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Recommendations on the Use of Commercial-Off-The-Shelf (COTS) Electrical, Electronic, and Electromechanical (EEE) Parts for NASA Missions – *Phase II*

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December 2022

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December 2022

Acknowledgments

The NESC team would like to thank all our consultants listed above from NASA, U.S. Army, Missile Defense Agency (MDA), U.S. Navy, and Federal Aviation Administration (FAA). The team also would like to thank the following peer reviewers: Morgan Abney, Lewis Cohn, John Evans, Razvan Gaza, Teri Hamlin, Susan Hastings, Dennis Krus, Raymond Ladbury, Michael Moore, Jim O'Donnell, Don Parker, Wesley Powell, John Scarpulla, Jeffrey Sokol, Raphael Some, Catherine Venturini, Sara Wilson, Mary Beth Wusk and Allyson D Yarbrough.

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NASA Engineering and Safety Center
Technical Assessment Report

Phase II

Recommendations on the Use of Commercial-Off-The-Shelf (COTS) Electrical, Electronic, and Electromechanical (EEE) Parts for NASA Missions

November 10, 2022

Report Approval and Revision History

NOTE: This document was approved at the November 10, 2022, NRB.

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	NESC Director	Date

Version	Description of Revision	Office of Primary Responsibility	Effective Date
1.0	Initial Release	Dr. Robert F. Hodson, NASA Technical Fellow for Avionics, LaRC	11/10/2022

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Technical Assessment Report

1.0 Notification and Authorization

Dr. Peter Majewicz, NASA Electronic Parts & Packaging (NEPP) Program Manager, requested an independent assessment to summarize Commercial Crew Program (CCP) and NASA Centers' current and best practices, and lessons learned, on the use of commercial-off-the-shelf (COTS) Electrical, Electronic, and Electromechanical (EEE) parts for all mission risk classifications, and provide recommendations that could lead to future NEPP Program and/or Agency guidance on COTS parts.

The key stakeholders for this assessment included Dr. Peter Majewicz, NEPP Program Manager, Dr. Jonathan Pellish, NASA Electronic Parts Manager, Ms. Susana Douglas, acting NASA Electronic Parts Manager, EEE parts managers/leads/engineers at NASA Centers, program/projects managers, and the NASA Engineering and Safety Center (NESC).

2.0 Signature Page

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Signatories declare the findings, observations, and NESC recommendations compiled in the report are factually based from data extracted from program/project documents, contractor reports, and open literature, and/or generated from independently conducted tests, analyses, and inspections.

3.0 Team Members

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3.1 Acknowledgements

The NESC team would like to thank all our consultants listed above from NASA, U.S. Army, Missile Defense Agency (MDA), U.S. Navy, and Federal Aviation Administration (FAA). The team also would like to thank the following peer reviewers: Morgan Abney, Lewis Cohn, John

Evans, Razvan Gaza, Teri Hamlin, Susan Hastings, Dennis Krus, Raymond Ladbury, Michael Moore, Jim O'Donnell, Don Parker, Wesley Powell, John Scarpulla, Jeffrey Sokol, Raphael Some, Catherine Venturini, Sara Wilson, Mary Beth Wusk and Allyson D Yarbrough.

4.0 Executive Summary

This assessment had two Phases. Phase I captured NASA Centers' current practices for commercial-off-the-shelf (COTS) Electrical, Electronic, and Electromechanical (EEE) parts[1] used in spaceflight systems and ground support equipment (available at https://ntrs.nasa.gov/citations/20205011579) [ref. 1]. The Phase II report provides guidance for selecting and using COTS parts in NASA missions. The approaches proposed in this report differ from current agency practices. This top-level executive summary touches on these new approaches for using COTS parts but does not provide the detailed information that is critical in understanding the rationale behind these new approaches. *Readers will need to read the entire report to gain full understanding and effectively use the recommendations herein.*

NASA's historical approach to selecting and applying parts has been to define certain parts, primarily specific classes of military specification (MIL-SPEC) parts, as "standard", leaving all others, including COTS parts, as nonstandard. Standard parts typically are used without further testing ("use-as-is"). Nonstandard parts are subjected to initial screening and subsequent lot acceptance testing of representative samples from each procured lot per MIL-SPEC or similar requirements.

Decades later, top-tier commercial part manufacturers have evolved significant manufacturing, statistical control, and technological improvements that can now provide parts as reliable or more reliable than MIL-SPEC parts, when used within their datasheet limits. Concurrently, the space science and exploration community's needs demand technological advances unavailable with MIL-SPEC parts. This ongoing change necessitates using COTS parts for space missions.

Properly selected COTS parts in appropriate applications can offer performance and supply availability advantages compared to MIL-SPEC parts. Their utility and demonstrated reliability result from large volumes and automated production and testing processes. However, careful review and a thorough understanding of their specifications (i.e., datasheet limitations) is needed, and verifying that manufacturer specifications and reliability meet space hardware application needs are necessary.

This report recommends MIL-SPEC screening and non-radiation-related lot acceptance testing be reduced or eliminated in cases where evidence of sufficient quality and reliability exists for COTS parts. The extent of NASA's insight into COTS manufacturers and the amount and nature of the needed evidence will differ by mission and will likely be driven by a mission's resources and associated risk posture.

To facilitate this goal, two new terminologies have been defined and described: "Industry Leading Parts Manufacturer (ILPM)" and "Established COTS parts." An ILPM is a COTS manufacturer that produces high quality and reliable parts. Some parts produced by ILPMs, defined as Established COTS parts, do not need any additional MIL-SPEC or NASA screening and lot acceptance testing to be used in space applications.

This report provides guidance for selecting, procuring, and applying COTS parts and for performing part-, board-, and system-level COTS parts verification. The recommendation to select Established COTS parts from ILPMs will assure those COTS parts will have comparable quality to corresponding MIL-SPEC parts. Selecting, applying, and verifying Established COTS

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[1] Note that "parts" will be used for "EEE parts" hereafter throughout the report.

parts from ILPMs requires a holistic team approach, engaging parts engineers, circuit designers, quality, reliability, and systems engineers, procurement specialists, radiation specialists, avionics leads, and program/project managers. A mission-specific approach tailored to a project's Mission, Environment, Applications and Lifetime (MEAL) [ref. 2] requirements should be developed and approved by program/project managers. Any associated risks should be clearly identified, quantified, mitigated, and/or accepted.

Different approaches are recommended according to program/project Risk Classes A, B, C, and D [ref. 3] and human-rated missions [ref. 4]:

1. Recommend Classes A and B and human-rated missions consider a "MIL-SPEC parts-based design" approach. "MIL-SPEC parts-based design" approach is one in which most parts are MIL-SPEC parts and Established COTS parts from ILPMs are used only when an equivalent MIL-SPEC part does not meet functional or size, weight, and power (SWaP) or performance requirements, or is not available.
2. Recommend Classes D and Sub-D missions consider a "System of COTS" approach. "System of COTS" approach is one which most parts are Established COTS parts from ILPMs.
3. Recommend Class C missions determine which approach is the best for their projects; that is, use either a "MIL-SPEC parts-based design" approach, "System of COTS" approach, or a combined approach utilizing elements of both.

This report intends to provide guidance in using COTS parts for NASA missions with risk classifications of A through D and human-rated missions; but it does not address the costs of using COTS parts. Costs of using COTS parts in different NASA mission classes can vary significantly even if the same parts are used in different risk postures, due to differing verification levels needed. The guidance does not distinguish between critical or non-critical systems, and a given project will need to apply the appropriate guidance based on their risk posture.

The intended audience of this report are NASA personnel and commercial practitioners who support NASA's spaceflight missions, including spaceflight program or project managers, parts engineers, parts manufacturers, radiation engineers, avionics engineers, system engineers, circuit design engineers, reliability engineers, safety and mission assurance (SMA) personnel, and parts procurement specialists.

The NEPP Program will perform a pathfinder study to explore implementing the guidance in this NESC report. An ILPM verification process is not the same as conventional vendor qualification processes performed according to military standards and specifications. This NESC report intends to provide guidance in utilizing available parts data from ILPM manufacturers for parts assurance assessments needed for NASA missions.

The report also captured the current practices from DoD and Federal Aviation Administration (FAA) in Section 10. Note each DoD and FAA report was provided by the corresponding agencies regarding their practices, which are independent from the NESC recommendations in the report.

5.0 Assessment Plan

This assessment was accomplished in two phases, Phase I and Phase II.

The initial request is listed below. The NESC team performed the initial tasks and published the Phase I report, available at https://ntrs.nasa.gov/citations/20205011579. The Commercial Crew Program (CCP) partners' related practices and their lessons learned were not included in the Phase I or Phase II reports.

1. Discuss and summarize different or various parts standards and approaches used by CCP partners, including parts selection, evaluation, screening, and qualification processes and criteria, and lessons learned from CCP parts leads/team and potentially from CCP partners.
2. Discuss, compile, and summarize the state of practices and/or best practices on use of COTS parts for various programs/projects at NASA Centers. The practices and best practices should provide the correlation between parts selection, evaluation, screening, and qualification process with respect to project category/classification, and address MEAL for COTS parts.
3. Based on 1 and 2, develop recommendations that could lead to future NASA Electronic Parts and Packaging (NEPP) Program and/or Agency guidance on COTS parts selection, evaluation, screening, qualification, and usage in space systems to perform as required over the life cycle for all types of space missions, by leveraging the lessons learned from CCP and the best practices currently being used across the Agency.

This Phase II addressed the following tasks:

1. Captured the current practice for COTS parts usage from the U.S. Department of Defense (DoD) and Federal Aviation Administration (FAA).
2. Defined the criteria of an *Industry Leading Parts Manufacturer* and part-level verification.
3. Provided guidance on using COTS for NASA missions.

6.0 Problem Description

An increasing number of programs and projects are driving the use of COTS parts to meet challenging SWaP, and/or performance, requirements, and to align with current parts technological advancements since the late 1990's and early 2000's. Missions of high importance to the Agency increasingly are requiring using parts that are only available as COTS and that cannot be screened effectively using current Agency practices.

NASA must capture best practices and lessons learned and document the current practices as they evolve to promote uniform knowledge sharing and skill development across the Agency. Various projects at NASA Centers, along with their CCP partners, have used various guidance standards, techniques, and philosophies to select, evaluate, screen, and qualify different COTS part types. This increasing COTS hardware utilization requires a multi-disciplinary approach provided through diverse feedback from current users to ensure MEAL [ref. 2] requirements are met across the Agency's wide-ranging needs having differing risk postures.

This task addresses part of the first short-term strategic vector for the parts community (i.e., "develop appropriate guidance for testing, screening, qualifying, and reliably using COTS and emerging parts technologies for all types of space missions”). Recording and organizing experiences, knowledge, and lessons learned at NASA Centers is essential if the Agency is to benefit through sharing this information.

7.0 NESC Guidance on Using COTS Parts for NASA Missions

Section 7.1 provides the scope of this assessment and some essential parts-related terms including three new terminologies defined in the report. Section 7.2 provides the NESC recommended guidance in using COTS parts for NASA missions.

7.1 Scope of Assessment and Essential Terms

Commercial parts technologies are evolving rapidly. Spaceflight program demands for improved performance and their constrained budgets and schedules have increased needs to infuse COTS parts across all NASA space missions (e.g., Categories 1-3, Classes A-D, and sub-Class D).

This assessment’s scope, and that of the preceding Phase I assessment, is described. Then, several terms including new terminologies are defined beyond an acronym listing to provide more detail regarding how these terms affect parts selection, use, and applications. Subsequently, the evolution of approaches and standards for military specifications (MIL-SPEC) and COTS parts are discussed.

7.1.1 Assessment Scope

This assessment’s scope was performed in two phases.

Phase I of the assessment’s scope was to:

1. Capture NASA Centers’ current practices, best practices, lessons learned and recommendations on using COTS EEE parts in spaceflight systems. Centers included were: Ames Research Center (ARC), Glenn Research Center (GRC), Goddard Space Flight Center (GSFC), Jet Propulsion Laboratory (JPL), Johnson Space Center (JSC), Kennedy Space Center (KSC – for their COTS EEE parts, components and assemblies used in Ground Support Equipment (GSE)), Langley Research Center (LaRC), and Marshall Space Flight Center (MSFC); and
2. Provide recommendations for using COTS parts in spaceflight systems and GSE.

The NESC Phase I report [ref. 1] was published in December 2020. Center reports on using COTS processes and practices with COTS parts project examples were included in Appendix A, and Appendix B summarized two NESC COTS-related assessments. NASA current practice is to use MIL-SPEC parts and NASA-screened COTS parts for safety and mission critical systems on missions of all risk classifications. Some Class D and sub-Class D missions and payloads, as well as non-critical applications, have used COTS parts without additional part-level MIL-SPEC/NASA screening and qualification.

In the Phase I investigations, there was a lack of consensus between Centers in two areas:

1. On risk perceptions in using COTS parts for safety and mission critical spaceflight system applications. Perceptions varied from feelings of “high risk” when part-level MIL-SPEC/NASA screening and qualification were not fully performed to “no elevated risk when sound engineering was used” and part applications were understood.

2. On the type and source of COTS parts data that would have been sufficient for COTS part-level verifications.

This Phase II assessment's scope defines criteria for ILPMs and associated part-level verifications, provides updated COTS usage guidance for NASA missions, and captures COTS usage practices from DoD and the FAA.

The Phase I report provided NASA Centers' current practices for COTS parts used in spaceflight systems and in GSE. This Phase II report focused on COTS parts used in space hardware; COTS assemblies, including hybrid microcircuits, were not addressed in Phase II. The procurement and usage of COTS assemblies is a different topic albeit with many similar considerations. To some extent, this report might address some of the internal concerns one would have about using COTS assemblies. Nonetheless, use of such components would demand a more specialized document.

7.1.2 Terms and Clarifications

Some commonly used terms, such as COTS part and parts screening, are defined and discussed below, as other organizations may use the same words with different meanings. These terms are used throughout this report and their specified interpretations are important to understanding the recommendations. Additional terms and acronyms are provided in Sections 11 and 12.

The NESC team has defined three new terms in this report: NASA-screened COTS parts in Section 7.1.2, and ILPM and Established COTS parts, both in the Section 7.1.3.

7.1.2.1 Part Categories

MIL-SPEC Part: A part that is produced by a manufacturer listed on the Defense Logistics Agency's (DLA)[2] Qualified Manufacturers List (QML) and certified by compliance to MIL-SPEC documents. These manufacturers are part of the military components standardization program to manufacture, screen, and qualify products to the required quality levels in accordance with MIL-SPECs for each part type. These manufacturers also agree to undergo periodic audits to maintain certifications of their manufacturing and testing facilities.

COTS Part: A part for which the manufacturer solely establishes and controls specifications for configuration, performance, quality, and reliability. This includes design, materials, processes, assembly, and testing with no Government-imposed requirements (i.e., no Government oversight). COTS parts typically are available on a manufacturer's catalog (e.g., website) or from various distributors. Many manufacturers use Government standards and test methods in their quality and reliability programs without participating in the QML program or being subject to DLA certification audits. This does not mean those parts should automatically be considered compliant to MIL-SPECs or similar to MIL-SPEC parts.

Types of COTS parts include:

1. **"Space Rated or Graded" COTS part:** A COTS part that is produced on manufacturer production lines with enhanced process controls and screening intended to provide parts suitable for certain space applications, as determined by the manufacturer and based on MIL-SPEC Class S requirements. Enhancements also may include radiation testing and characterization. COTS qualification and screening

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[2] https://landandmaritimeapps.dla.mil/programs/qmlqpl/

practices and design rules are not subject to Government oversight and vary by manufacturer, and thus should not be interpreted as completely compliant to MIL-SPEC standards. Often, Space Rated or Graded COTS parts are not recognized by users to be COTS parts.

2. **Automotive Grade COTS part**: A COTS part produced on manufacturer production lines with enhanced process controls and screening intended to provide parts suitable for automotive applications in accordance with recommendations and requirements listed in automotive industry standard specifications (e.g., Automotive Electronics Council's AEC-Q100 [ref. 5] for packaged integrated circuits, AEC-Q101 [ref. 6] for discrete semiconductors, and AEC-Q200 [ref. 7] for passive electronic components, etc.) and meeting other applicable standards such as IATF 16949[3].
3. **NASA-screened COTS part**: A COTS part that after procurement is screened, and in many cases qualified, per NASA Agency, Center, or Program parts requirements documents, such as EEE-INST-002 [ref. 8] or equivalent documents, by NASA, NASA contractors, a third-party, or the part manufacturer. Space radiation is not addressed in these screening or qualification processes.

   Note: It is common to use the term "upscreening" to represent NASA screening, however this term should be avoided.

7.1.2.2 Part Screening and Qualification

Part *Screening* refers to the process of subjecting 100% of parts in a manufacturing lot to nondestructive tests (e.g., electrical and environmental stress) to remove nonconforming or defective parts. These tests may occur within manufacturing steps (i.e., in-line) or on completely manufactured parts, prior to shipping.

MIL-SPEC Part Screening comprises a sequence of tests defined by the applicable MIL-SPECs. Such screening typically includes temperature cycling and burn-in at maximum thermal and electrical ratings with electrical parameters measured before and after.

NASA screening – Specific tests and required thresholds that are listed in applicable NASA requirements documents employed to screen parts.

COTS manufacturer production tests – COTS manufacturer production testing is one element of COTS parts "screening". Electrical parametric and functional tests that are defined and implemented by parts manufacturers, performed on 100% of parts, and intended to verify part functionality to full or typical datasheet parameter specifications. These tests typically are performed at room temperature, or per manufacturer-defined temperature ranges, and are intended to remove defective parts and those considered likely to fail early and/or identify parametric outliers. Methods employed may vary among different manufacturers and are typically proprietary.

Notes: MIL-SPEC and NASA screening include burn-in, intended to remove parts considered likely to fail early. COTS manufacturers define their own screening, which can differ among manufacturers, especially across different part types (e.g., between semiconductor and passive parts). COTS manufacturers may perform burn-in only during

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[3] https://en.wikipedia.org/wiki/IATF_16949

qualification and sample burn-in (burn-in on sampled parts) to monitor production line performance.

Part *Qualification* is the process of subjecting a sample of manufactured parts to destructive and nondestructive tests (e.g., electrical and environmental stresses) to validate the part's design and manufacturing processes, to ensure the parts meet datasheet requirements, and to provide a baseline for subsequent screening tests. Qualification testing parametric limits typically are more extreme (more stressful), that accelerate failure mechanisms, than limits used in screening tests.

> **Note 1:** QML manufacturers produce MIL-SPEC parts in accordance with requirements (e.g., screening and qualification testing) listed in MIL-SPECS. COTS parts manufacturers determine testing requirements needed to produce and verify their devices. The word "screening" used by different organizations may have different meanings among, for example, MIL-SPEC and COTS manufacturers.
>
> **Note 2:** Lot Acceptance Testing is performed to confirm that a lot of parts meets an expected performance and quality (percent defective allowable) requirements against known stresses. Lot Acceptance Testing is not considered as a qualification in this report[4].
>
> **Note 3:** In addition to part qualification, manufacturers perform fabrication process qualification, which is described in Section 7.1.3.2.

Best Practices – Methods or techniques that have been demonstrated to consistently achieve good and desired results.

7.1.3 New Terms: Industry Leading Parts Manufacturer (ILPM) and Established COTS Parts

This section defines and describes ILPM and Established COTS parts, provides the criteria of an ILPM, and compares Established COTS parts, NASA-screened COTS parts and MIL-SPEC parts.

7.1.3.1 ILPM and Established COTS Parts

It is important for NASA space programs and projects to select and procure high quality and high reliable COTS parts from manufacturers who have demonstrated they can produce high quality and reliable parts consistently that are comparable to or better than MIL-SPEC parts.

ILPMs and Established COTS Parts, as defined and discussed in this section, form the basis for the NESC team's recommendations in selecting COTS parts for space systems in this report. The report provides user guidance on how to verify a COTS part has the necessary design, qualification, and testing needed to perform to its datasheet parameters in an intended operational environment for a project-required lifetime.

ILPM is a COTS manufacturer that produces high quality and reliability parts that do not benefit from additional MIL-SPEC screening and lot acceptance testing, common in current NASA and MIL requirements for using nonstandard parts in space. Such additional MIL-SPEC screening may be more detrimental than beneficial when applied to COTS parts when the test parameters exceed the limits listed in the parts' datasheets.

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[4] EEE-INST-002 provides a definition for qualification that is both inaccurate and incomplete, and thus will not be used in this report. NASA-STD-8739.11 will use a revised definition consistent with that in this report.

Established COTS Part is a part that

1. is produced using processes that have been stable for at least one year so there are enough data to verify the part's reliability;
2. is produced in high volume. High volume is defined as a series of parts sharing the same datasheet having a combined sales volume over one million parts during the part's lifetime;
3. is 100% electrically tested per datasheet specifications at typical operating conditions in production prior to shipping to customers. Additionally, the manufacturer must have completed multi-lot characterization over the entire set of operating conditions cited in the part's datasheet, prior to mass production release. Thus, production test limits are set for typical test conditions sufficient to guarantee that the parts will meet all parameters' performance specifications on the datasheet;
4. is produced on fully automated production lines utilizing statistical process control (SPC), and undergoes in-process testing, including wafer probing for microcircuits and semiconductors, and other means appropriate for other products (e.g., passive parts). These controls and tests are intended to maintain process tolerances and eliminate defective parts at various stages of production; and
5. has demonstrated consistent yield trend appropriate for high volume commercial technologies at that technology node.

Note: The terms ILPMs and Established COTS parts are not intended to be used for certification by NASA.

7.1.3.2 Criteria and Characteristics of an ILPM

ILPMs qualify parts before officially releasing them for high volume production. A typical parts qualification process begins with fabrication process qualification steps, such as high-temperature operating life (HTOL), high-temperature storage, temperature-humidity, and temperature cycling tests being carried out, if the process has not been qualified fully. These processes also include qualifying starting materials (e.g., blank wafers from multiple vendors for microcircuits). Then, part specific qualification steps such as burn-in (rarely used on newer technologies) or voltage or power conditioning, HTOL, environmental stress, and wear-out tests (e.g., time-dependent dielectric breakdown, hot carrier injection, electromigration, negative bias temperature instability, etc.) are performed. These tests must be completed successfully over multiple lots, usually a minimum of three. Finally, part assembly and packaging processes are qualified (e.g., die-package interactions, temperature cycling, wire bond tests, if packages have not been qualified previously by similarity). During subsequent high-volume production, SPC, six sigma, or "zero defects" approaches for continuous improvement should be implemented to enable delivering parts having high yield and consistent quality when produced on multiple production lines.

Criteria for an ILPM

The NESC team has established the criteria for an ILPM as listed below. These five ILPM criteria are applicable to microcircuit, discrete semiconductors, capacitors, and resistor manufacturers. Hybrid microcircuits and other passive part types are not addressed in this assessment.

1. An ILPM may have various COTS part categories and must have at least one Established COTS Part category.
2. An ILPM is willing to share parts quality and reliability data with NASA, including estimated production DPPM, field failure DPPM and/or part failure rates (FITs), and how those statistics are derived.
3. An ILPM is willing to provide NASA documents substantiating parts quality and reliability.
    a. If the manufacturer is supplying AEC parts, documentation needed includes:
        i. IATF 16949 certification (QMS),
        ii. Level 3 PPAP,
        iii. AEC 004 related practices,
        iv. Sales volume of parts, and
        v. Designed operating life.
    b. If the manufacturer is supplying AEC parts but does not provide a Level 3 PPAP, or does not supply AEC parts, documentation should conform to one of the options listed below:

    Option 1: A Level 3 PPAP equivalent, including quality certifications for the specific manufacturing site(s), a Part Submission Warrant (PSW), a Certificate of Design, Construction and Qualification (CDCQ), engineering change documents, a design FMEA, a process FMEA, a process control plan, material performance test results, process studies, and measurement system analyses.

    Option 2: Process and test data to:

    - demonstrate fabrication processes stability in key processes over 12 months production, such as process capability index (C_{pk}) statistics, and root cause analyses and corrective actions resolving low C_{pk} processes;
    - demonstrate process capability by examining processing data as a function of control limit requirements;
    - demonstrate process and manufacturing yield capability by an examination of yield inhibitors with an appropriate yield improvement plan in place;
    - demonstrate assembly and test (A/T) operations stability, such as final test yields over 12 months production, and root cause analyses and resolutions for any low final test yields; and
    - demonstrate high volume produced parts qualification processes, such as CDCQ, fabrication process qualification or qualification by similarity (QBS) to other parts, packaging qualification process or QBS, part qualification results, and final characterization reports per datasheet parameters including C_{pk}'s.
4. An ILPM implements processes similar to a "Zero Defects strategy" [ref. 9], or similar continuous improvement approaches. For a similar continuous improvement approach, documentation is needed to:
    a. describe the processes and practices for eliminating statistical outlier parts [ref. 10] before shipment;

    Per AEC-Q001, outlier parts refer to parts within manufacturer's specification limits that are outside the main population distribution;

   b. describe the reliability monitoring program, such as wafer level reliability, daily end of production parts testing, testing bias and thermal conditions, sample sizes, failure criteria, etc.; and
   c. control limit improvement process
5. An ILPM is willing to allow NASA to visit on-site and/or to work with NASA or prime contractors to maintain a strong customer-manufacturer relationship. Manufacturers may contact the NEPP at https://nepp.nasa.gov/ to establish a NASA-manufacturer relationship.

Primary Characteristics of an ILPM

ILPMs achieve high quality and reliability by using industry best practices. Organizations such as JEDEC[5] and AEC[6] are good sources for information on industry best practices. Some characteristics of an ILPM include:

1. The manufacturer implements a "Zero Defects" program, as described in AEC-Q004 [ref. 9] or a similar source.
2. The manufacturer designs parts for manufacturability, testability, operating life, and field reliability. Tools facilitating these part characteristics include Design and Process Failure Modes and Effects Analyses (DFMEA, PFMEA).
3. The manufacturer manufactures parts on automated, high-volume production lines with minimal human touch labor. Parts not built on such production lines do not benefit from "sameness" in part-to-part or lot-to-lot variability of datasheet parameters (i.e., consistency and minimal variability and thus are potential candidates for part-level screening and qualification).
4. The manufacturer understands and documents their entire manufacturing and testing processes and impacts and sensitivities of each process step on product characteristics and quality. The manufacturer implements a robust manufacturing plan verifying and assuring step-by-step that in-process work meets standards before moving to subsequent manufacturing steps. This is done through implementing a Process FMEA, a robust control plan, process characterization [ref. 6], SPC (e.g., Society of Automotive Engineers (SAE)-EIA-557[7]) and other standards for process variability control. For example, automotive manufacturers commonly require a C_{pk} greater than 1.67 for key processes steps.
5. The manufacturer's production testing includes 100% verification of datasheet electrical parameters, multi-lot qualification (e.g., JESD47 [ref. 11], AEC-Q100 [ref. 5]), shift-based, lot-based, daily, weekly, and quarterly sampling for process monitors and ongoing reliability testing, generating relevant Early Life Failure Rates (e.g., JESD74 [ref. 12]), outgoing DPPM (e.g., JESD16 [ref. 13]), and useful life Failure In Time (e.g., JESD85 [ref. 14]) statistics.

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[5] https://en.wikipedia.org/wiki/JEDEC
[6] https://en.wikipedia.org/wiki/Automotive_Electronics_Council
[7] https://standards.globalspec.com/std/10279308/eia-557

6. The manufacturer implements rules for removing outlier parts (i.e., AEC-Q001 [ref. 10]) and removes abnormal lots (AEC-Q002, ref. 7]); these rules may apply either in-process or with finished parts.
7. The manufacturer implements a robust change system that assures all major changes are properly qualified (JEDEC and AEC and others provide requirements for requalification) and that customers are notified of major changes (JESD46, [ref. 15]).
8. The manufacturer implements a robust quality management system (QMS) acceptable for spaceflight. AS9100 [ref. 16] and IATF16949 [ref. 17] are certification examples that indicate a good QMS. Note that AS9100 audit and approval is certifying the QMS, not the outgoing product's quality.

7.1.3.3 Comparison among Established COTS, MIL-SPEC, and NASA-Screened COTS Parts

NASA-STD-8739.10 “establishes a consistent set of Agency-level requirements to control risk and to assure lot-level quality of NASA spaceflight hardware and critical GSE”[8]. Additionally, Center-level parts management and control document (e.g., GSFC EEE-INST-002) are used at their respective Center for additional requirement in selecting, screening, and qualifying parts. These documents establish baseline part-level assurance processes for using various part classes/grades/levels, including the use of COTS parts.

These documents recommend MIL-SPEC parts as the first choice, and typically list a MIL-SPEC Class or Grade that can be used without any additional testing based on a project's or program’s required parts “Level.” For example, for a Level 1 Parts Program that requires the highest amount of parts assurance or equivalent to the MIL-SPEC class designed for space applications, the documents list Class V microcircuits and JANS discrete semiconductors as “Use As Is” or “Standard”, meaning that no further testing is required for approval (unless testing is required to satisfy a specific programmatic MEAL, such as Radiation Hardness Assurance (RHA), that is not covered by the MIL-SPEC). A COTS part is considered as a “non-standard” part and thus needs to be qualified and screened per the documents and becomes a NASA-Screened COTS part as defined in Section 7.1.2.

