

E.P.I.C. (Enterprise, Partnerships, Innovation, Culture) Speed Electronics: A Pre-RFP Application Guide for Alternate-Grade Electronics in Small Satellites and Resilient Systems

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Abstract

Alternate grade¹ electronics are highly desirable, due to their advanced capability, low procurement cost, and ready availability. These characteristics are key enablers to new mission concepts that address a wide range of compelling needs. These include resiliency, regular technology refresh, lower cost, rapid acquisition cycles, shorter mission durations, flexible risk tolerance, and continuous production agility. Also included is the need for greater emphasis on achieving holistic, system level reliability versus a singular focus on individual vehicle, subsystem, unit, or part level reliability.

That said, alternate grade electronics do not come with the same insight, processing, and test information as Qualified Manufactures List (QML)/Qualified Parts List (QPL) products for military and space applications. Nor do the existing MIL (military) standards reflect or apply to alternate grade electronics. Yet programs still need a body of evidence to establish these parts' fitness for space, the definition of which must reflect mission type, criticality, risk, duration, orbit, and other factors.

The preparation of this pre-RFP application guide is a result of the Enterprise Corp's technical leadership in advancing the tenets of SMC (Space and Missile Systems Center) 2.0 and E.P.I.C. (Enterprise, Partnerships, Innovation, Culture) Speed as they apply to alternate grade electronics. This guide is intended to help developers balance mission assurance effort based on the use of alternate-grade electronics, consistent with the program's constraints. The document delivers practical parts selection and test guidance and identifies options with corresponding risk consideration. The guidance is intended to help inform decisions based on reasonable and acceptable modifications to existing standards and best practices according to mission attributes. The end goal is to reduce acquisition cost and accelerate acquisition schedule timelines, within a reliability trade space, leaving the decision makers flexibility to take increased risk to deploy a new capability on-orbit more quickly.

¹ Parts designed for applications in which the specifications, materials, and processes are established solely by the manufacturer or vendor pursuant to market forces not specific to space. These parts are not explicitly designed for space applications and may have additional requirements imposed by users or external organizations (e.g., screening to assess product quality and qualification to establish reliability baselines). Examples of such parts include automotive, aviation, commercial, industrial, and medical-grade components. Alternate grade electronics are intended to be of the same form, fit, and function as their space grade counterparts, with quality and reliability that allows the specific end-to-end mission needs to be met.

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1. Introduction

1.1 Intent and Audience

The Government is pursuing acquisition enablers to meet rapidly evolving threats and needs. One such enabler is the use of alternate grade electronics in systems. This application guide was produced to help communicate, prior to release of one or more eventual Requests for Proposal (RFP), the Government's intent to embrace the use of alternate-grade electronics in space systems. The target systems under consideration may span LEO missions, experimental testbeds, instruments, technology demonstrations, and missions intended to advance previously flown technology to the next Technology Readiness Level, among others. This guide focuses on small satellites weighing less than 1,000 kg, mission duration of less than 5 years, and a development cycle of 3 years. The context is constraints-driven vs requirements-driven programs. Neither nationally critical missions nor small launch vehicles are addressed at this time.

The pre-RFP guide provides holistic parts selection guidance that aligns with a range of mission attributes and offers tradeoffs to balance mission assurance risk. The intended audience for the document includes:

- Industry partners
- Government Source Selection team members and their support
- Early, mid-career and experienced Program Managers

1.2 Overview of Document Organization

The guide first offers brief introductory information here in Section 1. Context and taxonomy for the program categories addressed by this pre-RFP application guide appear in Section 2.1. A matrix of recommendations in three key mission assurance topic areas follows in Section 2.2. These are:

- Electronic Products: Assessment and Control
- Testing and Analysis
- Reliability and Sustainment

For ease of use, the most critical considerations and options appear in the matrix, with any necessary elaboration appearing in accompanying sections of text (Section 3) dedicated to each key mission assurance topic area. A few additional areas are not included in the matrix yet warrant special attention because of their importance to program formulation and in early program phases, especially for the fast-paced development cycles assumed here. They are addressed in separate sections, also in Section 3, and include:

- Mission Capabilities Definition and Planning
- Design Assurance
- Cost and Schedule

General suggestions and considerations as well as specific guidance by the appropriate taxonomy levels have been provided for each section throughout this document.

2. Background and Recommendations

2.1 Context and Taxonomy

The heritage paradigm for space systems acquisition and mission risk has been based on Class A, B, C and D categories^{2,3} shown in Table 2.1-1. This approach is and continues to serve as the foundation for many decades of US national security space supremacy.

Today, the need to outpace diverse, rapidly evolving threats have led to new mission concepts that address a wide range of compelling needs. These include:

- Resiliency
- Regular technology refresh
- Reduced acquisition timelines and cost
- Continuous production agility
- Shorter mission durations
- Flexible risk tolerance
- Optimized system level reliability
- Tradeoffs of mission attributes for balanced mission assurance

The missions and systems addressed in this pre-RFP application guide differ from the heritage approaches. This guide is intended to assist in advancing the tenets of Space and Missile Systems (SMC) 2.0 and Enterprise, Partnerships, Innovation, Culture (EPIC) Speed as they apply to alternate grade electronics enabling new mission concepts. Therefore, a distinct taxonomy was adopted to clearly distinguish the paradigm and categories of missions addressed by this pre-RFP guide from heritage approaches. The mission categories and recommendations presented here are based on a qualitative measure of resources available to reduce risk throughout the life cycle, i.e., *Constrained*, *Limited*, *Some*, *Many*. Table 2.1-2 summarizes the taxonomy for mission categories used in the context of this document. Notional example missions are included as potential scenarios to facilitate understanding. The *Constrained*, *Limited*, *Some*, and *Many* taxonomies have been italicized through this document for emphasis.

² Mission Risk Planning and Acquisition Tailoring Guidelines for National Security Space Vehicles, Aerospace Report No. TOR-2011(8591)-5

³ Mission Risk Posture Assessment Process Description, Aerospace Report No. ATR-2015-03151

Table 2.1-1. Heritage Mission Class

	Class D	Class C	Class B	Class A
Risk Acceptance	High	Moderate	Low	Lowest
National Significance	Not Critical	Not Critical	Critical	Extremely Critical
Payloads	Typically Experimental	Typically Experimental	Operational utility demonstration. May become operational	Operational
Acquisition cost	Lowest	Medium	High	Highest
Development Time	> 1 year	>2 years	> 3 years	> 4 years
Mission Life	< 1 year	< 2 years	<= 5 years	>5 years. Typically 8-10 years

Table 2.1-2. Pre-RFP Application Guide Taxonomy: *Constrained, Limited, Some, Many* resources available to reduce risk throughout the lifecycle. Resources may include personnel, expertise, equipment and infrastructure, funding, and schedule.

	Constrained	Limited	Some	Many
Taxonomy	Fully constrained schedule, cost, and resources available for Alt-Grade Electronics mission assurance (MA) beyond vehicle-level Acceptance-like testing.	Very constrained cost and resources available for Alt-Grade Electronics MA. Schedule and cost do not allow significant confirmation of capability beyond the Constrained case.	Mostly constrained. Schedule and cost allow confirmation of capability to achieve minimum success. Some resources available for Alt-Grade Electronics mission assurance (MA) beyond the Limited case.	Less constrained and more requirement driven. Schedule and cost allow confirmation of capability to achieve full success. Resources available for alternate grade electronics mission assurance beyond Come cases.
Example Mission	Hosted surveillance payload demonstration: Tracking of migrating wildlife 300 kg Secondary payload on GEO satellite	Earth observation: Monitor water resources in vicinity of remote military installations Constellation of 12 400 kg small satellites. 8 operational vehicles. 4 spares ready to launch on demand.	Rendezvous and constellation reconfiguration: Imaging for wildlife management Constellation of 100 90 kg small satellites. Launch 10 small satellites at a time every 6 months	Communication: Emergency preparedness, disaster relief support Three free flying 800 kg small satellites

The recommendations and options for the *Constrained, Limited, Some* and *Many* mission categories appear next as a matrix in Section 2.2.

2.2 Matrix

Resources Available	Constrained	Limited	Some	Many
Context and Taxonomy (Section 2.1)				
Taxonomy	Fully constrained schedule, cost, and resources available for Alt-Grade Electronics Mission Assurance (MA) beyond vehicle-level Acceptance-like testing.	Very constrained cost and resources available for Alt-Grade Electronics MA. Schedule and cost do not allow significant confirmation of capability beyond the Constrained case.	Mostly constrained. Schedule and cost allow confirmation of capability to achieve minimum success. Some resources available for Alt-Grade Electronics MA beyond the Limited case.	Less constrained and more requirement driven. Schedule and cost allow confirmation of capability to achieve full success. Resources available for alternate grade electronics mission assurance beyond Come cases.
Qualitative Risk	Low Cost, Highest Risk	Low Cost, High Risk	Med Cost, Med Risk	Med Cost, Low Risk
Electronic Products: Assessment and Control (Section 3.1)				
Type of Parts Acceptable for Mission	COTs baseline. AEC acceptable.	AEC baseline.	QML MIL Class Q or Y baseline. Add DPA and PIND for Class Q and DPA for Class Y.	QML MIL Class Q or Y baseline. Add DPA and PIND for Class Q and DPA for Class Y.
Qualification	Review COTs manufacturer's qualification for acceptability, if available. Perform qual testing as needed.	AEC parts get qualification by supplier per AECQ-XXX document qualification requirements.	Qualification included as part of applicable commodity mil-spec requirements.	Qualification included as part of applicable commodity mil-spec requirements.
Qualification time required and approximate cost	No time or cost required.	Minimal effort (1 week) to review AEC available data.	Mil-spec 6 to 14 weeks dependent upon commodity and \$20K - \$200K + cost of parts for test.	Mil-spec 6 to 14 weeks dependent upon commodity and \$20K - \$200K + cost of parts for test.
Screening	No screening recommended but should be considered.	Recommend limited screening of AEC parts to include 3-temp electrical testing and acoustic microscopy per the applicable commodity mil-specs.	QML parts already screened. Add PIND testing for QML Class Q.	QML parts already screened. Add PIND testing for QML Class Q.
Flight Heritage	Flight heritage results could be used to increase confidence in lieu of qualification data.	Flight heritage results could be used to increase confidence in addition to or in lieu of qualification data.	Flight heritage results could be used to increase confidence and reliability to meet mission requirements.	Flight heritage results could be used to increase confidence and reliability to meet mission requirements.

Resources Available	Constrained	Limited	Some	Many
De-rating	Parts derating per SMC standards or NASA-EEE-INST-002 for single string critical circuits. Refer to Reliability Section Redundancy Statement for trade off consideration.	Parts derating per SMC standards or NASA-EEE-INST-002. Refer to Reliability Section Redundancy Statement for trade off consideration.	Parts derating per SMC standards or NASA-EEE-INST-002. Refer to Reliability Section Redundancy Statement for trade off consideration.	Parts derating per SMC standards or NASA-EEE-INST-002. Refer to Reliability Section Redundancy Statement for trade off consideration.
Worst Case Circuit Analysis (WCCA)	Perform on single string critical circuits. Refer to Reliability Section Redundancy Statement for trade off consideration.	Perform on single string circuits considered critical and non-redundant. Refer to Reliability Section Redundancy Statement for trade off consideration.	Perform on all single string circuits and all critical circuits. Refer to Reliability Section Redundancy Statement for trade off consideration.	Perform on all circuits. Refer to Reliability Section Redundancy Statement for trade off consideration.
Product Knowledge	Understand device operation; radiation and reliability data	Understand overall device technology and operation; radiation and reliability data	Understand overall device technology and operation; radiation and reliability data and in-process controls; test philosophy.	Understand overall device technology; radiation and reliability data, and in-process controls; test philosophy location of product manufacture, assembly, test, and shipping.
Supplier Knowledge	Understand overall supplier technical approach and ensure products will meet mission and application requirements.	Understand overall supplier technical approach and manufacturing process controls. Evaluate reliability and failure history.	Understand overall supplier technical approach and manufacturing process controls; test approach and philosophy; failure analysis capability and corrective action system, traceability; reliability monitoring.	Understand supplier technical approach in design, manufacturing, assembly, test, reliability, and radiation; manufacturing process controls; test approach and philosophy; failure analysis capability and corrective action system, traceability; reliability monitoring.
Quality Management System	Documented system that includes, as a minimum, quality controls, inspections, MRB, GIDEP	Documented system that includes, as a minimum, quality controls, inspections, MRB, GIDEP, procurement controls, calibration and cause and corrective action process	System compliant to ISO 9001 or that meets intent of ISO 9001	System compliant to ISO 9001
Environmental Testing and Analysis - Dynamic Testing and Analysis – Vibration and Acoustics (Section 3.2.1)				
Test Unit				

Resources Available	Constrained	Limited	Some	Many
Test (margin, duration)	N/A	N/A	N/A	MQ: 6 dB, 2 min (1)
Can sustain flight levels				99/90
Demonstrated Lives				4X ATP + flight
Flight Risk				Not flown
1st Flight Unit				
Test (margin, duration)	ATP: 0 dB, 1 min	FP: 3 dB, 1 min	PQ: 3 dB, 2 min (2)	ATP: 0 dB, 1 min
Applies to Single Flight Unit	YES	YES	NO	NO
Can sustain flight levels	95/50	97.5/75	97.5/75	99/90
Demonstrated Acceptance Life	1	1	2	1
Demonstrated Life for Flight	NO	NO	NO	YES
Demonstrated Lives for Retest	NO	NO	NO	3
Flight Risk	Greatest	Risk > MQ Risk < PQ Test Unit	Risk > MQ	Lowest
Risk Mitigation ⁽¹⁾	Analysis	Analysis	Analysis	Not Required
Subsequent Flight Units				
Test (margin, duration)	ATP: 0 dB	FP: 3 dB, 1 min	ATP: 0 dB, 1 min	ATP: 0 dB, 1 min
Can sustain flight levels	95/50	97.5/75	97.5/75	99/90
Available Acceptance Life	1	1	1	1
Available Life for Flight	NO	NO	YES	YES
Available Life for Retest	NO	NO	NO	3
Flight Risk	Risk = ATP 1 st Unit	Risk = FP 1 st Unit Risk > PQ Subsequent Unit	Risk < PQ 1 st Unit Risk > MQ Any Flight Unit	Lowest
Risk Mitigation ⁽²⁾	Some analysis	Some analysis	Some analysis	Some analysis
Environmental Testing and Analysis - Dynamic Testing and Analysis – Shock (Section 3.2.1)				
Testing Condition	1 activation of significant events in sensitive axes	1 activation of significant events	1 activation of all shock events, 1 additional activation of significant events	1 activation of all shock events, 2 additional activations of significant events
Testing Condition	No test if shock velocity < 100 in/sec	No test if shock velocity < 100 in/sec	No test if shock velocity < 50 in/sec, unless shock sensitive components	No test if shock velocity < 50 in/sec, unless shock sensitive components
Testing Condition	Alternate testing and analysis may be acceptable	Alternate testing and analysis may be acceptable	N/A	N/A

Resources Available	Constrained	Limited	Some	Many
Environmental Testing and Analysis - Thermal Testing and Analysis (Section 3.2.2)				
Test Unit				
Temp Margin above MPT ¹	N/A	N/A	N/A	10°C
Number of Cycles	N/A	N/A	N/A	27
Burn-In Hours	N/A	N/A	N/A	N/A
First Flight Unit				
Temp Margin above MPT	5°C	5°C	5°C	0°C
Number of Cycles	2	10	15	14
Burn-In Hours	No additional	100	150	200
Subsequent Flight Units				
Temp Margin above MPT	0°C	0°C	0°C	0°C
Number of Cycles	1	7	10	14
Burn-In Hours	No additional	100	150	200
Environmental Testing and Analysis - EMI/EMC Testing and Analysis (Section 3.2.3)				
EMI/EMC/E Note: The testing at the lower taxonomy level (constrained lowest) is assumed performed at higher levels in addition to stated testing.	For enclosed units: Analysis for electromagnetic self-compatibility based upon estimated MIL-STD-461 compliance and need for CONOPS. For bolt-on units: Add RE102 for launch vehicle receiver bands	Analysis for electromagnetic self-compatibility based upon estimated MIL-STD-461 compliance and need for CONOPS.	Tailored EMI tests RS103 at platform Tx frequency RE102 at platform Rx bandwidth. Focused equipment layout architecture review based upon minimizing noise coupling to selected sensitive electronics. Estimate need to close out S/C structure gaps to provide sufficient shielding.	Full set of EMI unit tests including CE102, CS101, CS114, CS06, RE102 & RS103 per MIL-STD-461. Add receiver front end testing (CS103, CS104, CE106) and CE101 as needed. General equipment layout architecture review based upon minimizing noise coupling to sensitive electronics. Estimate need to close out S/C structure gaps to provide sufficient shielding.

