Space Shuttle Program
Tin Whisker Mitigation

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Agenda

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Introduction

- Space Shuttle Program implemented tin whisker (TW) remediation strategy following discovery of TW in Orbiter hardware
- Complex investigation and planning involved cooperation among many disciplines and geographic locations
- Overall goal to arrive at two products:
  1. Flight rationale (should we fly near-term flights with TW?)
  2. Plan for TW removal/mitigation (what is long-term plan for removal of TW?)
- What was the project management decision-making process?

Background

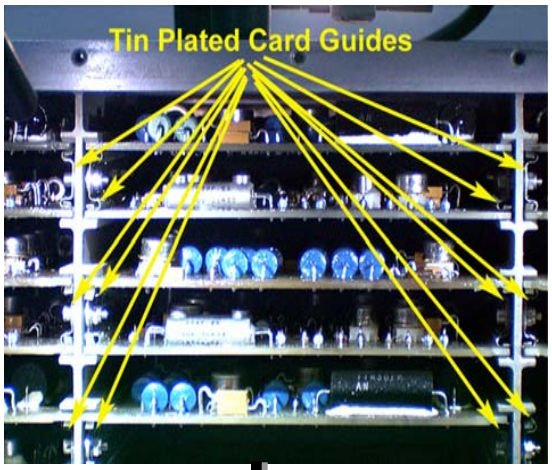
- In March 2006, a Flight Control System (FCS) avionics box failed during vehicle testing, and was routed to the NASA Shuttle Logistics Depot for testing and disassembly
- Internal inspection of the box revealed TW growth visible without magnification
- Among hundreds of electrical boxes on the Space Shuttle, the particular type of box with the initial finding of TW is populated 4 per vehicle
- The family of similarly designed boxes is populated 12 per vehicle

