NEPAG FY22 Task:

Fracture Mechanics in Electronic Parts

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Fracture Mechanics

Fracture Mechanics in Electronic Parts:

- This task initiated in 2nd Quarter of FY22.
- In Phase I of this activity, we will address the parts built with plastic encapsulants.
- In Phase II, non-plastic-packaged device types will be explored.

Fracture Mechanics

Problem Statement

- Plastic encapsulants, dielectric polymers, and underfill materials are subject to delamination and cracking with thermal cycling (TC). Crack propagation during use-environment exposure drives the potential for failure of plastic-packaged devices and is therefore a necessary focal point in qualification and life testing.

- Looking across the standards development covering the entire applications spectrum, it is clear that the community is making a huge investment in packages made of these materials. It, therefore, behooves us to review the fundamentals of these packages, their assembly and other related aspects.

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Goals/Objectives

- Determine if the potential impact of stress/pressure build up in plastic/organic packages is being adequately addressed, to identify any gaps in requirements and, assess their impact
- Develop methodology for evaluating the time-dependent mechanical failure of plastic-packaged devices resulting from combined effect of stress, temperature, moisture absorption and crack-like defects
- Leverage existing knowledge by working with academia, industry, manufacturers and government partners

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- **Scope of Study**
  - Material Data
    - Who are the major suppliers?
    - What tests do they run to demonstrate quality/reliability?
    - How do they arrive at Glass Transition Temperature (Tg), Coefficient of Thermal Expansion (CTE) and other data?
  - Device Issues
    - Tg – is it different for a screened product?
    - What are the TC requirements?
      - NEPAG task team is monitoring JEDEC 'PEMs for Space' task group
      - MIL-STD-883, Test Method 1010
        - Should it be Condition B (-55C to +125C) or Condition C (-65C to +150C)?
        - How about the ramp rates, dwell times?
      - According to JPL Design Principles Document 43923, "In the absence of a specific mission thermal cycling profile, electronic hardware shall be capable of surviving 200 cycles each at 155 degrees C delta-T excursion (or the equivalent of 3,000 cycles at 40 degrees C delta-T)."
    - Is biased HAST testing required for space applications?
    - Are ceramic and plastic packages equally prone to cracking?

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- Device Issues (Cont'd)
  - Focused searches: Review of published literature, JPL's test and FA database, GIDEP
    - Analysis and Test Lab (ATL) Database @ JPL: ATL database searched for keywords - crack, fracture, split, fissure, break, rupture, slit, crazing etc. to locate related tests, inspection and FA
    - Parts Issues Dashboard (PID) Database @ JPL: To perform similar searches in PID
    - Papers on Fractures and Delaminations:
      i. NEPAG to conduct a literature survey on fractures related to board mounting, TC, aging and harsh environment as applicable to space exploration.
      ii. Convert the finds in to a NASA EEE Parts Bulletin
      iii. EEE Parts Bulletins are published in OSMA website

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- Focused searches (cont'd)
  - Explore leveraging an university's existing research: Status of existing models to predict fracture mechanism
  - Review JPL-upscreened COTS PEMs that are used in various flight projects: NEPAG plans to leverage this activity to, potentially, develop a model to predict the onset of fracture propagation as a function of TC and aging

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- <u>Assembly Issues</u>
  - What are the common issues?
    - To be discussed with NASA Centers and DoD Organizations
  - Perform Limited Testing, Post-Assembly:
    TC followed by aging, with pre- and post-electrical test
    - Leveraging exiting PEMs test hardware at NASA:
      Look in to JPL and other NASA centers for availability of parts/boards/assemblies that can be made available for testing
    - Review existing PEMS upscreen test data, especially, pre- and post- TC and burn-in electrical test data and DPAs to understand behavioral changes in the PEMS – physical change, degradation in performance and their correlation, if any
    - Potentially, specify additional burn-in or TC leveraging the existing work that has been completed
  - Collaboration with part manufacturers and test labs: Propose manufacturers and test labs to participate in assembly-level testing with simple PEMS as well as complex devices

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- Perform Limited Testing, Post-Assembly (cont'd)
  - NEPAG would like to form partnerships with manufacturers/universities to collect the following sets of data on the 2D and 3D package architectures:
    - ✓ TC followed by aging with pre- and post-electricals
    - ✓ Use Mil-Spec conditions applicable to space products
    - ✓ In case of failures with Mil-Spec conditions, use NASA mission environments and, repeat the TC followed by aging, with pre- and post-electricals