Resources Available	Constrained	Limited	Some	Many
Testing (development testing, ESS, Life testing, Radiation testing)	Reliability organization (Reliability Analysis) provides KPPs and Failure Concerns/Modes mapping /correlation table (output of the above IETM) to testing organization then support testing organization to formulate most viable and efficient/effective test plans to mitigate alternate part usage risks. Test plans and testing results are used as part of the evidence for failure concerns/modes mitigation. Keep analysis and test results for record.	In addition to all statements in the Constrained Col., enhance the test data analyses that fit to program resource with increased confidence of achieving the program objectives. Submit the reliability analysis data sheets with testing as part of mitigation for customer review.	In addition to all statements in the Limited Col., enhance the test data analyses that fit to program resource with increased confidence of achieving the program objectives. Submit the reliability analysis data sheets with testing as part of mitigation for customer review and approval.	Full testing per contractual requirements, standards, and industry best practices. Full test data analysis, reliability analysis and documentation. Submit to customer for review and approval.

Environmental Testing and Analysis – Radiation Testing and Analysis (Section 3.2.4)

Radiation Environment	Minimal magnetic shielding, high flux of electrons, full GCR spectrum, no shielding to solar events (high flux of protons and heavy ions).	Heavily variable depending on orbital plane. Assume some polar vehicles and LEO orbit which interacts with the edge of the inner Van Allen belt. Will have some magnetic shielding from GCR and solar events but will cross the poles/higher latitudes. Expect moderate proton flux from Inner belts. Results in higher dose requirements than low LEO, some high LET particles, and occasional high proton flux.	Heavily variable depending on orbital plane. Assume some polar vehicles and LEO orbit which interacts with the edge of the inner Van Allen belt. Will have some magnetic shielding from GCR and solar events but will cross the poles/higher latitudes. Expect moderate proton flux from Inner belts. Results in higher dose requirements than low LEO, some high LET particles, and occasional high proton flux.	Heavily variable depending on orbital plane. Assume some polar vehicles and LEO orbit which interacts with the edge of the inner Van Allen belt. Will have some magnetic shielding from GCR and solar events but will cross the poles/higher latitudes. Expect moderate proton flux from Inner belts. Results in higher dose requirements than low LEO, some high LET particles, and occasional high proton flux.
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Resources Available	Constrained	Limited	Some	Many
Single Event Effects Design Mitigation	Design system/circuit to avoid destructive events in key parts that could cause a cascading failure. Accept that soft errors will happen and employ EDAC, TMR, or other system mitigation when possible.	Design system/circuit to avoid destructive events in key parts that could cause a cascading failure. Accept that soft errors will happen and employ EDAC, TMR, or other system mitigation to keep the upset rate low, when possible.	Design system/circuit to avoid destructive events in key parts that could cause a cascading failure. Accept that soft errors will happen and employ EDAC, TMR, or other system mitigations that address high upset rates on both satellite and constellation levels, when possible.	Design system/circuit to avoid destructive events in key parts that could cause a cascading failure. Accept that soft errors will happen and employ EDAC, TMR, or other system mitigations that address high upset rates on both satellite and constellation levels.
Part Selection Criteria for Single Event Effects	For key parts, review radiation test data from the manufacturer, open literature, or flight heritage results.	For key parts, review radiation test data from the manufacturer, open literature, or flight heritage results. Attempt to find rad tolerant parts for key components, if possible.	For key parts, review radiation test data from the manufacturer, open literature, or flight heritage results. Attempt to find rad tolerant parts for key components.	Purchase rad tolerant/tolerant parts when possible based on schedule and performance. Alternative grade parts can be used with a focus on performance. Heritage parts or parts with some data are preferred.
Single Event Effects Testing	For key parts, review radiation test data from the manufacturer, open literature, or flight heritage results. Depending on orbit, e.g., GEO, proton testing will have limited value, but could be used as a quick "screen" for major failures.	Depending on design/resources, either proton testing of key parts or limited board level testing.	More focus to part level testing, especially with heavy ions. Emphasize proton testing depending on the actual orbit.	Test parts with no data, targeting key components or potential design upsets which could be destructive. Depending on schedule, board level testing (proton heavy ion) can be useful.
Total Ionizing Dose/Displacement Damage Design Mitigation	Design system/circuit to allow for part failure but with key parts which can prevent a cascading failure. Apply spot shielding.	Design system/circuit to allow for part failure but with key parts which can prevent a cascading failure. Shielding will be a useful mitigation when possible, allowing higher orbits. Assume part degradation or failure earlier than expected. Accept some amount of variation over satellites.	Design system/circuit to allow for part failure but with key parts which can prevent a cascading failure. Apply spot shielding when possible. Part selection will be key. Understand variation in parts to prevent large variation in satellite responses.	Design system/circuit to allow for part failure but with key parts which can prevent a cascading failure. Even spot shielding will be a useful mitigation when possible, allowing higher orbits. Part selection will be key.

Resources Available	Constrained	Limited	Some	Many
Part Selection Criteria for Total Ionizing Dose/Displacement Damage.	With enough shielding, no special criteria may be needed. Exposed parts/sensors should have some heritage or knowledge about dose performance (especially displacement damage) or else an understanding about how the performance may degrade over time.	Select parts which fit performance and cost, but also have heritage or community data which suggest the parts do not have an exceptionally low TID limit. Try to avoid bipolar or ELDRS sensitive parts when possible.	Select a mixture of rad tolerant parts and COTS parts, targeting rad tolerant parts for key components to maintain operation. May use COTS for lower risk parts or for performance reasons. Recommend a more thorough shielding analysis to better assess dose levels. May consider avoiding ELDRS sensitive parts.	Purchase rad hardened/tolerant parts when possible. Add shielding to COTS parts where needed. Use a full Monte Carlo-like shielding analysis.
Total Ionizing Dose/Displacement Damage Testing	No testing is expected. Expect to use shielding to mitigate dose low enough to accept risk or mitigation via design.	Perform lower level testing for screening (vs characterizing) key parts to avoid incredibly soft parts.	Perform TID testing for key parts which are not rad tolerant. RLAT could be targeted for key parts or may not be needed based on the expected dose.	Testing not needed for rad hardened/tolerant parts. COTS parts will need some level of RLAT testing in order to cover variations.
Reliability and Sustainment (Section 3.3)				

Resources Available	Constrained	Limited	Some	Many
Program Level Reliability Planning (Section 3.3.1)	Establish a Reliability Plan that identifies Key Performance Parameters (KPPs), Functional Success Criteria (FSC), and any System, Range and Personnel Safety Hazards that are affected by alternate grade part usage. May use tools like FMECA, Fault Tree or Hazard Analysis to identify risks and communicate to customer for acceptance.	Establish a Reliability plan that identifies Key Performance Parameters (KPPs), Functional Success Criteria (FSC), and any System, Range and Personnel Safety Hazards that are affected by alternate grade part usage. May use tools like FMECA, Fault Tree or Hazard Analysis to identify mitigations. Document an informal system level reliability model and use to manage reliability allocations at lower levels for increased confidence of achieving the program objectives.	Establish a Reliability plan that identifies Key Performance Parameters (KPPs), Functional Success Criteria (FSC), and any System, Range and Personnel Safety Hazards that are affected by alternate grade part usage. May use tools like FMECA, Fault Tree or Hazard Analysis to identify mitigations. Document a formal system level reliability model, including what-if sensitivity analyses, and use to manage reliability allocations at lower levels for increased confidence of achieving the program objectives. Document and verify mitigation task completion.	Comply with the intent of requirements in SMC-S-013 Reliability Program for Space Systems or Aerospace TOR-2007(8583)-6889) Reliability Program Requirements for Space Systems for the system/sub-systems/ components/parts that are affected by alternate grade part usage. Follow the framework in ATR-2019-01877 for Functional Availability Analysis methodology.
FMECA and Hazard Analysis, Fault Tree Analysis, Range Safety Analysis (Section 3.3.2)	Use internal command media to perform baseline analyses that identify critical failures and single point failures. For those potential failures that cannot be designed out or mitigated, develop critical-item control plans (CICP) and communicate to customer for review and acceptance. At a minimum, identify all single point failures (SPFs).	Perform baseline analyses to identify and limit critical failures/single point failures, prevent failure mode propagation, and identify reliability critical items. For those potential failures that cannot be designed out or mitigated, develop critical-item control plans (CICP) and communicate to customer for review and acceptance.	Perform baseline analyses to identify, prioritize and mitigate critical failures/single point failures. Focus on preventing failure mode propagation and mitigating reliability critical items. For those potential failures that cannot be designed out or mitigated, develop critical-item control plans (CICP) and communicate to customer for review and acceptance.	Perform analyses to meet the intent of SMC-S-013 Reliability Program for Space Systems or Aerospace TOR-2007(8583)-6889) Reliability Program Requirements for Space Systems.

Resources Available	Constrained	Limited	Some	Many
Card Redundancy (Section 3.3.2)	Single string is acceptable if risk trades support. Pay special attention to any Single Point Failures. Also consider other analyses and testing as part of trades (Worst Case Analysis, De-rating, Thermal, Vibration Testing, Reliability Prediction, FMECA).	Single string may be considered if risk trades and program's risk acceptance support. Pay special attention to Worst Case Analyses and Single Point Failures. Also consider other analyses and testing as part of trades (De-rating, Thermal, Vibration Testing, Reliability Prediction, FMECA).	Dual redundancy is recommended where risk is identified. For further relaxation of redundancy, consider cost and risk trades and program's risk acceptance tolerance. Pay special attention to Single Point Failures. Also consider other analyses and testing as part of trades (Worst Case Analysis, De-rating, Thermal, Vibration testing, Reliability Prediction and FMECA).	Dual redundancy is recommended where risk is identified and prioritized. Consider triple redundancy for critical function cards. For further relaxation of redundancy, consider cost and risk trades and program's risk acceptance tolerance. Pay special attention to Worst Case Analyses and Single Point Failures. Perform other analyses and testing as part of trades, i.e., De-rating, Thermal, Vibration testing, Reliability Prediction and FMECA.
Assembly Redundancy (Section 3.3.2)	Single string is acceptable if risk trades support. Pay special attention to any Single Point Failures. Also consider other analyses and testing as part of trades (Worst Case Analysis, De-rating, Thermal, Vibration Testing, Reliability Prediction, FMECA).	Single string may be considered if risk trades and program's risk acceptance support. Pay special attention to Worst Case Analyses and Single Point Failures. Also consider other analyses and testing as part of trades (De-rating, Thermal, Vibration Testing, Reliability Prediction, FMECA).	Dual redundancy is recommended where risk is identified. For further relaxation of redundancy, consider cost and risk trades and program's risk acceptance tolerance. Pay special attention to Single Point Failures. Also consider other analyses and testing as part of trades (Worst Case Analysis, De-rating, Thermal, Vibration testing, Reliability Prediction and FMECA).	Dual redundancy is recommended where risk is identified and prioritized. Consider triple redundancy for critical function cards. For further relaxation of redundancy, consider cost and risk trades and program's risk acceptance tolerance. Pay special attention to Worst Case Analyses and Single Point Failures. Perform other analyses and testing as part of trades, i.e., De-rating, Thermal, Vibration testing, Reliability Prediction and FMECA.

Resources Available	Constrained	Limited	Some	Many
System Redundancy (Section 3.3.2)	Dual redundancy is recommended where risk is identified and as applicable to the mission architecture. Single string may be considered if cost and risk trades support. Pay special attention to Worst Case Analyses and Single Point Failures. Also consider other analyses and testing as part of trades (De-rating, Thermal, Vibration testing, Reliability Prediction, FMECA).	Dual redundancy is recommended where risk is identified and as applicable to the mission architecture. For further relaxation of redundancy, consider cost and risk trades and program's risk acceptance tolerance. Pay special attention to Worst Case Analyses and Single Point Failures. Also consider other analyses and testing as part of trades (De-rating, Thermal, Vibration testing, Reliability Prediction and FMECA).	Dual redundancy is recommended where risk is identified and as applicable to the mission architecture. For further relaxation of redundancy, consider cost and risk trades and program's tolerance on risk acceptance. Pay special attention to Worst Case Analyses and Single Point Failures. Also consider other analyses and testing as part of trades (De-rating, Thermal, Vibration testing, Reliability Prediction and FMECA).	Dual redundancy is recommended where risk is identified, prioritized, and as applicable to the mission architecture. Consider triple redundancy for critical function systems. For further relaxation of redundancy, consider cost and risk trades and program's tolerance on risk acceptance. Pay special attention to Worst Case Analyses and Single Point Failures. Perform other analyses and testing as part of trades i.e., De-rating, Thermal, Vibration testing, Reliability Prediction and FMECA.
Fault Tolerance (Section 3.3.2)	Zero fault tolerance is recommended if risk trades support.	Single fault tolerance is recommended where risk is identified. For further relaxation of fault tolerance, consider cost and risk trades and program's risk acceptance tolerance. Also consider other analyses and testing (Worst Case Analysis, De-rating, Thermal, Vibration testing, Reliability Prediction and FMECA).	Minimal single fault tolerance is recommended where risk is identified. For further relaxation of fault tolerance, consider cost and risk trades and program's risk acceptance tolerance. Consider other analyses and testing (Worst Case Analysis, De-rating, Thermal, Vibration testing, Reliability Prediction and FMECA).	Minimal dual fault tolerance where risk is identified. For further relaxation of fault tolerance, consider cost and risk trades and program's risk acceptance tolerance. Perform other analyses and testing as part of trades, i.e., Worst Case Analysis, De-rating, Thermal, Vibration testing, Reliability Prediction and FMECA.

Resources Available	Constrained	Limited	Some	Many
Reliability Predictions (Section 3.3.3)	Use internal command media or processes to engage Specialty Engineering functions to perform informal reliability related analyses. Focus on assessing KPPs affected by alternate grade part usage. Pay special attention to any Single Point Failures and to Heritage Data Evaluation. Conduct a qualitative assessment to group all items with similar acceptable risk, along with rationale, and identify affordable/feasible mitigations for communication and acceptance by the customer.	Use internal command media or processes to engage Specialty Engineering functions to perform informal reliability related analyses. Focus on assessing KPPs affected by alternate grade part usage. Pay special attention to any Single Point Failures, Heritage Data Evaluation, Sneak Circuit Analysis and Worst-Case Analysis. Conduct a qualitative assessment to group all items with similar acceptable risk, along with rationale, and identify affordable/feasible mitigations for communication and acceptance by the customer.	Use internal command media or processes to engage Specialty Engineering functions to perform formal reliability related analyses. Focus on assessing KPPs affected by alternate grade part usage. Pay special attention to any Single Point Failures, Heritage Data Evaluation, Sneak Circuit Analysis, Worst Case Analysis, Critical Items Analysis and Reliability Allocations. Conduct a formal assessment to prioritize all risk items, along with rationale, and identify affordable/feasible mitigations for communication and acceptance by the customer.	Use internal command media or processes to engage Specialty Engineering functions to perform formal reliability related analyses. Focus on assessing KPPs affected by alternate grade part usage and meeting the intent of SMC-S-013 Reliability Program for Space Systems or Aerospace TOR-2007(8583)-6889) Reliability Program Requirements for Space Systems.

Resources Available	Constrained	Limited	Some	Many
Sustainability/Replenishment (Section 3.3.4)	Based on knowledge of KPPs, derive Functional Success Criteria and use them to perform a Functional Availability Analysis applicable to the mission architecture. Document rationale and assumptions for communication and acceptance by the customer. Reference Aerospace Report ATR-2019-01877, Functional Availability (FA) Analysis.	Based on knowledge of KPPs, derive Functional Success Criteria and use them to perform a Functional Availability Analysis applicable to the mission architecture. Document rationale and assumptions for communication and acceptance by the customer. Reference Aerospace Report ATR-2019-01877, Functional Availability (FA) Analysis.	Based on knowledge of KPPs, derive Functional Success Criteria and use them to perform a Functional Availability Analysis applicable to the mission architecture. Identify any scenarios that could drive premature replenishment. Document rationale and assumptions for communication and acceptance by the customer. Emphasize sensitivity analyses reflecting scenarios with enhanced redundancy or use of multiple orbital planes. Reference Aerospace Report ATR-2019-01877, Functional Availability (FA) Analysis.	Based on knowledge of KPPs, derive Functional Success Criteria and use them to perform a Functional Availability Analysis applicable to the mission architecture. Identify any scenarios that could drive premature replenishment and reflect the accumulation of on-orbit life and adjustments for any component failures. Generate extrapolations of depletion of fuel or other expendables, and satellite- or mission- life limiting systems (wear-out models). Document rationale and assumptions for communication and acceptance by the customer. Emphasize sensitivity analyses reflecting scenarios with enhanced redundancy or use of multiple orbital planes. Reference Aerospace Report ATR-2019-01877, Functional Availability (FA) Analysis.

