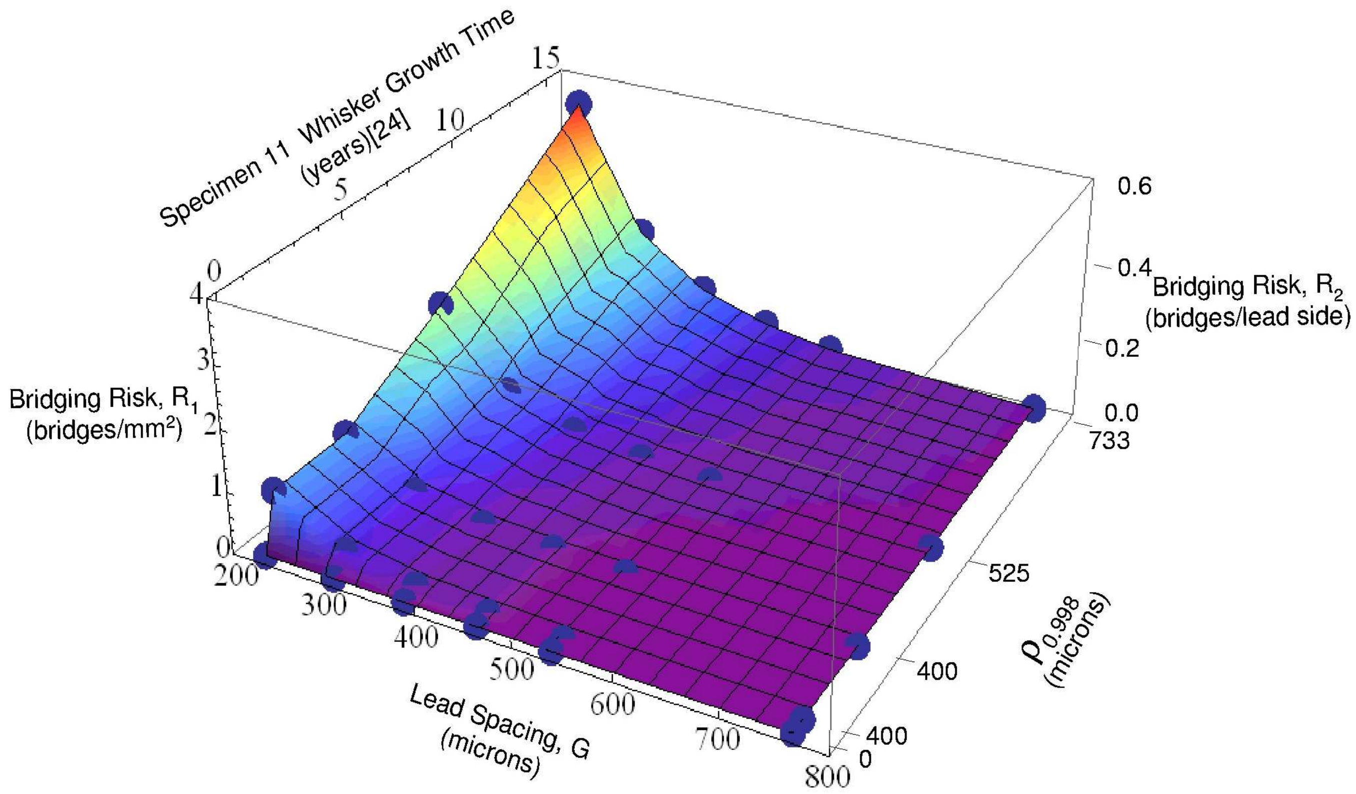


Normal electroplated bright tin over brass with a copper underplating.
Middle of the road tin over copper specimen: Not the worst whisker growing C-Ring nor the best

Significant variation in observed whisker lengths of specimens maintained in a desiccated environment at ~20 °C

Dunn B. 15½ Years of Tin Whisker Growth – Results of SEM Inspections Made on Tin Electroplated C-Ring Specimens, 2006

Risk Map



Until growth models become mature, can use risk map strategy to assist evaluation of field whisker findings where component gap spacings are known.

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Summary

- A versatile geometric and Monte Carlo-based model for bridging risk has been established that allows the lead spacing and $\rho_{0.998}$ parameters to be combined into a 3-D risk map allowing design tradeoffs to be made.
- A dual-tail constraint strategy for producing probability-density functions for whisker lengths that incorporate measurements from different research experiments has been developed and applied herein.
- Reliability gains can be achieved by greatly reducing the bridging risk when the dimensionless lead gap spacing, *G** is greater than 1.0 . However additional tin whisker mitigations may be necessary depending on the reliability requirements

Future Work

The authors plan to

- perform further assessments of the $\rho_{0.998}$ and gap-spacing parameters in the 3-D risk map in order to create maps that show lines of constant whisker-bridging risk.