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- **Forward Plan**
  - Review Military and NASA standards and performance specifications and make recommendations
    - Identify any gaps in requirements and assess their impact
      - CTE mismatches
      - Temperature excursion dependence
      - Time dependence
    - Bring part manufacturers and board assembly communities together
      - Could a QCI type test and/or set of guidelines be developed at the piece-part manufacturing and testing-level?
      - Look at MIL-PRF-38535 and MIL-PRF-19500 products as well
    - Recommend standards updates

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- Forward Plan (Cont'd)
  - Collaboration with NEPAG International Partner Agencies - CSA, ESA and JAXA
  - Periodically report progress in NEPAG Telecons
  - Quarterly Reports to NASA HQ
  - Present at JEDEC-SAE meetings
  - **Workshop on Fracture Mechanics** – To share information with the community
    - Tentatively targeting Dec 14, 2022 for Workshop

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Fracture Mechanics Phase I: Work Completed

- Device Issues
  - Analysis and Test Lab (ATL) Database: Ramon Salallandia completed ATL database search with keywords - crack, fracture, split, fissure, break, rupture, slit, crazing etc.

    ✓ All commodities (Capacitors, Diodes, Magnetics etc.) exhibit anomalies related to fractures, cracks etc.

    ✓ 30 test reports were reviewed to narrow down to the final 4 that had significant work done at JPL ATL in the area of concern (table shown in backup slides)

    ✓ Root cause for these cases remain inconclusive

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Fracture Mechanics Phase I: NASA Testing Planned

Post-assembly TC and aging with complete set of pre and post electrical test data using a simple and a complex plastic Microcircuit:

- **Simple PEM (i.e. Opamp):**
  - Select a PEM that JPL already upscreened – test flow includes 100% screening and sample-based lot acceptance test (LAT) with complete set of electrical test data taken for each SN and, with pre-screen and post-qual DPA
  - Using the same part numbers, NEPAG plans to collect data after assembly-level TC and aging with complete set of pre- and post-electrical test data taken for each SN
- **Complex Device (i.e. Zynq SoC processor in BGA package):**
  EMIT project and NEPAG joint testing
  - EMIT has upscreened Zynq SoC processor in BGA package
  - NEPAG to leverage the above work and perform the assembly-level testing as previously described

- **Additional assembly-level testing is planned, as needed**

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Backup

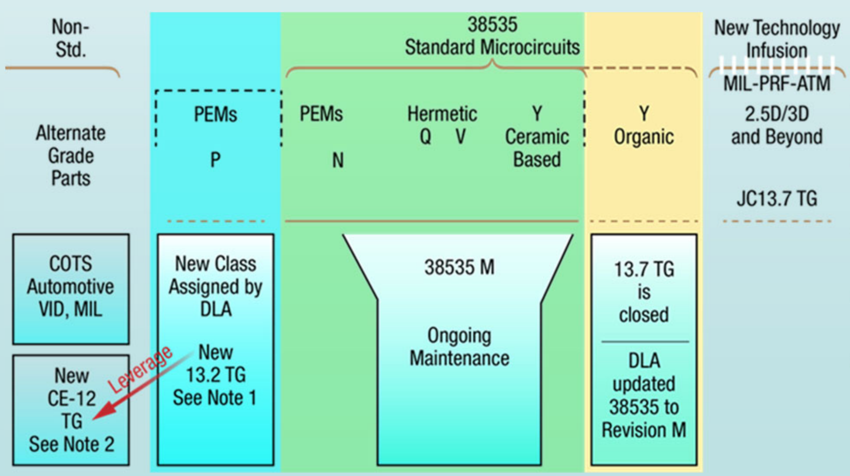
Fracture Mechanics

- <u>ATL Database Reports</u>: 30+ reports were reviewed to narrow down to the final 4 to show relevant work done at JPL ATL in the area of concern