3. Mission Assurance Topic Area – Elaborations

3.1 Electronic Products: Assessment and Control

3.1.1 General Suggestions and Considerations

A specification for a satellite/payload defines specific performance requirements that must be satisfied when such equipment is deployed in an orbit in space. The equipment specification also calls for reliable, dependable, and within-specification performance during the mission despite the hazardous space environment. Reliable and dependable operation means that the equipment must operate continuously without exceeding the allowable number of outages during the mission. These requirements drive the need to have a robust design with sufficient margins to accommodate the space hazard and ensure the specified performance. Since the manufacturer of space systems must guarantee that the equipment will satisfy these requirements, the manufacturer must also pay attention to the (1) nuts, bolts, rivets, weld joints, etc., that hold together the spacecraft structure, (2) material properties, manufacturing processes, protective coatings, etc., of all mechanical components of a space vehicle to ensure that they will withstand the rigors of the launch environment and of space; and (3) resistors, capacitors, semiconductor components, and all other Electrical, Electro-mechanical, and Electronic (EEE) parts so that the system will operate reliably during the mission and at End Of Life (EOL). EEE parts must have known and stable performance characteristics over the mission life and in the presence of the natural space radiation environment. In the past, space missions have relied upon military specification and radiation hardened space level devices, whose attributes differ significantly from commercial or industrial grade parts. In a changing global environment, various innovative approaches and operational configurations are being discussed and implemented. The old ways of utilizing all military and space grade electronics is evolving in lieu of evaluating commercial, industrial, automotive, and medical alternative devices for use in high reliability systems. This approach allows for the implementation of modern technologies and novel design techniques.

When a program initiates, one of the most important building blocks that needs to be evaluated is the type of electronic products selected and implemented for the mission. The designer must understand the mission objectives, orbit, length of the mission, radiation, reliability, thermal and other environmental exposures. This will help in identifying the appropriate part types, parts grades, and technologies.

The matrix in Section 2.2 defines four (4) distinct categories and types of missions. It provides the technical basis for a systems engineering team to delve into the intricacies of the mission and understand the impacts of trade studies and risk assessments that could be performed. The purpose of such activities is to aid in identifying the decision space of how and what can be done to meet the mission objectives.

As an example, all four scenarios will be presented, and the reader will be provided with the rationale for the defined field input.

3.1.2 Specific Guidance by Taxonomy Level

3.1.2.1 Constrained

Using the systems engineering approach, an analysis of the mission objectives, orbit, cost and program schedule factors, the type of parts selected as the baseline for this mission are Commercial Off The Shelf (COTS). COTS provide the latest technology available at the lowest cost and schedule but do have some drawbacks. Manufacturers of COTS parts usually provide little if any support to the user with the

exception of a major volume customer; COTS inherently have the risks of limited to no testing; short lifespan; and limited reliability and flight heritage.

COTS are usually not screened by the manufacturer (limited electrical testing at 25° C, no thermal or environmental tests, no burn-in nor mechanical tests and no radiation information). The manufacturer usually has performed some amount of qualification testing on the part or technology prior to the release of the product and is potentially willing to share the data.

Since this mission has fully constrained costs and schedules, one does not have the ability to mitigate risks by performing screening, qualification, or radiation testing. As a minimum, one should ensure the critical parameters and characteristics of the parts are de-rated from their absolute maximum ratings to provide the highest confidence and most reliable use of the product. One should request the qualification or any other test data the manufacturer is willing to provide and review it for any known concerns for mission success. In general, procuring the parts from a known good supplier who has been in business for a considerable time and is known for high quality product, or from an authorized distributor is recommended.

3.1.2.2 Limited

Based on the evaluation of the objectives and other factors, the parts baseline selected is Automotive parts qualified to Automotive Electronics Council (AEC) standards. Like COTS, these parts offer advantages over space grade product and provide the latest technology offered by the manufacturers with some testing and reliability heritage. The major drawback to AEC product is a different philosophy in testing. AEC product undergoes a formal qualification with statistical process controls implemented within the manufacturing process and then do not perform acceptance or any additional testing. The manufacturers believe the process controls are sufficient to ensure the “goodness” of product coming down the production line. Therefore, qualification is performed initially and is not done again unless major design or process changes are implemented. No 100% screening is performed and any data available is a matter of negotiation between the buyer and seller. Product has a longer lifetime on the market than COTS due to the longevity of cars but may undergo changes during the lifespan of the product. The product is designed to be used in various applications within the automotive electronics domain and may have some radiation data available. To mitigate and enhance the mission risk utilizing the AEC parts, it is recommended that a 100% three temperature (ambient, high, and low) electrical test be performed to ensure the parts will meet the mission environments. One should also ensure the critical parameters and characteristics of the parts are de-rated from their absolute maximum ratings to provide the highest confidence and most reliable use of the product. A Worst-Case Circuit Analysis (WCCA) on single string circuits considered critical and non-redundant should be performed. Detailed interactions with several AEC suppliers indicate an elevated level of commitment to disciplined processes and product quality.

3.1.2.3 Some

Based on the evaluation of the requirements of the mission, orbit and duration, the parts baseline selected is "Qualified Manufacturer List (QML)⁴ MIL Class Q or Y baseline." QML product is under the auspices of the Defense Logistics Agency (DLA) Land and Maritime which maintains a formal program that evaluates the supplier facilities, processes, technical capability, testing regime, management, quality assurance and radiation testing. QML product (Class Q and Class Y) undergoes extensive 100% screening to eliminate marginal or weak devices from the population. Qualification and Quality Conformance Inspection (QCI lot acceptance) on all product types are performed. QML Class Q product is hermetic and has been designed to meet the rugged environments of the military services but may not meet the additional rigorous space environment requirements. Class Y product is non-hermetic and was designed to be utilized in space. It represents newer and more complex technology than Class Q military product. Radiation tests are performed and available on specific types of devices under QML. DLA performs periodic audits and monitoring of the suppliers and product to ensure all requirements of the specification are met. The suppliers perform periodic reliability monitoring on product to ensure continuous adherence to requirements. Re-qualification is performed upon major changes being requested.

The only drawback to the use of QML product is the product lines tend to be more mature and stable so that the technology is generally a few generations behind the commercial activity. To mitigate risk, the only additional testing that may be required are 100% Particle Impact Noise Detection (PIND) testing and Destructive Physical Analysis (DPA) for QML Class Q devices and a DPA for QML Class Y devices. PIND testing evaluates whether there is loose foreign object debris material inside a hermetic cavity that could cause potential damage or degradation to the devices. DPA looks at the quality integrity and workmanship of the device and ensures the manufacturer has built the device in accordance with the baseline.

One should also ensure that the critical parameters and characteristics of the parts are de-rated from their absolute maximum ratings to provide the highest confidence and most reliable use of the product. A WCCA on all single string circuits and all critical circuits should be performed. QML suppliers are reputable and trustworthy.

The costs and schedules for qualification vary based on the commodity type and are included in the cost of procuring these parts under the QML system. The manufacturer bears the cost of the qualification based on market considerations. The costs and schedule range from 6 weeks to 26 weeks dependent upon commodity and \$20,000 to \$200,000 plus the cost of parts for testing.

⁴ As a minimum, QML and QPL government qualification programs require the supplier to apply a set of screens to every part. For QPL, quality conformance inspection (QCI) qualification tests are performed on specified samples of parts to guarantee the performance of the rest of the lot. For the QML program QCI is called "technology conformance inspection" (TCI). These are a set of destructive and non-destructive tests.

Specification "MIL-M-38510, Military Specification: General Specification for Microcircuits" for QPL and MIL-I-38535 for QML outline all the procedures necessary for parts and vendors to be included on government-endorsed lists. Under QML, the government qualifies a manufacturer's entire fabrication process. Under QPL, the government qualifies the device types fabricated by that process.

3.1.2.4 Many

Based on the analysis of the mission, it is determined that the objectives must be met, and the parts baseline selected is "QML MIL Class Q or Y baseline." The information relative to QML is the same as under scenario 3.

To mitigate risk, the only additional testing that required are 100% PIND testing and DPA for QML Class Q devices and a DPA for QML Class Y devices. PIND testing evaluates whether there is loose foreign material inside a hermetic cavity that could cause potential damage or degradation to the devices and a DPA looks at the quality integrity and workmanship of the device and ensures the manufacturer has built the device in accordance with his baseline.

One should also ensure that the critical parameters and characteristics of the parts are de-rated from their absolute maximum ratings to provide the highest confidence and most reliable use of the product. A WCCA on all circuits should be performed. QML suppliers are reputable and trustworthy.

The costs and schedules for qualification vary based on the commodity type and are included in the cost of procuring these parts under the QML system. The manufacturer bears the cost of the qualification based on market considerations. The costs and schedule range from 6 weeks to 26 weeks dependent upon commodity and \$20,000 to \$200,000 plus the cost of parts for testing.

3.2 Environmental Test and Analysis

This section addresses environmental test and analysis considerations for space system units that contain commercially available electronic components that may not be qualified for space applications. Although specific requirements are not provided, the outline presented here is based on practice and experience developed on DOD programs, modified for more general applications. The recommendations presented herein are provided to help verify design and establish confidence in achieving successful space systems. It is intended that these recommendations be tailored to each specific program after considering the design complexity, design margins, vulnerabilities, technology state of the art, in-process controls, mission criticality, life cycle cost, number of space vehicles involved, prior usage, and acceptable risk.

Successful space programs entail extensive analysis and testing. Tables 3.2-1 through 3.2-4 summarize some of the important environmental test recommendations that should be considered for space systems that employ alternate grade electronic components, subject to the four levels of resources (*Constrained, Limited, Some, Many*) described by the taxonomy in Section 2.1 of this document. The environments listed in the tables are not intended to be a comprehensive compilation of the test that should be considered as part of the design and verification of space systems. More complete lists can be found in Reference 1, typically considered for DOD programs.

In Tables 3.2-1 through 3.2-4, "R" indicates recommended tests and "ER" indicates evaluation recommended. The cells containing the recommended tests, R, are highlighted for emphasis. The evaluation recommended designation, ER, indicates that, as a minimum, analyses should be performed to assess the impact of the environments on the unit under consideration, followed by a disposition indicating the rationale for the selected course of action, which may or may not require testing. Notes that clarify the various tests shown in the four summary tables are listed after Table 3.2-4.

Table 3.2-1. Unit Test and Analysis Summary for “Constrained” Resources

Test	Electrical and Electronic	Antenna	MMA	Solar Panel	Pressure Component	Pressure Vessel	Thruster	Thermal	Optical
Inspection ⁽¹⁾	R	R	R	R	R	R	R	R	R
Performance ⁽²⁾	ER	ER	ER	ER	ER	ER	ER	ER	ER
Shock ⁽⁶⁾	ER	ER	ER	ER	ER	ER	ER	ER	ER
Vibration or Acoustic ⁽³⁾	ER	ER	ER	ER	ER	ER	ER	ER	ER
Thermal Cycle	ER	ER	ER	ER	ER	ER	ER	ER	ER
Thermal Vacuum	ER	ER	ER	ER ⁽⁴⁾	ER	ER	ER ⁽⁵⁾	ER	ER
Life ⁽⁹⁾	ER	ER	ER	ER	ER	ER	ER	ER	ER

Table 3.2-2. Unit Test and Analysis Summary for “Limited” Resources

Test	Electrical and Electronic	Antenna	MMA	Solar Panel	Pressure Component	Pressure Vessel	Thruster	Thermal	Optical
Inspection ⁽¹⁾	R	R	R	R	R	R	R	R	R
Performance ⁽²⁾	ER	ER	ER	ER	ER	ER	ER	ER	ER
Shock ⁽⁶⁾	ER	ER	ER	ER	ER	ER	ER	ER	ER
Vibration or Acoustic ⁽³⁾	ER	ER	ER	ER	ER	ER	ER	ER	ER
Thermal Cycle	ER	ER	ER	ER	ER	ER	ER	ER	ER
Thermal Vacuum	R ⁽⁷⁾	ER	R	ER ⁽⁴⁾	R	ER	R ⁽⁵⁾	ER	ER
Life ⁽⁹⁾	ER	ER	ER	ER	ER	ER	ER	ER	ER

Table 3.2-3. Unit Test and Analysis Summary for "Some" Resources

Test	Electrical and Electronic	Antenna	MMA	Solar Panel	Pressure Component	Pressure Vessel	Thruster	Thermal	Optical
Inspection ⁽¹⁾	R	R	R	R	R	R	R	R	R
Performance ⁽²⁾	ER	ER	ER	ER	ER	ER	ER	ER	ER
Shock ⁽⁶⁾	ER	ER	ER	ER	ER	ER	ER	ER	ER
Vibration or Acoustic ⁽³⁾	R	ER	ER	ER	ER	ER	ER	ER	ER
Thermal Cycle	R ⁽⁷⁾	ER	ER	ER	ER	ER	ER	ER	ER
Thermal Vacuum	R ⁽⁷⁾	ER	R	ER ⁽⁴⁾	R	ER	R ⁽⁵⁾	ER	ER
Life ⁽⁹⁾	ER	ER	ER	ER	ER	ER	ER	ER	ER

Table 3.2-4. Unit Test and Analysis Summary for "Many" Resources

Test	Electrical and Electronic	Antenna	MMA	Solar Panel	Pressure Component	Pressure Vessel	Thruster	Thermal	Optical
Inspection ⁽¹⁾	R	R	R	R	R	R	R	R	R
Performance ⁽²⁾	R	R	R	R	R	R	R	R	R
Shock ⁽⁶⁾	R	ER	ER	ER	ER	ER	ER	ER	ER
Vibration or Acoustic ⁽³⁾	R	R	R	R	R	R	R	R	R
Thermal Cycle	R ⁽⁷⁾	ER	ER	ER	ER	ER	ER	ER	ER
Thermal Vacuum	R ⁽⁷⁾	ER	R	ER ⁽⁴⁾	R	ER	R ⁽⁵⁾	ER	ER
Life ⁽⁹⁾	ER	ER	ER	ER	ER	ER	ER	ER	ER

Notes:

- (1) Inspection and functional tests should be conducted prior to, during, and following each environmental test, as appropriate.

- (2) Performance to specification is conducted in conjunction with inspection; the need and extent of such testing should be based on analysis and risk assessment.
- (3) Where "R" indicated perform either vibration or acoustic, with the other discretionary according to sensitivity and magnitude of responses.
- (4) Thermal vacuum testing of solar panels may be performed on solar arrays.
- (5) Thruster thermal vacuum recommendations may be satisfied with hot fire testing.
- (6) Recommended for non-electrical/electronic units when they provide required electromagnetic shielding, when there is a passive intermodulation requirement or when the unit contains active or passive electrical components.
- (7) Burn-in recommended for flight units.
- (8) Externally induced shock testing may be deferred to higher level of assembly.
- (9) Life consideration includes all ground testing, launch, ascent, and on-orbit operations; analysis or life testing using flight-like assemblies should be performed to demonstrate at least 2X margin for all susceptible failure modes.

3.2.1 Dynamic Testing and Analysis

3.2.1.1 General Suggestions and Considerations

The combination of mechanical analyses and dynamic testing are needed to ensure the unit and the integrated parts have adequate structural and fatigue margins to survive random vibration, acoustics and shock dynamic loads induced during ground testing and launch [2]. Demonstrating margin with analysis prior to building hardware and performing dynamic testing reduces the likelihood of failures during testing and the mission. Dynamic testing is performed to confirm that the unit and the integrated alternate grade parts have adequate structural margin and to screen for workmanship defects.

Most vibration environments experienced in flight are random in character and their magnitudes and durations are predicted as statistical estimates from previous flight and test data. Reference 1, SMC-S-016, provides recommended environmental requirements for DOD space systems, including technical rationale and background information that can be used as a reference for the derivation of test levels for other applications such as space hardware containing alternate grade electronic components. For multiple builds launched separately, over time, the environmental testing may be performed as a two-step approach consisting of higher margins for the first unit (qualification or proto-qualification testing), which can then be lowered to Acceptance Test Program (ATP) levels for subsequent flight units. This strategy has been used successfully for testing DOD space systems and it can also serve as the basis for testing space hardware that contain non-space qualified electronic components. These environments are tailored for specific applications, considering both the program risk posture and the hardware under consideration. For single flight space hardware, environmental testing is typically performed with lower or minimal margins, enough to demonstrate a desired capability for the flight and workmanship screening.