The lack of government oversight and limited insight into COTS parts manufacturers may be challenging for part-level verification or obtaining detailed knowledge of a COTS part's materials, construction, and processes. The NESC team recognizes that government control is not a prerequisite for high quality and reliable parts. COTS manufacturing and assurance processes vary among manufacturers, but some commercial manufacturers, such as ILPMs, have developed rigorous process controls and screening methods to ensure consistent yield leading to high reliable parts.

Table 7.3.3-1 compares the attributes for Established COTS parts from ILPMs and MIL-SPEC and NASA-screened COTS parts.

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[8] GSE is ground support equipment – equipment that interfaces with flight hardware. Critical GSE is GSE that is used during launch operations to assure a successful and safe launch.

Table 7.3.3-1. Comparison among Established COTS ILPM, MIL-SPEC, and NASA-screened COTS Parts

	Established COTS Parts from ILPMs (microcircuits, discrete semiconductors, capacitors, resistors)	**MIL-SPEC Parts (microcircuits, discrete semiconductors, capacitors, resistors)**	**NASA-screened COTS Parts (microcircuits, capacitors, resistors)**
Attributes	1. Produced by an ILPM 2. Automated production line 3. High-volume parts 4. 100% electrical testing 5. Reliability monitoring 6. Process and parts qualification 7. Typically, non-standardized drawings and datasheets 8. Only a small percentage are rated for space radiation 9. May or may not be designed for launch and deep space environment	1. Automated production line 2. Not typically high-volume 3. 100% MIL-SPEC screened 4. Lot acceptance 5. Process and parts qualification 6. Standardized drawings, datasheets and MIL specs 7. Only a small percentage are rated for space radiation 8. May or may not be designed for launch and deep space environment	1. May or may not have automated production line 2. May or may not be high-volume 3. Post procurement 100% screened 4. Lot acceptance 5. Typically, non-standardized drawings and datasheets 6. Only a small percentage are rated for space radiation 7. May or may not be designed for launch and deep space environment

ILPMs employ high volume production facilities and have advantages over MIL-SPEC parts manufacturers as their large quantity production is facilitated by automated SPC that drive down manufacturing defects. These advanced process control methods address the same goals that MIL-SPEC screening and qualification intend to address – eliminating defective product. In fact, in-process controls can be more effective than post manufacturing screens, provided that the critical parameters in the manufacturing processes are understood. MIL-SPEC parts reliability is achieved through tight controls on proven designs, part qualification, and lot acceptance testing that screens out parts with features historically identified to cause weaknesses. COTS parts reliability is established through high volume production and automated SPCs that yield few fielded defective parts. ILPMs have and can provide data to support their part quality and reliability claims. Conversely, low volume, unknown, or newly established manufacturers may not have instituted advanced in-process control methods and end-of-line testing to assure part quality commensurate with space applications. Parts from such manufacturers may entail elevated part-level risks.

Therefore, the NESC team recommends that NASA programs and projects select the Established COTS parts from ILPMs when COTS parts are used. Selecting, verifying, and applying Established COTS parts from ILPMs requires a holistic approach and a team effort, engaging parts engineers, quality, reliability and system engineers, circuit designers, procurement specialists, radiation specialists, avionics leads, program/project managers, safety and mission assurance (SMA) personnel and other contributors. Therefore, when the recommended guidance outlined in Section 7.2 is followed, the NESC team believe that the Established COTS Parts from ILPMs have comparable quality to MIL-SPEC parts.

Note that part RHA is addressed separately in Section 7.2.9. Radiation hardening by design (RHBD) became viable at about the 250nm node, that use high volume commercial processes as the host technology has made it possible to obtain robustly hardened microelectronics that embody high volume commercial manufacturing. RHBD approaches are most useful for ASIC type developments or when commercial intellectual property is available.

7.1.4 Some Facts Regarding Parts

Parts selection, procurement, and any required testing before installation into flight hardware impact space systems' mission success. Parts implementation is one of multiple contributors to a successful space mission. System design considerations down through the individual circuit card assemblies and the system's design, fault tolerance, testing, and problem resolution effectiveness also strongly influence mission success.

Traditionally, more than about 25 years ago, parts manufactured to MIL standards and specification requirements documents dominated parts installed in space systems. Those standards, test methods, and parts manufacturing requirements originated during the 1960's when semiconductor devices were beginning to be introduced into electronic components and systems - both those designed for commercial and consumer products and industrial and military products. The latter included the earliest satellites. These MIL standards and specifications explicitly defined part materials and manufacturing and testing processes. The MIL specifications also created different quality assurance levels (also referred to as "Classes" or "Grades") within each part type. These included part Grades intended for space applications, a "standard" military Grade, and additional lower part Grades. During the 1960's through 1970's, semiconductor parts produced under MIL requirements trended from approximately 50% down to 30% of worldwide production. Many MIL testing methods and standards had been adopted by parts manufacturers for consumer, commercial and industrial products.

With the advent of the computer revolution in the mid- to late-1970's, parts produced for commercial and consumer products increased markedly and began to dominate parts produced worldwide. By the late 1980's and early 1990's, semiconductor devices produced under MIL specifications and standards diminished to less than 3 to 5% of worldwide production and by the mid- to -late 1990's accounted for less than 1%.

Concurrently, the U.S. DoD Perry Memorandum (the "Perry Memo") [ref. 18] instituted in 1994 drove revisions to MIL standard and specification requirements from mandated materials, manufacturing, and testing requirements to performance-based requirements. For example, the previous *MIL-M-38510 Microcircuits, General Specification for* was revised to *MIL-PRF-38535, Integrated Circuits (Microcircuits) Manufacturing, General Specification for*.

These revisions permitted device manufacturers to adopt best commercial practices while still meeting military environmental, performance, and quality needs. However, one result of these changes is that formerly required end-of-line continuous, sequential long-term life testing was replaced by periodic sample-based accelerated life testing. Most of these sequential tests were run for up to 10,000 hours. The formerly required continuous, sequential tests provided actual demonstrated (not predicted) part reliabilities, classified by assigning letter designators for demonstrated reliability levels at wide performance and environmental ranges. These practices have been discontinued when the MIL-PRF specification documents were adopted, replaced instead by periodic life testing. Thus, the present MIL-SPEC system provides quality assurance but not necessarily demonstrated reliability.

Properly selected COTS parts in properly designed applications (i.e., used well within their datasheet limitations) can offer performance and supply availability advantages compared to

MIL-SPEC parts. Their utility and demonstrated reliability results from large volumes and automated production and testing processes. However, careful review and a thorough understanding of their specifications (i.e., datasheet limitations) is needed, and verifying that manufacturer specifications and part reliabilities meet space hardware application needs is necessary.

The term “COTS parts” encompasses an array of technologies, features and performance that is seemingly unlimited. For this reason, one should avoid assumptions about a part's construction and long-term performance because it is labeled COTS. Since COTS parts generally include both those suitable for high-reliability applications and those that are not, there is a tendency to broadly denote COTS parts as “low-reliability” or “low grade” and neglect the fact there are significant COTS subsets fully suitable for high-reliability applications. Figure 7.1.3-1 notionally shows an overall “space” view[9] for COTS parts, compared to MIL-SPEC parts[10]. COTS parts generally cover the full spectrum of parts: those with low expected lifetimes through parts with high expected lifetimes, and parts with high radiation susceptibility and those with low radiation susceptibility. Typically, MIL-SPEC parts cover a similar regime, and MIL-SPEC processes can be effective at screening out infant mortals and assuring consistent manufacturing processes, irrespective of a part’s radiation susceptibility. Note there are parts, both COTS and MIL-SPEC, in the upper right corner that are tolerant to radiation by their technology, design or construction, although they may not be denoted as radiation-hard or radiation-tolerant. This diagram is notional as it provides a simple, one-dimensional view of radiation robustness, whereas, in reality, part radiation effects are complex and multi-dimensional. Furthermore, the reader should not infer minute details about part density dot depictions, as this is a *notional* graphic and part density depictions are only *approximate.*

This report will focus on providing the tools and recommendations for selecting and using COTS parts that are in the upper right-hand corner of Figure 7.1.3-1. Note that part-level radiation or reliability assurance by itself may not be sufficient to ensure system-level reliability or protection from radiation. In some cases, radiation effects can be mitigated by using combinations of shielding and/or fault tolerant circuit design practices. However, combined part and system-level considerations maximize assurance. Additionally, it is always important to use a consistent definition if practitioners or others make decisions based on using the term COTS because, without having a consistent definition, one might infer a specific area of the diagram when another area is intended.

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[9] “space” in this context is referring to space applications (orbiting, planetary, or deep space)

[10] This essentially would be a “United States” view unless the term MIL-parts were expanded to cover similar Government-controlled parts from other countries.

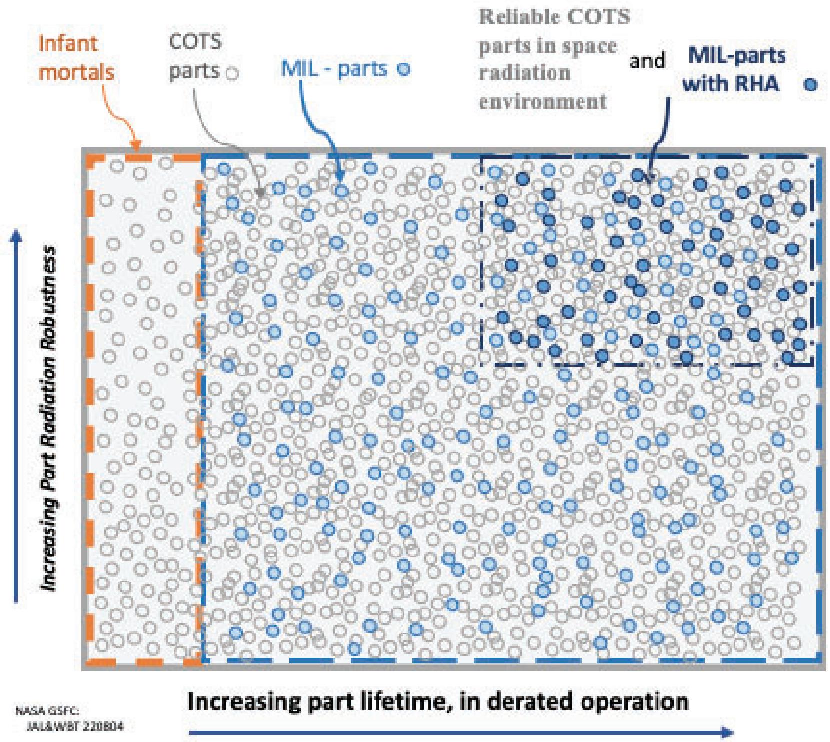
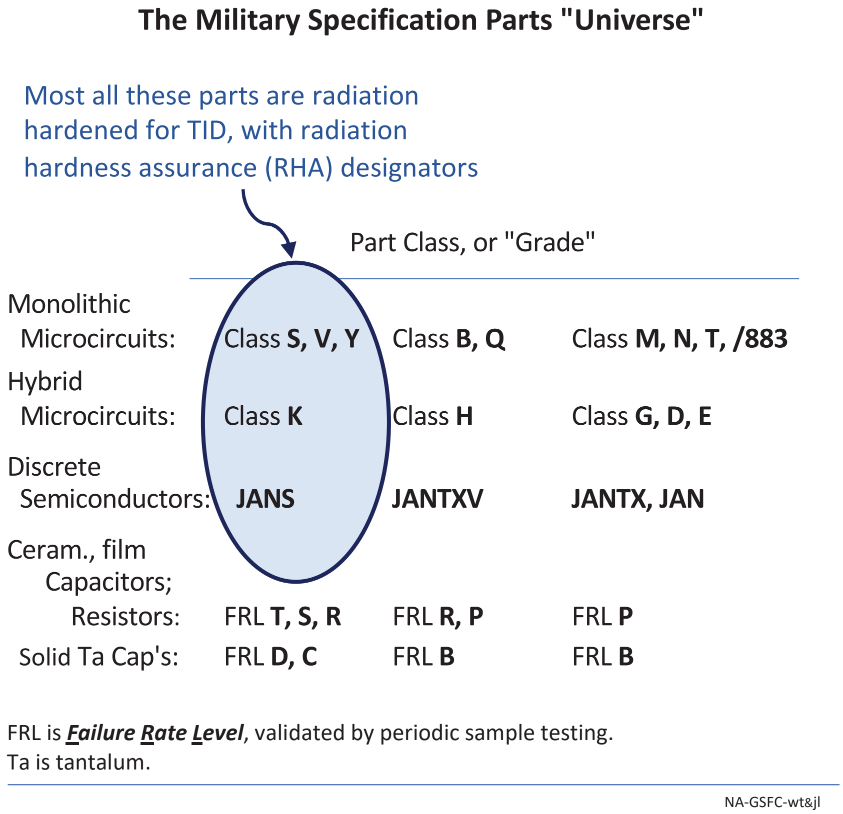


Figure 7.1.3-1. Notional Radiation Robustness versus Lifetime Trade-space Diagram for Space Parts

MIL-SPEC, used in the text is abbreviated as MIL- in this figure. This diagram is applicable for parts provided under U.S. DoD military standards and specifications and for commercial parts provided by suppliers world-wide.

Figure 7.1.3-2 illustrates that only a small proportion of MIL-SPEC parts are assured radiation hardened (i.e., they include RHA designators and can provide lot-specific test data) or are otherwise not susceptible to radiation. In other words, the radiation susceptibility (through either hardness assurance testing or by design) for the MIL-SPEC population parts continuum does not include all MIL-SPEC parts, only a small percentage; albeit most space grade MIL-SPEC parts include RHA designators. Additionally, RHA designators only represent hardness against total ionizing dose (TID), though most parts with RHA designators are also characterized for single-event effects (SEE) by their manufacturers. Certain COTS manufacturers offer radiation-hardened parts to meet the needs of space, medical, and for other applications that require operations in a radiation environment.



The Military Specification Parts "Universe"

Most all these parts are radiation hardened for TID, with radiation hardness assurance (RHA) designators

	Part Class, or "Grade"		
Monolithic Microcircuits:	Class **S, V, Y**	Class **B, Q**	Class **M, N, T, /883**
Hybrid Microcircuits:	Class **K**	Class **H**	Class **G, D, E**
Discrete Semiconductors:	**JANS**	**JANTXV**	**JANTX, JAN**
Ceram., film Capacitors; Resistors:	FRL **T, S, R**	FRL **R, P**	FRL **P**
Solid Ta Cap's:	FRL **D, C**	FRL **B**	FRL **B**

FRL is ***F****ailure* ***R****ate* ***L****evel*, validated by periodic sample testing.
Ta is tantalum.

NA-GSFC-wt&jl

Figure 7.1.3-2. MIL-SPEC Parts Spectrum[11], showing RHA Subset

7.2 NESC Guidance on Using COTS Parts

This section provides NESC recommendations for COTS parts selection, procurement, circuit application, RHA, and part-, board- and system-level verifications.

A different philosophy is required in using COTS parts compared to MIL-SPEC parts. Therefore, understanding the part, its datasheet parameters, and its manufacturer's processes are the most important steps in selecting, verifying, and applying COTS parts. The number one rule in using COTS is *respect the datasheet* and verify the part works for the intended purpose. The guidance below provides additional information for added screening and/or qualification (if applicable), handling/pre-processing, installation, circuit and system-level testing, and operating usage for COTS parts.

Section 7.2.1 outlines the top-level flow for NESC recommendations on using COTS parts for all NASA mission risk classifications.

Sections 7.2.2 and 7.2.3 describe guidance on parts selection processes and using COTS parts in space applications, respectively.

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[11] Please refer to military specifications for the definitions of the mil-parts classes, such as Class S, V, B, etc.

Sections 7.2.4 through 7.2.6 provide guidance on part-, board- and box-level verification for Established COTS parts from ILPMs for use in human-rated and Risk Classification A, B, C, and D missions.

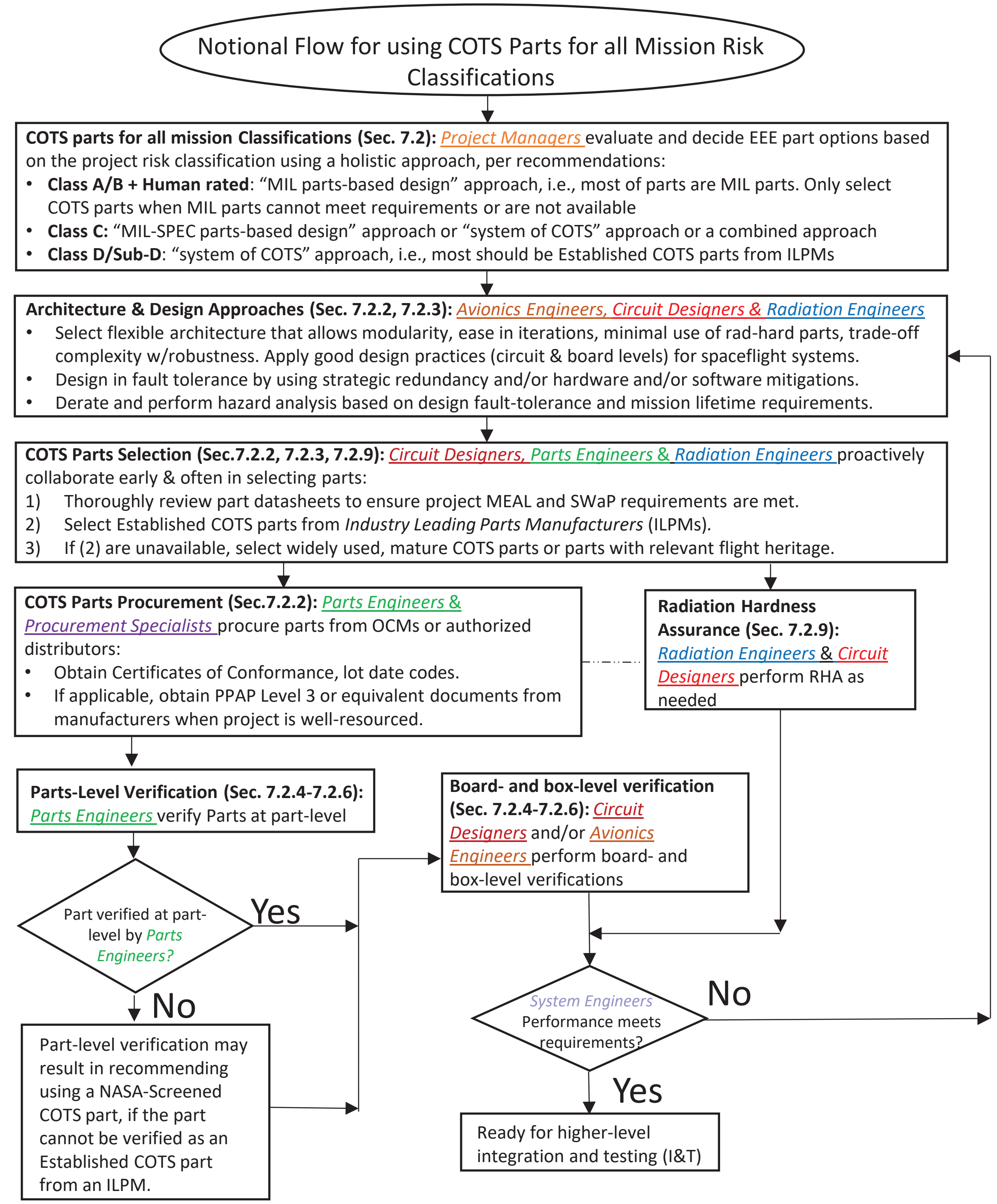
Section 7.2.8 discusses part risk assessment guidelines when using parts, that include COTS parts. This section presents introductory risk assessment concepts.

Section 7.2.9 provides RHA top-level summary and considerations for non-“rad-hard/tolerant” parts, either MIL-SPEC parts or COTS parts.

Sections 7.2.10 and 7.2.11 addresses the monitoring strategy for the Established COTS parts from ILPMs and some common perceptions associated with using COTS parts, respectively.

7.2.1 Guidance at Top-Level

Top-level recommendations are outlined in Figure 7.2-1. Part-, board- and system-level verification processes are provided in Figure 7.2-2. Different roles are highlighted in different colors.



Notional Flow for using COTS Parts for all Mission Risk Classifications

COTS parts for all mission Classifications (Sec. 7.2): Project Managers evaluate and decide EEE part options based on the project risk classification using a holistic approach, per recommendations:

- **Class A/B + Human rated**: "MIL parts-based design" approach, i.e., most of parts are MIL parts. Only select COTS parts when MIL parts cannot meet requirements or are not available
- **Class C:** "MIL-SPEC parts-based design" approach or "system of COTS" approach or a combined approach
- **Class D/Sub-D**: "system of COTS" approach, i.e., most should be Established COTS parts from ILPMs

Architecture & Design Approaches (Sec. 7.2.2, 7.2.3): Avionics Engineers, Circuit Designers & Radiation Engineers

- Select flexible architecture that allows modularity, ease in iterations, minimal use of rad-hard parts, trade-off complexity w/robustness. Apply good design practices (circuit & board levels) for spaceflight systems.
- Design in fault tolerance by using strategic redundancy and/or hardware and/or software mitigations.
- Derate and perform hazard analysis based on design fault-tolerance and mission lifetime requirements.

COTS Parts Selection (Sec.7.2.2, 7.2.3, 7.2.9): Circuit Designers, Parts Engineers & Radiation Engineers proactively collaborate early & often in selecting parts:

1) Thoroughly review part datasheets to ensure project MEAL and SWaP requirements are met.
2) Select Established COTS parts from *Industry Leading Parts Manufacturers* (ILPMs).
3) If (2) are unavailable, select widely used, mature COTS parts or parts with relevant flight heritage.

COTS Parts Procurement (Sec.7.2.2): Parts Engineers & Procurement Specialists procure parts from OCMs or authorized distributors:

- Obtain Certificates of Conformance, lot date codes.
- If applicable, obtain PPAP Level 3 or equivalent documents from manufacturers when project is well-resourced.

Radiation Hardness Assurance (Sec. 7.2.9): Radiation Engineers & Circuit Designers perform RHA as needed

Parts-Level Verification (Sec. 7.2.4-7.2.6): Parts Engineers verify Parts at part-level

Board- and box-level verification (Sec. 7.2.4-7.2.6): Circuit Designers and/or Avionics Engineers perform board- and box-level verifications

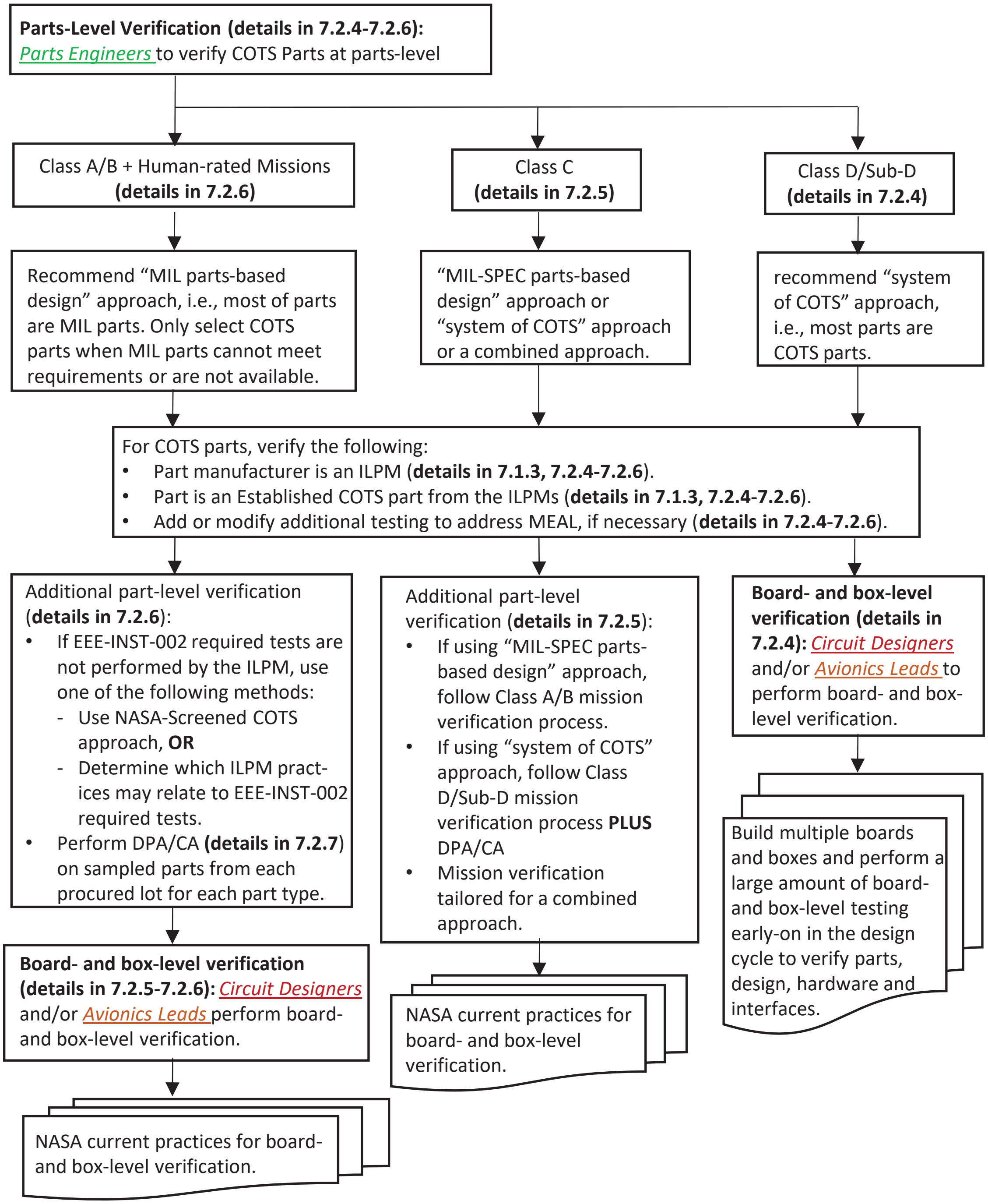
Part verified at part-level by *Parts Engineers?*

Part-level verification may result in recommending using a NASA-Screened COTS part, if the part cannot be verified as an Established COTS part from an ILPM.

System Engineers Performance meets requirements?

Ready for higher-level integration and testing (I&T)

Figure 7.2-1. NESC Recommendations on COTS Parts Selection, Procurement, Circuit Application, Rad Hardness Assurance and Part-, Board- and System-level Verification



Parts-Level Verification (details in 7.2.4-7.2.6):
Parts Engineers to verify COTS Parts at parts-level

Class A/B + Human-rated Missions **(details in 7.2.6)**

Class C **(details in 7.2.5)**

Class D/Sub-D **(details in 7.2.4)**

Recommend "MIL parts-based design" approach, i.e., most of parts are MIL parts. Only select COTS parts when MIL parts cannot meet requirements or are not available.

"MIL-SPEC parts-based design" approach or "system of COTS" approach or a combined approach.

recommend "system of COTS" approach, i.e., most parts are COTS parts.

For COTS parts, verify the following:
- Part manufacturer is an ILPM (**details in 7.1.3, 7.2.4-7.2.6**).
- Part is an Established COTS part from the ILPMs (**details in 7.1.3, 7.2.4-7.2.6**).
- Add or modify additional testing to address MEAL, if necessary (**details in 7.2.4-7.2.6**).

Additional part-level verification (**details in 7.2.6**):
- If EEE-INST-002 required tests are not performed by the ILPM, use one of the following methods:
  - Use NASA-Screened COTS approach, **OR**
  - Determine which ILPM practices may relate to EEE-INST-002 required tests.
- Perform DPA/CA (**details in 7.2.7**) on sampled parts from each procured lot for each part type.

Board- and box-level verification (details in 7.2.5-7.2.6): Circuit Designers and/or Avionics Leads perform board- and box-level verification.

NASA current practices for board- and box-level verification.

Additional part-level verification (**details in 7.2.5**):
- If using "MIL-SPEC parts-based design" approach, follow Class A/B mission verification process.
- If using "system of COTS" approach, follow Class D/Sub-D mission verification process **PLUS** DPA/CA
- Mission verification tailored for a combined approach.

NASA current practices for board- and box-level verification.

Board- and box-level verification (details in 7.2.4): Circuit Designers and/or Avionics Leads to perform board- and box-level verification.

Build multiple boards and boxes and perform a large amount of board- and box-level testing early-on in the design cycle to verify parts, design, hardware and interfaces.

Figure 7.2-2. NESC Recommendations on Part-level Verification

Sections 7.2.4 through 7.2.6 provide NESC guidance on part-, board- and box-level verification for Established COTS parts from ILPMs for use in human-rated and Risk Classification A, B, C, and D missions. The level of verification depends on the mission classification and Class A/B and human-rated missions have more level of verification than Class C or Class D. Table 7.2.1-2 is a "snap-shot" of the guidance and please refer to the sections for details.