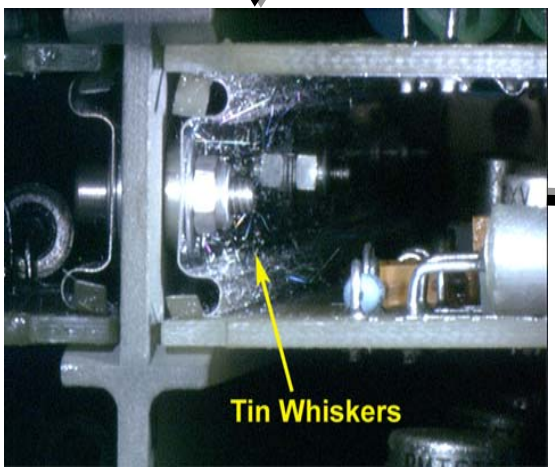
Initial Finding

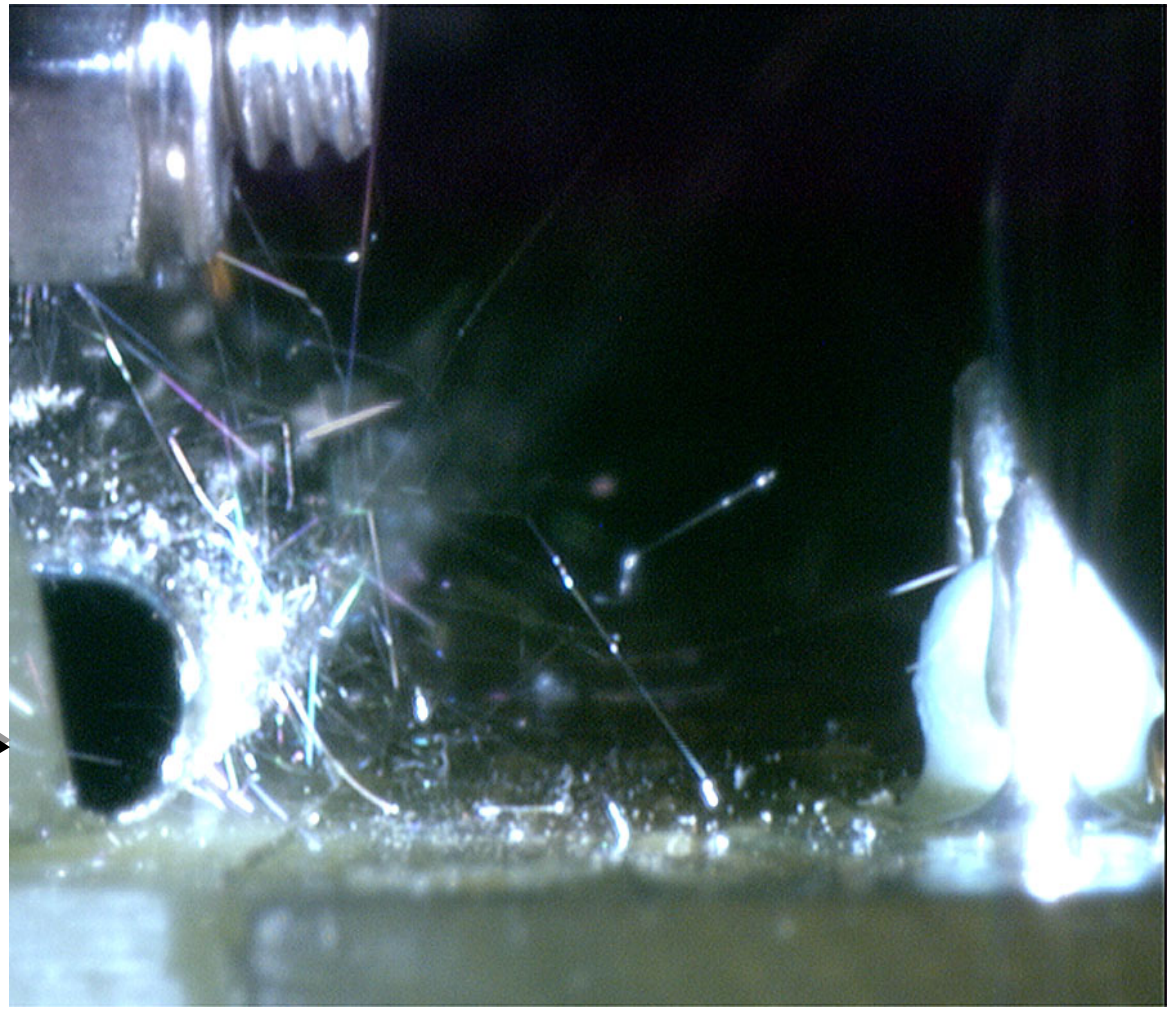
- Whiskers grew from pure tin plated circuit card retainers, not from electrical components
  - Intent of tin plating in original design was for corrosion protection of BeCu retainers
- Immediate Concerns:
  - All FCS avionics boxes in the same family were similarly designed and could fail because of TW
  - Whiskers could either grow into conformal coating, or touch electrical components having inadequate coating
  - Active concern for July 2006 launch; particularly if no clean spares exist to rotate into vehicle
  - How can the Program ensure that other Space Shuttle hardware isn't at high risk for TW failures?

Internal Photos of Tin Whisker Growth

- **Box with cover removed illustrates progressively finer detail**







Tiger Team Formed

- NASA formed multi-disciplinary Tiger Team to investigate extent of findings and develop recommendations
- Two Branches of Team's Investigation:
  1. Detailed investigation of Flight Controls H/W from same vendor (12 per vehicle)
  2. Broad investigation of 100+ other high-criticality Orbiter H/W
- Functional diversity: design engineering, logistics, test engineering, materials & processes (M&P), ground operations, research
- Geographic and corporate diversity: multiple NASA centers (JSC/KSC/GSFC), prime and major subcontractor sites, hardware vendor and supplier

FCS Conclusions

- Can TW concern be segregated by s/n?
- Quantity of FCS boxes:
  - 52 total quantity across fleet = 12 per vehicle + spares
  - All from same manufacturer, using same card retainer design
- Sampled 15 of the 52 boxes across four different types:
  - 1 & 2) Reaction Control Jets for on-orbit maneuvering (Fwd & Aft)
  - 3) Flight Control Surfaces (e.g. elevons, rudder)
  - 4) Main Engine and Solid Rocket Booster directional control
- All box types high criticality (Crit. “1/1” and “1R”)
- TW only growing from card retainers; up to 18 mm
- Some loose TW present
- Newer-build boxes (~1989) from Endeavour's initial assembly generally contain longer and more dense TW growth
- One box found to have no tin plating on card guides