3.2.1.2 Specific Guidance by Taxonomy Level

The technical rationale for random vibration and acoustic environments is similar and the following discussion applies to both. Table 3.2-5 provides an overview for this part of the discussion. Programs with *Many* resources entail less tailoring than programs with fewer resources. The modified qualification strategy is similar to the qualification strategy used on many DOD programs; it exposes the test unit to ATP + 6 dB test levels, except that the duration is only two minutes versus three minutes. As a result, this approach does not require the same level of design conservatism and reduces the fatigue exposure during the test which may be more amenable for certain programs seeking to use alternate grade electronic components. The Modified Qualification (MQ) approach qualifies and demonstrates that the hardware can withstand 99% of the flight/test loads with 90% confidence (P99/90). Having successfully survived this test, the test unit is not flown. Subsequent flight units can now be exposed to the lower acceptance environment, typically the P95/50 maximum expected environment. The test duration of 2 minutes demonstrates that the flight units can withstand four ATP exposures (which allows for up to 3 retests) and flight. The retest capability provides for repeats of the ground acceptance test should the need

arise to repair the flight unit after its initial acceptance test. For random vibration performed on a shaker, the test is conducted one axis at a time. For acoustics, the test is performed by immersing the unit in the acoustic environment which excites all directions simultaneously.

Table 3.2-5. Summary of Random Vibration and Acoustic Testing

		LEVEL OF RESOURCES			
		CONSTRAINED	LIMITED	SOME	MANY
Test Unit	Test (margin, duration)				MQ: 6 dB, 2 min (1)
	Can sustain flight levels				99/90
1 st Flight Unit	Demonstrated Lives	N/A	N/A	N/A	4X ATP + flight
	Flight Risk				Not flown
	Test (margin, duration)	ATP: 0 dB, 1 min	FP: 3 dB, 1 min	PQ: 3 dB, 2 min (2)	ATP: 0 dB, 1 min
	Applies to Single Flight Unit	YES	YES	NO	NO
	Can sustain flight levels	95/50	97.5/75	97.5/75	99/90
	Demonstrated Acceptance Life	1	1	2	1
	Demonstrated Life for Flight	NO	NO	NO	YES
	Demonstrated Lives for Retest	NO	NO	NO	3
Subsequent Flight Units	Flight Risk	Greatest	Risk > MQ	Risk > MQ	Lowest
	Risk Mitigation ⁽¹⁾	Analysis	Risk < PQ Test Unit	Analysis	Not Required
	Test (margin, duration)	ATP: 0 dB	FP: 3 dB, 1 min	ATP: 0 dB, 1 min	ATP: 0 dB, 1 min
	Can sustain flight levels	95/50	97.5/75	97.5/75	99/90
Subsequent Flight Units	Available Acceptance Life	1	1	1	1
	Available Life for Flight	NO	NO	YES	YES
	Available Life for Retest	NO	NO	NO	3
	Flight Risk	Risk = ATP 1 st Unit	Risk = FP 1 st Unit	Risk < PQ 1 st Unit	Lowest
Subsequent Flight Units			Risk > PQ	Risk > MQ Any Flight Unit	
	Risk Mitigation ⁽²⁾	Some analysis	Subsequent Unit	Some analysis	Some analysis

Notes

(1) Analysis used to assess test unit for flight

(2) Some analysis should be performed to assess additional flight data accumulated between the 1st and subsequent units and impact on MPE

In current aerospace systems, sinusoidal vibration is rarely experienced by units mounted on spacecraft structures. Except for equipment mounted near rotating machinery such as pumps, most flight vibration environments tend to be random. Instabilities such as resonant burn in propulsion systems, pogo coupling between liquid propulsion systems and vehicle structure, flutter of exterior surfaces, rocket engine turbomachinery, and propellant slosh/control system coupling are assessed at the launch vehicle level and rarely imposed on the spacecraft as a sinusoidal environment. Consequently, a large majority of acceptance and qualification vibration testing will be random. For qualification and acceptance testing, the determination of whether a vibration test is sinusoidal, or random or a combination of the two should always be made on the basis of providing the best simulation of the service environment. Experience has shown that it is inadvisable to substitute one of these forms of vibration for the other. Conducting a sinusoidal vibration test to simulate a random flight environment can cause unrealistic ground test failures such as might be caused by excitation of high amplification resonances that would not occur in a flight random vibration environment. Conversely a sinusoidal test may not identify other failure mechanisms that may only be associated with a random environment such as those associated with the effects of simultaneous excitation of multiple resonances. In some cases, the flight environment may be a combination of sinusoidal and random excitations in which case combined sinusoidal and random testing should be performed. The Max Predicted Environment (MPE) for sinusoidal vibration is statistically the P95/50 vibration level derived from flight data. A minimum sinusoidal vibration for workmanship screening has not been established and, as a result, the ATP is equal to the MPE level. The test margins discussed for random vibration are also applicable to sinusoidal vibration, again, with the MPE designation used in place of ATP to avoid confusion.

The Proto-Qualification (PQ) strategy outlined for programs with *Some* resources is conducted to verify design requirements using reduced amplitude and duration margins in comparison to the MQ test. The

baseline PQ test consists of exposing the first flight unit to ATP + 3 dB test levels for 2 minutes. This demonstrates capability to sustain P97.5/75 random vibration and acoustics environments during flight. The test level is lower than qualification testing levels and avoids stressing the hardware at its peak capability. However, if flown, the PQ test unit will experience fatigue damage over and above that demonstrated by the test. So, the PQ unit is flown at risk. The unit will also face a 2.5% probability that flight will exceed test levels. Analysis is typically used to mitigate the risk of flying the PQ unit. Subsequent flight units are tested at the ATP (P95/50) level for 1 minute. For high reliability DOD applications, the first minute of PQ testing is reserved for the flight with margins for both level of environments and duration of exposure. This conservatism can be relaxed where the database of flight environments is extensive and the probability of encountering severe environments is diminished. The second minute of the PQ test is reserved for the ATP, leaving no demonstrated capability for retesting. Analysis is used to assess the units that do have to undergo refurbishment and retesting before flight. This approach demonstrates fatigue margin so that the subsequent flight units can safely withstand two ATP exposures (which allows for 1 retest) and flight. If additional rework and retests are needed, analyses and/or offline testing of the fatigue susceptible component(s) can be performed to assess the risk of failure during the flight. If additional flight data is accumulated between the flight of the PQ unit and the flight of subsequent units, the data should be examined and assessed for impact on the predicted MPE (Maximum Predicted Environment). This is indicated in Table 3.2-5 by the “some analysis” notation for risk mitigation for subsequent units.

The Flight Proof (FP) test strategy outlined for programs with “limited” resources is conducted to demonstrate satisfaction of design requirements using reduced amplitudes like those used for PQ testing and durations like those used for acceptance testing. These types of tests are selected for designs having single production runs where the test units will be used for flight. The FP test consists of exposing the test unit to ATP + 3 dB test levels for 1 minute, which is equivalent to an enhanced acceptance test. This demonstrates capability to sustain P97.5/75 random vibration or acoustics environments for flight. The FP test program is supplemented with analyses and development testing to demonstrate acceptability for flight of the FP test hardware. The risk of exceeding test levels in flight is the same as for the PQ unit described above, however, the life consumed by the FP test is less than for PQ testing and, as a result, the risk of exceeding life is decreased. This approach, therefore, is preferable for single unit builds over the PQ approach. Again, FP testing does not validate an acceptance program. Analysis is required to assess both the unit, especially for remaining life, and the predicted MPE as described above.

Finally, for programs with *Constrained* resources, ATP can be selected as the environmental test strategy. Of the four types of tests discussed here, this represents the approach with the highest risk. This test entails the application of ATP levels for 1 minute which demonstrates capability to sustain P95/50 environments. Stating it differently, this indicates an even chance of exceeding the test environment once in twenty flights. It also does not demonstrate life for flight. In other words, the unit is flown at risk of exceeding both test levels and fatigue life and the exposure in flight can be, again, over and above that which has been demonstrated by test. Just as mentioned above, this approach needs to be supplemented with analyses and development testing to demonstrate acceptability for flight of the test hardware.

At this point it is important to clarify the definition of ATP. The Maximum Predicted Environment (MPE) for random vibration is defined as the P95/50 statistical environment derived from several flights and test data measurements. Experience with testing and flying space hardware over the past four decades has led to the observation that a test level of $0.04 \text{ g}^2/\text{Hz}$, Figure 3.2.1-1. Minimum random vibration spectrum, unit acceptance test. Overall acceleration = 6.9 Grms, is the effective minimum random vibration level for screening flight hardware for workmanship defects. As a result, for DOD programs, the acceptance random vibration test level is defined as the envelope of the expected MPE prediction and the minimum workmanship spectrum. This implies that in the frequency bands where the

minimum workmanship spectrum dominates, the acceptance environment may exceed the P95/50 levels. For alternate grade electronics, the user could select their definition of ATP as the MPE level for those cases where a reduced test effectiveness for workmanship screening is accepted to reduce the likelihood of failure during testing due to high vibration loads. The minimum acoustic environment is shown in Figure 3.2.1-2. Minimum acoustic spectrum, unit acceptance. OASPL of 136.8 dB. The detailed numerical distribution is provided in Reference 1. The acoustic environment may also be defined by the launch vehicle provider for the specific mission and that takes precedence over the minimum acoustic spectrum. Please note that exposure to both random vibration and acoustic testing is not necessary for the same units. Acoustic testing is selected for hardware with large surface areas that are more responsive acoustic excitation. Again, analysis should be performed to assess the need for one environmental test or the other, or both.

When needed to reduce failure risk during unit testing, these guidelines can be used to perform random vibration testing at the board level. The minimum test direction axis is normal to the board. Guidance regarding the need to test in the in-plane directions should be based on analysis. The fixture used for board level testing should be designed to duplicate board boundary conditions and local compliance within the corresponding unit. Allowance for functional and performance testing should also be made where necessary.

Table 3.2-6 provides an overview of the environmental objectives achieved by the types of tests discussed for random vibration and acoustic. The Limited margin demonstration of the PQ and FP test types was discussed above in the respective paragraphs.

Table 3.2-6. Summary of Objectives by Test Type

Objectives	TEST TYPE			
	MODIFIED QUALIFICATION (MQ)	PROTO- QUALIFICATION (PQ)	FLIGHT PROOF* (PF)	ACCEPTANCE (ATP)
Design Verification	Yes	Yes	Yes	Yes
Margin Demonstration	Yes	Limited	Limited	Yes
Workmanship Screening	No	Yes	Yes	Yes
Functional & Performance	Yes	Yes	Yes	Yes
Acceptance Test Validation	Yes	Yes	No	N/A

Table 3.2-7 provides a summary of the shock testing recommendations. The definition of the shock environment can be more complex in nature and it can range from analytical, to empirical, or a combination of the two. Shock testing should be performed to confirm that sensitive components (such as crystals, relays, and brittle ceramic parts) can safely survive all shock loads regardless of the source, self-induced or external. It has been found that shock levels with modal velocities less than 100 in/sec are unlikely to produce hardware damage and it may be invoked for programs with *Limited* and *Constrained* resources. A velocity value of 50 in/sec is deemed to be the threshold below which qualification shock testing may not be necessary and it can be applied more conservatively to programs with *Some* and *Many* resources. In both cases, the no-test approach should not be invoked for hardware that includes highly shock sensitive components that could lead to a sudden failure. If the shock can be characterized analytically by a shock spectrum, testing may be performed using various actuation mechanisms such as drop testing, impact testing, resonant plate testing, vibration shaker, etc. This type of testing approach requires, in most cases, a significant amount of development testing and tuning to achieve the correct test

spectrum before the run for record. In the case of pyrotechnic shock, it may be possible to subject the test article to the actuation of the pyrotechnic devices used in flight to demonstrate the capability to withstand the environment. Testing may also be limited to significant shock events if the MPE is within 6 dB of the envelope of shock MPEs from all shock events.

Table 3.2-7. Summary of Shock Test Recommendations

	RESOURCES			
	CONSTRAINED	LIMITED	SOME	MANY
Test Conditions	1 activation of significant events in sensitive axes	1 activation of significant events	1 activation of all shock events, 1 additional activation of significant events	1 activation of all shock events, 2 additional activations of significant events
	No test if shock velocity < 100 in/sec	No test if shock velocity < 100 in/sec	No test if shock velocity < 50 in/sec, unless shock sensitive components	No test if shock velocity < 50 in/sec, unless shock sensitive components
	Alternate testing and analysis may be acceptable	Alternate testing and analysis may be acceptable	N/A	N/A

Finally, when performing the environmental testing of units and boards, consideration should be given to the test configuration and test set-up to ensure the results represent the desired flight conditions and that the test is sufficiently perceptive to detect anomalies. For example, detection of electrically intermittent states during exposure to environments require that the units be electrically energized and monitored during the test to the maximum extent feasible, and safe, to do so. If harnesses attached to the unit in the flight configuration influence the unit dynamic characteristics, then the same harness should be included in the test set-up to the first attachment point off the unit. If the unit is mounted on shock isolators in flight, then the random vibration and acoustic tests should be performed with and without the isolators. With isolators to verify the assembled configuration and without to verify the capability and workmanship of the unit by itself. Again, Reference 1 should be consulted for additional information. Similar documents published by NASA, Reference 3 as an example, also provide helpful environmental test information.

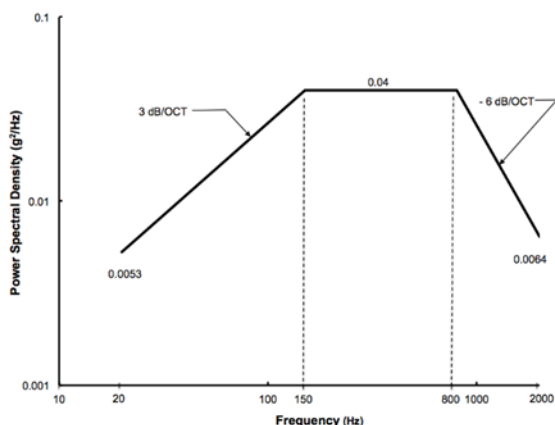


Figure 3.2.1-1. Minimum random vibration spectrum, unit acceptance test. Overall acceleration = $6.9 G_{\text{rms}}$

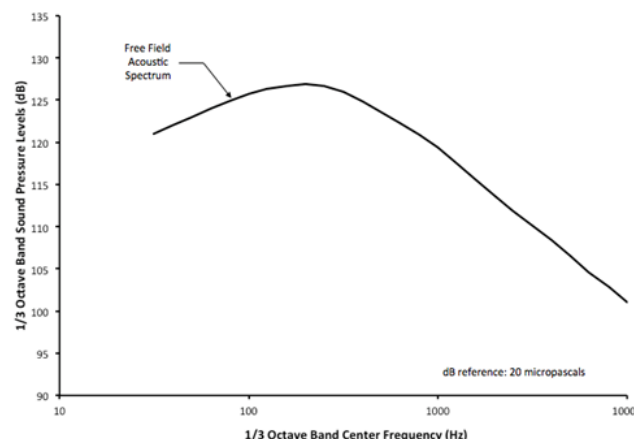


Figure 3.2.1-2. Minimum acoustic spectrum, unit acceptance. OASPL of 136.8 dB

3.2.1.3 References

1. SMC-S-016, *Test Requirements for Launch, Upper-Stage and Space Vehicles*, Air Force Space Command, Space and Missile Systems Center Standard, 5 September 2014.
2. Steinberg, Dave S., *Vibration Analysis for Electronic Equipment*, John Wiley & Sons, Third Edition, 2000.
3. GSFC-STD-7000A, *General Environmental Verification Standard (GEVS)*, NASA Goddard Space Flight Center, 22 April 2013.

3.2.2 Thermal Testing and Analysis

3.2.2.1 General Suggestions and Consideration

Thermal analyses are conducted to design a thermal control subsystem that will maintain parts and units within allowable thermal limits for all mission phases with temperature margins and control authority. These analyses are required to design the thermal control subsystem and reduce the likelihood of operational and performance failures during ground testing and the mission. Thermal testing is conducted to:

1. Reduce the risk associated with complex thermal designs in development testing,
2. Identify design defects in functionality and performance,
3. Screen units for assembly errors and workmanship defects,
4. Provide a flight-like thermal environment for verification of mission performance requirements, and;
5. Obtain thermal test data for thermal model correlation [1].

Thermal structural analyses are performed to ensure adequate mechanical and fatigue margins exist for the unit to survive thermal cycling during assembly, thermal testing, and mission operations [2]. The effectiveness of a thermal test is its ability to meet these test objectives. In terms of detecting failures, the test effectiveness is the ratio of the number of defects found in a test compared to the number of defects that could have been detected in the test.

The thermal test parameters that can be tailored for spacecraft units and vehicles with alternate grade electronics are the number of unit thermal test cycles, the test temperature ranges, and the burn-in test duration. The degree of tailoring will depend upon the level of risk assumed by the program and the capability of the alternate grade electronics. The risk levels established by the tailored requirements are compared against the baseline risk levels per the requirements specified in SMC S-016. The methodology used in this report to tailor these three thermal test parameters is to (1) establish test effectiveness goals for each program type and then (2) use test effective data and test objectives to select test parameter values that match goal levels. Thermal and mechanical analyses are key to confirm that adequate margin exists for the alternate grade electronics to safely survive the thermal test parameters.