Table 7.2.1-2. NESC Guidance for Part-, Board- and Box-level Verification in Sections 7.2.4 – 7.2.6 for Classes A/B/C/D and Human-Rated Missions

Verification at Integration Level	Guidance "P" for part-level; "B" for board-/box-level	Sections	Class D/Sub-D missions	Class C missions	Class A/B/human rated misisons
Part-level Verification	Guidance P#1	7.2.4	x	x	x
	Guidance P#2		x	x	x
	Guidance P#3		x	x	x
	Guidance P#4		x	x	x
	Guidance P#5		x	x	x
	Guidance P#6	7.2.5		x	x
	Guidance P#7			x	x
	Guidance P#8			x	
	Guidance P#9	7.2.6			x
	Guidance P#10				x
Board-/Box-level Verification	Guidance B#1	7.2.4	x		
	Guidance B#2		x		x
	Guidance B#3	7.2.5 &7.2.6		x	x
	Guidance B#4			x	x

7.2.2 Guidance to Circuit Designers and Parts Engineers for Selecting and Procuring COTS Parts and Performing Obsolescence Management and Counterfeit Avoidance

Selecting appropriate parts for a project or program is not an isolated effort and is made with an understanding that the following system level requirements typically are imposed on human-rated, and to some extent, Risk Classes A and B missions:

1. Designs are fault tolerant,
2. Workmanship is performed per J-STD Space Addendum,
3. Derating is performed in accordance with EEE-INST-002 [ref. 8] or equivalent,
4. Failure Analysis to root cause is performed on all EEE anomalies when possible,
5. System-level Worst Case Circuit Analysis (WCCA) is performed for critical items,
6. Box (assembly) level(s) are accepted and qualified by testing per SMC-S-016 or equivalent
7. Printed Circuit Boards are procured and inspected per IPC Space Addendums (or equivalent), and
8. Hazard Analyses(es) are performed according to project or program requirements.

7.2.2.1 COTS Parts Selection

Step 1: Ensure COTS parts meet project's MEAL requirements

Circuit Designers should work with Parts Engineers when selecting COTS parts or any parts for spaceflight systems; this collaboration is no different than when MIL-SPEC parts are selected for use. Selected parts should meet **MEAL** requirements [ref. 2]. MEAL is an acronym for **M**ission (mission risk classification, schedule, cost, etc.), **E**nvironment (thermal, vacuum, radiation, etc.), **A**pplication (fault tolerance, architecture, SWaP, functions, performance, etc.) and **L**ifetime (mission lifetime, system operating conditions during the mission).

COTS parts cover a broad trade space, as shown in Figure 7.1.2-1, and selection should be based on meeting MEAL requirements (i.e., datasheet parameters should satisfy all mission requirements, with proper derating). When MEAL requirements are not fully met, elevated risk is present that must be mitigated. Mitigations may include part, circuit, or system-level design approaches with appropriate testing.

Practices recommended in this report improve the likelihood of meeting MEAL requirements.

Since most COTS and MIL-SPEC parts are not designed or manufactured for space radiation environments, parts with unknown radiation tolerance will need to be evaluated for radiation susceptibility according to the mission's environment. More details regarding part RHA are provided in Section 7.2.9.

Step 2: Select "Established COTS parts" from ILPMs

ILPMs and their criteria and Established COTS parts from ILPMs were described in Section 7.2.1.

ILPMs are defined to have high volume automated production lines and to have implemented proven industry practices consistent with a "zero defects" continuous improvement strategy. Such processes minimize part infant mortal and/or early life failures when used in their intended environments. Also, ILPM Established COTS parts should exhibit part-to-part and lot-to-lot performance and yield homogeneity with respect to datasheet parameters and performance.

Note that while there is some overlap between manufacturers producing AEC-qualified parts and ILPMs, there may not be a direct correspondence between the two. An ILPM does not necessarily need to be an AEC-qualified part manufacturer and, conversely, an AEC-qualified part manufacturer may not meet all the criteria need to be to be considered an ILPM. AEC specifications include a broad and variable range of process control and verification requirements, and they rely extensively on manufacturer self-imposed requirements and self-certification. Individual manufacturers' parts, processes, and documentation need review to determine if they meet the criteria to be recognized as an ILPM manufacturer. Many concepts described in AEC specifications also are applied to determine if a manufacturer should be considered an ILPM. However, it is important to verify the ILPM criteria have been met for each AEC-qualified manufacturer.

When Established COTS parts from ILPMs are not available or cannot meet project MEAL requirements, the following recommendations are provided:

1. select COTS parts with mature technology;
2. select COTS parts that are widely used in commercial electronics products;
3. recognize that leading edge technology parts may require significant specialized efforts to ensure their reliability; thus, avoid selecting COTS parts early in their technological development, not produced in high volume, or designed at the limit(s) of their technology (e.g., a 24-bit analog-to-digital converter (ADC) in a process where the previous highest resolution was 16 bits); and
4. when a part is selected based on "flight heritage" (i.e., the part was used on a previous mission), it is critical to compare the MEALs of the missions to ensure the new mission's MEAL is within the previous mission's requirements. If that is not the case, a delta qualification will be needed, based on the MEAL differences.

    a. Sections 7.2.5 and 7.2.6 provide guidance when considering Class C and Class A/B/human-rated missions versus Class D missions. When moving from a Class D heritage mission to a higher mission classification, additional part-level verification is needed even if the MEAL of the two missions is comparable.

7.2.2.2 COTS Parts Procurement

Parts engineers should work with the project procurement organization when procuring COTS parts for spaceflight hardware to follow best practices including, but not limited to, the following recommendations:

1. Procure COTS parts from Original Component Manufacturers (OCMs) and authorized distributors *only*;
2. Obtain Certificate of Compliance (CofC) and lot trace code so that parts can be traced to a specific manufacturer, part number, and lot number;
    a. Communicate with the OCMs and authorized distributors to ensure the parts are from the same wafer lots, for space radiation purposes; and/or procure one reel of the parts to maximize the probability parts come from a single wafer lot.
    b. If traceability to the manufacturing lot cannot be verified fully when only non-ILPM established parts are available, post-procurement testing is highly recommended to verify performance to the device specifications.
3. Request, obtain, and review Level 3 PPAP (Production Part Approval Process) Package for AEC parts.
4. Procure a quantity of parts based on planned and potential future builds, contingency for unexpected performance, and potential future consideration (e.g., expected contract additions or additional testing).
    a. When not cost-prohibitive, procure at least 3 or 4 times the quantity of COTS parts needed for the mission if only non-ILPM Established COTS parts or otherwise unfamiliar COTS parts will be available to build multiple or subsequent versions of the avionics assemblies.

7.2.2.3 COTS Parts Obsolescence Management

Per NASA-STD-8739.10, the NASA EEE Parts Assurance Standard, obsolescence management should be implemented at the center-level to ensure parts availability meet project life cycle requirements. Parts Engineers should participate in the design and part selection process to ensure parts with manufacturing longevity are selected for flight use. Regardless of part qualification level (space, military, or commercial), all components should be evaluated for obsolescence impacts.

Regardless of mission risk class, all parts should remain under product obsolescence surveillance throughout all system life cycle phases. The following strategies provide obsolescence management guidance for parts used in spaceflight hardware:

1. Utilize predictive analysis tools, such as commercially available obsolescence management software, to assess COTS part availability.
2. Monitor supplier announcements and compare to parts lists continuously for obsolescence alerts.
3. Select preferred manufacturers that possess DLA certifications for military product lines.

4. Review manufacturer’s life cycle management policy to ensure end-of-life notification is provided.
5. Procure sufficient part quantities for test, installation, and sparing requirements.
6. Implement counterfeit avoidance strategies to ensure obsolescence mitigations do not include aftermarket procurements.

COTS parts are often more susceptible to obsolescence due to rapid changing technology and high demand for consumer electronics. For this reason, COTS parts should be monitored more closely for product discontinuance notification than MIL-SPEC parts.

7.2.3 Guidance to Circuit Designers and Parts Engineers for Using Parts in Space Applications

This section applies to all parts for all missions (i.e., MIL-SPEC parts, COTS parts, or Established COTS parts, regardless of mission risk classes).

Best application practices for using any parts require verifying that part functional and environmental parameters meet MEAL requirements. These include determining part RHA levels and assessing a part’s reliability in its intended application. Implementing circuit-level fault-tolerant designs and applying appropriate derating practices are other best practices for assuring mission success.

MIL-SPEC parts are standardized across manufacturers (per MIL-STDs, MIL-PRFs, MIL-SPECs, SMDs, etc.), while COTS parts' environmental ranges and electrical parameter limits are defined by their datasheets. Therefore, no assumptions regarding COTS parts’ tolerance to operating and environmental exposure should be made without reviewing the specific part datasheets. Most COTS parts should not be expected to survive NASA and/or MIL-SPEC screening and qualification tests at MIL-SPEC conditions when those conditions exceed specified COTS part operating ranges. These differences need to be recognized since they may present design, reliability, and environmental (including radiation susceptibility) challenges if they are not considered.

MIL-SPEC parts generally have more built-in operational margins per their datasheet limits (e.g., rated voltage, temperature, or frequency of operation) than COTS parts. COTS parts have unique datasheets and manufacturers tend to push the performance to the limits of the technologies’ capabilities. For these reasons, screening or testing COTS parts beyond their datasheet limits can be more problematic than doing so with MIL-SPEC parts.

EEE-INST-002 provides guidance for derating parts, although some COTS parts, such as passive parts, may need additional derating [ref. 8]. Space radiation considerations for parts are included in the Section 7.2.9.

The following recommendations are provided:

1. Circuit Designers should collaborate with Parts Engineers to assure required performance characteristics are within specified datasheet parameters over the mission lifetime.
    a. For example, a part datasheet might specify a range for a parameter while the application requires that parameter to be within a tighter parametric range, or an application might not be tolerant to parametric drift (with time, temperature, or radiation) even though it would be allowed by the datasheet. In such cases, the Circuit Designers would re-design the circuits and/or would work with Parts

Engineers to select another part or identify tests and/or other actions that would sufficiently prove the part's ability to meet these tight requirements.

2. Circuit Designers and Parts Engineers should collaborate in identifying environments (e.g., thermal, humidity, shock, vibration, helium or other gases, vacuum, atmosphere, etc.) that might cause problems in their applications (whether at the part or at higher integration levels). Such issues may require additional testing and/or analysis to verify the circuit(s) operates as intended.
3. Circuit Designers should use manufacturers' models (e.g., SPICE, Verilog, VHDL), if available, to verify worst-case conditions (e.g., temperature, voltages, timing, radiation degradation, end-of-line- electrical performance degradation, SEE impacts, Single Event Transit circuit impacts, residual rates after TMR implementation, etc.). Use demonstration and/or evaluation boards for circuit verification. Implement board- and box-level verification early in the development cycle to avoid negative impacts on cost and schedule should any problems or failures arise.
4. Circuit Designers should use more conservative derating for COTS parts, mainly passive parts, where appropriate, compared to MIL-SPEC counterparts, notwithstanding other pertinent attributes of either type of part. For example, MIL-SPEC ceramic capacitors (e.g., MIL-PRF-55681 and MIL-PRF-123) are designed to handle extended operation at twice the rated voltage, but COTS ceramic capacitors are designed largely to tolerate the datasheet limits with minimal over-rated voltage excursions.
5. When resources or availability prohibit using rad-hard MIL-SPEC parts, Circuit Designers and Parts Engineers should consider the commercial version of rad-hard parts, if the rad-hard parts and commercial version of the rad-hard parts have the same silicon die. Some rad-hard parts have non-rad-hard commercial versions available with the same die, where the main difference is that no radiation testing has been performed on the commercial version. These parts offer similar radiation tolerance (but without the radiation hardness guarantees of the rad-hard versions) and may allow savings in cost and procurement time. When using the commercial version, it must be acknowledged that the part is considered non-rad-hard and is subject to relevant guidance in this report. For Class D and Sub-Class D projects, this would provide a good solution when available, and in some cases, it might be the only choice available in lower-risk-tolerant applications.

7.2.4 Guidance on COTS Parts Verification Process for Class D/Sub-Class D Missions

Since Class D/Sub-D missions are intended to be more risk tolerant while being cost and schedule constrained, using COTS parts may be the best choice in optimizing risk versus reward. Furthermore, Class D and Sub-D missions often employ current or new technologies that can only be realized using COTS parts.

The NESC team recommends that the Class D/Sub-D projects:

1. Consider a "System of COTS" approach. "System of COTS approach" is one which most of parts are Established COTS parts from ILPMs.
2. Select and use the Established COTS parts from ILPMs.
3. Perform the part-, board- and box-level verifications outlined in the following subsections 7.2.4.1 and 7.2.4.2.

Please note when a selected part is not an Established COTS part from ILPMs, a qualification process may be necessary at the part- and board-level. Part-level qualification may include DPA/CA, accelerated testing, qualification by similarity, and other forms of evaluation. Board- and box-level verification is outlined in the next section.

7.2.4.1 Part-Level Verification for Established COTS Parts

COTS part-level verification may require different testing than what MIL-SPECs specify. Confidence in the manufacturers and the quality of their parts is vital when deciding to use COTS parts in any mission. Once the Established COTS parts from the ILPMs are selected, the NESC team advises the following part-level verification guidance:

Guidance P#1	Verify the part manufacturer is an ILPM using the definition and the criteria of ILPMs described in Sections 7.2.1.1 and 7.2.1.3.
Guidance P#2	Verify the part is an Established COTS part from an ILPM using the criteria for ILPMs described in Section 7.2.1.2.
Guidance P#3	Review manufacturers' parts datasheets to ensure that the parts meet the MEAL of the project. When anything is not clear on the datasheets but critical to the project, the ILPMs should be contacted for application support.

a. If additional part-level testing or screening need to be performed, always consult datasheets to ensure specified operational limits are not exceeded. Exceeding specification limits can result in latent damage in parts that can lead to failures in flight.
b. Do not repeat the same tests that the manufacturers have already performed, including burn-in, highly accelerated testing, etc., since there is no added value in so doing and it may result in part damage or degrade the COTS parts.
c. If part-level testing becomes complicated, costly, and time-consuming with complex parts (e.g., with ASICs, programmable logic electronics, high-performance analog/mixed-signal parts), then the most direct means to characterize part reliability is to test the parts in the actual applications at board- or box-levels. Board- or box-levels testing may be a more appropriate and optimal approach for verifying part reliability since test coverage may not be 100% or some functions may not be used in a particular application. While board- and box-level testing will likely never operate the COTS part in the regime of maximum rating, emphasis is placed on evaluating the performance and reliability of the part in its worst-case operating conditions for the application. Additionally, in-situ testing helps debugging hardware and software in circuits and the system simultaneously.
d. Often, no suitable parts with datasheet limits covering MEAL requirements will be available. For example, when selecting new parts or ones employing recent technologies that do not have long-established usage, choosing suitable parts may be extremely limited – even among COTS parts. These new or new technology parts likely will have little data (i.e., evidence) to support a needed lifetime within requisite operating conditions, if data are even available. For such

cases, the ILPM's extant reliability basis data are no longer applicable and elevated risk may be present, particularly for parts used outside their design limitations. Thus, it is vital to engage the manufacturer in communications to identify if a project's needs exceed a parts design limits or if the parts have not been tested or warrantied to the project's requisite conditions. After consulting with the manufacturer, a qualification program consistent with MEAL requirements may mitigate this risk if parts from a subsequently qualified lot are used.

Guidance P#4 Review ILPM parts quality and reliability data, including estimated production DPPM and field failure data – either fielded failure frequencies (often reported as fielded DPPM) and/or part failure rates (e.g., ppm/hour, FITs).

Guidance P#5 Request parts with designed or expected lifetime based on appropriate operating condition, consistent with mission requirements and supporting data and/or analysis. This may include reviewing process qualification and part qualification data to evaluate that part long-term reliability is sufficient to meet mission lifetime requirements.

7.2.4.2 Board- and Box-Level Verification When Using Established COTS Parts from ILPMs

The recommended approaches below apply to all the other risk classifications, but for Class D and Sub-Class D missions, part verifications may be limited by resources, to only those performed at higher levels of assembly.

After Established COTS parts from ILPMs are selected and verified at part-level, the NESC team advise the following board- or box-level verification guidance:

Guidance B#1 Board- or box-level verification of parts should include thermal-cycling, shock-and-vibration, high temperature and humidity, and outgassing (if required per project MEAL) since these are not typically performed by the COTS manufacturers.

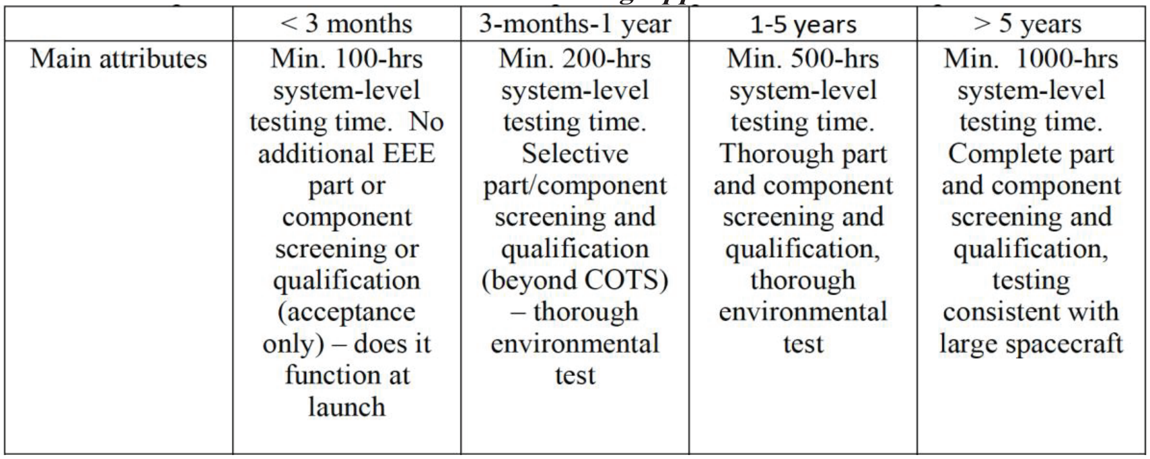
Guidance B#2 Perform more testing at board- and box-level.

a. Build multiple boards and boxes, and perform a large amount of board-, box-, and system-level testing early in the design cycle to not only verify the parts but to identify design errors by doing concurrent engineering in hardware, software, and subsystems.
    i. Building multiple boards and boxes is encouraged regardless of mission classifications, although it is more feasible for Class D or Sub-D missions when most parts are COTS parts.
    ii. For example, ARC focuses on testing at board- and subsystem-levels instead of at the part-level for Class D and Sub Class D missions, since using ILPM COTS parts allows large quantity of multi-revision engineering units to be built efficiently and affordably, which makes ARC's

        current “test early and often” a viable flight hardware development strategy [ref. 1].

- b. Typically, some number of cumulative hours of power-on testing, corresponding to the duration of missions, is used to verify that the flight and the flight spare units are performing properly. See Table 7.2.4-1.
    - i. For example, GSFC’s GOLD rules [ref. 19] require 1000+ hours minimum of powered testing time for all hardware; however, for Class D and below missions, the GOLD rules are flexible. Generally, 500 hours is maintained as a standard practice minimum for any mission requiring a year or more of operation.
    - ii. Another example is that GSFC missions using largely COTS parts have more closely followed the guidance in GSFC-HDBK-8007 [ref. 20], Mission Success Handbook for CubeSat Missions, shown in Table 7.2.4-1. The handbook does not refer to the use of EEE-INST-002 for part-level screening and qualification. It also provides guidance on the system-level test duration based on mission lifetimes.

Table 7-2.4-1. Planned Lifetime versus Testing Approach GSFC-HDBK-8007 Table



	< 3 months	3-months-1 year	1-5 years	> 5 years
Main attributes	Min. 100-hrs system-level testing time. No additional EEE part or component screening or qualification (acceptance only) – does it function at launch	Min. 200-hrs system-level testing time. Selective part/component screening and qualification (beyond COTS) – thorough environmental test	Min. 500-hrs system-level testing time. Thorough part and component screening and qualification, thorough environmental test	Min. 1000-hrs system-level testing time. Complete part and component screening and qualification, testing consistent with large spacecraft

7.2.5 Guidance on COTS Parts Verification Process for Class C Missions

By definition, a mission with a Class C risk classification has a moderate risk tolerance. While the general mission life for Class C missions is 1 to 3 years, it is not uncommon for Class C missions to have a mission life of 5 years or greater, likely classified as such due to other factors such as a medium priority assignment or medium technical complexity. Therefore, a “one size fits all” approach is not suitable for all Class C missions when evaluating the part level verification required on a COTS part for that mission. Rather, when considering the use of a COTS part for a Class C mission without MIL-SPEC testing or screening, part-level verification will be dependent on the mission life, application criticality, and available data from the manufacturer for that part.

The NESC team recommends that the Class C projects:

1. Determine which approach is best for their project, that is, use either a “MIL-SPEC parts-based design” approach, “System of COTS” approach, or a combined approach. “MIL-SPEC parts-based design” approach is one which most parts are MIL-SPEC parts. “System of COTS approach” is one which most of parts are Established COTS parts from ILPMs.
2. When the “MIL-SPEC parts-based design” approach is adopted, selecting COTS parts should only occur when an equivalent MIL-SPEC part does not exist with respect to MEAL performance/function or to meet SWaP requirements. When a COTS part is to be used, select and use the Established COTS parts from ILPMs.
3. Perform the following part-, board- and box-level verification outlined in the following subsections 7.2.5.1 and 7.2.5.2.

The NESC team recommends selection and use of the Established COTS parts from ILPMs and perform the following part-, board- and box-level verification outlined in the sections below.

Please note that, when a selected part is not an Established COTS parts from ILPMs, a qualification process may be necessary at the part- and board-level. Part-level qualification may include DPA/CA, accelerated testing, qualification by similarity, and other forms of evaluation. Board- and box-level verification is outlined in the next section. Note that the current process is to follow EEE-INST-002. Note that many part technologies since the early 2000’s are not covered by EEE-INST-002 or MIL-STDs, in which case EEE-INST-002 should not be force-fit based on part type. These include, but are not limited to, technologies such as silicon carbide (SiC) semiconductors and polymer tantalum capacitors. Usage of such parts require focused efforts, coordinated with the manufacturer, to provide assurance.

7.2.5.1 Part-Level Verification for Established COTS Parts

COTS part-level verification may require different testing than MIL-SPEC. Confidence in the manufacturers and the quality of their parts is vital when deciding to use COTS parts in any missions. Once the Established COTS parts from the ILPMs are selected, the NESC team advise the following part-level verification guidance.

The following are duplicated from Class D part-level verification guidance (Section 7.2.4.1):

Guidance P#1 Verify the part manufacturer is an ILPM using the definition and the criteria of ILPMs described in Sections 7.2.1.1 and 7.2.1.3.

Guidance P#2 Verify the part is an Established COTS part from an ILPM using the criteria for ILPMs described in Section 7.2.1.2.

Guidance P#3 Review manufacturers’ parts datasheets to ensure that the parts meet the MEAL of the project. When anything is not clear on the datasheets but critical to the project, the ILPMs should be contacted for application support.

   a. If additional part-level testing or screening need to be performed, always consult datasheets to ensure specified operational limits are not exceeded. Exceeding specification limits can result in latent damage in parts that can lead to failures in flight.

b. Do not repeat the same tests that the manufacturers already have performed, including burn-in, highly accelerated testing, etc., since there is no added value in so doing and it may result in part damage or degrade the COTS parts.

c. If part-level testing becomes complicated, costly, and time-consuming with complex parts (e.g., with ASICs, programmable logic electronics, high-performance analog/mixed-signal parts), then the most direct means to characterize part reliability is to test the parts in the actual applications at board- or box-levels. Board- or box-levels testing may be a more appropriate and optimal approach for verifying part reliability since test coverage may not be 100% or some functions may not be used in a particular application. While board and box level testing will likely never operate the COTS part in the regime of maximum rating, emphasis is placed on evaluating the performance and reliability of the part in its worst-case operating conditions for the application. Additionally, in-situ testing helps debugging hardware and software in circuits and the system simultaneously.

d. Often, no suitable parts with datasheet limits covering MEAL requirements will be available. For example, when selecting new parts or ones employing recent technologies that do not have long-established usage, choosing suitable parts may be extremely limited – even among COTS parts. These new or new technology parts likely will have little data (i.e., evidence) to support a needed lifetime within requisite operating conditions, if data are even available. For such cases, the ILPM’s extant reliability basis data are no longer applicable and elevated risk may be present, particularly for parts used outside their design limitations. Thus, it is vital to engage the manufacturer in communications to identify if a project’s needs exceed a parts design limits or if the parts have not been tested or warrantied to the project’s requisite conditions. After consulting with the manufacturer, a qualification program consistent with MEAL requirements may mitigate this risk if parts from a subsequently qualified lot are used.

Guidance P#4 Review ILPM parts quality and reliability data, including estimated production DPPM and field failure data – either fielded failure frequencies (often reported as fielded DPPM) and/or part failure rates (e.g., ppm/hour, FITs).

Guidance P#5 Request parts with designed or expected lifetime based on appropriate operating condition, consistent with mission requirements and supporting data and/or analysis. This may include reviewing process qualification and part qualification data to evaluate that part long-term reliability is sufficient to meet mission lifetime requirements.

The following are additional guidance for Class C missions:

Guidance P#6 Review manufacturers’ parts datasheets to ensure that the parts meet the MEAL of the projects. If there is anything not clear on the datasheets but critical to the projects, the ILPMs should be contacted for their application support. If a part is not tested by the ILPMs over the full rated temperature range, testing at the mission operating temperature may be necessary for applications where device performance in the rated minimum/maximum temperature ranges are critical.

Guidance P#7 Review documentation and data packages provided by the ILPMs on their quality certifications, technology, process and products qualification, part qualification, production and process control, quality and reliability monitoring program, and zero-defect practices, etc.

a. Understand the ILPM's processes and practices, and assess the range of quality practices and test methodology used by the ILPMs and where within that range parts fall;

b. Request and review Level 3 PPAP or equivalent for all parts. The PPAP should be inspected for uncorrected high-risk priority number (RPN) elements of the PFMEA, and for key processes where C_{pk} is less than 1.67. Inspect the CDCQ to verify that qualification by similarity representation appears appropriate.

c. Review part qualification data, reliability monitoring program, and zero-defect practices to assess the effectiveness of the ILPM's processes and practices for detecting potential parts reliability concerns and eliminating statistical outlier parts before shipment. For example, wafer level reliability, designed operating life, daily end of production parts testing, testing bias and thermal condition, sample size, criteria of failure, etc.

d. This verification process requires a relationship between NASA and the part manufacturer. This is not a one-time meeting. On-site meetings may be required for the ILPM to share proprietary information and for NASA to engage in thorough discussion. Based on the specific situation, an acceptable level of confidence may be reached even if the ILPM does not allow an on-site visit, but makes all requested information available through other means.

e. Manufacturers who refuse to share information with NASA should not be considered ILPM.

Guidance P#8 Perform the DPA/CA on sample parts for technology with little or no history in space application (e.g., parts with Cu wire bonds used in thermally stressful applications), and/or when a part's construction is not fully understood to help identify areas of concern that should be considered during electrical testing or that should prompt a discussion with the manufacturer.

7.2.5.2 Board- and Box-Level Verification When Using Established COTS Parts from ILPMs

After the Established COTS parts from the ILPMs are selected and verified at part-level, the NESC team advise the following board and box-level verification guidance:

Guidance B#1	Board- or box-level verification of parts should include thermal-cycling, shock-and-vibration, high temperature and humidity, and outgassing (if required per project MEAL), since these are not typically performed by the COTS manufacturers.
Guidance B#3	If feasible, build multiple boards and/or boxes and perform more board- and/or box-level testing early in the design cycle to not only verify the parts but identify design errors by doing concurrent engineering in hardware, software, and subsystems.
Guidance B#4	Follow GSFC's GOLD rules [ref. 19], which require 1000+ hours minimum of powered testing time, with the last 350 hours being failure free for all hardware, to demonstrate trouble-free parts performance and help reduce the risk of failures after launch

7.2.6 Guidance for COTS Parts Verification Process for Classes A and B and Human-Rated Missions

Class A/B and human-rated missions require[12] the use of parts whose survivability to the project's MEAL requirements have been proven by a methodology consisting of qualification (or lot acceptance testing) on a representative sample of parts and 100% screen testing. For Class A/human-rated missions, the use of space-rated MIL-SPEC parts from manufacturers listed on the DLA's QML is standard. This is a very conservative process where parts are used that have passed rigorous qualification and screening procedures, including environmental testing, that typically exceed MEAL requirements. Additionally, manufacturer or archival radiation test data are typically available for these parts that can be analyzed to determine if any additional radiation testing is necessary. The required part "assurance level" for a given project is listed in the project's Mission Assurance Requirement (MAR), Project EEE Parts Management and Control (PPMC) documentation or similar, but typically consists of space grade MIL-SPEC parts for Class A or human-rated missions and military grade MIL-SPEC parts for Class B missions.

For both MIL-SPEC and COTS parts, specific project requirements that are outside of the environmental testing limits of any part type will need a qualification and screening test plan to ensure part survivability. In addition, communication with the manufacturer along with DPAs/CAs are recommended on each procured lot and tested samples to assess lot-to-lot differences and the presence of any negative effects from testing.