JPL PN/ Mfr PN	Package Type	Inspection Summary
10342788-002	28-Pin TQFN	10 samples went through 30 thermal cycles from -45˚C to 85˚C with a ramp rate of 5˚C/min and a dwell time of 15 minutes at temperature limits. Post 30 cycles inspection showed no major changes, but CSAM showed lead frame delamination on 2 out of 10 samples. Upon cross-section, FIB polish and SEM, only 1 out of these 2 samples exhibited delamination on the lead frame at the locations identified during CSAM inspection. An additional 30 thermal cycles (same conditions as above) were performed on the remaining 8 samples with no further findings post 60 cycles.
JANSR2N7626UB	UB	Parts with ceramic body and metal lid exhibited cracks and chip outs during pre-assembly inspections. Projects, on a case by case basis, replaced parts with ceramic body-ceramic lid, wherever possible and available.
CDR32BX103BKUS	C1206	Noisy current reading of the GSE bus power supply was observed during post-pyroshock functional testing of the Transmitter (TX) assembly. The failure was isolated to suspected capacitor C170 which was identified as having possible cracks. The capacitor measured as an open circuit, giving no capacitance reading and a crack through the entire ceramic body was observed. Inspection of the fracture surface revealed features that radiated upward and outward from a centrally-located origin along the bottom, at the edge of the termination metal. Analysis of the fracture face gave no indication of fabrication level mechanical damage such as evidence of an impact site. Electrical overstress ruled out as a cause based on the capacitor's application. This indicates that the failure was, most likely, due to thermal and mechanical stresses induced during installation, testing, and/or board-level handling.
JANS1N4104UR-1	DO-213AA	Electrical measurements show short in reverse and forward direction. A crack in the die that leads to a breakout of die material after glass removal was observed. No fault could be found that could explain the short in the electrical measurements and the failure mechanism leading to this.

Developing Standards for Microcircuits

Being the NASA point of contact for standard microcircuits, S. Agarwal (5140) has worked with the community to establish standards coverage for the entire application spectrum of microcircuits. Some excellent progress was reported by task groups (TGs) developing standards. (a) QMLP, Standard for rad hard/rad tolerant plastic encapsulated (PEM) devices. The TG Chair has reported that they have developed the requirements and will forward them to the Defense Logistics Agency (DLA) for incorporation into the microcircuit's specification, MIL-PRF-38535. This would enable NASA and other agencies/users to be able to procure standard PEM parts (QMLP) for use in space applications without having to worry about upscreening, yield losses and potential non-conformances. The flight projects around the globe would realize considerable cost savings. Several manufacturers have already planned releases of their QMLP products. NASA is planning to include QMLP in its yet to be released 8739.11 document. See blue shaded area in the figure below. (b) Organic Class Y. The draft of MIL-PRF-38535 revision M which includes Organic Class Y was released Feb 28, 2022. There is a 30-day comment period before the requirements are finalized. This is shown as the yellow area. NASA/JPL HPSC project has baselined Organic Class Y. The green area shows existing standards coverage.



- Note 1: Standard PEMs for Space (QMLP) initiative using SAE AS6294 as baseline. Supported by NASA Parts Bulletins on PEMs.
- Note 2: For alternate grade microcircuits, follow the activity in 13.2 TG to avoid any duplication of effort.
- Note 3: ATM = Advanced Technology Microcircuits. Supported by NASA parts bulletin on KGD.
- Note 4: VID = Vendor Item Drawing. Contact DLA for latest information.
- Note 5: ***The boundaries separating various classes/grades must be clearly defined - future outreach activity.***