3.2.2.2 Specific Guidance by Taxonomy Level

Test effectiveness goals corresponding to the appropriate available resources are shown in Table 3.2-8. For a program with low risk acceptance and *Many* resources, test effectiveness values are consistent with testing to SMC-S-016 requirements (qualification of a non-flight test unit followed by acceptance testing all flight units). As risk acceptance increases and/or resource availability decreases, tailoring for reduced test effectiveness goals and practices may be warranted. For a program with *Some* resources available, the first flight unit will be acceptance tested (test effectiveness of 95%), followed by testing to a test effectiveness less than acceptance (90%) for subsequent flight units. For a program with *Limited* resources, the first flight unit is tested to a test effectiveness level less than acceptance (90%) and subsequent flight units are tested to a test effectiveness value even lower. For a program with *Constrained* resources, the test effectiveness values for all flight units are significantly lower and represent a minimum test level to achieve the thermal test objectives.

Table 3.2-8. Test Effectiveness Values for Different Program Types

Hardware	Resources Available			
	Constrained	Limited	Some	Many
Non-Flight Test Unit	N/A	N/A	N/A	99%
First Flight Unit	60%	90%	95%	95%
Subsequent Flight Units	50%	80%	90%	95%

With test effectiveness goals in Table 3.2-8, test effectiveness curves, Figure 3.2.2-1[3 – 5], can be used to determine the corresponding number of thermal cycles and burn-in test duration. Table 3.2-10 summarizes the data selected from these two figures for test effectiveness values.

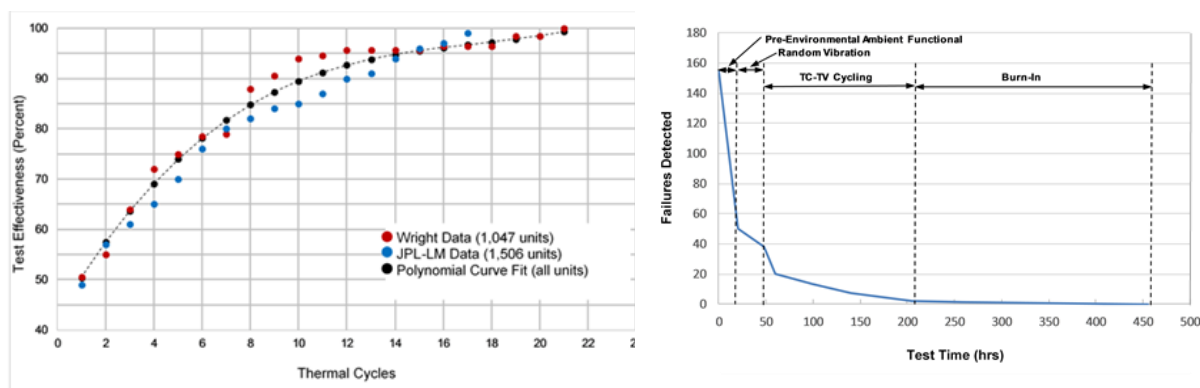


Figure 3.2.2-1. Test effectiveness curves for selection thermal cycles (left) [1, 2] and burn-in test duration (right). [3]

Table 3.2-9. Number of Cycles and Burn-in Test Duration for Test Effectiveness Values

Test Effectiveness	99%	97.5%	95%	90%	80%	70%	60%	50%
Thermal Cycles	27	20	14	10	7	4	2	1
Burn-in Test Hours	200	200	200	150	100	50	25	25

It was presumed that only programs with *Many* resources would conduct thermal testing on non-flight test units. Other program types would begin testing with the first flight unit. Furthermore, it was felt that keeping the number of burn-in hours, the same within a program type would provide benefit in consistency with test plans and procedures, so a value consistent with the test effectiveness goal for all subsequent units was generally selected. Table 3.2-10 lists the test parameters consistent with the test effectiveness goals.

Table 3.2-10. Thermal Test Parameters based upon Test Effectiveness Goals

	Resources Available			
	Constrained	Limited	Some	Many
Test Unit				
Temp Margin above MPT ¹	N/A	N/A	N/A	10°C
Number of Cycles	N/A	N/A	N/A	27
Burn-In Hours	N/A	N/A	N/A	N/A
First Flight Unit				
Temp Margin above MPT	5°C	5°C	5°C	0°C
Number of Cycles	2	10	15	14
Burn-In Hours	No additional	100	150	200
Subsequent Flight Units				
Temp Margin above MPT	0°C	0°C	0°C	0°C
Number of Cycles	1	7	10	14
Burn-In Hours	No additional	100	150	200

¹ MPT = Max Predicted Temperature

The proposed thermal test cycles and burn-in duration are:

- Programs with *Many* resources follow SMC-S-016 requirements of 27 qualification and 14 acceptance cycles with 200 hours of burn-in testing.

- For programs with *Some* resources, the first and subsequent flight units are tested to 15 and 10 cycles, respectively. The value of 15 cycles was chosen instead of 14 cycles, because there is heritage in industry of testing higher risk programs to 20 qualification, 15 PQ, and 10 acceptance cycles. The burn-in test duration is 150 hours.
- For programs with *Limited* resources, the first and subsequent flight units are tested to 10 and 7 cycles, respectively, and the burn-in test duration is 100 hours.
- For programs with *Constrained* resources, the first and subsequent flight units would be tested to 2 and 1 cycles, respectively, and the duration of this testing would be adequate such that no additional burn-in testing would be required. This represents very minimal thermal testing.

Selecting the appropriate temperature margin used to establish test temperatures was not based on program risk level, but by the unit build and the capability of the alternate grade components. All first flight units are tested with a $\pm 5^{\circ}\text{C}$ PQ margin (except for a program with *Many* resources which can use an acceptance level (0°C margin over MPT) because it has a qualified test unit). Subsequent units in all four program types use the acceptance margin (0°C). The reason for this is that all flight units should experience flight-like temperature ranges with the first flight units being subjected to a slightly wider range (PQ margins) for design verification. Furthermore, for all program types, a thermal uncertainty margin of $\pm 11^{\circ}\text{C}$ should be included in the MPT range, although for alternate grade parts with narrow allowable temperature ranges, the thermal uncertainty margin may need to be reduced.

For a program with *Many* resources, if a PQ test approach is taken and a test article is not qualified, the first flight unit is tested to PQ test level and subsequent flight units at the acceptance test level. The first flight unit temperature margin increases from 0°C to 5°C and the number of thermal cycles increases from 14 to 20.

Thermal cycles testing is conducted on all electrical units because it is a highly effective screen for detecting defects in design and workmanship. Thermal vacuum testing is added for units whose design, operation, or performance is sensitive to vacuum. The thermal vacuum test may be waived if it can be demonstrated that the unit is insensitive to vacuum conditions. Burn-in testing is conducted as a continuation of the unit thermal cycle test with the unit either cycling over the acceptance temperature range or soaking at the acceptance hot temperature. While SMC-S-016 requires burn-in testing to be conducted over a temperature range, ambient temperature burn-in testing may be necessary for higher risk programs with *Constrained* and *Limited* resources. To detect defects early, thermal testing can be performed at the printed wiring board level prior to integration into the unit. SMC-S-016 provides guidelines for conducting such testing and the credit given at the unit level in reducing the number of required thermal cycles and the burn-in test duration.

The durations established in these guidelines represent test effectiveness levels in line with customer goals. More testing beyond these established duration levels may find more infant mortality failures but also consumes additional useful life and increases the likelihood of wear-out failures due to fatigue during the mission.

Corrective actions associated with anomalies found in ground testing are typically built into the test schedule as added margin following the test. While a portion of this margin may be used for test start delays and unexpected events during the test, there should be time margin to fix defects following the test. It is important that test schedules are not overly optimistic in estimating the overall test flow duration by assuming that test failures will be minimal. The design should have adequate fatigue margin to safely survive additional thermal cycles if failures are detected during the first round of screening.

3.2.2.3 References

1. Gilmore, D. G. (editor), *Spacecraft Thermal Control Handbook, Fundamental Technologies*, 2nd Edition, Aerospace Press, 2002.
2. *Design Guidelines for Reliable Surface Mount Technology Printed Board Assemblies*, Interconnecting and Packaging Electronic Circuits, IPC-D-279, July 1996.
3. Wright, C. P., *Test Effectiveness of SMC-S-016 Unit Acceptance Thermal Testing*, 26th Aerospace Testing Seminar, March 2011.
4. Cornford, S. and Plumb, P., *Thermal Testing Study Report*, JPL D-11958, October 1994.
5. D. A. Smith, *Acceptance Test Effectiveness Including High Level Acoustic Testing*, Institute of Environmental Sciences, 34th Annual Technical Meeting, Proceedings, p. 120-130, May 3-5, 1988.

3.2.3 EMIC/EMC Testing and Analysis

3.2.3.1 General Suggestions and Considerations

A combination of analyses and testing are performed to ensure that integrated parts within units are electromagnetically self-compatible, and compatible in their intended electromagnetic environment. Conducted compatibility is assessed by verifying the powerline filtering of unintended conducted emissions are below the conducted susceptibility levels for other units attached to the same power bus. Radiated compatibility is assessed by predicting radiated emissions from the unit over frequency bands associated with co-located receivers, and the unit noise immunity to external electromagnetic fields.

3.2.3.2 Specific Guidance by Taxonomy Level

3.2.3.3 Constrained and Limited

When mission assurance resources are Constrained, or Limited, hardware analysis is performed at the parts assembled unit level to assess electromagnetic compatibility. If electrical noise levels are unacceptable then a CONOPS (concept of operations) can be developed for mitigation. For bolt on units, it is sometimes necessary to perform “do no harm” limited radiated emissions testing over launch vehicle receiver frequency bands for the launch provider.

3.2.3.4 Some

When there are Some mission assurance resources available, adequate electrical noise containment is estimated by reviewing the architecture layout relative to noise sources, and wiring attached to sensitive electronics. Mitigation of radiated emissions is assessed by reviewing unit and harness shielding to determine if additional shielding is needed. This shielding can be provided by closing physical gaps in the spacecraft structure. Testing is limited to radiated susceptibility testing at platform transmitter frequencies and radiated emissions testing over the platform frequency ranges.

3.2.3.5 Many

When Many mission assurance resources are available, a full set of EMI unit testing is performed in addition to the analysis discussed for the Some resources case.

3.2.3.6 Reference

SMC-T-008, Tailoring for AIAA S-121A-2017, Electromagnetic Compatibility Requirements for Space Equipment and Systems

3.2.4 Radiation Testing and Analysis

3.2.4.1 General Suggestions and Considerations

Sensitivity to the natural space radiation environment is one of the most important and challenging aspects of using alternate-grade electronic products. Because such products were neither designed nor tested to be flown in space, radiation performance data can be difficult or expensive to acquire. Therefore, to gain confidence that the products will meet requirements for their intended applications, users procure them and then:

- a) Perform analyses
- b) Leverage previous similar flight history and/or
- c) Perform selected testing

It is recommended that when using alternate grade parts, radiation mitigation needs to be introduced early in the system design to make sure that the design will have the required resources to perform mitigation. Specifically, if very radiation sensitive parts are planned to be used, then the system will need to provide some resources such as space and power for mitigation. As an example, a watchdog component or redundant parts (assuming primary and redundant parts are not all subject to the identical vulnerability) may be needed to help prevent a single upset from ending the mission. The mitigation scheme needs to be understood early in the design and not as an end-of-design afterthought.

The purpose of this section is to help define the radiation testing recommended for the distinct levels of mission assurance resources available (*Constrained*, *Limited*, *Some*, *Many*) considered in this guide. In the context of short (< 5-year duration) missions, the radiation concerns relate primarily to expected Single Event Effects (SEE), Total Ionizing Dose (TID), and Displacement Damage Dose (DDD).

There are also additional radiation effects such as damage to materials and coatings as well as electrostatic charging either on the surface of the spacecraft or inside. Spacecraft charging is highly dependent on the materials used and can show similar effects as SEE during a discharge. While standard EMI practices are useful to mitigate spacecraft charging for short duration, benign environment missions, a more thorough analysis should be performed for missions with more available resources or with a low risk posture.

3.2.4.2 Specific Guidance by Taxonomy Level

3.2.4.2.1 Radiation Environment

While the radiation environment is driven by the mission orbits and durations, some orbits are more benign than others. Therefore, one could attempt to avoid certain orbits to avert stressing environments, if feasible for the mission.

For example, with *Constrained* or *Limited* resources, a low-altitude, low-inclination orbit can be particularly useful as the magnetic shielding will limit high Linear Energy Transfer (LET) Galactic Cosmic Ray (GCR) particles and solar events. At a low altitude, the Van Allen belts may only be

experienced in the South Atlantic Anomaly. When moving to other orbits such as a polar or GEO orbit, more resources will be needed to account for the full GCR spectrum and full exposure to a solar event. In addition, GEO orbits will have more effects from the outer electron Van Allen belt to worry about. A HEO orbit will require the most resources as it will not only experience GEO-like GCR and solar events, but it will also interact with the energetic protons in the Van Allen belt. A MEO orbit can vary based on the exact location of the orbit.

3.2.4.2.1.1 Single Event Effects Design Mitigation

3.2.4.2.1.1.1 Constrained

Design the system or circuit to allow for part failure but with key parts (i.e., parts impacting mission critical functions) which can prevent a cascading failure. The key design driver is to avoid destructive events and accept that soft errors (e.g., errors that can be readily corrected by resetting or powering down the device) will happen. Use Error Detection And Correction (EDAC), Triple Modular Redundancy (TMR), or other system mitigation when possible. Depending on the orbit, a high particle flux may defeat the mitigation, but this may be a rare and acceptable event. Overall, system mitigation is the key.

3.2.4.2.1.1.2 Limited

Design the system or circuit to allow for part failure but with key parts which can prevent a cascading failure. The key design driver is to avoid destructive events and accept that soft errors will happen but need to keep the rate low to allow for more mission performance. Use EDAC, TMR, or other system mitigation when possible. Concept of Operations (CONOPS) decisions may be required to help mitigate the upset rate. Mitigation needs to look at high upset rates on a satellite level and constellation level, especially for the chance of a solar event, in which case the upset rate is lower for a single vehicle, but higher for the constellation.

3.2.4.2.1.1.3 Some

The system or circuit design is still key but expect to use less soft (more radiation tolerant) parts, which will make the mitigation circuits easier and smaller. The intent is to work to keep soft errors at an exceptionally low rate except during rare events like a solar storm. Use EDAC, TMR, or other system mitigation when possible. CONOPS decisions may still be used, but the intent is to avoid operational outages. Mitigation needs to look at high upset rates on a satellite level and constellation level, especially for the chance of a solar event, in which case the upset rate is lower for a single vehicle, but higher for the constellation.

3.2.4.2.1.1.4 Many

The system or circuit design is still key but expect few soft parts, which will make the mitigation circuits easier and smaller. Use EDAC, TMR, or other system mitigation when possible. The intent is to avoid implementing any CONOP mitigations to provide a very consistent error free system. Mitigation needs to look at high upset rates on a satellite level and constellation level, especially for the chance of a solar event, in which case the upset rate is lower for a single vehicle, but higher for the constellation.

3.2.4.2.1.2 Part Selection Criteria for Single Event Effects

3.2.4.2.1.2.1 Constrained

It is recommended that key parts (i.e., those parts impacting mission critical functions) should have some radiation test data either from the manufacturer, open literature or from flight heritage. Data for other parts may or may not be available or even be required depending on how damaging a failure could be to the mission. The intent is to design the system to mitigate unknown failures and attempt to avoid complete destructive failure.

3.2.4.2.1.2.2 Limited

It is recommended that key parts should have some radiation test data either from the manufacturer, open literature or from flight heritage. Data for other parts may or may not be available or even be required depending on how damaging a failure could be to the mission. Attempt to find rad hard parts for key components if possible. In this case, information about how parts fail, and their failure rates are particularly useful to planning how the system will mitigate upsets.

3.2.4.2.1.2.3 Some

It is recommended that key parts should have some radiation test data either from the manufacturer, open literature or from flight heritage. In this case, information about how parts fail, and their failure rates are particularly useful to planning how the system will mitigate upsets. Data for other parts may or may not be available or even required depending on how damaging a failure could be to the mission. Attempt to find rad hard parts for key components if possible.

3.2.4.2.1.2.4 Many

It is recommended to purchase rad hard/tolerant parts when possible based on schedule and performance. Alternate grade parts can be used with a focus on performance, but radiation data is needed. If a part is crucial, then a radiation test campaign is needed to determine how and how often this crucial part will fail. Most rad hard parts selected should have no strong failure mechanism to make mitigation simpler.

3.2.4.2.1.3 Single Event Effects Testing

3.2.4.2.1.3.1 Constrained

It is recommended that the key parts (i.e., parts impacting mission critical functions) should have some radiation test data either from the manufacturer, open literature, or from flight heritage. Data for other parts may or may not be available or even required depending on how damaging a failure could be to the mission. Proton testing (at the part or board level) will have value as a quick "screen" for major failures. There will not be resources for testing but will instead resources may be spent on system design or use parts with known behaviors.