The NESC team recommend that the Class A/B and human-rated programs:

1. Consider a "MIL-SPEC parts-based design" approach and select COTS parts only when equivalent MIL-SPEC parts do not meet functional or SWaP requirements or is not

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[12] Classes A and B mission commonly use EEE-INST-002 as their parts requirements. Human-rated programs, such as Orion, ISS, SLS, have their own similar requirements.

available. “MIL-SPEC parts-based design” approach is one which most parts are MIL-SPEC parts.

2. When a COTS part is to be used, select and use the Established COTS parts from ILPMs.
3. Perform the following part-, board- and box-level verification outlined in the following subsections 7.2.6.1 and 7.2.6.2.

7.2.6.1 Established COTS Part-Level Verification

It should be recognized that COTS part-level verification may require different testing than MIL-SPEC. Confidence in the manufacturers and the quality of their parts is vital when deciding to use COTS parts in any missions. Once the Established COTS parts from the ILPMs are selected, the NESC team advise the following part-level verification guidance.

The following are duplicated from Class D part-level verification guidance (Section 7.2.4.1):

Guidance P#1 Verify the part manufacturer is an ILPM using the definition and the criteria of ILPMs described in Sections 7.2.1.1 and 7.2.1.3.

Guidance P#2 Verify the part is an Established COTS part from an ILPM using the criteria for ILPMs described in Section 7.2.1.2.

Guidance P#3 Review manufacturers’ parts datasheets to ensure that the parts meet the MEAL of the project. When anything is not clear on the datasheets but critical to the project, the ILPMs should be contacted for application support.

  a. If additional part-level testing or screening need to be performed, always consult datasheets to ensure specified operational limits are not exceeded. Exceeding specification limits can result in latent damage in parts that can lead to failures in flight.
  b. Do not repeat the same tests that the manufacturers already have performed, including burn-in, highly accelerated testing, etc., since there is no added value in so doing and it may result in part damage or degrade the COTS parts.
  c. If part-level testing becomes complicated, costly, and time-consuming with complex parts (e.g., with ASICs, programmable logic electronics, high-performance analog/mixed-signal parts), then the most direct means to characterize part reliability is to test the parts in the actual applications at board- or box-levels. Board- or box-levels testing may be a more appropriate and optimal approach for verifying part reliability since test coverage may not be 100% or some functions may not be used in a particular application. While board and box level testing will likely never operate the COTS part in the regime of maximum rating, emphasis is placed on evaluating the performance and reliability of the part in its worst-case operating conditions for the application. Additionally, in-situ testing helps debugging hardware and software in circuits and the system simultaneously.
  d. Often, no suitable parts with datasheet limits covering MEAL requirements will be available. For example, when selecting new parts or ones employing recent technologies that do not have long-established usage, choosing suitable parts may be extremely limited –

even among COTS parts. These new or new technology parts likely will have little data (i.e., evidence) to support a needed lifetime within requisite operating conditions, if data) are even available. For such cases, the ILPM's extant reliability basis data are no longer applicable and elevated risk may be present, particularly for parts used outside their design limitations. Thus, it is vital to engage the manufacturer in communications to identify if a project's needs exceed a parts design limits or if the parts have not been tested or warrantied to the project's requisite conditions. After consulting with the manufacturer, a qualification program consistent with MEAL requirements may mitigate this risk if parts from a subsequently qualified lot are used.

Guidance P#4 Review ILPM parts quality and reliability data, including estimated production DPPM and field failure data – either fielded failure frequencies (often reported as fielded DPPM) and/or part failure rates (e.g., ppm/hour, FITs).

Guidance P#5 Request parts with designed or expected lifetime based on appropriate operating condition, consistent with mission requirements and supporting data and/or analysis. This may include reviewing process qualification and part qualification data to evaluate that part long-term reliability is sufficient to meet mission lifetime requirements.

The following are duplicated from Class C part-level verification guidance (Section 7.2.5.1):

Guidance P#6 Review manufacturers' parts datasheets to ensure that the parts meet the MEAL of the projects. If there is anything not clear on the datasheets but critical to the projects, the ILPMs should be contacted for their application support. If a part is not tested by the ILPMs over the full rated temperature range, testing at the mission operating temperature may be necessary for applications where device performance in the rated minimum/maximum temperature ranges are critical.

Guidance P#7 Review documentation and data packages provided by the ILPMs on their quality certifications, technology, process and products qualification, part qualification, production and process control, quality and reliability monitoring program, and zero-defect practices, etc.

a. Understand the ILPM's processes and practices, and assess the range of quality practices and test methodology used by the ILPMs and where within that range parts fall;

b. Request and review Level 3 PPAP or equivalent for all parts. The PPAP should be inspected for uncorrected high-risk priority number (RPN) elements of the PFMEA, and for key processes where C_{pk} is less than 1.67. Inspect the CDCQ to verify that qualification by similarity representation appears appropriate.

c. Review part qualification data, reliability monitoring program and zero-defect practices to assess the effectiveness of the ILPM's processes and practices for detecting potential parts reliability concerns and eliminating statistical outlier parts before shipment. For example, wafer level reliability, designed operating life, daily end of production parts testing, testing bias and thermal condition, sample size, criteria of failure, etc.

d. This verification process requires a relationship between NASA and the part manufacturer. This is not a one-time meeting. On-site meetings may be required for the ILPM to share proprietary information and for NASA to engage in thorough discussion. Based on the specific situation, an acceptable level of confidence may be reached even if the ILPM does not allow an on-site visit, but makes all requested information available through other means.

e. Manufacturers who refuse to share information with NASA should not be considered ILPM.

The following are recommended for Class A/B and human-rated missions:

Guidance P#9 Review ILPM qualification, screening, and conformance testing processes and data and then compare to all the required testing delineated in EEE-INST-002. If the tests required by EEE-INST-002 are not performed by the ILPM, one of the following methods should be employed:

i. Use NASA-Screened COTS approach (i.e., qualify and screen the Established COTS parts from ILPMs per EEE-INST-002 or equivalent document.) This approach should involve the part manufacturer to gain confidence that parts will not be damaged by the testing. As mentioned earlier, note that some technologies since the early 2000's are not covered by EEE-INST-002 and the screens and qualification processes should not be force-fit based on part type. These include, but are not limited to, SiC semiconductors and polymer tantalum capacitors.

OR

ii. ILPMs with Established COTS parts are likely to employ processes that "build quality into the part" and can demonstrate part quality and reliability through design, SPC, in-process inspections, insightful part testing, and periodic testing of production samples. Such methodologies can reduce or eliminate the need for the sort of part-level-testing described by EEE-INST-002. Documents (e.g., JEP121 [ref. 21]), should be used to determine which practices used by an ILPM may relate to tests required by EEE-INST-002.

Guidance P#10 Perform DPA/CA on sample parts from each procured lot of each part type to ensure consistency of parts construction and understand the part technology. Historical records of DPA/CAs should be maintained and compared to verify lot-to-lot changes. For passive parts, that means identifying "families" of parts and performing DPA/CA on min/mid/max of each family. For example, all resistors that share a datasheet may be considered a family. DPA/CA would be performed on the min, mid, and max of footprint and resistance values.

7.2.6.2 Board- and Box-Level Verification When Using Established COTS Parts from ILPMs

After the Established COTS parts from the ILPMs are selected and verified at part-level, the NESC team advise the following board- or box-level verification guidance:

Guidance B#1	Board- or box-level verification of parts should include thermal-cycling, shock-and-vibration, high temperature and humidity, and outgassing (if required per project MEAL), since these are not typically performed by the COTS manufacturers.
Guidance B#3	If feasible, build multiple boards and/or boxes and perform more board- and/or box-level testing early in the design cycle to not only verify the parts, but identify design errors by doing concurrent engineering in hardware, software, and subsystems.
Guidance B#4	Follow GSFC's GOLD rules [ref. 19], which require 1000+ hours minimum of powered testing time, with the last 350 hours being failure free for all hardware, to demonstrate trouble-free parts performance and help reduce the risk of failures after launch.

7.2.7 Destructive Physical Analysis (DPA) and Construction Analysis (CA)

DPA is a systematic, detailed examination of parts during various physical disassembly stages performed on a sample of procured parts. Parts are examined for a wide variety of design, workmanship, materials, and processing indicators that may not show up during manufacturing and testing. This examination's purpose is to determine parts that may have anomalies or defects that subsequently could result in early part failure. DPA also can be used in problem evaluations, failure analyses, manufacturer comparisons, corrective actions, and improvements in manufacturing processes, controls, and screening test procedures.

CA is a more general examination to gain insight into a part's design. Where DPA typically has pass/fail criteria, the goal of CA is to observe, identify, and evaluate all key physical part characteristics. CA typically has no pass/fail criteria.

Class A, Class B missions, and human-rated programs are recommended to consider DPA and CA to provide independent evidence of part quality and of documenting part's construction, since part-level verification primarily relies on manufacturer-supplied data. Class C missions are highly recommended to perform DPA/CA for newer technologies in space applications and when a part's construction details are not fully known.

One should not assume that a nonconformance, discrepancy, or "failure" identified during a COTS part DPA indicates a defective part. Such occurrences could be an inevitable outcome when comparing a good part using an inappropriate requirement or standard; in other words, the nonconformance or discrepancy might have resulted from applying evaluation standards not applicable for the part being evaluated. These standards, of which MIL-STD-1580 [ref. 22] is most widely known, have been written for military parts designed to specified manufacturing requirements for military and space applications. Thus, it is not unexpected that COTS parts will fail such criteria. There currently are no general DPA standards suitable for evaluating COTS parts. Some COTS parts examples with features that commonly conflict with MIL-based DPA standards are listed below. Each would likely trigger a DPA "failure". However, such results should not automatically be assumed to be a risk to avionics functioning as intended.

- Parts with pure tin finishes are prevalent in many COTS parts and often no option for obtaining a tin-lead or other acceptable finish is available. The risk associated with pure tin surfaces on COTS parts is likely able to be mitigated with minimal impact. GEIA-HDBK-0005 and GEIA-STD-0005 offer guidance and multiple mitigations for dealing with pure tin. Among the discussed mitigations are review of any existing manufacturer whisker testing, the use of lead-bearing solder for assembly, and conformal coating. No known evidence exists that indicates using Pb-free solder balls on ball grid array (BGA) packages will grow tin whiskers. Ensuring proper solder selection and reflow during printed wiring board (PWB) assembly can avoid re-balling components prior to board assembly, a process that adds risk by potentially damaging components during re-balling.
- COTS discrete semiconductors and microcircuits may utilize Cu wire bonds. A separate NESC study[13] is currently being conducted to evaluate long-term reliability of COTS with Cu bond wires, and various other JEDEC efforts are ongoing to establish proper decapsulation methods and bond wire pull strengths for these parts. For programs and projects that obtain data for additional assurance purposes from the ILPMs representing their detailed practices, the wire bond reliability test data should be considered in the associated evaluation and assurance efforts. AEC-Q-006 has specific recommendations for best practices for manufacturers who use Cu bond wires.
- For ceramic capacitor manufacturers to achieve higher capacitance values in a smaller size, they might use thinner dielectric thicknesses and narrower end/side margins (the ceramic portion of a ceramic capacitor that envelopes the active area containing the electrode plates). Therefore, some COTS ceramic capacitors will not meet the dimensional requirements of EIA/ECA-469 currently used as the DPA standard for military and space qualified capacitors. However, the EIA-469 requirements for the margins are designed to provide sufficient electrical insulation, address quality of the as-manufactured parts, but might not be sufficient because they do not consider cracking-related issues associated with reflow soldering. Note that for capacitors intended for automotive industry, some manufacturers have stricter requirements for the margins compared to the military standards. Since the primary cause of electrical degradation failures in ceramic capacitors are related to defects such as inclusions, cracks, delaminations[14], or voids in the dielectric layer, any evidence of such defects detected during construction analysis should be carefully evaluated. NASA subject matter experts should be consulted for a review of available screening and reliability test data when such features are identified, to ensure test coverage of the selected COTS capacitors over the MEAL.
- Delaminations[15] in plastic encapsulated package types can commonly be identified during C-mode scanning acoustic microscopy (C-SAM) testing and dye penetrant testing and is a cause for rejection per MIL-STD-1580 DPA criteria [ref. 23]. COTS manufacturers are

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[13] NESC assessment "Assessment of EEE parts Copper Wire Bonds for Space Programs TI-18-01317.

[14] Delamination in an MLCC is a separation of electrode and dielectric layers.

[15] Delamination in PEMs refers to a flaw where plastic compounds fracture into layers that look like it is peeling.

aware of delamination and actively work to control and minimize it. Periodic reliability monitor tests, including thermal cycling, using parts randomly taken from production should be seen as evidence that parts are capable of meeting requirements despite having delaminations. There is no established correlation between C-SAM failures and premature electrical failures.

When a specification is verified as appropriate for a given part, any discrepancies identified during DPA should be evaluated for its potential to cause functional part degradation or failure and how that would affect the associated circuit. Parts exhibiting potential problem causing DPA defects may be used if nondestructive screens can be implemented to eliminate parts with that defect from the rest of the population. Parts exhibiting design weaknesses may be flown if their application is such that the weakness is mitigated. All observations in a CA should be reviewed to confirm the part's construction is understood and is suitably robust for its intended application.

7.2.8 Risks Associated with Parts and Mission Application Considerations

The prior discussions have been focused at the part level with limited mission level considerations. This section intends to bridge the gap between part-focused considerations and mission risk and reliability. Doing so will require some additional terminology and clarification on previously introduced terminology that will translate common parts-related terms into terms needed to characterize mission risks and reliability. These terms include *quality, reliability, defect, failure, failure rate,* and *DPPM*. Some of these terms fold into technical risk and reliability determinations (e.g., on-orbit failure threats) and others into programmatic risks whose consequences is cost or schedule outside of planned (e.g., threats of failure during ground testing).

Parts Reliability versus Quality

When comparing parts selection and assurance approaches, it is essential to distinguish *quality* and *reliability*. Mistaking part(s) quality with reliability commonly causes problems when selecting parts for NASA’s applications, primarily spaceflight uses.

Part *quality* is defined as a part meeting a set of applicable specifications at the end of its manufacturing processes, including any and all tests performed to validate the part does meet those specifications. On the other hand, part *reliability* is defined as the probability that it will successfully perform its intended function under specified conditions in a specified environment over some specified time. Part quality may contribute to a part's reliability, but it alone does not establish its reliability.

Quality can be a positive driver for reliability, but only when a part’s quality specifications align with its manufacture and actual application (usage). Applying quality specifications to a part not consistent with its actual use can induce unknown effects on its reliability, even degrading its useful life. One example is applying MIL-PRF-38534 to COTS hybrids whose datasheet limits are far more restrictive than the required MIL-PRF test limits (e.g., applying the MIL 3000g constant acceleration test to a COTS part limited to 500g). Another involves applying the MIL-PRF-123 testing regimen to capacitors that are outside of the MIL-PRF-123 “catalog” limits (e.g., higher capacitances in small packages). Both approaches can overstress the parts and cause either unnecessary parts rejections or, in worst-cases, latent failures.

Part Nonconformance versus Part Failures

A part *nonconformance* occurs when a part does not meet some requirement, either a MIL-SPEC specification or a manufacturer's datasheet. A nonconforming part may not have failed to function in its application or in an operating state.

A part *failure* occurs when a part (whether or not the part conforms to a given specification) causes an incorrect circuit operation (e.g., an electrical short or open or any other inability to perform the circuit's intended function). Any of those can cause a circuit failure.

It is essential to distinguish differences between a part nonconformance and a part failure when evaluating manufacturers' part failure data. It is important when estimating a mission failure likelihood caused by a part failure; the methods for estimating likelihoods are very different for quality (frequency) and reliability (temporal) data. Whether or not a part failure leads to a system failure, for example, in an instrument, spacecraft, or mission, depends on its failure mode (an identifying characteristic associated with its functional failure), failure mechanism or mechanisms (proximate failure causes), and where in the system the part is located. Circuitry and/or system design affect whether or not an individual part will cause the circuit or system to propagate to a mission failure. A part failure cannot be assumed to cause a system failure without assessing its impact at the top (mission) level.

Part Failure Rate

Failure rate is a reliability statistic expressing the number of failures occurring *per unit of time*, such as Failures In Time (FITs, the number of failures in one billion device-hours operation) or other time-based statistic (e.g., failures per million hours, cycles, or one hundred thousand miles).

It is *not* the fraction or percentage of nonconforming parts or the number of parts failing functionally within a population of parts; that properly is expressed as a frequency statistic – a proportion or percentage.

Part DPPM (defective parts per million)

DPPM is a statistic used to express the number(s) of defective parts within a stated population of parts; it is *defined* as the *number of defective parts per million parts* in the population.

From a manufacturer's perspective, delivering a defective part or failed part has the same negative effect; it is viewed as a part failure by the manufacturer. Manufacturers typically use "DPPM" to represent what they call a failure rate, a part reliability statistic. This use can be misleading because DPPM is a frequency statistic. Thus, one must be cautious to understand the context of "DPPM" when used to characterize part fielded (in-service) performance, such as when estimating part reliability or a likelihood in a risk assessment.

There is no equivalence between FITs, or fielded failure rates, and a "fielded DPPM;" the former is fielded-failures-per-exposure-hours whereas the latter is the fraction or proportion that has failed.

7.2.8.1 Risk Considerations

As engineering organizations change fundamental and longstanding processes, it is essential to consider the risks: first, to avoid making a change that would do more harm than good, and second, to assure that a change itself simply is not equated to a higher risk. The latter could preclude transitioning to a better approach. In particular, when following the recommendations from the report, some might postulate that an approach that involves more extensive use of COTS parts or using COTS parts without any added MIL-SPEC screening or testing will result in an elevated level of risk compared to historical practices. Consequently, this section offers tools for organizations to assess risks related to many of the concepts provided in this report.

Numerous definitions of the word *risk* exist, most focusing on undesired events that potentially might occur. Such definitions are useful for characterizing fears or concerns, many of which are hypothetical conjectures with little or no insight into how these realistically would affect mission success. Often, occurrence likelihoods of such risks are very remote, do not apply to a specific application, or have not been characterized. Such risk assertions are not useful for identifying what one can or would do about a so-stated "risk", whether it needs to be addressed, or how one would prioritize addressing one risk compared to another.

In some cases, the term risk is used to represent a requirement violation, even if the cited violation will not, or is highly unlikely to, impact the mission. In other cases, the term risk is used to express emotions. Both the aforementioned characterizations of risk can result in unproductive or even negatively impacting actions or decisions implemented to avoid them. In other words, imprecise definitions of risk are not helpful for efficiently *managing* risks.

Accurately and precisely characterizing a risk is important because virtually all approaches to mitigate or eliminate that risk can create one or more additional risks that may be more severe than the initially identified (i.e., first) risk. These additional risks – called *secondary risks* – are often less apparent than the risks one is trying to mitigate.

The most important elements in characterizing risk, for aerospace or space system risk management, are an existing factual *context* for the risk and a well-defined *consequence* that affects the *mission*[16].

Context includes all factors, direct and ancillary, that will cause the risk to manifest. For instance, if a part is tested and found to violate a requirement that is not relevant to the part operating in its intended application, that risk is not credible as it will not impact the mission's successful operation. Another example: A Transistor Outline (TO)[17]-packaged transistor with a poor hermetic seal failed via internal corrosion during ground testing and the corrosion was caused by an aggressive circuit card assembly cleaning process. Another project using these same devices and not using the aggressive cleaning process would not be impacted by this part defect (and would not experience the failure mechanism) and thus this risk is not credible for this other project.

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[16] The use of the term *mission* is certainly not necessary for characterizing risks in general, but it is important when considering risk in aerospace and other similar systems.

[17] Transistor Outline (TO) are industry standard documents describing the physical/mechanical dimensions of semiconductor parts. TO drawings are specific to discrete transistors. Similar industry standards exist for diodes and microcircuits.

The following subsections begin with a broad definition of risk and related terms and subsequently provide several general parts risk examples. Then, several COTS-parts-specific examples are discussed. The risk discussion's scope in this report is limited to defining and assessing risks. Thus, waiver and communication processes, risk mitigation processes, risk management and dispositioning processes, and performing risk trades are not presented.

7.2.8.1.1 Understanding Risk

Per GSFC-HDBK-8005 [ref. 24], "In performing any activity that has uncertainty in achieving an outcome, it is natural to have concerns that represent the things that can go wrong or may not be well-understood. These concerns may have a range of plausibility and uncertainty (e.g., occurrence of the event may be impossible, improbable, possible, probable, etc.) based on analysis, prior experience, observation, brainstorming, or even speculation."

At the core of risk is a *concern*, defined as "a *logical* determination that an undesired event may occur or that the protections against such an event may not be sufficiently well-understood based on available data." The following are general examples of concerns for three common risk categories (safety, technical, and programmatic):

- Safety – a spacecraft may fall off the crane,
- Technical – a part may fail, and
- Programmatic – the cost of an item may grow, or delivery may be delayed.

A risk is the concern put into a context. It is the combination of:

- a factual context or scenario that exists to cause the risk to be present,
- the consequence or impact of the undesired event, and
- the likelihood (qualitative or quantitative) that an undesired event will occur.

Thus, a risk is an expectation of loss based on an existing condition. A *concern* does not become a *risk* until *consequence and likelihood* are established for the risk. A *risk factor* is a characteristic or feature that *might* lead to risk when pertinent conditions exist. For example, pure tin existing in a part is not always a risk factor because, without a means for tin whiskers to travel or bridge conductors, it does not threaten the mission.

Baseline risk is the "normal" level of risk generally considered unavoidable as a practical matter in the relevant activity (e.g., developing and manufacturing a product). This level of risk is accepted by a project or organization without requiring debate, additional analysis, or further tracking.

Appendix B provides some risk statement examples to help understand parts risk.

7.2.8.2 Context for Parts Risk at the Part-Level

As suggested earlier, the word *risk* is sometimes misused to convey fear, lack of familiarity, not meeting a requirement, or an imagined (hypothetical) worst-case scenario. Such usage of the word *risk* does not coincide with risk that is a *credible* threat to a mission (*credible* meaning having a likelihood high enough to be on the risk likelihood scale). Generally, such usage of the term "risk" is an attempt to relay a concern, without the context needed to frame a risk. (The word *level*, in this use, is referring to the assembly level, not a Part Assurance Level as in EEE-INST-002.)

There are many perceived risks associated with using COTS parts because of the commonly used and often-ill-defined term “COTS”. An analogy is to state that walking on a sidewalk by a busy street is a risk. Other than lacking the substance of a risk as expressed in a risk statement, such a broad statement of risk is not useful.

Risk statements become useful when there is an accurate and proper context. This section’s purpose is to steer the reader towards a critical view of what types of conditions drive elevated risks in parts. Doing this will facilitate communication of substantive risks. The *context for risk* includes the existing conditions, features, or state that provides a clear, elevated threat that a part might fail. That is, there must be a defined path toward a credible failure mechanism for a credible risk to be present.

Table 7.2.8-1 illustrates example risk contexts in parts that often come from different part categories. Note that these contexts may not always exist – each situation is unique and should be assessed for its own existing contexts for risk.

The table provides some known risk contexts for the three-part categories listed; those contexts are not all inclusive – other risk contexts may exist or be discovered. The MIL-SPEC column refers to cases where there is a requirement to use MIL-SPEC parts, not to risks associated with MIL-SPEC parts themselves. Having such a requirement does not avoid situations where a low-volume COTS part or one with a variety of special features brings risk. That is, if the project has a requirement to use MIL-SPEC parts and the circuits require high-speed switching at 10 kV, the same context for risk would exist whether the overall requirement was to use a COTS or MIL-SPEC part unless the choice would be not to include the circuit to avoid the noncompliance, thus avoiding the risk altogether – the do-nothing approach.

When the risk context is understood for any part used, the approach to assure the part’s reliability can be established. The reason the MIL-SPEC and NASA-screened categories carry all the risk contexts from the COTS category is because the need to use MIL-SPEC or NASA-screened parts, in most cases, derives from design and performance needs, not simply because a COTS parts option was chosen. Even when there is a decision to use predominantly COTS parts, avoiding or mitigating risk contexts when feasible would be best practice. Nonetheless, the contexts for risk should be identified and recognized.

Table 7.2.8-1. Contexts for Risk in Parts

COTS	MIL-SPEC	NASA-screened COTS
• Parts with special features that are difficult to manufacture consistently (not available in MIL-SPEC parts) - For example: extra-low ESR and ESL ceramic capacitors. • Parts used in extreme regimes, e.g., - High voltage (especially > 3 kV) - Cryogenic and very low temperature applications. • Low volume and hand-produced parts - Often, manufacturing processes are not optimized. - Lack a basis for knowing reliability. • Parts used in very sensitive (poor) designs (i.e., those having parametric variabilities – not on part specifications). • Parts used in applications in which the environment is unknown or ill-defined. • Radiation susceptibility is not listed in the datasheet. • No "high rel" or automotive-grade parts are available. • Parts from unknown or poorly performing vendors (currently, there are no recent examples)	❖ **All Risk context for COTS *, plus:** • Low volume parts • Performance limitations may lead to weak designs. • Specified test processes may miss new manufacturing flaws. • Long lead times and higher costs can reduce system testing resources. • When used broadly across system, can bring false sense of system performance and extensive problems can ensue. • Performance and reliability are not driven by continuous development; instead, business model is to produce parts meeting specified requirements.	❖ **All Risk context for COTS *, plus:** • Parts often are over-tested since, in many cases, MIL-SPEC testing regimes are not related to actual application; parts often are not designed or optimized to endure MIL-SPEC testing conditions. • False hope that screening is relevant to application operation. • False hope (mistaken assumption) that qualification, screening, and testing increases quality or reliability. • A prospect of "burying" a problem or of reducing a part's life by "over-testing by design."

Note: Risk contexts in COTS parts all arise from mission requirements that exist irrespective of which parts approach is used, so they apply to all cases.

7.2.8.3 Framework for a Part-driven Mission Risk Assessment

Generally, it is not necessary to perform risk assessments for every instance a COTS part is used in a critical application. However, while COTS parts usage is being phased into applications with low tolerance for risk (e.g., Risk Classes A and B and human-rated spaceflight systems), there often will be concerns raised by stakeholders and the developers about the risk in using a particular part. Also, situations may exist where some assurance and trust elements recommended in this report are not present. For these cases, it will be necessary to perform structured and consistent risk assessments that apply to such missions associated with the specific parts being used.

The first step in considering risks when selecting the various part classes and categories is to estimate a failure likelihood for an individual part based on how it is manufactured and tested at the parts level and how it is used in its system application. Transitioning from piece part failures to actual project risk involves propagating the failure effects through the system and mission architecture and evaluating the system's fault-tolerance at multiple levels. This form of risk assessment will have an additional benefit of identifying overall system reliability[18].

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[18] This additional benefit only will manifest if all system parts are integrated into the assessment uniformly; i.e., using the same or equivalent analytical methods.

There will be situations in which no data are available to establish a failure likelihood or where there is no trust basis for the part manufacturer. In these cases, such as when a custom part must be used or there is some other specific risk context, there is no general algorithm[19] to determine risk. Therefore, a particular part may need to be fully qualified to ensure that the system's architecture is resilient to possible failures or anomalous performance or failure of such parts. For projects under tight resource constraints, in many cases the only choice is to characterize the risk, identify and implement mitigations, and accept the residual risk.

While this report does not intend to provide a full textbook with means to calculate mission-level risks, the following flow chart, Figure 7.2.8-3, portrays a path for evaluating part-level attributes and discrepancies impacting mission risks. Thus, it provides proper considerations that can be used in making part selection or other part-related decisions.

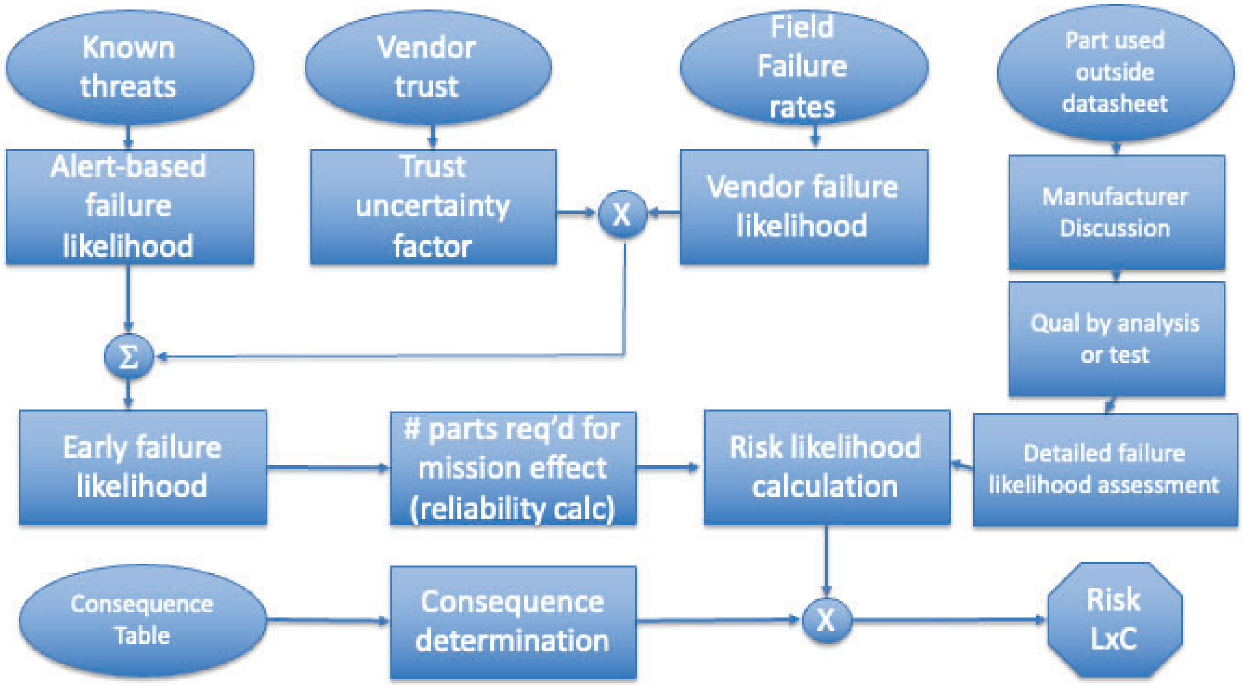

Figure 7.2.8-3. Framework for a Part-driven Mission Risk Assessment

In this framework, known threats come from various sources, such as:

- GIDEP alerts and advisories,
- Warnings from other projects inside and outside the organization,
- NASA, Missile Defense Agency (MDA), The Aerospace Corporation, or SQIC advisories, and
- Discoveries within the current project.