FCS Conclusions

- Conformal Coating:
  - Coating cannot completely prevent TW growth into coating, but lowers likelihood of contact with underlying electronics
  - Some circuit cards found to have incomplete conformal coating due to "shadowing" of spray-on technique
- M&P investigated sampled cross-sections of card retainers under scanning electron microscope
  - Plating method cannot exonerate TW boxes
  - More prominent TW growth in newer Endeavour-era boxes could not be correlated with processing variables such as plating material, time, temperature, pressure, etc.
  - M&P recommends 100% inspection
  - Tin plating not needed to prevent corrosion of card retainers

FCS Conclusions

- Assessment of vendor's build records could not exonerate/segregate boxes
- Design team's position:
  - 51 boxes still at risk
  - Based on component layout on circuit cards, even the shorter whiskers (~2 mm) are long enough to cause failure

FCS Remediation Plan

- Remediation plan developed:
  - Avionics Lab: Remove tin plating and TW
    - Expedite procurement of non-plated card retainer assemblies from vendor
    - Cycle boxes through Lab
    - Incoming testing, disassembly / card removal
    - Assess gross order-of-magnitude quantity of loose whiskers
    - Clean chassis and circuit cards
    - Cards pass magnified inspection
    - Conformal coating touch-up via brush coating as needed
    - Reassemble with non-plated card retainers
    - Full acceptance testing at box level: vibration, thermal, functional
  - Flight Operations: Prioritize Reaction Control Jet firing to minimize likelihood of critical risks

FCS Remediation Plan

- Plan phased in over multiple years/flights
  - Flight Controls design team tracks 51 boxes rotating through remediation plan
  - Higher criticality (non-redundant) boxes given schedule priority over redundant boxes
  - Pace of plan accommodates Avionics Lab staffing level, quantity of test stations (2), and diversion of equipment and personnel for unrelated failures on same boxes

Outline of FCS Flight Rationale

- Is it safe to fly non-repaired FCS boxes?
  - Remediation of all boxes prior to flight would result in significant delays for Space Shuttle and International Space Station programs
- Jet Drivers (high criticality / non-redundant)
  - Inadvertent jet firing concern: risks loads on or contact with Space Station
  - TW-caused inadvertent jet firing is not spontaneous; must be coupled with a commanded jet firing
  - Loose TW needs to bridge specific pin combinations; simultaneously avoiding other pin combinations that can vaporize TW
  - Prioritized jet selection to minimize likelihood of plume and contact loads for Space Station
  - Software limits worst case duration of inadvertent firing to very short duration
  - Installed unique box containing non-plated card guides

Outline of FCS Flight Rationale

- Control Surface & Engine Directional Control
  - System architecture mitigates catastrophic failure via hardware redundancy
  - Dual-redundant failure mode requires identical failures to occur within small duration window
- General Rationale
  - Conformal coating protects circuits
  - Loose TW would need to migrate from growth sites to critical "smart" locations on circuit cards
  - Sampling of quantity of loose whiskers in three boxes led to belief that actual quantity is small, not large

Additional High Criticality H/W

- Tiger Team assessed other high criticality H/W:
  - Listing of high criticality H/W screened through Materials database of as-built configuration, searching for pure tin
  - List of essential questions distributed to design teams responsible for H/W at risk for pure tin
- Types of criteria:
  - Conformal coating, solder coverage on leads, physical separation, worst case effects having lesser criticality, history of inspections, history of unexplained anomaly trends
- Some H/W inspections authorized

Additional High Criticality H/W

- Findings on two high criticality boxes:
  - Some short TW found on tin plated eyelets on circuit cards
    - Corrective Action: conformal coating applied to eyelets without removal of circuit cards
  - One design allowed for either tin plated rivets or solid aluminum rivets on chassis
    - Spectroscopy performed on large sample of boxes verified solid aluminum rivets

Conclusion

- Program elected to fly with tin whiskered avionics hardware in parallel with implementing remediation plan and adopting operational controls
- TW growth in programs with high reliability standards such as human spaceflight can result in lengthy and costly investigations and remediation plans
  - Remediation plan phased in for flight: July 2006, Sept. 2006, Dec. 2006, and STS-117
  - TW remediation plan continues into CY2009
  - No failures to date positively attributable to TW
- As electrical components adopt lead-free philosophy, caution should be taken when designing and procuring new hardware
- Design decisions can have unintended consequences
- Development and refinement of TW mitigation techniques will benefit programs that have future TW findings