3.2.4.2.1.3.2 Limited

It is recommended to target testing of key parts or limited board level testing. Board level testing could be used to help understand system level performance but may not help pin-point key weaknesses. Testing will be limited to proton-only testing due to cost and schedule, although heavy ion testing of a key part is particularly useful, if possible. Note that often testing a key part, like an Field Programmable Gate Array (FPGA) or processor, could be a major test campaign due to the complexity of the device.

3.2.4.2.1.3.3 Some

In this case, increased focus part level testing is recommended, although board level testing could also be used based on the confidence in the parts being used. Heavy Ion testing is preferred to best understand part response, especially for key parts or very soft parts. It is worthwhile to do some select heavy ion testing of the key complex parts, such as an FPGA or processor, to determine how often the user's design will experience upset. It is recommended to place strong emphasis on proton testing depending on the actual orbit but may have to use heavy ion testing as a proxy.

3.2.4.2.1.3.4 Many

Testing parts with no available radiation data is recommended. While there are resources for extensive tests, schedule may prevent full testing of all parts. Target the testing for key components or potential design upsets which could be destructive. Nonetheless, the use of "rule of thumb" estimates for effects such as transients may still be required. Depending on schedule, board level testing (proton and heavy ion) can be useful. In general, both proton and heavy ion testing is useful.

3.2.4.2.1.4 Total Ionizing Dose, Displacement Damage Design Mitigation

3.2.4.2.1.4.1 Constrained

Design the system or circuit to allow for part failure but with key parts (i.e., parts impacting mission critical functions) which can prevent a cascading failure. The key driver is to avoid destructive events that may happen before end of life. Shielding will be particularly useful to reduce any dose, so spot (localized) shielding is particularly useful. Depending on vehicle shielding, the dose may be very low for mission life and mitigation requirements may be minimal or not needed. Expect that there may be some part-to-part variation which could result in a change in performance near end of life.

3.2.4.2.1.4.2 Limited

Design the system or circuit to allow for part failure but with key parts which can prevent a cascading failure. The key driver is to avoid destructive events that may happen before end of life. Shielding will be a useful mitigation when possible and is the most effective use of resources. Spot shielding may be needed when possible. It is recommended that part degradation or failure earlier than expected due to part-to-part variations may need to be assumed.

3.2.4.2.1.4.3 Some

Design the system or circuit to allow for part failure but with key parts which can prevent a cascading failure. Shielding and part selection are the best mitigation tool. Spot shielding may be needed when possible. Part selection will be key. While some part-to-part variation may happen, more parts will have good data to limit that variation and help with any needed mitigation.

3.2.4.2.1.4.4 Many

Design the system the circuit to allow for part failure but with key parts which can prevent a cascading failure. The key driver is to avoid destructive events that may happen before end of life. Shielding and part selection are the best mitigation tool. Spot shielding may be needed when possible. Part selection will be key with the expectation of minimal variation.

3.2.4.2.1.5 Part Selection Criteria for Total Ionizing Dose, Displacement Damage

3.2.4.2.1.5.1 Constrained

This scenario will be heavily driven by shielding analysis and requirements. For short missions and enough shielding, no special criteria or actions may be needed. It is recommended that exposed parts or sensors should have some heritage, or there should be knowledge about dose performance (especially displacement damage), or else it is understood how the performance may degrade over time.

3.2.4.2.1.5.2 Limited

With *Limited* resources, part selection and design at the start is key. It is recommended to select parts which meet performance and cost goals, and have heritage or community data which suggest the parts do not have a very low TID or DDD limit. In this scenario, there may be the ability to select a few parts which are more rad hard or rad tolerant and use those parts in key functions. More resources will be spent in testing than in part selection. Avoiding bipolar or Enhanced Low Dose Rate (ELDR) sensitive parts should be considered when possible.

3.2.4.2.1.5.3 Some

It is recommended to select a mixture of rad hard parts and COTS parts. Target rad hard parts for key functions to maintain operation but selecting COTS for lower risk parts or for performance reasons is an option. At this level of resources, it may be advisable to do a more intense shielding analysis to better understand dose levels. Avoiding ELDR sensitive parts when possible is recommended.

3.2.4.2.1.5.4 Many

Purchase rad hardened or rad tolerant parts when possible. Adding shielding to COTS parts where needed and performing a full Monte Carlo-like shielding analysis are recommended.

3.2.4.2.1.6 Total Ionizing Dose, Displacement Damage Testing

3.2.4.2.1.6.1 Constrained

No testing is expected. It is expected that shielding will be applied to reduce the dose to a sufficiently low level compatible with accepted risk or that mitigation will be accomplished via design.

3.2.4.2.1.6.2 Limited

Due to the lower cost of Co-60 TID testing, part level testing is recommended for key parts. This testing more closely resembles screening rather than characterization. DDD testing may be possible for key parts or performed in concert with any proton testing.

3.2.4.2.1.6.3 Some

Some amount of TID testing is recommended for key parts which are not rad hard. Radiation Lot Acceptance Test (RLAT) could be targeted for key parts or may not be needed at all based on the expected dose. DDD testing may be possible for some parts without data or performed in concert with any proton testing. RLAT testing may be done for parts which appear most likely to fail early.

3.2.4.2.1.6.4 Many

Testing is not needed for rad hard or rad tolerant parts. COTS products will need some level of RLAT testing to cover part-to-part variations.

3.3 Reliability and Sustainment

3.3.1 Program Level Reliability Planning

It is recommended that all programs prepare a Reliability Program Plan (RPP) as a best practice. The plan should establish the policy for alternate grade part usage and identify methods for addressing impacts of their potential degraded performance. For example, the policy may cover what is and is not allowed and define the risk management approach. It is important to define the risk of not achieving the reliability requirements or goals and identify the criteria for accepting the associated risk early. Risk mitigation actions can be prioritized to fit within the program constraints throughout the design, development, testing, qualification, and integration phases.

It is also important to plan for contingency and emergency actions in case a risk is realized (e.g., a system or component fails due to commercial part usage). These actions may include the containment of the failure to minimize its consequence, planning for an effective failure investigation, and allocating resources to recover from the failure. Potential impacts of alternate grade electronics on Key Performance Parameters (KPPs) and Single Point Failures (SPFs) deserve special attention.

The plan also needs to address how the Reliability Engineering function will interact and integrate with other disciplines, including Parts, Materials, and Processes (PM&P), design, testing, analysis, and supplier management to ensure a holistic approach. The same should apply for redundancy design decisions, especially for single string and zero-fault tolerant designs associated with mission critical functions.

3.3.2 FMEA/FMECA and Related Analyses

One recommended method for gaining insight into the effects of alternate grade parts on the mission's success is to perform Failure Modes and Effects Analysis / Failure Modes, Effects and Criticality Analysis (FMEA/FMECA). Depending on the program requirements and resources available, FMEA/FMECA can be tailored to fit any program needs with the resources allocated. Where possible, it is recommended to refer to the Aerospace FMECA Guide, TOR-2009(8591)-13. As part of the tailoring effort under the program constraints, one may create a spreadsheet that documents relevant failure modes, causes and their effects on mission KPPs due to alternate part usage. The sheet also documents and manages necessary mitigations and controls of the failure modes and causes with the intent of using FMEA/FMECA to drive the actions. The FMEA/FMECA may also document redundancy design considerations that include card level redundancy, assembly level redundancy, and system level redundancy as the Section 2.2 Matrix Table recommends. As part of the analysis, FMEA may also document fault tolerant possibilities and design considerations.

Besides FMEA/FMECA, other reliability and safety analyses also need to be considered, depending on program requirements, mission specific concerns and regulatory requirements. These analyses include Hazard Analysis (HA), Fault Tree Analysis (FTA), and Range Safety Analysis (RSA). HA is a systematic method to address system hazards and associated mitigation and controls. HA can be a good supplement to FMEA/FMECA in that it starts looking at system hazards in a top down manner versus FMEA/FMECA's bottoms up approach. FTA depicts top down system hazards tracing down to the

hazard causes with AND and OR gate logic. RSA concerns mission failure consequence to the public. Each of these analyses has corresponding government, military or commercial standards. For HA, see MIL-STD-882E; for FTA, see NASA FTA Handbook for Aerospace Applications, V1.1; for RSA, see AFSPCMAN 91-710). Similar to FMEA/FMECA, meaningful and affordable tailoring can always be considered for the best value these analyses can provide within the program's constraints.

3.3.3 Reliability Prediction

3.3.3.1 Historical Overview of Reliability Prediction Approaches for Electronic Parts

Developing quantitative reliability predictions for spacecraft is a valuable tool for assessing risk to achieving design goals and facilitating design trades. These trades may involve the potential addition of redundancy and the use of parts with varying levels of quality. Historically, the standard methodology for developing these predictions is a bottoms-up approach that begins with calculating part failure rates based upon the methodology laid out in MIL-HDBK-217 Reliability Prediction of Electronic Equipment. However, the latest revision to the handbook (version F, notice 2, referenced here as MIL-HDBK-217 FN2) was released in 1995, so practitioners will encounter difficulty in applying it to more modern parts due to technology advancements in design, materials, equipment and manufacturing processes.

Various approaches to modernizing or replacing MIL-HDBK-217 FN2 have been put forward or proposed. A draft version G of the handbook was developed but never finalized. 217Plus is a similar effort with a separate commercial tool intended as a replacement but is not currently widely accepted by spacecraft contractors. Most contractors still use MIL-HDBK-217 FN2 as a baseline with tailoring based on an individual company's experience and operational data, when available, to update failure rates.

Rome Laboratory (RL) initiated a project to develop a new reliability assessment technique to supplement Mil-HDBK-217, and to overcome some of its perceived problems. RL awarded a contract to Reliability Analysis Center (RAC) which formed a team composed of personnel from ITT Research Institute (ITTRI) and Performance Technology. They developed a model that used data collected to estimate a reliability growth factor for each part type in Mil-HDBK-217 FN2. The results were used to update the failure rate shown in MIL-HDBK-217 FN2 with a failure rate reduction projection to a later date based on the part reliability growth pattern. It should be noted that the part reliability growth pattern does not extend beyond 2010 for the Mil-HDBK-217 FN2 values. The approach and model were documented in RAC Factors Report A06830 New System Reliability Assessment Report, June 1998.

ANSI-VITA 51.1 -2013 (R2018): Reliability Prediction MIL-HDBK-217 Subsidiary Specification provides some updates to MIL-HDBK-217 FN2 and has been used by some spacecraft and launch vehicle prime contractors. The document consists primarily of several observations and recommendations. Section 2.3.2 Quality Factor pointed out that MIL-HDBK-217 FN2 is overly pessimistic for the quality factors assigned to commercial parts. Section 2 recommends some lower quality factor values⁵ that can be used to better reflect the potentially higher quality parts being manufactured today under the condition that those parts are of "known pedigree". Known pedigree is interpreted as the buyer having insight into the manufacturer's process with a well-known Original Equipment Manufacturer (OEM). It advises to exercise caution regarding the quality factor if procuring from other than an OEM or one of their

⁵ The lower the quality factor, the higher the part quality. This terminology may be counterintuitive to some readers.

authorized distributors. The quality factor can vary from one commercial supplier to another for the same family of parts. The default values assume that one knows little about the supplier, but action is taken to make sure the parts are appropriate for the application. The quality factor can be lowered from the default value provided there is evidence to justify the change, such as knowing more about the supplier's quality program and the level of controls that are implemented.

Telcordia SR-322: Reliability Prediction Procedure for Electronic Equipment recommended methods for predicting device and unit hardware reliability. The document contains several forms and tables to facilitate the derivation of reliability predictions. It contains instructions for suppliers to follow when providing predictions of their device, unit, or serial system reliability. Device and unit failure rate predictions generated using this procedure are applicable for commercial electronic products whose physical design, manufacture, installation, and reliability assurance practices meet the appropriate Telcordia (or equivalent) generic and product-specific requirements. It is still maintained and used by the telecommunications industry. Some space companies use the reliability data for photonic devices unless manufacturer data is available.

Another resource is the Handbook of 217PlusTM Reliability Prediction Models. The handbook's development was funded by the Department of Defense (DoD) and sponsored by the Defense Technical Information Center (DTIC). The Reliability Information Analysis Center (RIAC) released 217PlusTM in July 2006 (latest version is 2015 Notice 1) as the DoD-designated replacement for the earlier RAC PRISM software. The tool is based on a process that includes component effects similar to MIL-HDBK-217 plus additional system level factors which try to account for non-component effects, e.g. operational profiles, manufacturing processes, assembly processes, and reliability growth, which are difficult to determine.

In 1999, several major French companies joined their efforts to define the specifications for a new reliability prediction methodology for electronic parts, called FIDES. The output of a study conducted between 2001 and 2004 resulted in the FIDES methodology, which was first issued in 2004 and standardized as a French standard under the UTE C80-811 "FIDES guide 2004 Issue A – Reliability Methodology for Electronic Systems". The methodology was updated in 2010, along with an updated FIDES application guide. A third edition is scheduled for 2020. Although not yet widely accepted in the US space industry, it is gaining wider acceptance in Europe as a replacement to MIL-HDBK-217 FN2. The tool is available from the FIDES website (<https://www.fides-reliability.org/>).

As is evident from this historical overview, although various efforts were carried out for improving electronic part reliability prediction, none of the alternatives or replacements have been widely adopted in the US space industry. The baseline approach remains applying the framework put forward in MIL-HDBK-217 FN2, with customer-approved tailoring to resolve its shortcomings and derive more realistic results. Specific examples of tailoring include substituting failure rates derived directly from test or operational data or adjusting the values of the multiplicative " π factors" used to calculate failure rates. Satellite contractors may establish reliability command media or corporately established technical approaches that define a consistent tailoring approach across the programs they support. These will vary from contractor to contractor. Contractors and customer program offices are strongly encouraged to consult with reliability engineers during acquisition to specify tailoring guidelines together with requirements. Regardless of the approach(es) followed, the details of the tailoring for a specific satellite program are less important than clearly establishing a tailoring process early in the development of the program and obtaining customer buy-in. Establishing the tailoring process early allows for an informed selection of a numerical reliability requirement, if applicable, and provides clear expectations of how compliance with that requirement will be demonstrated.

3.3.3.2 Tailoring Guidance for MIL-HDBK-217 Quality Factor

A specific aspect of the tailoring relevant to the use of alternate grade parts is the choice of quality factor in MIL-HDBK-217 FN2, namely π_Q , when developing reliability predictions. MIL-HDBK-217 failure rate predictions are derived from variations of an equation like the following for the microcircuits (MIL-HDBK-217 FN2, Sec. 5.1):

$$\lambda_p = (C_1 \pi_T + C_2 \pi_E) \pi_Q \pi_L \quad (\text{Eq. 3.1})$$

Where in Eq. 3.1,

λ_p is the predicted failure rate,

C_1 and C_2 are base failure rates (for die complexity and package, respectively),

π_T is the Temperature Factor,

π_E is the Environment Factor,

π_Q is the Quality Factor, and

π_L is the Learning Factor.

This equation, specific to Integrated Circuits (ICs) but similar to those used for most part types, illustrates how several factors are used to arrive at the failure rate to be used in the prediction (λ_p). The part quality factor π_Q is one of the factors that directly impacts the prediction failure rate. This is particularly relevant to alternate grade part usage. The following table shows MIL-HDBK-217 FN2 π_Q values for ICs.

Table 3.3-1. MIL-HDBK-217 FN2 π_Q Values for ICs

Screening Level	MIL-HDBK 217F N2 π_Q (Sec. 5.10)
Class S	0.25
Class B	1.0
Class B-1	2.0
Other Commercial and Unknown	10.0

Screening Level Class S, B and B-1 are screening level designations for microcircuits, which depend on the number of screens defined in MIL-STD-883 (or equivalent) the parts are subjected to. For other parts (such as discrete semiconductors, capacitors, resistors, coils, and other passive components), MIL-HDBK-217 FN2 Table 3.3-1 defines respective screening level designations.

Industry and the reliability community have been evaluating the electronic part reliability trend and reliability growth patterns throughout the last 30 years as discussed in Sec. 3.3.1 “Historical Overview”. A number of papers and reports were also published that studied the reliability trend and reliability growth rates since the early 1990’s (see References 1-7). It is observed from these publications that industry has reached a consensus that MIL-HDBK-217 based reliability predictions are too conservative. The rationale is that

- The handbook’s underlying data were at least 20 years old
- Modernization of the recent manufacturing processes and quality control practices were not reflected in the failure rate data and therefore, some Corrective Factors (CFs) should be applied to the HDBK’s Quality Factor π_Q to reduce the predicted failure rates.

After reviewing the publicly available reference documents [1-7], recommendations for CFs as starting points for commercial ICs and passive parts are shown in Table 3.3-2. The adjusted π_Q (i.e., π'_Q) after applying the recommended CF is also included.