Vendor trust assesses an individual's or organization's confidence[20] that a vendor's part(s) will meet a mission's operational needs. A vendor trust uncertainty factor is a multiplier that is equal to or greater than 1; 1 represents 100% trust in the vendor and the specific part and a larger

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[19] "Algorithm," in this sentence, is used in its more general definition, not in its mathematical construct.

[20] Confidence, as used here, is a qualitative measure of *trust*, not in a statistical sense.

vendor trust uncertainty factor characterizes less trust in the part and/or vendor. This vendor trust uncertainty factor could include a lack of trust in an individual part, as applicable, even if there is an open and trusted relationship with and credible historical part data from the vendor. As an example, a trusted vendor may state that this is a new part yet to be established, which in this case, would imply a trust uncertainty factor greater than 1. A large value indicates reduced trust in the manufacturer and/or the specific part; thus, the trust uncertainty factor actually represents lack of or diminished trust. A couple of examples are provided in Appendix B for illustration purpose; however, this approach's emphasis should not be on the exact numerical trust uncertainty factors but more on the overall risk calculation's sensitivity to the trust uncertainty factor.

The level of trust that any organization or even an individual within the organization will have with a manufacturer and a specific part may vary among persons. That is expected, because the uncertainty in the risk, compared to a part having extensive fielded data, will be based on individual perspectives. Often there will be subjective perspectives when there is an incomplete basis for trust. However, after performing multiple risk assessments across several systems, it will become apparent that some systems and components within them are less vulnerable to elevated trust factors than others. This observation may be used to indicate which parts have a greater concern for system impacts, and thus may require more attention and confidence. While this report is focused on the Established parts from ILPMs, the approach is general enough to cover non-ILPM parts, which would use larger vendor trust uncertainty factors as applicable. Part failure data preferably should be field failure data, but may be limited to DPPM[21], DPPB, or other metrics that either represent or conservatively encompass part failures for the given part.

General failure likelihood is the failure likelihood that considers whatever information is available for field failure data, potentially modified by an adjustment factor accounting that all failures might not be reported. For example, if the field failures per part delivered are based on 4 million fielded parts and, given such factors as high minimum order quantities, that not all those parts have been installed in fielded equipment, the general failure likelihood could be reduced to, for example, ~2 million parts, thus adjusting for possible under-reported failures. The vendor trust uncertainty factor multiplies this general failure likelihood to obtain an estimated *early failure likelihood* (EFL) for the part. This EFL is inserted into a mission-specific calculation to determine a mission degradation or failure likelihood.

Again, it is important to emphasize that lack of data to establish a part failure likelihood estimate will require other methods to characterize and mitigate risk, as also would be the case for a one-of-a-kind custom part. Generally, such a scenario should focus on fully qualifying the part, or a concentrated approach to assure fault-tolerance (e.g., a backup element, within the circuit or system). There is no "free lunch" when using a custom, one-of-a-kind part, irrespective of overarching parts requirements.

Lastly, this approach provides a tool to integrate trust into an overall risk likelihood assessment. Its best use would be in comparing risks among different scenarios in an overall risk management approach. Local tailoring of the approach is encouraged, and the primary emphasis should be that the scenario that leads to risk should be factual and the consequence should be an actual effect on the mission. Otherwise, risks cannot be traded reasonably against one another.

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[21] This usage of DPPM means *defective* parts per million, not DPPM used to represent field failures; see Using "DPPM" (defective parts per million) in Section 7.1.3. DPPB is defective parts per billion.

In other words, it would not be logical to trade one risk with its consequence "noncompliance to parts requirements" against another risk with consequence "loss of mission after 80% of objectives are complete."

7.2.8.3.1 ILPM Established COTS, MIL-SPEC, and NASA-screened COTS Qualitative Comparisons for Early Failure Likelihood

When selecting parts for an application, the primary concern is whether the parts will meet the application and lifetime requirements for the mission. While part selection, screening, and qualification cannot completely establish the reliability in an application, it is important to characterize part-level attributes to compare different parts categories by how they likely affect reliability in an application. One approach is to consider each part category's attributes and how they might establish sufficiently low failure likelihoods when the parts are used nominally within datasheet limits, including expected part lifetimes. Manufacturers' processes, such as statistical process controls and extensive quality metrics combined with known failure rates and lot-based accelerated testing, can provide subjective characterizations of EFL[22]for the purposes of comparing different assurance approaches.

While radiation is another important factor in space applications, it is discussed separately since most COTS and MIL-SPEC parts are not manufactured to radiation hardened or tolerant requirements.

Table 7.2.8-2 provides discrete subjective comparative early failure likelihood determinations and associated attributes for three common parts categories. These attributes are not meant to provide a computed EFL, but rather to establish comparable levels of part-based risk contributions for a range of different part selection options, including those consistent with current Agency requirements – those in the two right columns. It is not possible to identify actual risks for any part selection approach without all the requisite information and context. Nonetheless, this table provides a tool for considering the factors needed to determine risk.

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[22] *Early failure likelihood* in this context means failure before the manufacturer's specified expected lifetime. This should not be confused with "early failure rate" per the JEDEC definition.

Table 7.2.8-2. Comparison between ILPM Established COTS, MIL-SPEC, and NASA-screened COTS Parts

	Established COTS Parts (microcircuits, discrete semiconductors, capacitors, resistors)	**MIL-SPEC Parts (microcircuits, discrete semiconductors, capacitors, resistors)**	**NASA-screened COTS Parts (microcircuits, capacitors, resistors)**
Attributes	1. Produced by an ILPM 2. Automated production line 3. High -volume parts 4. 100% electrical testing 5. Reliability monitoring 6. Process and parts qualification 7. Typically, non-standardized drawings and datasheets 8. Not typically space radiation qualified 9. May or may not be designed for launch and deep space environments.	1. Automated production line 2. Typically not high-volume 3. 100% MIL-SPEC screened 4. Lot acceptance performed 5. Process and parts qualified by DLA 6. Standardized drawings, datasheets and MIL specifications 7. Not typically space radiation qualified 8. May or may not be designed for launch and deep space environments.	1. May or may not use automated production line 2. May or may not be high-volume 3. Post procurement 100% screened 4. Lot acceptance tested 5. May or may not have standardized drawings or datasheets 6. Not typically space radiation qualified 7. May or may not be designed for launch and deep space environments.
To achieve very low part-level early failure likelihood	• Review datasheet and use the parts within their limits. • Obtain design lifetime from the ILPM. • Verify with ILPM attributes 2-6. • Verify with ILPM that part's field failure rate is < 10 ppm. • Check part prior history including Alerts, similar designs, etc. • Ensure part performance meets application and mission requirements. • Derate Passive parts per EEE-INST-002 guidelines. • Derate microcircuits and discrete semiconductors using engineering judgement per datasheets.	• Review datasheet and use the parts within their limits. • Check prior history of the part including Alerts, similar designs, etc. • Ensure part performance meets application and mission requirements. • Derate parts per EEE-INST-002 guidelines.	• Select establish COTS parts. • Use parts within datasheet limits. • Lot acceptance testing and screening per EEE-INST-002. • Derate parts per EEE-INST-002 guidelines.

7.2.9 Space Radiation Hardness Assurance Considerations

7.2.9.1 Space Radiation Environments and Effects on Electronics

The boundary between the atmosphere and the beginning of space is generally taken to be the von Karman line at 100 km altitude[23]. Most electronic parts, including most COTS and MIL-SPEC parts, are not designed explicitly for space applications. The space environment is qualitatively and quantitatively more severe than the atmospheric or terrestrial radiation environment. Peak particle fluxes (mainly neutrons in the atmosphere and protons in LEO) are two or more orders of magnitude higher in space than in the atmosphere. Additionally, even the most benign space environment also pose~~s~~ threats of galactic cosmic rays (GCRs) and Solar Particle Events (SPEs) heavy-ion components, which can cause destructive effects with greater probability than protons or neutrons. Space radiation environments are captured in the Design

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[23] https://www.nesdis.noaa.gov/content/where-space

Specification for Natural Environments (DSNE) [ref. 25], which includes specifications for GCR and SPE fluxes, and trapped radiation.

Space environment radiation effects can be either cumulative (dose effects) or sudden (SEEs) in the natural space environment. Dose effects include TID, which causes degradation and eventual functional failure, and total non-ionizing dose (TNID), which mainly degrades performance and causes eventual failure in bipolar, detector, and other minority-carrier devices.

The SEE modes that can occur when space radiation environments interact with electronic systems can be categorized as destructive and nondestructive effects. Destructive effects result in permanent functional loss for the electronic part. Destructive effect examples are Single Event Latch-up (SEL), which can occur in complementary metal oxide semiconductors (CMOS) circuits, and Single Event Burnout (SEB) and Single Event Gate Rupture (SEGR), which can occur in metal–oxide–semiconductor field-effect transistors (MOSFETs) and other power devices. Nondestructive radiation effects include Single Event Upsets (SEUs), Single Event Functional Interrupts (SEFIs), which are common in semiconductor memories, processors and other complex devices, and Single Event Transients (SETs), which induce a transient voltage that can propagate to the device output and throughout the system that potentially changes the device or system's state. These examples do not form in-depth list of electronics radiation effects; there are additional destructive and nondestructive effects that must be managed to build successful spaceflight systems. Note that the underlying device's technology is important to understanding radiation effects. For example, two microprocessors, one built using a bulk CMOS process and another built using a Silicon-on-Insulator (SOI) process, likely will have different SEL behaviors. Bulk CMOS devices can be prone to latch up, whereas SOI devices will be latch-up immune. This occurs since the parasitic circuit that causes latch-up, found in bulk CMOS, is not present in SOI designs. Radiation effects occur over a range of timescales. SEEs occur in nanoseconds while dose effects often take years to manifest. More information and guidance on radiation effects and testing is provided in NESC-RP-19-01489, Guidelines for Avionics Radiation Hardness Assurance, April 1, 2021 [ref. 26].

7.2.9.2 Managing Radiation Effects in Non-"Rad-Hard/Tolerant" Parts

Radiation failure modes depend on device technology, operating duration and environment, circuit application, and other factors, so one might ask, "*What does it mean for a part to be radiation-hard (rad-hard) or rad-tolerant?*" For the purposes of this discussion, a "rad-hard/tolerant part" is defined as: A part that has been characterized and guaranteed to some manufacturer-established radiation specifications. Characterization is achieved through device radiation testing to ensure that the part will perform to its specification. The corollary of this is: parts not listed as "rad-hard/tolerant" (i.e., non-"rad-hard/tolerant" parts) have not been characterized for a radiation environment by the manufacturer. While some parts meet this definition of "rad-hard/tolerant", most COTS and MIL-SPEC parts do not. Therefore, if mission needs drive designers to use parts that are not "rad-hard/tolerant", radiation characterization or other experimental data linking to the current mission will be needed, with appropriate mitigation strategies based on those results being implemented to ensure mission success.

When a part is not "rad-hard/tolerant", appropriate radiation characterization and mitigation or the use of other experimental data with linkage to the current mission are typically needed to meet MEAL requirements. This can be accomplished by a combination of techniques, such as reviewing past performance of the same part or the circuit or component that houses it in a given environment and knowing if and how the part design, usage, or manufacturing might have changed and then followed by appropriate radiation testing. However, implementing non-“rad-hard/tolerant” parts in space application is not solely part-focused; a holistic approach is needed (e.g., shielding, circuit design and architecture, operational constructs, etc.). The system design should consider part performance, including radiation effects and prior space operational performance and implement mitigation strategies to meet mission requirements.

Characterizing non-“rad-hard/tolerant” parts that are likely susceptible to radiation effects and have no prior testing or on-orbit experience for the mission radiation environment can only be accomplished through testing when no information is available to understand the radiation susceptibility. Part-level tests depend on the part technology, generally falling into two categories: SEEs testing and dose effect testing. Proton, laser, and heavy ion testing can characterize device SEE performance. Proton and laser testing can cost-effectively identify devices with poor SEE performance, although it is not always reliable for revealing destructive SEE susceptibility. Board-level proton testing has also been used effectively in some cases (e.g., non-critical International Space Station (ISS) projects). More costly heavy ion testing characterizes a device’s SEE performance more fully and predicts destructive and nondestructive failure rates for some SEE types. Depending on the technology, radiation environment, and mission duration, TID or TNID testing also may be needed to understand the parts’ accumulated dose effects performance degradation. The right combination of radiation tests can characterize the device’s destructive and nondestructive (recoverable) failure modes. The radiation test data, a circuit design with considerations for radiation effects, and system-level mitigation strategies, consistent with mission risk classification and requirements, can then be used to accept the circuit and associated parts or take further action to mitigate adverse effects.

Depending on the device technology, function, and radiation performance, a variety of mitigation techniques have been used effectively. Following is a non-exhaustive list of mitigations:

1) Shielding for TID and TNID effects.
2) Error Detections and Correction (EDAC) encoding of data and scrubbing for SEUs.
3) Monitoring circuits (e.g., watch-dog timers) and reset circuitry for SEFIs.
4) Latch-up detection circuitry and reset logic can be effective for some devices exhibiting SELs. However, such circuitry is disruptive if SEL rates are too high, may be false-positive SEL indications, and should be validated to demonstrate that it is effective against both prompt failure and latent damage [ref. 27].
5) Fault masking redundancy. This mitigation strategy can be implemented at any design level. Within a programmable device (e.g., Field Programmable Gate Array (FPGA)), Triple Modular Redundancy (TMR) can be used internal to the device. Alternatively, at the other end of the design hierarchy, redundancy can be implemented at the spacecraft level (e.g., small-, micro-, and nano- sats).
6) Operational constraints such as strategically powering off parts of the system in high radiation environments (e.g., in the South Atlantic Anomaly or during Solar Particle Events) can provide mitigations to some radiation effects.
7) Part derating for SEB and SEGR.

A well-characterized part implemented with a well-defined mitigation strategy, as needed, will determine a part’s suitability in meeting mission requirements.

7.2.9.3 ILPM RHA Considerations

A part's radiation performance depends on its fabrication technology (e.g., CMOS-bulk, CMOS-SOI, Bipolar, etc.). Additionally, process parameters (e.g., oxide thickness, doping levels, etc.) impact performance. TID and SEL device radiation performance are particularly sensitive to process controls. Lot-to-lot TID performance variation has been well-documented at the piece part level [ref. 28]. Due to these variations, the ILPM relationship must be leveraged to obtain lot designators. The same parts from different wafer lots may have variability in their level of TID tolerance. SEL performance is also process sensitive but usually not to the same degree as TID; it also depends on doping level and circuit layout geometry defined by the mask set. Once a specific wafer diffusion lot is characterized for SEL performance, other lots may also be acceptable if there are assurances through the ILPM that there have been no mask or wafer fabrication process changes. Therefore, when working with an ILPM, one must understand lot traceability and any mask or wafer fabrication process changes. However, subtle process changes that may seem to be innocuous and do not impact form, fit, and function can impact both TID and SEL performance at the piece part level. These changes are not necessarily reported by a manufacturer and thus it is incumbent upon the user to protect against such occurrences (e.g., periodic lot acceptance testing).

7.2.9.4 Radiation Management Considerations

Project leadership and system engineers collaborating with design, parts, radiation, test, and assurance engineers must decide the best approach to meet their mission requirements given programmatic constraints (e.g., cost and schedule). The RHA approach, including requirement decomposition, should be started early in the design process. Assuming the same desired RHA risk endpoint, there are no fundamental differences in the RHA process for RHA- versus non-rad-hard parts. Even for more risk-tolerant projects, non-rad-hard parts usage shifts the responsibility of executing part-level RHA assurance from the part manufacturer to the project/end-user. Radiation characterization testing involves cost and schedule (facility availability) impacts and performance risks. In addition, the user may assume the risk of part susceptibility variations due to manufacturing process changes. Using rad-hard parts in systems comes with associated cost and the potential of extended procurement times, but it also comes with some level of assurance in that the parts themselves have been characterized for typical radiation environments encountered by spacecraft. However, part assurance alone is typically insufficient to assure circuits and systems operate properly in severe radiation environments. Programs/projects must leverage fault tolerant design practices and mitigation approaches at appropriate levels. For some parts, such as bulk CMOS, it is not uncommon to encounter SEL during testing [ref. 29]. Projects must be willing to manage the impacts of poor radiation performance uncovered during the test campaign or weaknesses in the design. Leveraging test data from other programs/projects can sometimes help reduce uncertainties and inform the test campaigns. Another consideration is the cost and availability of test facilities. In particular, heavy ion facilities are a limited resource in high demand and the cost of beam time (~$1000 to $5000/hour) must also be managed. Note that SEE test facility beam time has become increasingly hard to obtain and timely scheduling is important.

There can be multiple means for a project to achieve an acceptable risk level, including using non-rad-hard parts when appropriate-radiation effects analyses and subsequent mitigation strategies are employed. Ultimately, this is an informed risk decision accounting for radiation performance consistent with other programmatic and technical considerations to meet mission success.

7.2.10 Monitoring Strategy for Established COTS Parts from ILPMs

The COTS parts landscape is vast and continuously evolving. NASA is not the authority for maintaining a status or list of all ILPMs. Instead of providing such a list, this document provides the guidance needed for individual organizations and spaceflight hardware developers to establish their own assessments of the COTS parts and manufacturers used in their product lines. If the guidance herein is followed, and that the spaceflight hardware developers can present their summary of the assessment, NASA expects to accept the results of that assessment, and proceed in accordance with the remaining guidance of this document.

There are several additional factors that should be considered in cases of continuous use and continuous evaluation of ILPM parts. An ILPM assessment reflects the period of time during which it was performed. For long-term product lines and arrangements, it may be necessary periodically to re-evaluate previously verified ILPMs and the Established COTS parts from the ILPMs. This statement is broad to allow flexibility in how much re-assessment is required, but one factor in determining ILPM suitability should be timely relevance of available data.

Spaceflight hardware developers should establish and maintain ongoing relationships and open lines of communications with their ILPM manufacturers. These relationships and communications provide insight into recent production statistics, facility and process changes, and access to technical support, and demonstrate that an ILPM assessment process is conducted continuously and is up to date.

Independently, spaceflight hardware developers should monitor updates and alerts (e.g., Process Change Notices (PCNs), GIDEPs, and NASA Advisories that may impact their ILPM parts) and consider that information in determining or updating an ILPM part assessment. It should be noted that largely, high-volume ILPM parts are controlled by the market and SPC and thus GIDEP alerts would rarely apply or be necessary. Recent changes should be reviewed, and the appropriate parties notified.

As part of the recommendation of this NESC assessment, NEPP Program will perform a pathfinder study to explore the implementation of the guidance in this report. The ILPM process does not equal a conventional vendor qualification process followed by the MIL-SPECs. The intent of this NESC report is to provide guidance in the utilization of available parts data from the manufacturer for needed parts assurance assessments for NASA missions.

7.2.11 Common Perceptions for COTS Parts and the Team's Comments

There are many perceptions about COTS parts that are based largely on the less robust subsets of the COTS trade space, such as parts that receive minimal or no in-process or end-of production testing by the manufacturer. This report, throughout, focuses on Established COTS parts from ILPMs (see Section 7.1.3 for definitions and descriptions). *Any COTS parts outside that category have no expectations for performing reliably without, in many cases, substantial additional testing and verification. None of the team's responses are to be interpreted as recommendations.*

1. **“COTS parts are unscreened. They might fail at any moment.”**

   a) Are COTS parts “unscreened”?

   Production testing performed at COTS parts manufacturers’ facilities involve in-process (e.g., wafer probing, pre-encapsulation, or pre-packaging testing) and end-of-production testing (i.e., final testing of finished parts prior to shipping to customers). Those stating that COTS parts are “unscreened” mean, in some cases, that most COTS parts do not undergo part-level 168-hour burn-in and thermal cycle testing, common among MIL-SPEC parts. In other cases, they simply are stating that post-procurement screening per EEE-INST-002 is not performed on COTS parts. This report discusses Established COTS parts from ILPMs that are well-screened.

   Screening tests, most commonly thermal cycling and burn-in, do not improve parts quality. At best, they discover defective parts, and, at worst, they may damage parts through physical or electrical mishandling or over-testing. This is because ILPMs’ modern-day manufacturing processes for Established COTS parts (Section 7.2.1) ensure specifications compliance and eliminate defective parts. For these and other reasons (cost, schedule, efficiency), ILPMs accomplish screening goals for COTS parts by other means; their intent is that defective parts are never produced to proportions (i.e., DPPM) at which traditional screening tests would be effective. The military system has learned this lesson and allows reducing or eliminating screening tests, called test optimization, as described in JEP121 [ref. 21], if those tests are shown to be unnecessary (i.e., evidence has been provided that any defective parts have been removed before screening). DLA-approved optimizations may be found here Sourcing and Qualification (dla.mil), and current optimization report is at https://landandmaritimeapps.dla.mil/Offices/Sourcing_and_Qualification/resource.aspx.

   The “COTS parts are unscreened” argument may also refer to the lowest COTS parts grades wherein not every part goes through final testing prior to shipping to customers. Such parts are produced for strictly low-cost applications (e.g., parts used in high-volume inexpensive consumer products such as toys that come with fast food meals). These parts are not categorized as Established COTS parts, as defined in this report, and should never be considered for space or other applications that require high reliability.

   b) Is COTS parts manufacturer “screening” acceptable?

   The process controls and screening practices used by ILPMs in producing their Established COTS parts are based on large volumes subjected to statistical process control and continuous improvement and highly effective at eliminating defects and produce quality parts at least commensurate with the quality achieved using MIL-SPEC processes.

   c) COTS might fail at any moment.

   Many believe COTS parts have higher failure rates; this may be the case for some COTS parts. Established COTS parts from ILPMs used within datasheet limits and designed operating lifetime and appropriate design margins are no more likely to fail than MIL-SPEC or NASA-screened parts. Refer to Section 7.1.3 for details.

2. **"COTS parts are qualified in families. Only a few part numbers within the family are qualified."**

   This statement is true. Qualification families and qualification by similarity is also used within the MIL system. Established COTS parts from ILPMs follow JEDEC and/or AEC qualification guidelines, including qualification by similarity criteria. This alternative qualification-by-similarity is comparable to MIL-SPEC parts qualification-by-similarity. COTS parts users should review available qualification-by-similarity data to confirm they meet spaceflight application needs for part-level verification.

3. **"COTS parts can be made in multiple locations."**

   This statement is true. ILPMs as defined in the report are expected to guarantee their parts meet datasheet-specified performance parameters regardless of where they are fabricated indicates they have satisfactory production and test process controls. Part-to-part and lot-to-lot production variability does occur, and the datasheet parameter limits are expected to have accounted for this variability. All needs to be verified by part procurement and part-level verification in Section 7.2. The traceability to wafer level or wafer lot level is challenging even some of Established COTS parts from ILPMs.

4. **"COTS parts do not have traceability."**

   Traceability is typically considered in two ways. First is the ability to trace the active die inside a semiconductor back to the original wafer. This is a requirement for some MIL-SPEC devices and is useful with respect to conducting radiation testing on a sample of devices. The other way traceability is considered is in the ability to determine if a group of devices were manufactured at the same time, using the same processes, materials, personnel, etc., referred to devices being traceable to a single "manufacturing lot". This is also a factor when selecting samples to determine if they representative of all the devices procured at the same time. ILPMs qualify their parts with respect to the limits listed in their data sheets. This includes the processes, materials, etc. that may be subject to changes by the manufacturer. Using the Established COTS parts from ILPMs within their data sheet limits will result in high quality parts, even if the procured parts do not have 100% lot homogeneity. Additionally, projects should contact the manufacturer or authorized distributer to determine if wafer traceability or lot homogeneity is an option if a specific need exists.

5. **"COTS parts made in different fabrication facilities can have different radiation characteristics."**

   This statement is true. It applies to all parts, MIL-SPEC or COTS, that are not radiation rated or radiation-hard assured. Two differences may exist for parts fabricated at different sites that may affect part radiation performance. First, parts may have different designs, that is, use different mask sets and different fabrication processes. Design likeness can be verified with the manufacturer. However, it is possible that relatively small changes in layout can affect radiation effects failure modes such as SEL. Second, parts manufactured in different facilities will invariably experience differences in processing significant enough to affect radiation performance. An example of this is that subtle changes in the process flow can have a dramatic impact on steady state total ionizing performance. Most parts, including both COTS and MIL-SPEC parts, are not designed for space radiation environments. Parts manufacturers, including ILPMs, adjust their processes for characteristics affecting published datasheet parameters. If radiation performance is not a specified datasheet characteristic and the part will be used in a space radiation environment, part-level verification (Sections 7.2.4 through 7.2.6) commensurate with the mission risk posture (Section 7.2.8) should include verifying that fabrication variables affecting radiation performance are controlled adequately by the manufacturer. However, as indicated above, this can be a difficult task since the relationship between many processing parameters and radiation performance are not obvious.

The external radiation environment is modulated by the spacecraft shielding. In the majority of cases, shielding has a beneficial effect on radiation performance of electronics for TID and SEEs. Analysis of shielding configuration and radiation transport modeling should be considered for accurate quantification of the spacecraft-internal radiation environments and effects.

A manufacturer's ILPM standing is not affected by either of the two (above) radiation-related concerns. Section 7.2.9 provides more detailed information regarding part radiation susceptibilities and radiation hardness assurance.

6. **"COTS parts manufacturers may change their fabrication, manufacturing, and inspection and test processes at their discretion."**

   This statement is true. As there is no Government oversight over COTS parts manufacturers, they are free to change their fabrication, manufacturing, and inspection and test processes. They may be subjected to industry consensus standards and negotiated customer contracts.

   The key to successfully using COTS parts in any application is a strong relationship between the manufacturer and customer. One aspect of this relationship is the customer (e.g., NASA) being cognizant of current part technologies and keeping up with production, design, obsolescence, and other significant changes. The customer/manufacturer relationship should ensure adequate change notifications the customer deems important. Manufacturers, in general, report changes that impact form, fit, and function; however, it has been shown that less dramatic changes in design and process flow can impact radiation performance. Thus, it is incumbent on a customer to verify the radiation performance of a COTS technology using radiation lot acceptance testing for failure modes such as steady state TID. This caution may extend to other failure modes such as SEEs if it is suspected that a commercial manufacturer has made process and/or layout changes.

8.0 Findings, Observations, and NESC Recommendations

The NESC team provides the following findings, observations and NESC recommendations. No unique hardware, software, or data packages, outside those contained in this report, were disseminated to other parties outside this assessment. No recommendations for NASA lessons learned were identified as a result of this assessment. Recommendations for NASA EEE part standard update is included as a NESC recommendation in this section.

8.1 Findings

The following findings were identified.

F-1. NASA's current practice is using MIL-SPEC parts and NASA-screened COTS parts for safety and mission critical systems on missions of all risk classifications. Some Class D and sub-Class D payloads and missions, or non-critical applications have used COTS parts successfully without additional part-level MIL-SPEC/NASA screening and qualification.

F-2. MIL-SPEC parts are standardized across manufacturers (e.g., per MIL-STDs, MIL-PRFs, MIL-SPECs, SMDs), while COTS parts' environmental ranges and electrical parameter limits are defined by their datasheets. Therefore, no assumptions regarding COTS parts' tolerance to operating and environmental exposure can be made without reviewing the specific part datasheets.

F-3. There is a lack of consensus within NASA on the risk of using COTS parts for safety and mission critical applications in spaceflight systems. Risk contexts (i.e., factual factors that may increase the risk, with details provided in Section 7.2.8) in using any Class of part are important to understanding and characterizing project and/or mission risks.

F-4. Part-level verification for COTS parts used in spaceflight systems remains a significant challenge, since currently there are no formal communication channels existing between NASA and the COTS parts manufacturers.