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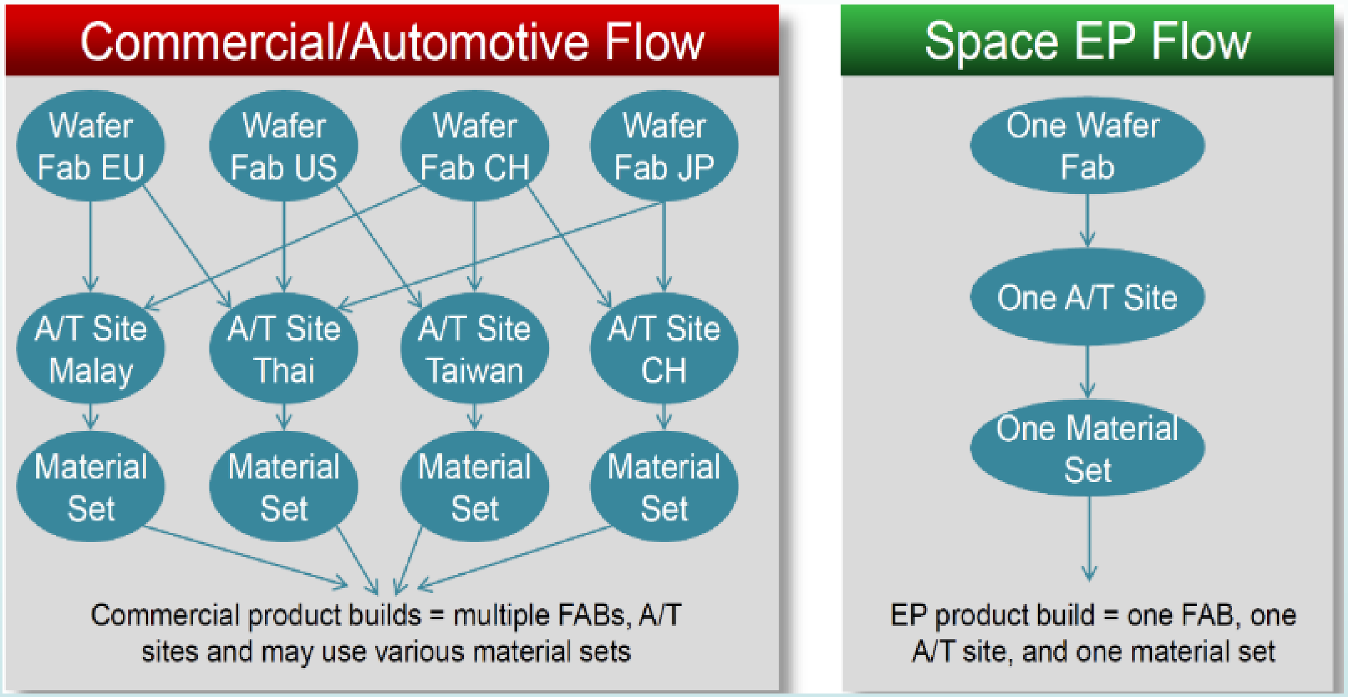
Texas Instruments (TI)

Space EP Baseline Controlled Flow



- The above chart provided by TI shows that their commercial/automotive products maybe built at multiple foundries, assembly/test facilities and may use various material sets.
- Contact manufacturer for a current version of this chart.

Some Notes on Fracture Mechanics in Plastic Packages
(S. Agarwal)

- **PEMs**
  - **Lots of JC13/CE-12 activity to develop Standards for Microcircuits**
    - **Heavy discussion on plastic parts in the next 2-3 years (and beyond)**
    - **Both ends of the spectrum: overmolded, and organic**
    - **Now is a good time to review the fundamentals of plastic packages – the community is making heavy investment in them to cover expanded application spectrum/ infuse new technology**
  - **Temp cycling**
    - **Done per MIL-STD-883, Test Method 1010**
      - **Condition C: -65C to +150C, used for ceramic parts**
      - **Condition B: -55C to +125C, being proposed for PEMs for Space**
      - **Condition A: -55C to +85C**
      - **How about the ramp rates, dwell times?**
  - **Glass Transition Temperature**
    - **No one seems to talk about it any more, has been a mystery**
      - **Always measured lower than specified (JPL experience from several years ago)**
  - **Packages are getting smaller, thinner**
    - **A GaN device that NASA/JPL wants to use, comes in a 8mm x 8mm size package**
  - **Post Assembly**
    - **Are any parts issues (e.g., crack propagation) off limits (IPC problem?)**
      - **CTE mismatches**
      - **Time dependence**
    - **(Ceramic) SMD-.5 packages had problems at temp cycling after they were mounted on boards**
      - **Would plastic parts be worse?**
    - **Bring parts, IPC, manufacturer communities together**
      - **Could a QCI type test/set of guidelines be developed at the part level?**
      - **Look at 38535 and 19500 products**
  - **What tests do the materials suppliers run to demonstrate quality/reliability?**
  - **Making improvements to standards, performance specifications**
    - **Is the potential impact of stress/pressure build up in plastic packages being adequately addressed?**
- **Is it time to address Fracture Mechanics and Microcircuit Standards?**
  - To identify any gaps and assess their impact
  - Plastic encapsulants, dielectric polymers, and underfill materials are subject to delamination and cracking with thermal cycling. Crack propagation during use environment exposure, drives the potential for failure of microelectronic devices and is therefore a necessary focal point in qualification and life testing.
  - Develop methodology for evaluating the time-dependent mechanical failure of semiconductor packages
    - Resulting from combined effect of stress, temperature, moisture absorption and crack like defect