- evaluate the relationship between whisker length and time with additional whisker length observations from experimental and field data.

Questions

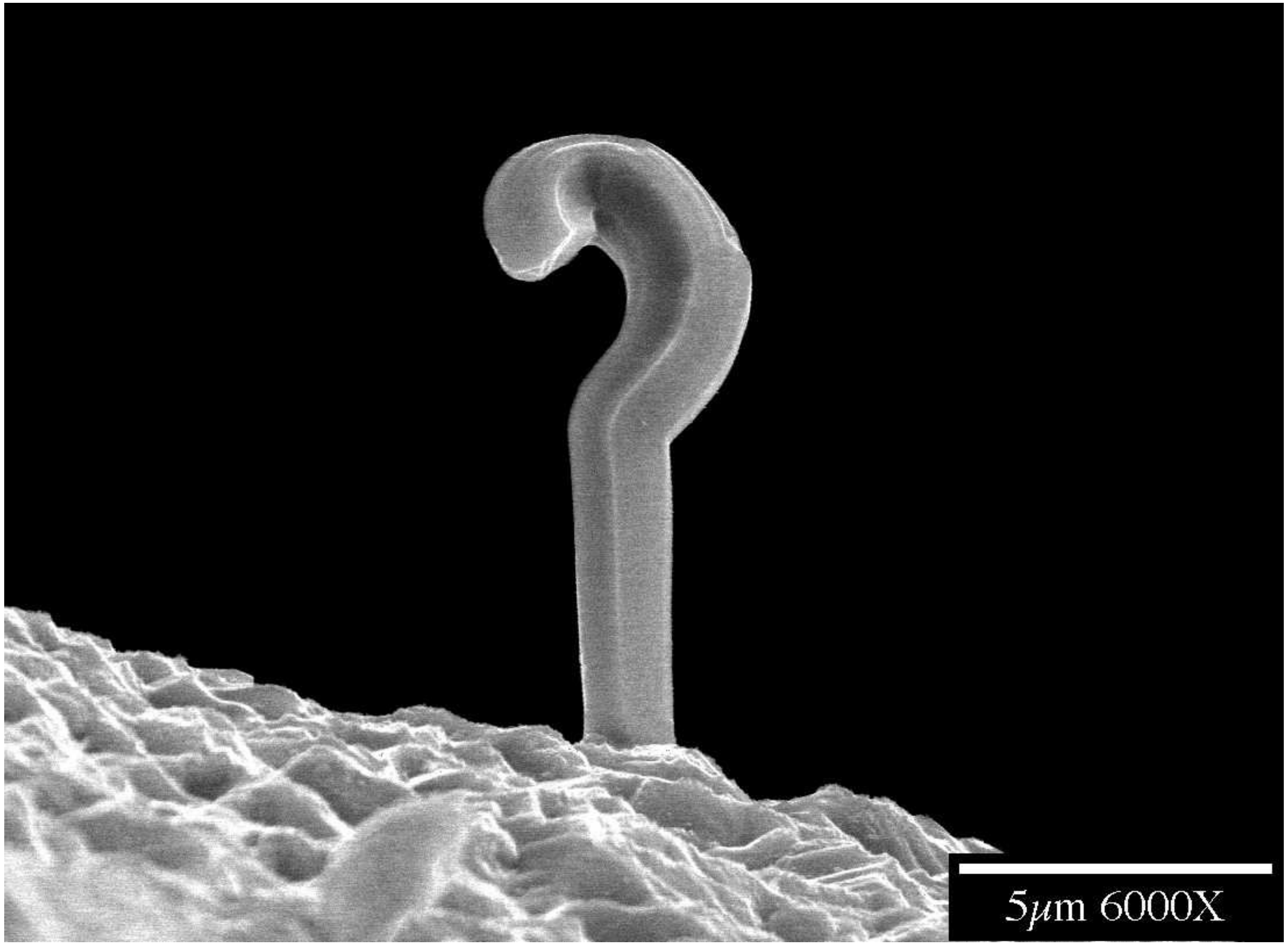

Photo courtesy of Peter Bush, SUNY at Buffalo