F-5. There is a lack of consensus within NASA regarding part-level verification on COTS parts. Current practices vary from no verification at part-level to full verification at parts level, depending on the Center's practices and project's risk posture.

F-6. Not all COTS parts are created equal due to wide variability in parts manufacturers' process control and quality assurance, as well as their classes, categories, and grades they offer. Some COTS parts manufacturers (i.e., ILPMs in Sections 7.1.2 and 7.2.1.1) have parts with reliabilities established by, among other things, high volumes, SPCs, and 100% manufacturer testing. Those parts are defined as Established COTS parts in Section 7.2.1.1.

F-7. Not all AEC parts are from ILPMs. AEC specifications and automotive grade part manufacturers alone do not necessarily guarantee all of the quality and production control aspects needed to be considered as an ILPM.

F-8. The majority of parts are not designed or manufactured with intent for space environments.

F-9. MIL-SPEC parts generally have more built-in margins per the datasheet limits (e.g., rated voltage, temperature, or frequency of operation) than COTS parts, therefore operating COTS parts beyond their datasheet limits can be more problematic than doing so with MIL-SPEC parts.

F-10. The standards such as MIL-STD-1580 for DPA/CA have been written around military parts designed to rigorously specified and highly prescriptive manufacturing requirements for space applications. Thus, nonconformances or failures identified during a COTS part DPA/CA should not be assumed to indicate a defective part. They could be the outcome of judging a good part against an inappropriate standard.

F-11. Many COTS parts have pure-tin finishes.

F-12. COTS parts are susceptible to obsolescence and counterfeiting issues because of increased product obsolescence rates and supply chain traceability deficiencies.

F-13. The current NASA practice of applying EEE-INST-002 based testing for commercial parts is largely based on the MIL-SPEC system when the technologies we use today were in the early stages of development and fabrication. The EEE-INST-002 processes do not, in general, account for the modern manufacturer processes for fabrication, qualification, and statistical process controls.

8.2 Observations

The following observations were identified.

O-1. Selecting COTS parts in lieu of standard MIL-SPEC parts solely on the expectation to save cost rarely succeeds, particularly under strict adherence to current Agency guidelines for Class A-C missions. In most cases, COTS are chosen to provide performance, availability or, in some cases, reliability advantages.

O-2. A recurring practice has been to have projects approach manufacturers to change a feature or material in a COTS part and the manufacturer obliges. This often changes the established basis for the part and then causes serious problems with the part.

O-3. Most NASA parts engineers do not have expertise in semiconductor device physics and other device technology and fabrication processes, and very few of the Agency's parts engineers have knowledge of the modern part production and device qualification processes in the commercial world (COTS parts manufacturers). This leads to outdated or ineffective screening processes for COTS parts that are either not relevant or may even be harmful to the parts. This is reflected in the fact that many part failures or design errors have been traced to lack of understanding of the datasheets.

O-4. The current common practice for NASA parts engineers is to disapprove of individual parts being manufactured in different locations. This is because modern fabrication process has consistency that allow replication across multiple fabrication lines. The parts are produced at different locations worldwide subject to the same statistical process control and to the same datasheets. For parts manufactured in different locations, they may not be uniform in parameters not specified in the datasheets (e.g., radiation susceptibility).

O-5. Lessons learned on COTS parts failures show that the NASA community is biased assuming COTS parts themselves are root causes of system failures while MIL-SPEC parts represent the best possible solution, and thus subsequent failures are because nothing is perfect.

O-6. FAA aircraft and component certification processes are based on top-down verifications to legally mandated requirements contained in Federal Air Regulations (FARs) and other subordinate derivative requirements. Although processes used in certifying compliance to

FAA requirements are similar to methods used to validate certain NASA mission criteria, (e.g., FMEAs, FTAs, and hazard analysis), the FAA's strictly top-down approach is not consistent with NASA's utilizing both top-down/bottoms-up processes in its mission design, manufacture, and validation processes.

8.3 NESC Recommendations

The following NESC recommendations were identified and are directed towards the spaceflight program or project managers, project avionics engineers, system engineers, circuit design engineers, parts engineers, radiation engineers, reliability engineers, parts procurement specialists, and the NESC:

COTS Parts Risk Identification and Mitigation

R-1. Programs/projects should understand and effectively manage the risk of COTS parts, using a holistic approach incorporating inputs from across the Programs/projects to make informed decisions and mitigate risk. Risk should be considered in the appropriate context, based on knowledge of part technology, whether the parts manufacturers are ILPMs, and how the parts are being used. ***(F-1, F-2, F-3, F-5)***

R-2. When COTS parts are used in safety or mission critical applications, a mission specific approach tailored to the project's MEAL should be developed and approved by Program/Project Managers with any pertinent risks clearly identified, mitigated, and/or accepted. ***(F-1, F-2, F-3, F-5)***

R-3. Recommend different approaches for Class A/B/C/D and human-rated missions. ***(F-1, F-2, F-3, F-5, F-6)***

  a. Recommend Class A/B and human-rated missions to consider a "MIL-SPEC parts-based design" approach (i.e., most of the parts are MIL-SPEC parts, and only select COTS parts when equivalent MIL-SPEC parts do not meet functional or SWaP requirements or are not available).
  b. Recommend Class D/Sub-D missions to consider a "system of COTS" approach (i.e., most parts should be Established COTS parts from ILPMs).
  c. Recommend Class C missions to determine which approach is the best for the programs/projects (i.e., "MIL-SPEC parts-based design" approach, a "system of COTS" approach, or a combined approach).

R-4. Circuit Designers, Parts Engineers, and Radiation Engineers should ensure MEAL requirements are addressed in COTS parts datasheet explicitly or perform additional testing or analysis, as needed. ***(F-2, F-6, F-8, F-9, F-12)***

R-5. When using COTS parts, Circuit Designers and Parts Engineers should select and use the Established COTS parts categories from verified ILPMs to assure that parts have a comparable quality level to that of MIL-SPEC parts. ***(F-2, F-6, F-7, F-8, F-12)***

R-6. At the project level, use a single whisker mitigation plan to cover all pure tin uses as recommended by GEIA-STD-0005-2. Some common example mitigations for space applications include using tin-lead solder and using conformal coating, when feasible. When COTS parts have the option for other than pure-tin plating compositions, verify with the manufacturer that the alternative compositions still provide the requisite reliability, and select such an option to eliminate the risk factor entirely. ***(F-11)***

R-7. Refrain from requesting a manufacturer to change any features or materials in Established COTS parts. For example, if a COTS part uses pure-tin plating without any other plating options, do not request a change in plating materials. Realize when a request is made to the manufacturer to make a change, it will negate the Established COTS part's basis. ***(F-11, O-2)***

COTS Parts Selection, Procurement, and Obsolescence

R-8. When selecting COTS parts for spaceflight units, Circuit Designers should work with EEE Parts Engineers to follow the recommendations provided in Section 7.2.2, including: ***(F-6, F-7)***

a. Ensure COTS parts meet project's MEAL requirements;
b. Select Established COTS parts from ILPMs;
c. When Established COTS parts from ILPMs are not available or cannot meet project MEAL requirements, the NESC team provides the following recommendations:
    i. select COTS parts with mature technology;
    ii. select COTS parts that are widely used in commercial electronics products;
    iii. recognize that leading edge technology parts may require significant specialized efforts to ensure their reliability; thus, avoid selecting COTS parts early in their technological development, not produced in high volume, or designed at the limit(s) of their technology (e.g., a 24-bit ADC in a process where the previous highest resolution was 16 bits); and
    iv. when a part is selected based on "flight heritage" (i.e., the part was used on a previous mission), it is critical to compare the MEALs of the missions to ensure the new mission's MEAL is within the previous mission's requirements. If that is not the case, a delta qualification will be needed based on the MEAL differences.

R-9. When purchasing COTS parts for spaceflight units, EEE Parts Engineers and Project Procurement Organization should follow the recommendations provided in Section 7.2.2.3, including: ***(F-6, F-7, O-1)***

a. Procure COTS parts from Original Component Manufacturers (OCMs) and authorized distributors *only*;
b. Obtain Certificate of Compliance (CofC) and lot trace code so that parts can be traced to a specific manufacturer, part number, and lot number;
    i. Communicate with the OCMs and authorized distributors to ensure the parts are from the same wafer lots, for space radiation purposes; and/or procure one reel of the parts to maximize the probability parts come from a single wafer lot.
    ii. If traceability to the manufacturing lot cannot be verified fully when only non-ILPM established parts are available, post-procurement testing is highly recommended to verify performance to the device specifications.
c. Request, obtain, and review Level 3 PPAP (Production Part Approval Process) Package for AEC parts.

d. Procure a quantity of parts based on planned and potential future builds, contingency for unexpected performance, and potential future consideration (e.g., expected contract additions or additional testing).
    i. When not cost-prohibitive, procure at least 3 or 4 times the quantity of COTS parts needed for the mission if only non-ILPM Established COTS parts or otherwise unfamiliar COTS parts will be available to build multiple or subsequent versions of the avionics assemblies.

R-10. COTS parts should be monitored for obsolescence impact on a more continuous basis than MIL-SPEC parts due to the shorter life cycle of commercial components. Parts obsolescence analysis plan should be included in parts requirements plan per NASA-STD-8739.10, as outlined in Section 7.2.2.3. ***(F-12)***

COTS Applications in Space Systems

R-11. When using COTS parts for spaceflight circuit designs, Circuit Designers should work with EEE Parts Engineers and Radiation Engineers to follow the recommendations provided in Section 7.2.3, including: ***(F-8, F- 9)***

a. Circuit Designers should collaborate with Parts Engineers to assure required performance characteristics are within specified datasheet parameters over the mission lifetime.
    i. For example, a part datasheet might specify a range for a parameter while the application requires that parameter to be within a tighter parametric range, or an application might not be tolerant to parametric drift (with time, temperature, or radiation) even though it would be allowed by the datasheet. In such cases, the Circuit Designers would re-design the circuits and/or would work with Parts Engineers to select another part or identify tests and/or other actions that would sufficiently prove the part's ability to meet these tight requirements.

b. Circuit Designers and Parts Engineers should collaborate in identifying environments (e.g., thermal, humidity, shock, vibration, helium or other gases, vacuum, atmosphere, etc.) that might cause problems in their applications (whether at the part or at higher integration levels). Such issues may require additional testing and/or analysis to verify the circuit(s) operates as intended.

c. Circuit Designers should use manufacturers' models (e.g., SPICE, Verilog, VHDL), if available, to verify worst-case conditions (e.g., temperature, voltages, timing, radiation degradation, End-of-Line- electrical performance degradation, SEE impacts, SET circuit impacts, residual rates after TMR implementation, etc.). Use demonstration and/or evaluation boards for circuit verification. Implement board- and box-level verification early in the development cycle to avoid negative impacts on cost and schedule should any problems or failures arise.

d. Circuit Designers should use more conservative derating for COTS parts, mainly passive parts, where appropriate, compared to MIL-SPEC counterparts, notwithstanding other pertinent attributes of either type of part. For example, MIL-SPEC ceramic capacitors (e.g., MIL-PRF-55681 and MIL-PRF-123) are designed to handle extended operation at twice the rated voltage, but COTS ceramic capacitors are designed largely to tolerate the datasheet limits with minimal over-rated voltage excursions.

e. When resources or availability prohibit using rad-hard MIL-SPEC parts, Circuit Designers and Parts Engineers should consider the commercial version of rad-hard parts, if the rad-hard parts and commercial version of the rad-hard parts have the same silicon die. Some rad-hard parts have non-rad-hard commercial versions available with the same die, where the main difference is that no radiation testing has been performed on the commercial version. These parts offer similar radiation tolerance (but without the radiation hardness guarantees of the rad-hard versions) and may allow savings in cost and procurement time. When using the commercial version, it must be acknowledged that the part is considered non-rad-hard and is subject to relevant guidance in this report. For Class D and Sub-Class D projects, this would provide a good solution when available and, in some cases, it might be the only choice available in lower-risk-tolerant applications.

COTS Verification

R-12. When verifying COTS parts at the part-level, EEE Parts Engineers should follow the guidance provided in Sections 7.2.4 through 7.2.6 for Class A-D and human-rated missions. ***(F-5, F-6, F-7)***

Verification at Integration Level	Guidance "P" for part-level; "B" for board-/box-level	Sections	Class D/Sub-D missions	Class C missions	Class A/B/human rated misisons
Part-level Verification	Guidance P#1	7.2.4	x	x	x
	Guidance P#2		x	x	x
	Guidance P#3		x	x	x
	Guidance P#4		x	x	x
	Guidance P#5		x	x	x
	Guidance P#6	7.2.5		x	x
	Guidance P#7			x	x
	Guidance P#8			x	
	Guidance P#9	7.2.6			x
	Guidance P#10				x

R-13. When verifying COTS parts at board- and system-levels, Circuit Designers, Avionics Leads, and EEE Parts Engineers should follow the recommendations provided in Sections 7.2.4 through 7.2.6 for human-rated missions and Classes A-D and Sub-D: ***(F-5, F-6, F-7)***

a. For Class A-C and human-rated missions, COTS parts verification should be performed at part-, board-, and system-level. If part-level verification is largely based on the Established COTS parts data from an ILPM, then the recommended current best practice is to test the board/system for at least 1,000 hours of accumulated biased power-on time, with the last 350 hours being failure free, to demonstrate trouble-free parts performance, validate the design, and help reduce the risk of failures after launch.

b. When using mostly COTS parts, programs/projects, especially Class D/Sub-D missions, should build multiple revisions of engineering units as resources permit to start functional testing, environmental testing, qualification, and verification early in the design cycle so that any issue can be addressed to minimize the impact on system risk, cost, and schedule.

R-14. For unfamiliar COTS parts, EEE Parts Engineers and Failure Analysis Specialists should perform CA instead of DPA focusing on identifying relevant failure modes and mechanisms rather than a predefined pass-fail assessment against traditional MIL-STD requirements. ***(O-5)***

R-15. Upon failure of a COTS part, the program/project should initiate a failure analysis, and all efforts within available resources should be made to determine root cause. The first steps to root cause determination should be to verify that the part's datasheet was not violated in processing, testing, or usage. ***(O-5)***

Specifically for Class D and Sub-Class D Missions

R-16. For general practice and COTS board- and system-level verification, Program/Project Managers for Class D and Sub-Class D missions are recommended to use ARC's process and best practices for using COTS parts (Section 7.2.4) as guidelines, while also exercising good engineering judgement and ensuring associated risks are thoroughly assessed by the Program/project. ***(F-3)***

For the Agency

R-17. Recommend NEPP to perform a pathfinder study to explore implementing the guidance in this NESC report prompting updates to NASA standards. ***(F-13, O-3, O-4)***

R-18. Recommend NEPP to promote training to increase skills in semiconductor device physics including the impact of radiation on semiconductor performance, other device technologies and modern fabrication processes for those who use and/or qualify EEE parts. An efficient way of training may be bringing in experts to provide a series of classes or seminars to large groups of employees. ***(F-13, O-3, O-4)***

R-19. Recommend that future EEE parts engineering hires have sufficient skills in semiconductor device physics, device technology, and modern fabrication processes. ***(F-13, O-3, O-4)***

R-20. Recommend NASA to reinstate a modern version of the processes, facilities, and personnel to take in broad classes and categories of COTS EEE parts, understand and fully characterize them through analysis, testing and mitigation evaluation, as was done when forming and maintaining the original NASA Parts Selection List and GSFC Preferred Parts List. The purpose will be to provide a strategic means for the Agency to efficiently and effectively use COTS. ***(F-13, O-3, O-4)***

9.0 Alternative Technical Viewpoint(s)

There was an alternate viewpoint described below:

At the end of Section 7.2.5.1, Cu wire bonds are called out as an example to prompt a DPA or CA to be performed. While it is true that the manufacturing process for Cu wire bonds have proven to be much more challenging and extensive than those involving Au, Established ILPM manufacturers have already optimized the process and parts are continuously verified by SPCs and thus do not necessitate any special attention. If there is an emphasis on a thermally stressing application that either violates a part datasheet or is not well captured in the datasheet, then special attention is required regardless of the material used in the wire bonds. Furthermore, Section 7.2.7 already provides a focused recommendation specific to the presence of Cu wire bonds that is in line with the other recommendations within the report. Lastly, the fact is that there are no recent reported instances of Cu wire bond failures in space or other challenging and critical applications. The callout of Cu in Section 7.2.5.1 provides an unnecessary red flag, and possibly is a distraction.

10.0 Current Practices on Use of COTS from NASA, DoD, and FAA

Summaries of current practices for using COTS parts in the DoD and FAA are provided in the following subsections. *Note each DoD and FAA report below was provided by the corresponding agencies regarding their current practices (not NASA's) which is independent from the NESC recommendations, and agencies may use different definitions for certain terms*.

10.1 NASA

NASA Centers' current practices on using COTS parts in spaceflight systems at ARC, GRC, GSFC, JPL, JSC, LaRC, and MSFC, and current practices on using COTS parts and assemblies in critical GSE at KSC were documented in the NESC Phase I final report [ref. 1].

Key findings in Phase I included:

For safety and mission critical systems on missions with categories 1-3 and Classes A-C per NPR 7120.5 and NPR 8705.4, respectively, NASA Centers current practices typically use MIL-SPEC parts and NASA-screened COTS parts.

For non-safety or non-mission critical systems, current Center COTS parts usage practices range from NASA-screened COTS parts, best effort part-level verification, or using COTS parts without any additional MIL-SPEC/NASA part-level screening and qualification.

NASA has used COTS parts without additional part-level MIL-SPEC/NASA screening and qualification in space systems in sub-Class D missions and some Class D payloads, and other non-critical applications.

Current Centers' practices on COTS selection and part- and board-verification across the Agency differ widely for mission critical Class D and sub-Class D mission systems.

10.2 U.S. Army Combat Capabilities Development Command (DEVCOM), Aviation, and Missile Center (AvMC)

The use of COTS provides advantages in reduced item development costs, access to advanced technology, the possibility of leveraging high volume manufacturing benefits, among others. The use of COTS may require greater integration effort and higher costs for performance characterization and application qualification. The standard EIA-933 [ref. 30] (SAE) documents a framework for managing electronic COTS usage to meet particular application requirements. Successful use of COTS parts and assemblies requires careful definition of the application life cycle requirements and effective characterization of the COTS item capability to meet those requirements.

10.2.1 Agency Programs and Projects

The DEVCOM and AvMC supports programs developing, producing, and fielding Army aviation and missile systems. These systems include a broad range of application categories from ground, benign (e.g., fixed emplacements with environmental control) to manned, airborne vehicles (e.g., helicopters and fixed wing aircraft) to unmanned missiles. This wide variety requires a flexible approach to determining requirements for any particular equipment.

Typical system requirements include useful life of 5 to 30 years with the potential for long periods of storage and wide-ranging operating environments.

10.2.2 Agency Strategy of Use of COTS

The DoD requires consideration of using COTS for any system element (whole systems down to piece parts) to take advantage of potential benefits afforded by COTS, while also taking into account risks and disadvantages. The Defense Acquisition Guidebook (DAG at https://www.dau.edu/tools/dag), Chapter 3, Systems Engineering, provides an overview of these issues for programs to consider and manage.

10.2.3 Agency Governing Parts Documents

In November 2020, DoD published DoD Instruction (DoDI) 5000.88 [ref. 31] on Engineering, which requires Parts Management for all programs in development through production and fielding, and references MIL-STD-3018 [ref. 32] for implementation. Also, in November 2020, DoD published DoDI 4245.15 on Diminishing Manufacturing Sources and Material Shortages Management, which includes requirements to address COTS obsolescence. In addition, the DAG identifies the need for Parts, Materials, and Processes management in development and production to support meeting reliability requirements and cites MIL-STD-11991 [ref. 33] for implementation.

10.2.4 Agency Practices on COTS Selection, Screening, Evaluation and Qualification

Best practices have been identified for COTS use in various scenarios of application criticality and other considerations. MIL-STD-11991 describes the general approach for assuring that parts, materials, and processes meet the application requirements, and all those criteria apply to COTS. The successful use of COTS requires detailed knowledge and definition of the system life cycle requirements with allocation of effects to the COTS item application in the system. These life cycle requirements will include environmental life cycle effects, operating and storage times and duty cycles, maintenance approaches, along with functional capability and other criteria. Figure 10.2.4-1 provides a general environmental life cycle profile for a typical missile system.

Determining the effects of the life cycle requirements on the COTS item and its ability to meet those requirements requires knowledge of the COTS design and construction, and manufacturing processes and controls. Environmental, operating life, and similar performance characteristics often depend on accelerated testing to characterize performance, and the design and construction of an item determines how those accelerated tests will correspond to the actual use conditions (e.g., through “acceleration factors” established by testing and analysis). Figure 10.2.4-2 defines the general test requirements to address the life cycle environments of Figure 10.2.4-1 for plastic encapsulated devices. This test flow leverages the assumption that the device manufacturer has suitable data to address issues such as operating life but, in general all relevant failure mechanisms and modes must be addressed in the qualification approach for a part.

The process to identify relevant failure mechanisms for a particular part type includes reviewing industry and MIL-SPECS for parts of the same construction, and literature searches on the part type to determine latest technology capabilities and issues. These sources provide the starting point for developing test and analyses to determine the test data required to confirm failure mechanisms and the stress acceleration factors relevant to the projected application. If sufficient data does not exist to verify suitable coverage of failure mechanisms or determination of stress acceleration factors, then additional testing (i.e., design of experiments.) should be performed to properly address risks of not having sufficient part technology data to successfully characterize or qualify a part for the intended application.

Existing data for COTS items often do not fully address the intended application requirements, so these knowledge gaps need to be addressed through further test and analysis, taking into account the design and construction of the COTS item. The process of assessing existing data and performing any additional efforts to assure meeting the application requirements should "qualify" the COTS item for the system application. Some system requirements and goals, such as high manufacturing and system integration yield and no fielding infant mortalities, may require additional practices (e.g., screening of the COTS item). Effective screens would also depend on the design and construction of the COTS item. Based on the failures experienced, the screens would need to be tailored for the particular application requirements.

Military equipment and part standards often provide good frameworks for developing COTS item screens and qualification tests since the standards rely on significant industry and Government effort and historical knowledge.

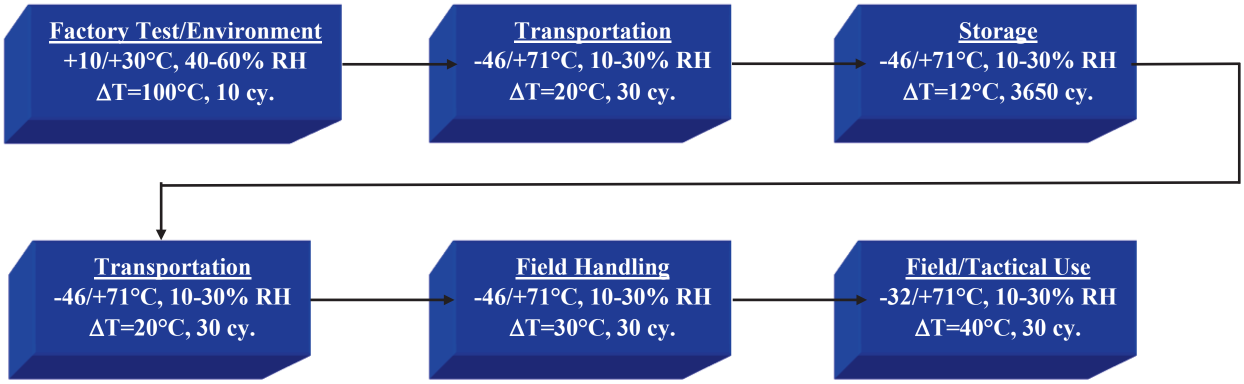

Figure 10.2.4-1. Notional Life Cycle Environmental Profile

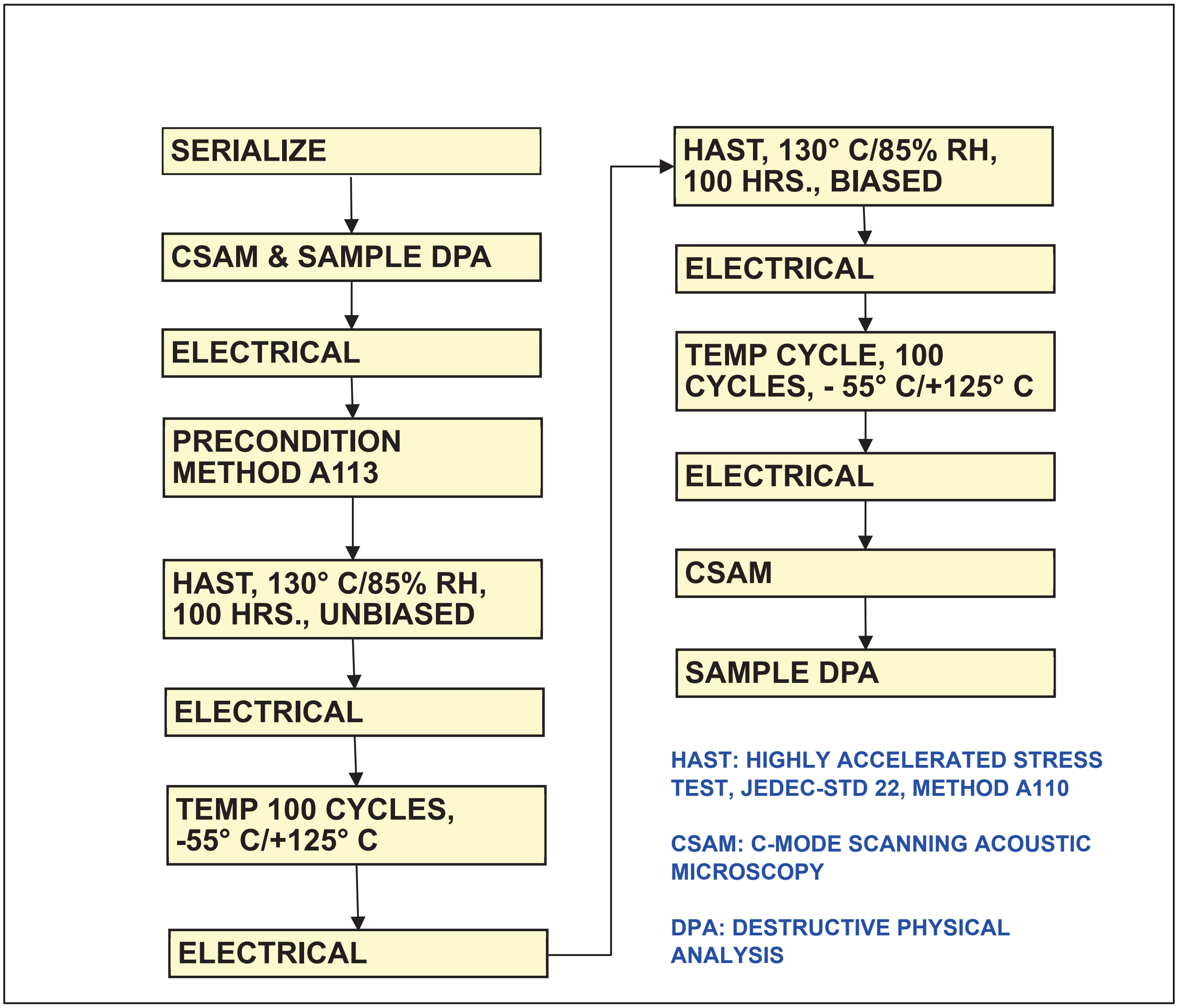

Figure 10.2.4-2. Plastic Encapsulated Device General Qualification Test Flow (Assumes completion of testing by manufacturer that meets JESD47)

Any system development or production contract should require the implementation of a Parts (materials and processes) Management Plan complying with MIL-STD-11991 (or MIL-STD-3018, only for Parts) with approval by the Government. This plan should include criteria for parts and assembly selection to include COTS items, qualification criteria, and identification of "prohibited" or restricted items that require Government approval (based on documented risks). The implementation of such a Management Plan benefits greatly from the use of a Parts (materials and processes) Management Control Board that includes the prime contractor, key subcontractors, and the Government working within an Integrated Product Team framework to support part (materials and processes) selection, including the development of tailored qualification requirements, as needed.

Generally, production experience does not indicate the need for screening tests for electronic part acceptance, which primarily derives from the fact that the high-volume users of parts mainly demand high initial assembly yield. Past experience does indicate the benefit of independent data to establish qualification basis, and this may leverage suitable generic data (same manufacturer, technology, material set, location) and requalification for product changes. This approach significantly leverages manufacturer data to help establish inherent reliability, and then uses the independent test data to put bounds on the extrinsic reliability. It also helps to leverage the product assurance ecosystem of the part for its class. For instance, a truly automotive grade part has significant oversight from its entire supply and fielding chain.

Part selection should prioritize parts with long-term availability and established reliability. For many applications, AEC Q100/Q101/Q200 provide adequate assurance for qualification, but also additional sequential environments qualification is often necessary (now documented in SAE AS6294/2 [ref. 34] and /4 [ref. 35], and likely soon in MIL-PRF-19500 [ref. 36], Appendix J). In addition, assembly level accelerated life tests (sequential environments) can support qualification of some parts. Verifying and achieving the necessary reliability level remains a major concern in applying COTS parts and assemblies.