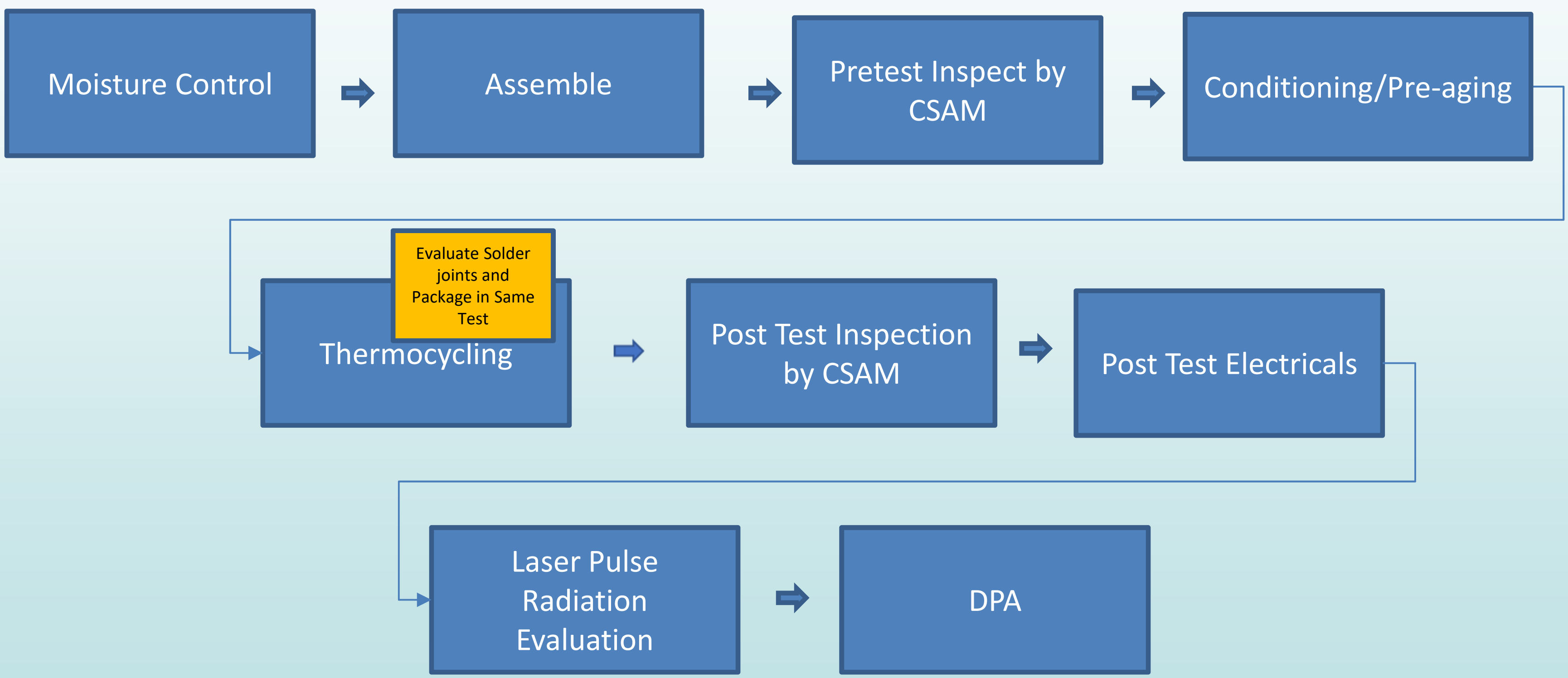
Applying Fracture Mechanics to PEMs Qualification - Key Points

(J. Evans, NASA)

- Fracture is a critical reliability issue for the packaging
  - Cracking of enclosure
  - Delamination
  - Cracking of polymer passivation
- Fracture mechanics can inform our testing
- Most critical stresses occur in assembly: greatest opportunity for defect formation
  - Thermomechanical
  - Hydromechanical
- Moisture control and handling of packages of critical importance
- Screening by Thermomechanical Loading Imposes Risk
- Defect propagation may occur post assembly in thermomechanical loading
- Risk increases with complex packaging

Idea for Informed Qualification

(J. Evans, NASA)



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Informed Qualification Testing

(J. Evans, NASA)

- Select Sample Size for Desired Use Risk Posture
  - Demonstrated reliability
  - Confidence Level
- Acceleration Factor: Power Law Models
- Set Test Gates for Use Life and Use Environment
- Execute and Inspect for Defect

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