Table 3.3-2. MIL-HDBK-217 FN2 π_Q Values and Recommended Starting Values for CF (Correction Factor)

Part Type	MIL-HDBK-217F N2 π_Q (Commercial Grade)	Corrective Factor (CF)	π'_Q (Adjusted π_Q with CF)
IC Parts	10.0	0.3	$10.0 \times 0.3 = 3.0$
Passive parts	10.0	0.1	$10.0 \times 0.1 = 1.0$

3.3.3.3 References

1. New System Reliability Assessment Method, RAC June, 1998
2. Paul Plumb, “New Blueprint for ESS”, Quality Magazine, Nov 1990, Page 53.
3. J. Healy, A. Jain, & J. Bennett, “Reliability Prediction”, 1997 Annual Reliability & Maintainability Symposium, Tutorial Notes, Jain-6.
4. Motorola Microcontroller Technologies Group, Reliability and Quality 1996 Annual Report, www.mot.com
5. Cypress reliability data, www.cypress.com
6. National Semiconductor Failure Rate Trends, www.national.com
7. The Quality and Reliability of Intel’s Quarter Micron Process, www.developer.intel.com

3.3.3.4 MIL-HDBK-217 Quality Factor Tailoring Guidance for Alternate Grade Parts

Throughout this document in various sections, military grade parts are preferred for the *Some* and *Many* mission cases. Alternate grade parts are recommended for the *Constrained* and *Limited* cases. Here the discussion focuses on the quality factor for alternate grade parts, $\pi_{Q:A}$, informed by a set of questions and considerations. With π'_Q from Table 3.3-2 as a baseline, the following recommended Considerations #1 – 4 are used to further adjust this π'_Q value to derive $\pi_{Q:A}$ applicable to the modern alternate grade parts addressed by this work’s four scenario cases (Constrained, Limited, Some and Many).

For topic areas discussed earlier, recommendations specific to the cases of Constrained, Limited, Some and Many available mission assurance resources were offered. For the reliability topic, however, responses to Considerations #1 – 4, i.e., scores, are used to shape the recommended action to be taken instead. This allows the user the greatest flexibility in reflecting the unique attributes of their specific program’s circumstances as they apply the quality factor tailoring guidance. Note that the recommendations and suggestions offered below are intended to be applied at the piece part level wherever a π_Q for an alternate grade part is used.

1. Did the part accumulate extensive proven usage history under a comparable space or military application environment? Assign a score of 1 to 3 with 1 being the most extensive usage history and 3 being the least extensive. Score 1 denotes extensive history with more than five comparable applications; score 3 denotes no history and no reliability data at all. [Consideration #1]

2. Is the part on an industry-recognized certified (or qualified) part list? Assign score 1 if the part is on a recognized list; assign score 3 if not on any certified part list. Examples of such lists could also include an Approved Parts List for a different program or one sanctioned by corporate technical policy. [Consideration #2]
3. Is the part manufacturer an industry-recognized certified supplier? Assign score 1 if the manufacturer is ISO 9001, AS9100 or ISO 16949 certified; assign score 3 if not certified. [Consideration #3]
4. Does the manufacturer have a good Quality Control (QC) system for the part? Evidence includes a documented Process Capability Assessment, Statistical Process Control/Control Plan, in-line inspection, Acceptance Sampling Plan, and Closed Loop Corrective Action system. Assign score 1 to 3 with 1 being the most robust QC system with full evidences from four or more QC activities, and 3 being the least robust with no evidence at all. As an alternative to this question, the program can assess whether all the guidance in Section 3.5 Design Assurance and Section 3.6 Knowledge of Provider is followed. If the guidance is followed closely and the mission assurance resource level is at *Many* or *Some*, assign score 1; if the guidance is not followed closely or the resource level is *Constrained* or *Limited*, assign score 3. [Consideration #4]

The sum of the total scores, namely, S_{sum} from Considerations #1 – 4, ranges from [4 to 12]. The following formula determines the Adjustment Factor (AF) on the π'_Q value to arrive at $\pi_{Q:A}$ applicable to the alternate grade electronics considered in this work's scenarios.

$$AF = S_{\text{sum}} / 12 \quad (\text{Eq. 3.2})$$

$$\pi_{Q:A} = AF \times \pi'_Q \quad (\text{Eq. 3.3})$$

In other words, S_{sum} captures and gives credit for the additional insight gained by conducting the extra due diligence in Considerations #1 – 4. This is absent from the existing quality factors in MIL-HDBK-217 FN2. The rationale for Eq. 3.2 and Eq. 3.3 is to anchor $\pi_{Q:A}$ to MIL-HDBK-217 FN2 based on the expanded insight.

For ICs, the high-end value of $\pi'_Q = 3$ is the adjusted Quality Factor recommended in Table 3.3-2. The low-end value of $\pi'_Q = 1$ matches the ANSI-VITA 51.1 -2013 (R2018) known pedigree value of 1 for commercial ICs.

For passive alternate grade parts such as capacitors, the Quality Factor $\pi_{Q:A}$ is based on the same set of questions used for ICs above to establish pedigree. The only difference is that $\pi'_Q = 1$, as shown in Table 3.3-2 is used as the starting point.

Example 1: An IC where considerations #1 – 4 result in the sum of the four scores $S_{\text{sum}} = 8$ and $\pi'_Q = 3$. Then $AF = 8/12 = .67$ and the adjusted Quality Factor $\pi_{Q:A} = AF \times 3 = .67 \times 3 = 2.0$.

Example 2: A passive component where Considerations #1 – 4 above result in the sum of the four scores $S_{\text{sum}} = 4$ and $\pi'_Q = 1$. Then $AF = 4/12 = .33$ and the adjusted Quality Factor $\pi_{Q:A} = AF \times 1 = .33 \times 1 = 0.33$.

3.3.3.5 Cautionary Notes for Implementing Suggested Quality Factors

It is always preferable to use direct part testing and field usage data for failure rate quantification, if applicable. If that is not possible, use of similar part data may be acceptable. It is always good practice to document data sources, analysis methodology, and justification for the usage.

Though there is consensus that CFs (Corrective Factors) are considered to be less than 1, the validity of Table 3.3-2's CF values are not fully confirmed and verified. In order to derive a set of more concrete and justifiable CFs, industry and the reliability community will have to perform more extensive testing and analyses in the long term.

While the use of alternate grade parts may be acceptable for space applications, especially if the guidance recommended in this document is adhered to, the use of MIL-STD compliant established reliability parts remains preferable and quality factors used should always reflect that.

Reliability prediction serves multiple purposes including reliability requirement compliance assessment, design tradeoff support, functional availability analysis, and others. It is usually difficult to quantify uncertainty associated with the predicted reliability. Therefore, assessing the risk of failing to achieve a reliability requirement should not solely rely on the reliability prediction. If a risk is identified through other means, then applicable and feasible risk mitigation should be taken.

An important application of reliability prediction is to conduct relative reliability comparisons during design concept tradeoffs. One key usage of the quality factor tailoring guidance presented here is to provide a tool for relative reliability comparisons with the objective of selecting a design that achieves reliability goals while remaining within resource constraints. This tailoring guidance is offered until studies and analyses specifically based on alternate grade parts are conducted and results made publicly available. In the meantime, any suggestions, or data for improving the guidance and formulas presented here are welcomed.

Considering the *Constrained to Many* taxonomy of this document, it would be expected in general that programs nearer the *Constrained* end of the spectrum would have less resources to perform additional screening or analysis in order to justify the application of lower π_Q values. As such, the resulting reliability predictions for such programs should be expected to demonstrate a lower probability of success than programs closer to the *Many* end of the spectrum. This is commensurate with the level of risk the customer is willing to accept. Overly aggressive tailoring that results in unrealistically high probabilities of success should be avoided. Numerous studies of historical satellite reliability have been performed, which may be consulted to inform what a reasonable probability of success prediction would look like. For example, Aerospace TOR-2010(8582)-3 Spacecraft Lifetime Study analyzed lifetime data for 283 US military and civil Earth orbiting satellites launched since 1980. The dataset included varying satellite classes, design lives, and mission types. The study found that the satellites studied achieved their design lives approximately 80% of the time, except for technology demonstration satellites which achieved their design lives approximately 60% of the time.

While the level of detail and rigor applied to developing a reliability prediction will vary depending on program constraints, in all cases some attempt should be made at estimating both the probability of the satellite achieving its nominal design life, and the expected lifetime of the satellite, as influenced by wear-out failure modes, sizing of expendables, orbital decay, or other life-limiting concerns. These estimates can also be used to perform a functional availability analysis as discussed in the next section.

In the current environment, traditional parts selection and reliability assessment paradigms are being challenged and are evolving rapidly. Decisions must be made as carefully as possible with the best available reliability data and knowledge at hand. As early in the program as possible, it is recommended that users and developers

- a) define the proposed reliability approach to be taken for the candidate alternate-grade electronics,
- b) document the approach, and

c) disclose the approach to the government program team possessing the requisite reliability and PMP expertise.

This will enable questions regarding alternate grade part usage or application of the guidance presented here to be addressed more quickly, effectively and efficiently.

3.3.4 Functional Availability, Sustainment and Replenishment

Functional Availability (FA) is the process of assessing the probability of success at the satellite constellation level, and how it varies over time. One of the key usage of reliability prediction is to support FA analysis. The typical use of FA analysis is to develop planned launch schedules, and in turn inform budgetary decisions or architecture trades. Related reliability estimates are used to perform an FA analysis in order to inform the sustainability of the capability the planned satellite or constellation is to provide, and to assess the replenishment and sparing that would be needed to maintain this capability over time. FA is also sometimes known as constellation availability or constellation reliability, and is a cornerstone of constellation risk assessment (See <https://aerospace.org/article/satellite-constellation-risk-assessment>). Note that each constellation must specify an availability goal, which is causally related to the risk posture of the constellation owner. Constellations with minimal risk tolerance (e.g. GPS) maintain high availability goals, while those with a higher risk tolerance will use a lower availability goal.

Key inputs to functional availability include the individualized reliability functions of the constellation's constituent satellites, up to and beyond design life, probability of success estimates for launch vehicles planned to deliver satellites to orbit, success requirements and design of the constellation, and launch schedules and strategies. Aerospace ATR-2019-01877 - Functional Availability (FA) Analysis describes the process of performing functional availability analysis and tailoring that analysis to the level of resources and design detail available. Even if the planned satellite is only intended as a technology demonstration, if the program is successful it may turn into a valuable capability, and some thought should be given to the ongoing level of resources that would be required to sustain that capability over time.

FA is typically performed via Monte Carlo simulation. In the course of a typical FA simulation for a satellite constellation, lifetimes of each constituent satellite are sampled from that satellite's unique reliability function, as are the outcomes of events such as satellite launches that can be modeled as Bernoulli trials. Pre-established or dynamically adjusted launch schedule information is combined with these sampled lifetimes and outcomes in order to track the constellation's state over time. That state is then compared against the functional success criteria⁶ (FSC). Statistics are calculated over thousands of Monte Carlo trials in order to predict the probability of constellation success (i.e. FA) over time. In an iterative process, launch schedules and strategies, satellite capability and count, and/or reliability inputs are adjusted until the predicted FA remains above the desired threshold for the duration of the mission epoch.

⁶ Functional Success Criteria (FSC) are usually determined from performance simulation tools or by developing reliability models reflecting requirements of the system or mission. The criteria are usually defined by stakeholders based on the requirements of each mission. FSCs can be defined at the satellite level, payload level, function level, and subsystem level. A simple FSC example is the successful operation of a given channel on a communications satellite. Another example is a satellite level FSC defined as the number of operational payloads of a single type. In computing FA, one must also consider modeling degraded capabilities of satellites and how they contribute to the constellation success criteria.

As demonstrated in Aerospace ATR-2019-01877 - Functional Availability (FA) Analysis, after specifying an availability goal and FSC (a minimum number of total satellites or satellites per plane is a usual starting point), FA analysis can be used to predict how many satellites and launch vehicles will be needed in the foreseeable future, which can in turn inform cost assessments. Sensitivity analyses should then be performed to ascertain how improvements to satellite reliability, whether through added redundancy, improved part quality, extended wear out life, or enhanced mission assurance might impact the number of satellites and launch vehicles needed over a given time frame, and therefore the life cycle cost of the constellation.

While such improvements to reliability would in general impact the unit cost of each satellite purchased, FA analysis may show that predicted life cycle cost is decreased. Conversely, FA may show that buying large numbers of inexpensive and unreliable satellites results in lower life cycle cost than buying a small number of expensive and highly reliable satellites. The results will of course depend upon the specifics of the satellite designs and constellation configurations chosen. Also important to consider when performing FA analysis is the possibility of the loss or degradation of satellites due to causes not typically captured in satellite or launch vehicle reliability analysis, such as space weather events, micrometeoroid or orbital debris, or actions taken by hostile actors (collectively known as extrinsic risks). Another risk to consider, known as effectiveness risk, expresses the risk of longer-lived, less frequently launched satellites becoming obsolete. These additional risks may be modeled with functions similar to reliability curves and factored into FA analysis, which may favor larger numbers of lower-reliability satellites when assessing life cycle cost. Figure 3.3-1 depicts the results of an FA analysis for a 25-satellite constellation, where FA results are compared between a baseline case and a case where a risk is identified that negatively impacts the reliability prediction of a soon-to-launch satellite.

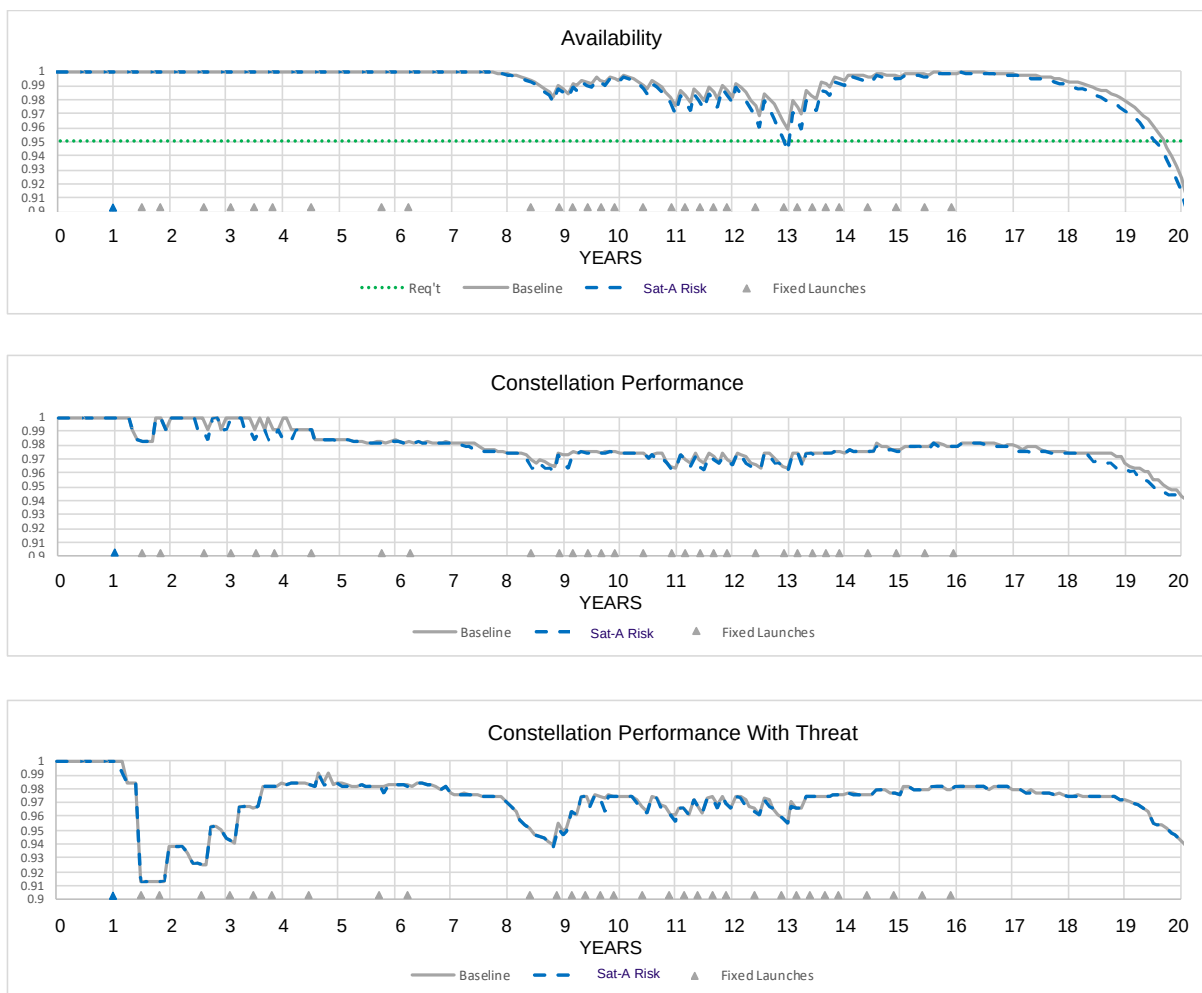


Figure 3.3-1. Functional availability analysis used to assess technical risk for a 25-satellite constellation.