Considerations for Assessment of COTS Electronic Parts and Assemblies
Prefer part level reliability verification test with requalification for changes.
Prefer validation with board level sequential environments to also address assembly issues, such as solder joint reliability.
Leverage generic data suitably
System level testing rarely addresses reliability concerns, so it typically primarily addresses interface concerns.

Generally, all part selections require rationale supported by data that the part meets the application requirements. It is possible to establish broad generic acceptance for some part types and qualification levels (e.g., MIL-SPEC resistors, or auto grade resistors). The risk depends on the product assurance system in place and supporting qualification and quality data. Risk mitigations may include independent qualification at part level, screening, characterization testing at assembly level, and historical data.

For COTS assemblies, use of the methodologies and requirements in EIA-933 [ref. 30] and MIL-STD-11991 [ref. 33] can support successful use in high reliability applications:

- Define the full application requirements (life cycle environments and operating profile, and reliability requirements).
- Understand the design and construction of the COTS item to establish suitable reliability and functional performance characterization tests.
- Implement characterization testing to assure meeting application requirements.
- Utilize Integration Laboratory for assessing potential (including undocumented) changes.

10.3 MDA

The MDA considers COTS piece parts as non-standard parts. However, these may be used on most systems with additional testing and specific risk mitigations. Low grade parts may not be used when a higher-grade, form, fit, function option exists.

10.3.1 Agency Programs and Projects

MDA has a wide variety of missions with a field life spanning from months to decades. Mission environments range from arctic, desert, sea-based, space, to controlled office equipment, and include stationary and flight hardware. All missions require a high level of reliability, but some are more rigorous than others. To account for this variability in requirements, the missions are broken into the following hardware categories:

A: Space; continuous use; non-repairable

B: Missile interceptor; long-term storage; single-shot[24]

C: Extended use aircraft

T: Targets; short-term storage; single-shot

D: Ground and sea-based mobile systems; continuous use

R: Stationary ground-based sensor, networking, or fire control processing systems; controlled environment; continuous use

E: Stationary ground systems; controlled environment; continuous use

10.3.2 Agency Strategy of Use of COTS

COTS piece parts are considered nonstandard parts at MDA, but may be used on programs after a Parts, Materials, and Processes Control Board (PMPCB) detailed review and approval.

The requirements for EEE parts are primarily implemented through the PMPCBs which are set up for every MDA program. The PMPCBs are co-chaired by representatives from the Government and prime contractor. The PMPCB meets regularly and is attended by Government, contractor, and sub-contractor parts and materials experts with support from manufacturing, engineering, and management, as needed. PMPCB roles and responsibilities include review and approval of parts, materials, and processes (PMP), COTS assemblies, failure analyses and corrective actions, PMP management plans, DPA reports, qualification test plans, and reliability and radiation test data.

Parts that do not meet the appropriate MIL-SPEC as defined in the Missile Defense Agency Parts Materials and Processes Mission Assurance Plan – MDA-QS-003-PMAP Revision C (PMAP) [ref. 37], Table 3.2.2.1 Minimum Quality and Failure Rate Level for Standard EEE Parts, are considered nonstandard and must be submitted by the contractor to the PMPCB through the use of a Nonstandard Part Approval Request (NSPAR) package. The NSPAR form includes fields for part information (e.g., location used, temperature range, materials, lead finish, and manufacturer). In addition to the completed NSPAR form, the package contains all necessary supporting documentation to include at a minimum: qualification data, part datasheet, OCM

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[24] “Single-shot” carries the same meaning as more generally used “one shot.”

reliability monitor data, PCNs evaluation, source control drawing (if applicable), and the procurement control drawing.

Government PMPCB members review the package and return comments to the contractor asking for additional data, clarification, or to fix mistakes. PMPCB meeting time is for discussion, as necessary, and for the co-chairs to disposition the packages. Possible dispositions include approved, rejected, approved with restrictions, or conditional approval pending future action (e.g., higher-assembly qualification testing).

OCM's qualification and reliability monitor data often are found sufficient for approval without requiring additional testing. This data has to be recent (i.e., within the last 3 years) and without significant PCNs issued since its release. If more testing is required, a recommended qualification or test plan is submitted to the PMPCB for review and approval prior to testing taking place. For Plastic Encapsulated Microcircuits (PEMs), the recommended qualification plan is defined in PMAP Appendix B.

The majority of the PMPCB work is done early in the program life cycle, but the process is ongoing for the life of the program as PCNs are issued for parts, or parts are changed on boards due to design changes or obsolescence.

Cu wire bonds represent a new challenge to reliability and are subject to additional requirements and mitigations. To use a Cu wire bond part in MDA hardware (Categories A, B, C, and T), the contractor must first provide evidence no gold (Au) wire bond options are available. If there are no Au wire bond options, the acceptable mitigations by priority are to use an AEC-qualified part. If that is not available, perform qualification testing in accordance with PMAP Appendix B or a PMPCB approved plan.

DPA in accordance with MIL-STD-1580B is also required for approval of Cu wire bond parts with the following extra requirements:

a) The DPA plan shall be approved by the PMPCB.
b) The plan shall focus on the wire bond, bond pad, ball bond, and wedge bond integrity and strengths.
c) Decapsulation of the PEM shall expose both the ball and wedge bonds without damaging the wire.
d) Pull strengths shall be a minimum of twice the pull strength of those for Au wire bonds of the same diameter per MIL-STD-883K [ref. 38].

Currently Cu wire bonds are treated as the highest severity level among all restrictions or prohibitions in accordance with PMAP. All requirements for Cu wire bonds parts also apply to parts with the less common silver wire bonds.

In addition to the program level PMPCBs, there is an Agency level MDA PMPCB tasked with ensuring reliability and uniform PMP requirements compliance across all PMPCB operations and assuring the reliability new or modified, safety critical or mission critical PMP. Some specific PMPB responsibilities include:

a) Establishing and ensuring consistent application of PMP requirements.
b) Providing management of Agency PMP resources.
c) Reviewing and jointly approving MDA Program Prime Contractor PMP Plans.

d) Reviewing PMPCB proceedings/minutes.
e) Helping programs develop adjudication processes to address issues arising out of PMPCBs.
f) Managing and updating the MDA As Designed Parts, Materials and Processes List (ADPMPL).
g) Dispositioning Severity Rating 1 Restricted PMP as defined in PMAP Appendix E.
h) Reviewing failure analyses and corrective actions performed by PMPCBs.
i) Sharing PMP lessons learned with all programs.
j) Reviewing Program Office PMP staffing levels.

COTS assemblies have unique requirements including a COTS assembly selection and acceptance process checklist the contractor completes in accordance with PMAP Appendix C, and submits it to the PMCPB as part of the NSPAR package. In addition, a Bill of Materials (BOM) from the manufacturer, or proof of denial, is to be provided with this package. An extra unit of the COTS assembly is purchased and submitted for a construction analysis to identify and monitor restricted PMP, assess quality and workmanship, identify logic-bearing devices, and understand piece part obsolesce status, among other PMP concerns.

Lastly, all COTS assemblies require the contractor to provide ongoing PCN/Engineering Change Notice (ECN) monitoring and quarterly reporting to the PMPCB on product yield returns and nonconformance data.

10.3.3 Agency Governing Parts Documents

The MDA approach to parts management is governed by the Missile Defense Agency Parts Materials and Processes Mission Assurance Plan – MDA-QS-003-PMAP-Rev C – October 2019 (PMAP) [ref. 37].

In addition, the Missile Defense Agency Assurance Provisions - MDA-QS-001-MAP-Rev C – October 2019 (MAP) [ref. 39] establishes higher-level Quality, Safety, and Mission Assurance processes and actions through disciplined application of system engineering; interface management, configuration management, risk management, cybersecurity and software assurance; and quality, safety, and management principles needed to achieve mission success throughout the acquisition process. The implementation of MAP disciplines promotes continual process improvement and cost reductions by improving productivity, mitigating risk, and enhancing quality, safety, and mission assurance.

Implementation of PMAP requirements on MDA Programs is accomplished through three program-specific Contract Data Requirements Lists (CDRLs):

- A Program PMP Plan following the guidance of PMAP Rev C
- An ADPMPL
- A Lead (Pb) Free Control Plan (LFCP) in accordance with GEIA-STD-0005-1 [ref. 40] and GEIA-STD-0005-2 [ref. 41]

Each MDA program uses PMAP as a baseline to draft and create their tailored Parts Materials and Processes (PMP) Plan. The PMAP itself provides unique requirements depending on the various hardware categories. An applicability matrix (Table 10.3.3-1) defines which sections of the PMAP apply to which Hardware Categories. For example, derating is not required for Category E hardware.

Additional requirements are specified through the Minimum Quality and Failure Rate Levels for each part type as defined in PMAP Table 3.2.2.1. COTS parts are screened and qualified to meet the intended application environment, and use each commodity's Quality Conformance Inspection (QCI) requirements as the objective for qualification requirements. For Category E, hardware commercial parts are acceptable with no additional data or screening.

Table 10.3.3-1. PMAP*

Minimum Quality Level (Class) and Maximum Failure Rate Levels (FRL)								
Part	Cat A	Cat B	Cat C	Cat T	Cat D	Cat R	Cat E	Reference Specification
Microcircuits	V or Y	Q	Q or N	Q	Q or N	Q or N	Commercial	MIL-PRF-38535
Hybrid Microcircuits	K	H	H	H	H	H	Commercial	MIL-PRF-38534
Discrete Semiconductors	JANS	JANTXV JANTX	JANTX	JANTXV JANTX	JANTX	JANTX	Commercial	MIL-PRF-19500
Capacitors, Established Reliability (ER)	S	R	R	R	P	P	Commercial	Ceramic: MIL-PRF-20 MIL-PRF-39014 MIL-PRF-55681 Tantalum: MIL-PRF-39006 Glass: MIL-PRF-23269 Plastic: MIL-PRF-83421
	D	C	C	C	B	B	Commercial	Tantalum: MIL-PRF-39003
	T	C	C	C	B	B	Commercial	Tantalum: MIL-PRF-55365
Capacitor (non-ER)	T	M	M	M	M	M	Commercial	Base Metal Electrode: MIL-PRF-32535
	QPL	QPL	QPL	QPL	QPL	QPL	Commercial	Ceramic: MIL-PRF-123 High Voltage: MIL-PRF-49467
Resistors (ER) 7/	S	R	R	R	P	P	Commercial	Film MIL-PRF-39017 MIL-PRF-55182 MIL-PRF-55342 Wirewound MIL-PRF-39005 MIL-PRF-39007 MIL-PRF-39015 Power: MIL-PRF-39009
Resistors (non-ER)	QPL	QPL	QPL	QPL	QPL	QPL	Commercial	High Voltage: MIL-PRF-49462 Network: MIL-PRF-83401
Coils, Molded (ER)	S	R	R	R	P	P	Commercial	MIL-PRF-39010
Coils, Molded (non-ER)	QPL	QPL	QPL	QPL	QPL	QPL	Commercial	MIL-PRF-83446
Magnetics	S	T	T	T	M	M	Commercial	MIL-PRF-27, MIL-PRF-21038, MIL-STD-981
Relays (ER)	R	R	R	R	P	P	Commercial	MIL-PRF-39016, MIL-PRF-83536
Crystals	QPL	QPL	QPL	QPL	QPL	QPL	Commercial	MIL-PRF-3098
Crystal Oscillator	S	B	B	B	B	B	Commercial	MIL-PRF-55310
Connectors	QPL	QPL	QPL	QPL	QPL	QPL	Commercial	MIL-DTL-38999, MIL-DTL-24308, MIL-DTL-83513, MIL-DTL-55302, MIL-PRF-39012
Filters	S	B	B	B	B	B	Commercial	MIL-PRF-28861, MIL-PRF-15733
Attenuators	T	S	S	S	N	N	Commercial	MIL-DTL-3933
Wire and Cable	QPL	QPL	QPL	QPL	QPL	QPL	Commercial	SAE-AS-22759, SAE-AS-81044, MIL-DTL-17

*Missile Defense Agency Parts Materials and Processes Mission Assurance Plan – MDA-QS-003-PMAP Revision C (PMAP), Table 3.2.2.1 Minimum Quality and Failure Rate Level for Standard EEE Parts

Requirements also are differentiated by Hardware Category through the Restricted PMP Severity Levels requiring special consideration (see PMAP Appendix E). These restrictions are placed on part attributes or materials to control their use in MDA systems. The Severity Level defines the level of approval required for use:

- Level 3 – Submit to PMPCB for notification
- Level 2 – Submit to PMPCB for approval
- Level 1 – Submit to PMPB for approval
- Level 0 – Submit to MDA Director of Quality and Director of Engineering for approval

Each restriction has a Severity Level defined for each Hardware Category. For example, Magnetics with Open Construction are Severity Level 1 for Category A Hardware, but Severity Level 2 for all other categories. Every restriction is expected to be submitted to the PMPCB with a justification and mitigation. Along with part test data, the PMPCB evaluates the restrictions, justification, and mitigations to disposition the part.

10.3.4 Agency Practices on COTS Selection, Screening, Evaluation and Qualification

MDA requires contractors to select the highest reliability parts available. The order of precedence from highest priority to lowest is:

1. Military Standard QML, Qualified Products List (QPL), Standard Military Drawings (SMDs), or other parts qualified to the military or SAE (wire only) specifications not included in Table 3.2.2.1).
2. Automotive Quality (AEC-Q100, -Q101, or -Q200 qualified), DSCC – Defense Supply Center Columbus (DSCC) DESC or Defense Electronics Supply Center(or DESC) Drawing qualified (each DSCC drawing has to be reviewed carefully to determine suitability for the application). Automotive parts require a PPAP level 2 minus the samples and warrant.
3. Manufacturer’s Enhanced Products; Military Specification or Standard compliant; AEC-Q100, -Q101, or -Q200 compliant; Table 3.2.2.1 SAE specifications compliant.
4. Manufacturer’s Industrial Quality; Medical Quality.
5. Commercial Quality.

All parts are submitted to and reviewed and dispositioned by the PMPCB. A low-grade part may sometimes be submitted to the PMPCB although a higher-grade part (or order of precedence priority) is available. For example, an Au wire bonded “Enhanced Product” part falls under lower priority level than an AEC-qualified, Cu wire bond equivalent part. These instances would be evaluated on a case-by-case basis and a disposition will highly depend on the specific program requirements.

Restricted PMP, as defined in PMAP Appendix E, are parts or part attributes that require additional risk mitigation and specific approval. Each has a designated severity level for each Hardware Category and often includes suggested mitigations. Standard parts that have restrictions are treated as nonstandard parts.

For example, Restriction 10.8 is “Pure tin (excluding insulated tin-plated copper wire).” This is due to “Pure tin (>97%) used in plating or, in other applications, can grow tin whiskers over time which can cause short circuits during system use.” It has a suggested mitigation of “Conformal coat discourages, but does not prevent the growth of whiskers. Use alloyed tin if possible. When alloyed tin is not available, use GEIA-STD-0006 [ref. 42] as a guide to replate contacts using alloyed solder to meet the 3% lead requirement. When tin-plated parts must be used, use current versions of GEIA-STD-0005-1 and GEIA-STD-0005-2 as guides."

Part derating guidelines are provided in PMAP Appendix A. The derating plan for each program is approved by the PMPCB. Any parts stressed beyond the criteria in the approved plan require PMPCB approval prior to use.

A DPA sample is required for each purchased lot of nonstandard microcircuits, hybrids, multichip modules, direct current/direct current (DC/DC) converters, custom devices, and stacked capacitors. For hardware Categories A, B, and T, the DPA sample size is 5 devices per lot. The methods found in MIL-STD-883 and MIL-STD-1580 are to be used to assess baseline conformity, design, workmanship, process quality, package integrity, die defects, potential latent defects and overall acceptability for use in MDA systems.

All EEE parts are screened to ensure that device infant mortality has been removed from delivered hardware. For Category A, nonstandard EEE parts are tested to equivalent end-of-line screening requirements as the MIL-SPEC parts. For Categories B and T programs, SMC-S-016 [ref. 43] satisfies screening for workmanship defects. Categories D and R screening ensures parts undergo 100 hours of burn-in or operating time, at the part or assembly level, prior to delivery of hardware.

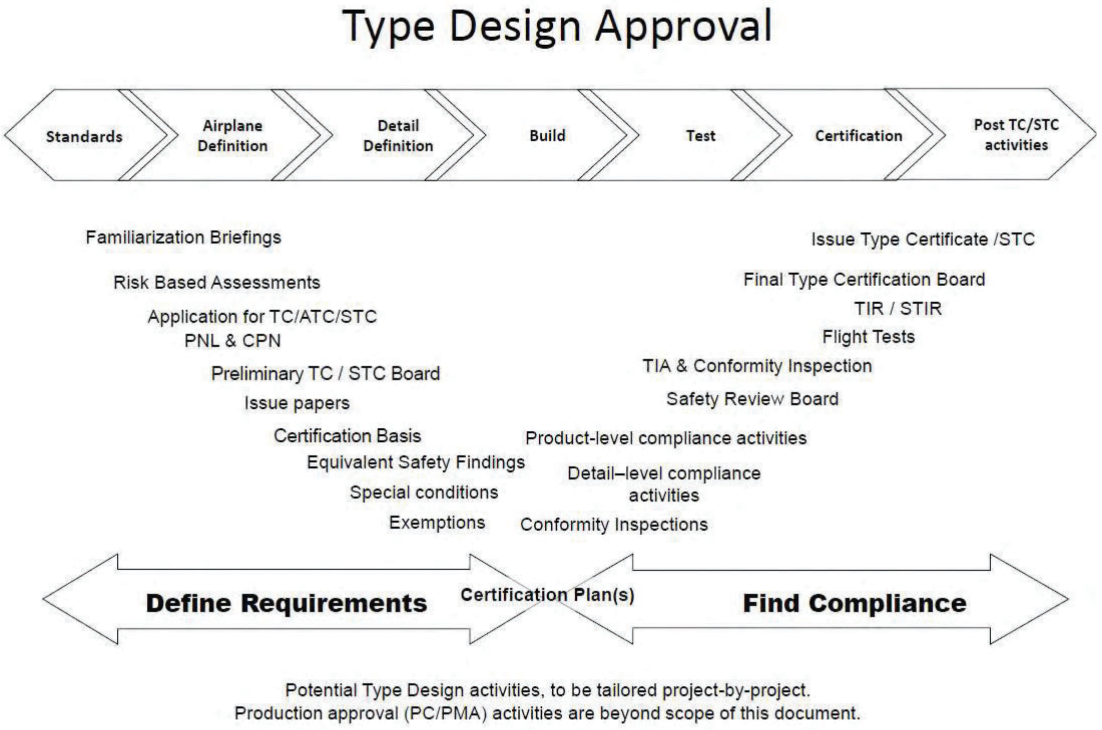
All cavity devices used in Categories A, B, C, and T must pass Particle Impact Noise Detection (PIND) testing. Parts that have passed PIND testing are clearly identified from parts that:

- have not yet been PIND tested
- have failed PIND testing
- do not require PIND testing

10.4 FAA

The FAA regulates all aspects of civil aviation in the U.S. National Airspace System (NAS) including air traffic management, aircraft and personnel certification, setting airports standards, and protecting U.S. assets during commercial space vehicle launch and re-entry. As this NESC assessment focuses on EEE parts (e.g., microcircuits, op-amps, capacitors), FAA aircraft certification standards and processes are discussed as those are most compatible to the NESC assessment's goals.

The FAA assures the safety of aircraft and associated components (e.g., powerplants, propellers, avionics, etc.) through Type Certification (TC), Supplemental Type Certification (STC), and their amendments, procedures and processes. The procedures and processes assure flight safety and continued operational safety through rigorous processes, requirements, and conformance validation, mandated legally. Technical requirements for products are defined in aircraft certification regulations 14 Code of Federal Regulations (CFR), 14 CFR part 23 (Airworthiness Standards: Normal Category Airplanes), 25 (Airworthiness Standards: Transport Category Airplanes), 27 (Airworthiness Standards: Normal Category Rotorcraft), 29 (Airworthiness Standards: Transport Category Rotorcraft), 33 (Airworthiness Standards: Aircraft Engines) and 35 (Airworthiness Standards: Propellers). The administrative procedures for certificates are provided in 14 CFR part 21 Certification Procedures for Products and Articles. FAA approves and certifies products (i.e., airplane, rotorcraft, engine, or propeller) through using Part 21 administrative regulations and technical regulations: 14 CFR Parts 23, 25, 27, 29, 33 and 35. The technical regulations provide the design, test, and operating requirements necessary to approve and certify products. Figure 10.4-1 shows an overview of the FAA's TC processes.



Potential Type Design activities, to be tailored project-by-project.
Production approval (PC/PMA) activities are beyond scope of this document.

Figure 10.4-1. FAA Type Design Approval Process

One important distinction to note is that FAA's use of the word "part" or "parts" differs from NASA's usage. NASA typically uses the word *part* or *parts* to denote EEE *piece* parts, whereas an FAA "part" may refer to a higher assembly level containing several or many parts. In this report, the word "EEE part" or "EEE parts" is used for EEE piece part/parts, while the word "equipment or assembly" or "equipment or assemblies" for any higher assembly levels is used for aircrafts.

The word "applicant", as used in the FAA's context, is an entity applying for and/or seeking design approval under TC or STC.

10.4.1 Agency Programs and Projects

There are different classes of aircraft that have their own unique functions, operating environments, weights, sizes, and passenger numbers. The applicant must show how the product performs its intended function, be airworthy, and be in a condition for safe operation. FAA approves and certifies products (i.e., airplane, rotorcraft, engine or propeller) through using Part 21 administrative regulations and technical regulations: 14 CFR Parts 23, 25, 27, and 29. The technical regulations provide the design, test, and operating requirements necessary to approve and certify products.

The FAA with the applicant discusses and defines the certification basis for the TC program. FAA approves the certification basis with defined technical regulatory requirements for the specific project. FAA determines and approves the length of time that will be allotted to the applicant for approving the project based on regulatory requirements.

10.4.2 Agency Strategy for Use of COTS EEE Parts

The FAA has no specific regulatory requirements or required category for COTS EEE parts. There is no restriction on the use of EEE parts since the assembly or equipment that contains the EEE parts is evaluated, tested, and validated to meet the design, production, and airworthiness regulations. The approval is based on compliance to installation requirements.

10.4.3 Agency Governing EEE Parts Documents

FAA governing documents include regulatory compliance documents, regulations, Advisory Circulars, Orders, Agency policies, and Industry Standards. COTS EEE parts, non-EEE parts, and equipment or assemblies within type designs are allowed, and do require that any EEE part and equipment or assembly within the product must meet the certification requirements for equipment or assembly test, design, and operation. Requirements are defined in the TC basis for the project. All these documents are evaluated, approved, and applied for use in the project by the FAA. The rigor of FAA evaluation and approval is commensurate with the design assurance level and criticality of the equipment or assembly (commercial or not) usage in-service.

FAA requires applicants to perform EEE parts level quality inspection and screening for all EEE parts. This EEE parts quality inspection and screening is the applicant's responsibility; the applicant must have a quality system and manual in place, and must surveille/oversee all suppliers the applicant uses for EEE parts and non-EEE parts sources. The FAA reviews an equipment or assembly's intended function and its safety analysis; all applicable airworthiness regulations must be met.

10.4.4 Agency Practices on EEE Parts Selection, Screening, Evaluation, and Qualification

The FAA design approval, production, and installation processes rely on robust analyses, testing, quality inspection systems and conformances thereto. All EEE parts, including COTS EEE parts, used in an equipment or assembly must meet the FAA design and quality certification program requirements. An approved COTS EEE part in a Type design will be listed as a BOM item in assembly drawing~~s~~. The final assembly, along with any COTS EEE parts, becomes part of the Type design and is controlled as an equipment or assembly number within the approved design. Any changes to the approved configuration will require re-evaluation and approval by the FAA.

The FAA, through its Aircraft Certification Office, addresses all potential design failures that could occur: minor, major, hazardous, and catastrophic. These entail, for example, hazard analyses and other risk analysis and risk management strategies assessing compliance and test planning.

For product certification, the environment to which a product will be exposed is explained, known, and defined. An applicant's design must be tested to meet all environmental conditions. The FAA is aware of space environmental exposure conditions; however, FAA-approved products are not designed or intended for space use.

Original equipment manufacturers (OEMs) obtain COTS EEE parts through their normal procurement processes. The OEM typically has an incoming receiving inspection process to assure it has a good functional non-defective part for use in the type design. EEE parts usually are identified, marked, bagged and received, usually with conformance paperwork. Conformance paperwork can include descriptions of dimensions, materials, or performance. COTS EEE parts are not differentiated with any other OEM EEE parts. COTS EEE parts are procured with their part number and approved via the Type design. Any COTS EEE part along with all other EEE parts, boards, and materials making up an assembly will then become an FAA-approved equipment or assembly.

An OEM typically selects its suppliers. The OEM provides specifications and drawings for the equipment or assembly in type design. The OEM is required by FAA to have oversight over its suppliers.

The applicant must provide extensive verification via analysis, testing, and data when any equipment or assembly (i.e., Standard Part, Critical Part, COTS) is used in a type design. The FAA must be able to verify compliance to regulations (cited above) with tests, analysis, and demonstrations provided and performed by the applicant. The use and environment in which the product will be operated determines the extent of testing required. For example, products used in humid, wet, and corrosive environments will require appropriate environmental tests. Rotorcraft with their high vibration characteristics may be subjected to appropriate "shake and bake", reliability, thermal, and vibration testing. Depending on the certification basis and requirements, tests as prescribed in Radio Technical Commission for Aeronautics Radio Technical Commission for Aeronautics (RTCA) DO-160 [ref. 44] and/or other standards may be required. Evaluation also involves addressing the Design Assurance Level of the equipment or assembly used, be it a COTS, standard, or other EEE part or equipment or assembly.

Failure Hazard Analysis (FHA), System Safety Assessment (SSA), Fault Tree Analysis (FTA), FMEA, etc., are required typically down to equipment or assembly level or EEE part level, depending on the criticality of the product, for the product approval. Appropriate 14CFR.XX1309 regulations (e.g., 14CFR 25.1309, 27.1309, etc.) describing the intended functions and failure rate testing and analysis are applied and required. The XX.1309 regulations ensure that the design must perform its intended functions under any foreseeable operating condition. The level of the testing and analysis depends on the criticality of equipment installed in the product. Testing is mandatory; however, analysis may be optional if the test is validated.

Once specified in the design within the FAA approval system, COTS EEE parts become integral in the Type Design. Any and all assemblies, regardless of whether they are COTS, standard, or critical, are approved by the FAA by requiring the applicant to provide appropriate analysis, testing, and verification processes defined in the certification basis. Any changes to these assembly designs also will follow a stringent assembly design reevaluation process. That is, for example, Advance Drawing Change Notice (ADCN), Engineering Order (EO), Engineering Change Order (ECO) are noted on the Type Design drawings for changes and modifications. Designated Engineering Representatives (DERs)[25] used by the applicant can be involved in this process by providing design analysis and substantiation. Expectations with COTS EEE parts is that, as with any other EEE part grades used and approved in the type design, they need to conform to their design specifications (drawings), have consistent design features and characteristics, and exhibit manufactured quality to support their intended function and continuous safe operation and flight of the product.

10.4.5 Conclusion

The FAA does not recommend that the FAA/AIR (aircraft certification) approach be used for COTS EEE parts used in space applications at NASA. More specifically, the FAA team does not recommend using FAA's aviation EEE parts approach combined with the rest of NASA mission safety and assurance process for space applications. The basic approval processes for EEE parts under the FAA and NASA systems are fundamentally different. NASA procures the EEE parts, uses the EEE parts within the design and system, tests the EEE parts in systems, and approves the overall system. The FAA process is fundamentally one of an oversight responsibility for applicants who install parts, equipment or assemblies into an aviation product design. It is incumbent upon the applicant to obtain the EEE parts, equipment or assemblies, show compliance to the FAA requirements by analysis and testing of the EEE parts incorporated into equipment or assemblies, and show that the incorporation of the equipment or assemblies into the aircraft or other product system ensures compliance to the airworthiness regulations applied to the product. Based on the tests and analysis provided by the applicant, the FAA makes a finding that compliance to the applicable regulations as specified by the certification basis for the product have been made. The FAA assures that only airworthy assemblies/equipment are incorporated into the product. The FAA does oversee the design, production, quality and operational aspects of the equipment or assembly being incorporated and approved in the product as a whole.

The FAA AIR approach is supported by assuring that the proper maintenance will be performed during the operation and life span of the product as appropriate to support the Instructions for Continued Airworthiness (ICA). The NASA approach is to keep the crew safe with maintenance opportunity intervals applied to the system that could be days, months, or years away during a mission. The FAA AIR aviation EEE parts approach has been successful ONLY with its

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[25] DERs are non-FAA personnel designated by the FAA to advise and perform engineering evaluations in specific areas of responsibility. Typically, DERs perform in one specific engineering discipline. DERs do not self-certify. Those responsibilities are performed by Organizational Designation Authorization (ODA).

infrastructure that supports compliance to the applicable airworthiness safety regulations commensurate with its original certification basis.

The FAA also imposes regulatory burden on the TC holder to oversee the operating fleet and report to the FAA any service difficulty issues/concerns of the operating fleet on a regular basis. This is mandated by USC 49, Title 14 of the CFRs, part 21, §§ 21.3, 21.5 and 21.99. This reporting system helps the FAA to initiate remedial processes when any issues are found in the operational environment and to update the design, testing, validation and implementation of all parts (a) already certified within the product. This is done on an ongoing basis for the life cycle of the approved part(s) in the system.

NASA has different infrastructure that may not provide the level of authority and access to the data needed to support a part’s use in the same manner as the FAA system, nor does it have the same level of regulatory compliance requirements. NASA systems do not require similar maintenance review opportunities.

11.0 Definition of Terms

Definitions are included in Section 7.1.3.

EEE Part Types

Active: A discrete EEE part that can inject power into a circuit and/or control the flow of electrical signals. Active devices include diodes, transistors, integrated circuits (microcircuits) as well as other complex microelectronic devices (e.g., application specific integrated circuits – ASICs, field programable gate arrays – FPGAs, etc.).

Discrete: An elementary electronic device constructed as a single unit that provides one circuit element, either passive (resistor, capacitor, inductor, etc.) or active (diode, transistor).

Hybrid Microcircuits: A microcircuit with multiple active and passive discrete electronic parts electrically interconnected onto one or more platforms (called substrates) and housed in a single package with external leads to provide electrical connection to external circuitry.

Microcircuit: An electronic integrated circuit (IC or chip), usually is fabricated with highly magnified photolithography, in a monolithic substrate and housed in a single package with external leads to perform a given circuit function. It also includes multi-chip-module (MCM) devices, where multiple semiconductor dice and/or other discrete elements are integrated onto a single substrate, so that it functions as if it were a larger IC. MCM allows integration of elements from different technologies to be combined in a small package to maximize and optimize performance while saving space and power.

Passive: A passive electronic part is a part that dissipates power or stores/releases energy. Passive parts include resistors, capacitors, inductors, and numerous other parts that do not control electric current by means of another electrical signal.

NESC Definitions

Finding	A relevant factual conclusion and/or issue that is within the assessment scope and that the team has rigorously based on data from their independent analyses, tests, inspections, and/or reviews of technical documentation.

Lesson Learned	Knowledge, understanding, or conclusive insight gained by experience that may benefit other current or future NASA programs and projects. The experience may be positive, such as a successful test or mission, or negative, as in a mishap or failure.
Observation	A noteworthy fact, issue, and/or risk, which is not directly within the assessment scope, but could generate a separate issue or concern if not addressed. Alternatively, an observation can be a positive acknowledgement of a Center/Program/Project/Organization's operational structure, tools, and/or support.
Problem	The subject of the independent technical assessment.
Recommendation	A proposed measurable stakeholder action directly supported by specific Finding(s) and/or Observation(s) that will correct or mitigate an identified issue or risk.

12.0 Acronyms and Nomenclature List

ADC	Analog-to-Digital Converter
ADCN	Advance Drawing Change Notice
ADPMPL	As Designed Parts, Materials and Processes List
AEC	Automotive Electronics Council
AEC-Q	Automotive Qualified
AI&T	Assembly, Integration, and Test
ARC	Ames Research Center
A/T	Assembly and Test
Au	Gold
AvMC	Aviation and Missile Center
BGA	Ball Grid Array
BOM	Bill of Materials
BME	Base Metal Electrode
Cu	Copper
CA	Construction Analysis
CCP	Composite Crew Program
CDCQ	Certificate of Design, Construction and Qualification
CDP	Command Data Processor
CDRL	Contract Data Requirements List
CFR	Code of Federal Regulation
CoC	Certificate of Conformance
CofC	Certificate of Compliance
CoP	Community of Practice
COTS	Commercial-Off-The-Shelf
Cpk	Process Capability Index
CSAM	C-mode Scanning Acoustic Microscopy
DAG	Defense Acquisition Guidebook
DC/DC	Direct Current/Direct Current
DER	Designated Engineering Representatives
DESC	Defense Electronics Supply Center
DEVCOM	Development Command (U.S. Army Combat Capabilities)

DFMEA	Design Failure Modes and Effects Analyses
DLA	Defense Logistics Agency
DoD	Department of Defense
DoDI	DoD Instruction
DPA	Destructive Physical Analysis
DPPB	Defective Parts Per Billion
DPPM	Defective Parts Per Million
DSCC	Defense Supply Center Columbus
DSNE	Design Specification for Natural Environments
ECN	Engineering Change Notice
ECO	Engineering Change Order
EDAC	Error Detections and Correction
EDCPAP	Engineering Directorate Certified Parts Approval Process
EEE	Electrical, Electronic, and Electromechanical
EFL	Early Failure Likelihood
EO	Engineering Order
ER	Established Reliability
FAA	Federal Aviation Administration
FAA/AIR	FAA Aircraft Certification
FAR	Federal Air Regulation
FHA	Failure Hazard Analysis
FIT	Failure In Time
FMEA	Failure Modes and Effects Analysis
FPGA	Field Programmable Gate Array
FR	Failure Rate
FRL	Failure Rate Level
FTA	Fault Tree Analysis
GCR	Galactic Cosmic Ray
GFE	Government-Furnished Equipment
GIDEP	Government Industry Data Exchange Program
GPR	Goddard Procedural Requirements
GRC	Glenn Research Center
GSE	Ground Support Equipment
GSFC	Goddard Space Flight Center
H/W	Hardware
HTOL	High-Temperature Operating Life
I&T	Integration & Test
IC	Integrated Circuit
ICA	Instructions for Continued Airworthiness
ILPM	Industry Leading Parts Manufacturer
IR	Insulation Resistance
ISS	International Space Station
IT	Information Technology
JPL	Jet Propulsion Laboratory
JPSS	Joint Polar Satellite System-1
JSC	Johnson Space Center

KSC	Kennedy Space Center
LaRC	Langley Research Center
LCC	Life Cycle Cost
LDC	Lot Data Code
LEO	Low Earth Orbit
LFCP	Lead Free Control Plan
M&P	Materials and Processes
MAP	MDA Assurance Provisions
MAR	Mission Assurance Requirements
MCM	Multi-Chip Module
MDA	Missile Defense Agency
MEAL	Mission, Environment, Applications and Lifetime
MIL-SPEC	Military Specification
MLCC	Multi-Layer Ceramic Chip
MRAM	Magnetoresistive Random-Access Memory
MSFC	Marshall Space Flight Center
NAS	U.S. National Airspace System
NEPP	NASA Electronic Parts and Packaging
NESC	NASA Engineering and Safety Center
NPR	NASA Procedural Requirements
NSPAR	Nonstandard Part Approval Request
NWS	NOAA’s National Weather Service
OCM	Original Component Manufacturer
ODA	Organizational Designation Authorization
OEM	Original Equipment Manufacturer
P_f	Failure Probabilities
Pb	Lead
PCB	Parts Control Board
PCN	Process Change Notice
PDF	Probability Distribution Function
PEM	Plastic Encapsulated Microcircuit
PFMEA	Process Failure Modes and Effects Analyses
PIND	Particle Impact Noise Detection
PMP	Parts, Materials, and Processes
PMAP	Materials and Processes Mission Assurance Plan
PMPCB	Parts, Materials, and Processes Control Board
P_{occ}	Occurrence Probabilities
PPAP	Production Part Approval Process
PPMC	Project EEE Parts Management and Control
PS	Power Supply
PSW	Part Submission Warrant
PWB	Printed Wiring Board
Q&R	Quality and Reliability
QAP	Quality Assurance Plan
QBS	Qualification By Similarity
QCI	Quality Conformance Inspection

QML	Qualified Manufacturer List
QMS	Quality Management System
QPL	Qualified Products List
QTP	Qualification Test Procedure
Rad-Hard	Radiation Hardness
RBD	Reliability Block Diagram
REDW	Radiation Effects Data Workshop (2017 IEEE)
RHA	Radiation Hardness Assurance
RMA	Reliability, Maintainability, and Availability
RNS	Relative Navigation Sensor
RPN	Risk Priority Number
RTCA	Radio Technical Commission for Aeronautics
S/W	Software
SAE	Society of Automotive Engineers
SEB	Single-Event Burnout
SEE	Single-Event Effect
SEFI	Single-Event Functional Interrupt
SEGR	Single-Event Gate Rupture
SEL	Single-Event Latchup
SET	Single Event Transient
SEU	Single-Event Upset
SiC	Silicon Carbide
SLS	Space Launch System
SMD	Standard Military Drawing
SMP	Safety & Mission Assurance Plan
SOI	Silicon-on-Insulator
SPC	Statistical Process Control
SPE	Solar Particle Event
SPF	Single Point Failure
SSA	System Safety Assessment
STC	Supplemental Type Certification
SWaP	Size, Weight, and Power
TC	Type Certification
TID	Total Ionizing Dose
TMR	Triple Modular Redundancy
TNID	Total Non-Ionizing Dose
TO	Transistor Outline

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Appendices

Appendix A. Questionnaire for COTS Parts Manufacturers
Appendix B. Examples for Risk Statements and Framework
Appendix C. Lessons Learned in Using Parts

Appendix A. Questionnaire for COTS Parts Manufacturers

Key topics to cover:

1.) Corporate quality & reliability (Q&R) policy
   a. Please provide
      i. copies of corporate product quality and reliability policies that are available to NASA as a customer
      ii. copies of industry certifications relevant to electronic parts manufacturing (IATF 16949, AEC, JEDEC, MIL-SPEC, SAE, ISO, etc.)
      iii. What is your policy 1 sample size, criteria of failure, etc.?
   b. Do you perform 100% testing per your datasheet of all shippable product? Please list any differences in testing between AEC versus other commercial grade product (electrical testing is screening?) What testing do you perform 100% per your datasheet of all shippable product (qualification, lot acceptance testing, screening)?
   c. Do you scrap lots with unusual yield loss?
   d. How do you establish the production test limits for your parts?
   e. Are there any major differences in construction between your COTS product and equivalent mil/space parts (if applicable)?
   f. Do you provide a Level 3 PPAP for all automotive grade product, and does this PPAP include all documentation listed below?
      i. Quality certifications for the specific manufacturing site, PSW, CDCQ, engineering change documents, design FMEA, process FMEA, process control plan, material performance test results, process studies, and measurement system analysis.
      ii. Show stability in fabrication processes, such as key process C_{pk} numbers over 6 months of part production, root cause analyses and corrective actions to resolve low C_{pk} numbers.
      iii. Show stability in A/T operations, such as final test yields over 6 months of part production, root cause analyses and resolution of any low final test yields.
      iv. Show qualification processes of mass-produced parts, such as Certificate of Design, Construction and Qualification, fabrication process qualification or qualification by similarity (QBS) to other parts, packaging qualification process or QBS to other parts, part qualification results, and final characterization report per datasheet parameters with C_{pk} numbers.
   g. Could similar data such as listed above in a Level 3 PPAP be made available for any other product categories other than automotive?

2.) Parts reliability data: DPPM, FIT, etc.
    a. Is reliability data available to the customer at request for all your parts (including commercial, automotive, etc.)?
    b. What is your customer return resolution process? How do you perform failure analysis, and do you perform FA in-house or through a 3rd party supplier?
    c. Do you have DPPM numbers for your parts in the field? How do you calculate your field DPPM?
    d. Do you publish a failure rate for each part type? If so, how is the FR determined? What is the environment (stresses) on the parts during the test? Do you include failures during your qualification testing? What is your approach determining the primary and secondary failure mechanisms for your parts?
3.) Traceability & counterfeit prevention
    a. How traceable are your parts (i.e., traceable to wafer level, lot level, reel, etc.)?
    b. How do customers get parts traceability and/or wafer lot traceability? Lot trace code or other terminology for your parts?
    c. Are customers allowed to get dies from specific wafer lot or wafer locations? If so, what is the process?
    d. How do you prevent your parts from being counterfeited?
    e. How do you prevent counterfeit parts and/or rejects from entering/re-entering your supply chain?
4.) Willingness to establish long-term mutually beneficial relationship with NASA to lower barriers for COTS use in space applications, especially given the significant progresses being made in private space travel
    a. Would you allow a NASA customer and/or representative to perform an on-site visit to review requested documentation that substantiates the required parts quality and reliability metrics?

Appendix B. Examples for Risk Statements and Framework

Examples for Parts Risk Statements

To lay groundwork for understanding parts risk, this section provides some risk statements for common parts problems, largely aligned with robotic missions, in which the risk scales (ranks) follow GSFC standard practices. With little effort, other Center risk scales, consequence definitions, and mission-specific references may be applied.

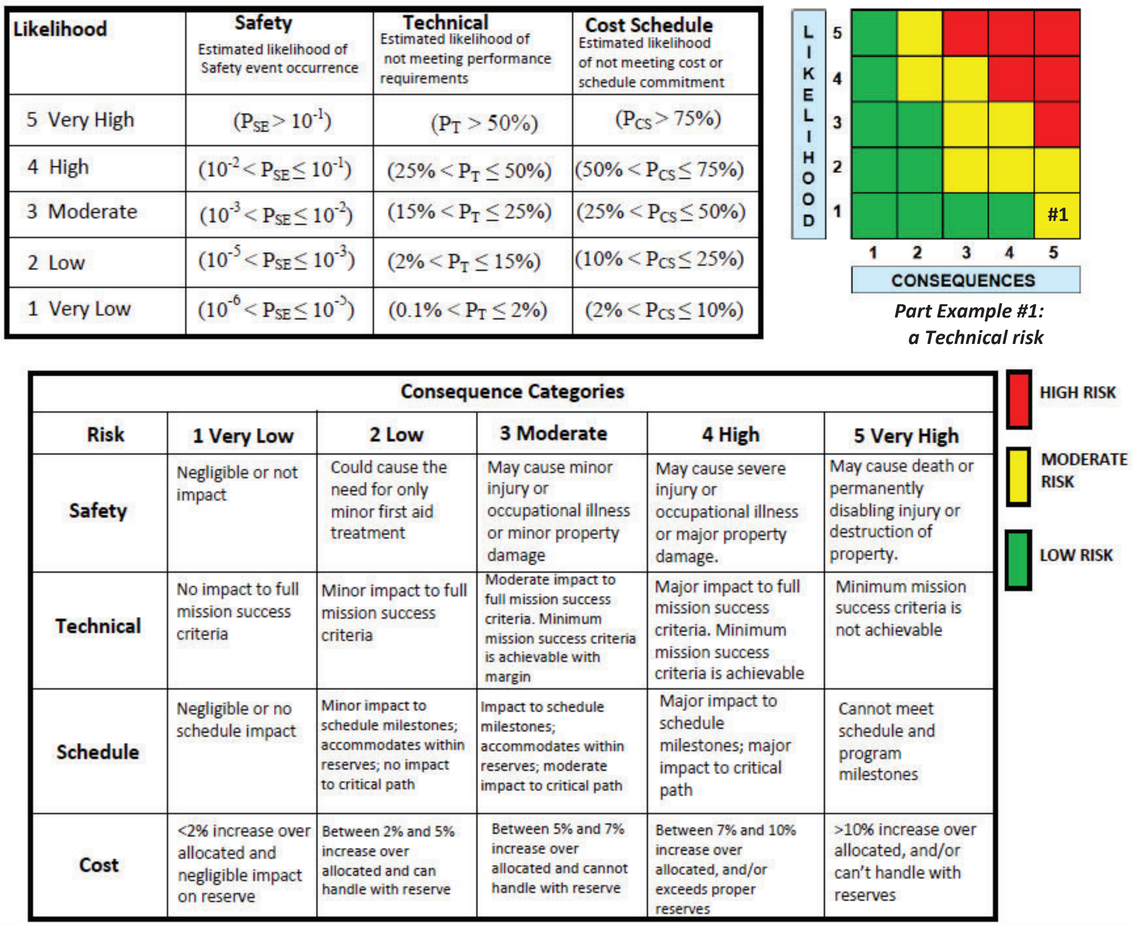
A common parts-related risk emanates from an Advisory that warns of a problem that has occurred in some location and context. For example, if the context from the Advisory overlaps with the current project's context and the project is using parts defined within the Advisory's scope, then the overlap can define a context for a new risk.

Example 1: Risk statement – a Technical risk:

> *Given that* twenty (20) MIL-PRF-55681 Multi-Layer Ceramic Chip (MLCC) capacitors within the affected scope of GIDEP Alert A#-A-##-## are used on the project.
>
> *It is possible that* three parts will fail in combined critical locations after successfully completing of I&T with no apparent problems, and the subsequent launch.
>
> *Resulting in* mission failure.
>
> In this case, GIDEP Alert A#-A-##-## identifies a problem that affects some percentage of lots over the affected time period and some different percentage of parts within the affected lots. The data provided are reviewed yielding a likelihood estimate of getting a problematic lot and then the likelihood of a part failing if a problematic lot is encountered. The conditions, and supporting data behind them, lead directly to the likelihood of realizing the "it is possible that …" event, while the "resulting in …" provides the ultimate threat to mission success criteria (i.e., the consequence).
>
> In the example above, assuming:
>
> - three part failures are required to cause a mission failure,
> - there are 20 parts in the application, out of which any three can cause failure,
> - 10% of lots in the time frame are affected (which has been assessed based on C-SAM) evaluations and analysis that links C-SAM findings to delaminations identified having cracks that resulted in shorted caps – assumed to have been provided in the GIDEP), and
> - there is a 20% chance of a latent defective part failure in an affected lot (this was estimated based on the historical collection of failures that occurred between months to years on-orbit and is assumed to be provided in the GIDEP).
>
> then, the mission failure likelihood resulting from this risk assessment, if it is not known whether there is an affected lot, becomes the following assuming binomial distribution:

$$1-\left[C(20,0)*(0.1*0.2)^{0}*\left(1-(0.1*0.2)\right)^{20}\right]-\left[C(20,1)*(0.1*0.2)^{1}*\left(1-(0.1*0.2)\right)^{19}\right]$$
$$-\left[C(20,2)*(0.1*0.2)^{2}*\left(1-(0.1*0.2)\right)^{18}\right]=0.00707, or\ 0.707\%$$

Using the GSFC risk matrix, this would be a 1x5 (yellow) technical risk, shown in Figure B-1.



Likelihood	**Safety** Estimated likelihood of Safety event occurrence	**Technical** Estimated likelihood of not meeting performance requirements	**Cost Schedule** Estimated likelihood of not meeting cost or schedule commitment
5 Very High	$(P_{SE} > 10^{-1})$	$(P_T > 50\%)$	$(P_{CS} > 75\%)$
4 High	$(10^{-2} < P_{SE} \leq 10^{-1})$	$(25\% < P_T \leq 50\%)$	$(50\% < P_{CS} \leq 75\%)$
3 Moderate	$(10^{-3} < P_{SE} \leq 10^{-2})$	$(15\% < P_T \leq 25\%)$	$(25\% < P_{CS} \leq 50\%)$
2 Low	$(10^{-5} < P_{SE} \leq 10^{-3})$	$(2\% < P_T \leq 15\%)$	$(10\% < P_{CS} \leq 25\%)$
1 Very Low	$(10^{-6} < P_{SE} \leq 10^{-5})$	$(0.1\% < P_T \leq 2\%)$	$(2\% < P_{CS} \leq 10\%)$

LIKELIHOOD					
5	🟩	🟨	🟥	🟥	🟥
4	🟩	🟨	🟨	🟥	🟥
3	🟩	🟩	🟨	🟨	🟥
2	🟩	🟩	🟨	🟨	🟨
1	🟩	🟩	🟩	🟩	🟨 #1
	1	2	3	4	5
	CONSEQUENCES				

Part Example #1: a Technical risk

Consequence Categories					
Risk	**1 Very Low**	**2 Low**	**3 Moderate**	**4 High**	**5 Very High**
Safety	Negligible or not impact	Could cause the need for only minor first aid treatment	May cause minor injury or occupational illness or minor property damage	May cause severe injury or occupational illness or major property damage.	May cause death or permanently disabling injury or destruction of property.
Technical	No impact to full mission success criteria	Minor impact to full mission success criteria	Moderate impact to full mission success criteria. Minimum mission success criteria is achievable with margin	Major impact to full mission success criteria. Minimum mission success criteria is achievable	Minimum mission success criteria is not achievable
Schedule	Negligible or no schedule impact	Minor impact to schedule milestones; accommodates within reserves; no impact to critical path	Impact to schedule milestones; accommodates within reserves; moderate impact to critical path	Major impact to schedule milestones; major impact to critical path	Cannot meet schedule and program milestones
Cost	<2% increase over allocated and negligible impact on reserve	Between 2% and 5% increase over allocated and can handle with reserve	Between 5% and 7% increase over allocated and cannot handle with reserve	Between 7% and 10% increase over allocated, and/or exceeds proper reserves	>10% increase over allocated, and/or can't handle with reserves

🟥 HIGH RISK

🟨 MODERATE RISK

🟩 LOW RISK

Figure B-1. GSFC Risk Matrix [ref. 45], depicting Example 1's risk

<u>Example 2:</u> Risk statement – a Programmatic risk:

Since system-level testing assures that most part failures occur in I&T, an additional pertinent risk statement would be a programmatic risk. Using the above example, the difference from the Technical risk case is that it only takes one capacitor failing in ground testing (versus three needed for this mission success case) to prompt rework. Therefore, I&T failure would be evaluated for its programmatic risk[26]. Additionally, for this particular part defect, there is a lower likelihood that a part will fail during I&T. since continuous operation and exposure time are factors inducing failure. Lastly, for an I&T failure, there is concern not only with the specific capacitors that will cause mission failure but for all of the capacitors in the system, regardless of criticality. This would include all 20 capacitors installed in the hardware. The risk statement is:

> *<u>Given that</u>* 20 MIL-PRF-55681[ref. 46] MLCCs within the affected scope of GIDEP xx are used on the project.
>
> *<u>It is possible that</u>* a part will fail in I&T, then require replacement.

---

[26] Programmatic risks formerly were stated as "cost and schedule risks."

Resulting in cost and schedule impacts for part procurement, replacement and regression testing.

In this case, one part failure is required to prompt rework and 100 parts are affected.

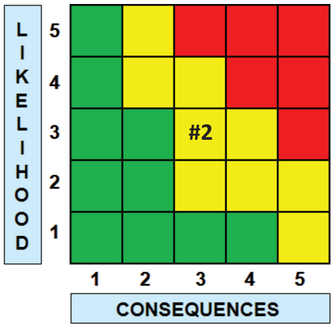
Assuming:

- the same likelihood of encountering a problematic lot (10%) exists, and
- the likelihood of having a failure in I&T is 5%,

the failure likelihood is:

$1 - [C(100,0)*(0.1*0.05)^{0}*(1-(0.1*0.05))^{100} = 0.394$ or 39.4%.

The consequence of performing such a replacement, which would almost certainly be late in I&T, is scored 3 on the GSFC scale, "Impact to schedule milestones; accommodates within reserves; moderate impact to critical path", thus giving a 3x3 programmatic risk (also yellow) on GSFC risk matrix, shown in Figure B-2.



LIKELIHOOD	1	2	3	4	5
5	🟩	🟨	🟥	🟥	🟥
4	🟩	🟨	🟨	🟥	🟥
3	🟩	🟩	🟨 #2	🟨	🟥
2	🟩	🟩	🟨	🟨	🟨
1	🟩	🟩	🟩	🟩	🟨

Figure B-2. Part risk Example #2, shown on GSFC Standard Risk Matrix

Vendor Trust-based Risk Examples

The examples below are to emphasize how risks are framed and calculated and how trust uncertainty factors are integrated. The specific reliability calculations are a function of the assumptions made and the applicable reliability block diagram and are unimportant to the framework concept. The examples are not intended to supplant a reliability engineering analysis that translates between individual part failures and those effects on a mission; such approaches are well-established.

Example 3: Consider the use of a base metal electrode (BME) capacitor from an ILPM.

Given that the use of a properly-derated, high-volume, established BME capacitor from a trusted ILPM with 10 reported field failures is caused by manufacturing defects out of 12 million parts delivered.

It is possible that three capacitors will fail, taking out the (non-redundant) power supply, within the mission's required lifetime.

Resulting in early mission failure.

In this case, all three of this type of capacitor must fail to cause the PS failure (i.e., there is no performance impact of losing one or two capacitors). Consequence would be ranked 5, for illustration purposes. Assume the pool is actually three million parts to account for parts that are not actually used and to adjust for non-reporting, even if manufacturer is trusted. Also, assume time is frozen to the current date. So, the vendor failure likelihood is $10/(3x10^{6})$. Vendor trust uncertainty factor is set at 1.5 (1.0 is complete trust) because there is no PPAP. Early failure likelihood of a single part then is $(1.5*10)/(3x10^{6}) = 5x10^{-6}$. The important consequence is the PS failure because that will end the mission. Three part failures are required, so the PS risk Likelihood $(5x10^{-6})^{3} << 0.001$, assuming independence of failures. This PS failure likelihood is well below the Likelihood rank 1 threshold on the GSFC technical risk scale. Thus, this Risk is noncredible; it is less than 0.1% or 0.001.

Note: One does not have to assume independence of failures – one also could have used a reliability engineering analysis to make the calculation, which might have provided a different likelihood. This example's importance is the illustration – how it is done – not the calculated number.

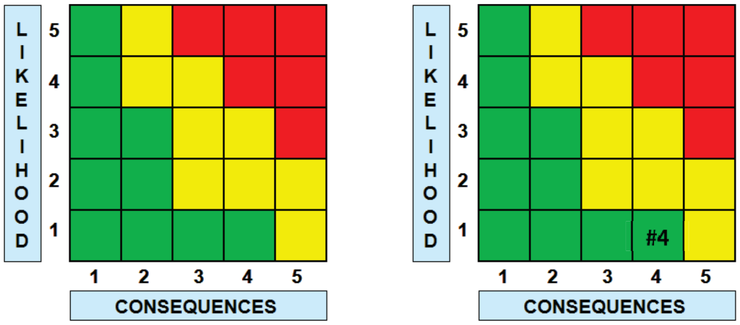
Example 4 - A slightly different situation involving a non-ILPM manufacturer.

Given that the use of a properly-derated, high-volume, established BME capacitor, with 50 reported field failures caused by manufacturing defects out of 20 million parts delivered.

It is possible that one capacitor will fail, taking out the star tracker, within the mission lifetime.

Resulting in severe mission degradation.

In this case, one capacitor failure causes star tracker failure, and the loss of the tracker greatly reduces science data value, a Consequence of 4, for illustration purposes. Assume the applicable parts population is 5 million parts to account for parts not actually used and adjusted for non-reporting. Also, the field data cumulative time is fixed time ("freeze time") for the reported field data. Therefore, vendor failure likelihood is $50/(5x10^{6})$. The vendor trust uncertainty factor is set at 100 because the vendor is not an ILPM, though there is past history with this vendor and no other known part failures have been reported to the assessment team. Early failure likelihood of a single part is $100*50/(5x10^{6}) = 1x10^{-3}$ = 0.1%. Since 0.1% is a 1 likelihood on GSFC's technical risk scale, the risk is 1x4. shown on the GSFC risk matrix in Figure B-3.



Example #3:
Likelihood <<0.1%; would
not be shown on Risk Matrix.

Example #4:
Tech. risk, with fielded
population adjustment and
vendor trust factor.

Figure B-3. Part Risk Examples #3 and #4, shown on GSFC Standard Risk Matrix

Appendix C. Some Lessons Learned in Using Parts

A number of failures and serious anomalies have occurred in ground testing and on-orbit traced to part problems since the early 2000's, some involving NASA-screened COTS and the others involving MIL-SPEC parts, but with lessons of relevance to the report.

1. Failure of (NASA-screened) COTS DC/DC Converters on the SAC-D mission. In screening the parts on this mission, the datasheet was seriously violated, the parts were overtested, and numerous parts failed in several applications over time. Unfortunately, the failures were attributed to workmanship issues in the parts because even after the failures occurred, the board did not check for the possibility that the parts were overtested by comparing the test limits to the datasheet: https://llis.nasa.gov/lesson/30601.
2. Two separate failures on the ground of JANS BJTs (due to corrosion) that were based on reliance on hermeticity to prevent corrosion caused a major programmatic hit to a project, contributing to a 6 month launch slip. Subsequently parts were broadly replaced that lacked a basis of being better than those they were replacing: https://llis.nasa.gov/lesson/30701.
3. Failure on the ground of a JANS BJT (due to corrosion) based on reliance on hermeticity to prevent corrosion: https://llis.nasa.gov/lesson/30702.
4. Lack of recognition of the context for risk when using high voltage, hand produced COTS parts well above previous experience levels: https://llis.nasa.gov/lesson/30604.
5. Failure of a rad-hard JANS MOSFET due to a radiation hit after failing to consider circuit level contributions to radiation susceptibility: https://llis.nasa.gov/lesson/27701.

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14. ABSTRACT
The NASA Electronic Parts & Packaging Program Manager, requested a NASA Engineering and Safety Center independent assessment to summarize Commercial Crew Program and NASA Centers' current and best practices, and lessons learned, on use of commercial-off-the-shelf (COTS) for all mission risk classifications, and provide recommendations that could lead to future NASA Electronic Parts and Packaging Program and/or Agency guidance on COTS parts. This document contains the outcome of the Phase II part of the assessment.

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