The first panel in the figure plots the probability of constellation success, i.e. FA, as a function of time, where success means having at least 25 operational satellites in the constellation. Note that the figure starts at time 0 with FA=1, and FA remains near 1 for at least 7 years. This implies that at the time of analysis the constellation studied would have had several spare satellites on orbit beyond the 25 required for success. The triangles shown along the x-axis depict the planned launches of replenishment satellites, and predicted availability shows a corresponding improvement shortly after each planned launch. After about 16 years, where replenishment launches are no longer programmed, availability gradually decreases and will eventually become zero, as a function of the decreasing reliability predictions of the remaining satellites. The two curves plotted represent the availability of the constellation with baseline modeling assumptions (gray), and with the impact of a technical risk that decreases the reliability prediction of a soon-to-launch satellite (dashed blue), perhaps due to the usage of an alternate grade part. The dashed green line represents the availability goal of the constellation. Replenishment launches are planned to assure that the predicted availability remains above this goal.

The second and third panels in the figure depict predictions of a direct measure of constellation performance, which complement the availability predictions in the first panel by demonstrating the performance a user can expect from the constellation. The results in the second panel are derived using the same reliability, schedule, and risk assessment assumptions as the availability results in the first panel.

The results in the third panel depict the performance of the constellation if its resilience is tested by introducing an additional extrinsic risk to the constellation that is likely to cause the loss of several satellites between years 1 and 2. The type of risk assessment illustrated in this example represents just one potential usage of FA analysis; but the ability of FA to translate from thinking about individual satellite reliability to constellation- and mission-level success has myriad applications in space system design and architecture planning. In particular, FA is a valuable tool to understand how the reliability implications of part selection will impact mission success, cost, and user satisfaction over the life cycle of a program.

3.4 Mission Capabilities Definition and Planning

Defining and planning the capabilities of a mission drives decisions about how the system will subsequently be designed, built, tested, and operated. The more clearly the users and acquirers can articulate the needed capabilities, the more quickly and effectively requirements can be developed and successfully implemented by a contractor team within program cost, schedule, performance, and risk constraints. This section provides suggestions for defining and planning mission capabilities for programs with *Constrained*, *Limited*, *Some*, and *Many* mission assurance resources available to reduce risk throughout the life cycle. The guidance provided here does not intend to tell programs what to do or how to do it. Rather, the goal is to lay out options and considerations that can be traded based on specific programmatic needs. The history of successfully executed programs, the body of program studies and acquisition research, and the experience of seasoned experts all attest to the significant and long-lasting program benefit gained by defining the mission's capabilities with discipline and purpose up front. In short, doing so is the hallmark of competent end-to-end systems engineering.

Although many more are also relevant, five of the most essential enablers are identified here for consideration and are worthy of time investment up front. They fall into the areas of Enabling Concept, Analysis of Alternatives, Systems Engineering Approach, Interfaces, and Integration and Test.

3.4.1 General Suggestions and Considerations

3.4.1.1 Enabling Concept

Clearly define the program objectives based on mission needs agreed to by the user community and stakeholders. Discuss how reasonable the program objectives are, given multiple stakeholder and user interests.

Define outcome-based performance measures that are linked to the user's strategic goals and maintain only those requirements necessary for achieving the intended mission purpose.

Understand and manage the alignment of the program objectives with the program's business case.

3.4.1.2 Analysis of Alternatives

Even if done only informally, an analysis of alternatives can help identify solutions or approaches that are unlikely to deliver the necessary capabilities or breach cost or schedule constraints.

Take the time to define key risks and their costs, as well as the level of risk tolerance for all viable alternatives.

The analysis of alternatives should include implementation of both the architecture and the specific solution. This is a high leverage point for affecting affordability.

3.4.1.3 Systems Engineering Approach

Establish the amount of leeway granted to trade functionality for timely delivery and reasonable costs, as long as KPPs are met. Ensure functionality is consistent with the concept of operations and expectations agreed upon by the users and stakeholders.

Decompose the system requirements and applied KPPs or, where not applicable, establish performance requirements for each functional area and interface. Review any qualification requirements, baseline processes, manufacturing control flow plans, and key process points to ensure requirements are satisfied end-to-end. Involve any test organizations early and often in order to ensure all requirements are testable and truly reflect what users need.

Plan a high-level FMEA and regular iterations, involving both hardware and software, to support system development and testing, and required responses to various errors and anomalous conditions.

3.4.1.4 Interfaces

To prevent any changes to characteristics that would affect compatibility with other boards, units, or subsystems, define and document electrical/functional, mechanical/physical, software and data communications interfaces within a system. Use an Interface Control Document (ICD) or process to ensure the subsequently detailed designs and construction adhere to the limits imposed by the ICD.

Work to identify and minimize external interface complexities, including dependencies on other programs, and seek to mitigate any complexities that could impact stability of requirements.

Use the respective interfaces assigned to the functional areas of responsibility to establish a set of tiered, traceable requirements. Verify the inter-related sides of an interface by testing or measurement to meet requirements.

3.4.1.5 Integration and Test

Evaluate assembly and integration processes, sequencing, and Integration and Test (I&T) schedules to ensure they enable successfully building up the spacecraft from the lowest level of assembly to a fully integrated system.

Assemble and examine integrated hardware and software elements at all levels of assembly to detect flaws or problems that might surface at higher levels of assembly, potentially causing expensive rework or loss of mission.

Perform Day in the Life (DITL), end-to-end testing, where the system elements are exercised as they would be during flight or on-orbit mission, controlling the flight equipment and SW by ground equipment and SW that will be used to operate it when fielded.

3.4.2 Specific Guidance by Taxonomy Level

3.4.2.1 Constrained

3.4.2.2 Enabling Concept

Develop an Enabling Concept, Operating Concept, and high-level goals that document user or customer needs. Use these concepts to inform objective-level Key Performance Parameters.

3.4.2.3 Analysis of Alternatives

Conduct an Analysis of Alternatives (AOA) or an equivalent exercise to survey the range of viable solutions. The analysis should include consideration of architectures, segments, costs, schedules, performance implications, and ability to satisfy the operational and technical requirements. Choose the option that best matches the developer's skill set and capabilities.

3.4.2.4 Systems Engineering Approach

Implement a systems engineering approach to translate the operational needs into the mission and architectural solution. Establish a technical baseline for the program.

3.4.2.5 Interfaces

Identify technical and segment (external) interfaces and the potential for incompatibilities. Accept, communicate, and document that such risks will not be mitigated due to constrained budget and schedule.

3.4.2.6 Integration and Test

Establish and document a high-level integration strategy or plan for the program. This includes an I&T Integrated Master Schedule (IMS).

3.4.2.7 Limited

3.4.2.8 Enabling Concept

Develop an Enabling Concept, Operating Concept, and high-level goals that document user or customer needs. Use the Enabling Concept and Operating Concept to inform objective-level Key Performance Parameters decisions. Identify objectives that should be formalized as requirements within the constraints of *Limited* resources.

3.4.2.9 Analysis of Alternatives

Conduct an AOA or an equivalent exercise to survey and prioritize the range of viable solutions. The analysis should include consideration of architectures, segments, costs, schedules, performance implications, and ability to satisfy the operational and technical requirements. Choose the option that best matches the developer's skill set and capabilities.

3.4.2.10 Systems Engineering Approach

Implement a systems engineering approach to translate the operational needs into the mission and architectural solution. Establish a technical baseline for the program. Prepare a plan for mission analysis

and requirements allocation and verification activities. As applicable, use analytical tools, simulations, prototyping and trade-off analyses to synthesize and develop, and ensure a self-consistent set of program requirements that are expected to meet user needs within resources available.

3.4.2.11 Interfaces

Identify technical and segment (external) interfaces and metrics and apply minimal mitigation of the potential for incompatibilities. Consider interface margins. Accept, communicate, and document rationale for the approach due to limited budget and schedule.

3.4.2.12 Integration and Test

Establish and document a high-level integration strategy or plan for the program. Translate the strategy into action plans (I&T plan, on-orbit plan, etc.) This includes an I&T IMS.

3.4.2.13 Some

3.4.2.14 Enabling Concept

Develop an Enabling Concept, Operating Concept, and high-level goals that document user or customer needs. Use the Enabling Concept and Operating Concept to inform threshold-level Key Performance Parameters decisions. Prioritize the formalized threshold-level requirements and implement them within the constraints of available resources (trade performance vs. resources).

3.4.2.15 Analysis of Alternatives

Conduct a formal AOA to gain a full understanding of the range of viable solutions. The analysis should include consideration of architectures, segments, costs, schedules, performance implications, and ability to satisfy the operational and technical requirements. Consider adding risk factors to analyses.

3.4.2.16 Systems Engineering Approach

Implement a systems engineering approach to translate the operational needs and requirements into the mission and architectural solution. Prepare a plan for mission analysis, system synthesis, requirements analysis and allocations, and requirements/specification development and validation activities; formalize requirements and verification analysis and processes (e.g., DOORS-Dynamic Object-Oriented Requirements System, ReqSuite, Caliber). As applicable, use analytical tools, simulations, prototyping and trade-off analyses to synthesize and develop, and ensure a self-consistent set of program requirements that are expected to meet user needs within resources available. Establish a technical and programmatic baseline for the program.

3.4.2.17 Interfaces

Identify technical and segment (external) interfaces and metrics and apply modest mitigation of the potential for incompatibilities. Analyze interface margins and failure modes. Accept, communicate, and document rationale for the approach.

3.4.2.18 Integration and Test

Establish and document a high-level integration strategy or plan for the program. Translate the strategy into action plans (I&T plan, on-orbit plan, etc.) with priorities and informal metrics. This includes an I&T IMS.

3.4.2.19 Many

3.4.2.20 Enabling Concept

Develop an Enabling Concept, Operating Concept, and high-level goals that document user or customer needs. Use the Enabling Concept and Operating Concept to inform threshold-level Key Performance Parameters decisions. Prioritize the formalized threshold-level requirements and implement them within the constraints of available resources (trade performance vs. resources)

3.4.2.21 Analysis of Alternatives

Conduct a formal AOA to gain a full understanding of the range of viable solutions. The analysis should include consideration of architectures, segments, costs, schedules, performance implications, and ability to satisfy the operational and technical requirements. Consider adding risk factors as part of quantitative analysis.

3.4.2.22 Systems Engineering Approach

Implement a systems engineering approach to translate the operational needs and requirements into the mission and architectural solution. Prepare a plan for mission analysis, system synthesis, requirements analysis and allocations, and requirements/specification development and validation activities; formalize requirements, allocation, derivation, and verification analyses and processes (e.g., DOORS-Dynamic Object-Oriented Requirements System, ReqSuite, Caliber). As applicable, use analytical tools, simulations, prototyping and trade-off analyses to synthesize and develop, and ensure a self-consistent set of program requirements that are expected to meet user needs within resources available. Establish a technical and programmatic baseline for the program.

3.4.2.23 Interfaces

Identify technical and segment (external) interfaces and metrics and apply modest mitigation of the potential for incompatibilities. Analyze interface margins and failure modes. Establish interface and boundary KPIs for trending and analysis. Accept, communicate, and document rationale for the approach.

3.4.2.24 Integration and Test

Establish and document a high-level integration strategy or plan for the program. Translate the strategy into action plans (I&T plan, on-orbit plan, etc.) with priorities and formal metrics. This includes an I&T IMS.

3.5 Design Assurance

3.5.1 General Suggestions and Considerations

Complex space systems require a number of tools and processes to ensure that the product will have the best chance to meet its requirements throughout its design, qualification, integration, and operation phases. The design assurance activity provides this framework which involves planning and verification activities that are embedded within other design processes throughout the product life cycle.

This area of mission assurance consists of three key aspects in a vehicle's design effort—Design Standards, Design Management and Design Execution.

3.5.2 Specific Guidance by Taxonomy Level

Each suggested activity within the program class (Constrained resources through *Many* resources) is progressively additive. That is, a program with *Limited* resources should be able to implement the design assurance activities of a *Constrained* program as well as those listed in the *Limited* class.

3.5.2.1 Constrained

3.5.2.2 Design Standards

Significant deviations - Developer uses existing in-house design standards and discipline. Developer institutes lessons learned and risk mitigation strategies at the preliminary design phase.

3.5.2.3 Design Management

Key Performance Parameters (KPPs) are identified in clear, comprehensive, and concise terms and the design baseline satisfies mission requirements. Nonconformance and noncompliance procedures are in place with tracking performed at higher level design management team only. Design margin verifications are performed on only critical KPPs.

Space system technology readiness and a risk burn-down plan are assessed, and applicable space system hardware and software functions are described in the space system specification.

3.5.2.4 Design Execution

The specialty engineering functions support design processes. Apply "design for manufacturing and assembly" and "design for test" standards and a well-defined software engineering process during design. Develop and control requirements for most complex and/or critical interfaces, in Interface Control Documents (ICDs) for example. Develop a streamlined WCCA plan at PDR (Preliminary Design Review) and perform prior to CDR (Critical Design Review) on electrical interfaces to discover part or circuit deficiencies and verify that all interface types will remain within specification throughout the mission life. Complete FMEA at component and subsystem levels and Mission Critical Fault Analysis. Subject matter experts are available to support design development and reviews, but on a limited basis.

All elements are single string; no redundancy schemes are applied. Evaluate electrical and mechanical design integration.

3.5.2.5 Limited

3.5.2.6 Design Standards

Moderate deviations - Developer augments in-house standards with readily accessible content from broader space industry's design standards.

3.5.2.7 Design Management

Developer establishes management and design assurance procedures. Developer follows established processes to track nonconformances and corrective actions as applicable. TRL (Technology Readiness Level) processes are well characterized and understood and are described in procedures. Electrical interfaces are managed within the higher-level project management team to ensure the appropriate level of end-to-end visibility.

3.5.2.8 Design Execution

Perform trade studies to assign assembly-level redundancy and anomaly recovery schemes, e.g., dual, or triple strings, single or dual fault tolerant. Perform trade studies to identify dead bus recovery capability versus constraints. Ensure that the dead bus recovery CONOP (Concept of Operations) is consistent with the defined dead bus recovery functions and agreed to by the customer. Document a clear method for Day in the Life (DiTL) testing.

SMEs are readily available to support development and reviews and are required to attend all major milestone reviews.

3.5.2.9 Some

3.5.2.10 Design Standards

Minor deviations - Developer adopts modified version of American Institute of Aeronautics and Astronautics (AIAA), NASA or military space design standards. There is a formal process to incorporate lessons learned into command media or corporately established technical approaches and design guides. The awareness and use of the media are at the program's discretion.

3.5.2.11 Design Management

Developer establishes formal management and design assurance procedures. Quantitative objectives are established for TRL process performance and uses them as criteria in managing processes. Design margin verifications are performed for all KPPs and are examined regularly in review boards. A program-level Change Control Board consisting of multiple disciplines is established with broad participation to ensure that potential impacts of proposed changes are examined across the system. Key personnel are trained in design assurance discipline and processes.

3.5.2.12 Design Execution

Perform trade studies to assign sub-system and system-level redundancy and anomaly recovery schemes, e.g., dual, or triple strings, single or dual fault tolerant. ICDs are fully developed and controlled for all interfaces. There is clear documentation of the method for designing operationally realistic Test Like You Fly (TLYF) and identifying associated TLYF exceptions. For each mission-ending failure situation,

develop a work product describing methods and associated artifacts for identifying potential fault paths and contributors. SMEs provide written design guides in key design areas.

3.5.2.13 Many

3.5.2.14 Design Standards

Few deviations - Developer adopts AIAA, NASA or military space design standards intact. Lessons learned and significant risk mitigation actions are continuously embedded into command media and design guides. Updated media is regularly provided to team members via training or notices from the enterprise.

3.5.2.15 Design Management

Design audits are performed at several levels of maturity throughout the design, and resolution plans are tracked to completion. Electrical interfaces are actively managed by a dedicated system engineer. All personnel are trained in design assurance discipline and processes.

3.5.2.16 Design Execution

Design development and changes are analyzed and documented regularly by an Interface Control Working Group and ownership of the integrated design is assigned to an Integrated Product Team. A comprehensive WCCA plan, performance, and closure is done prior to hardware qualification. Develop mission critical events and critical contributors or derive them from existing work products.

There is a network of SMEs who are readily accessible and is utilized by the project at all stages. They are certified through a standard process and are recognized for their expertise. Knowledge sharing includes ownership of design guides which are maintained regularly.

3.6 Knowledge of Providers Business Model Viability

3.6.1 General Considerations and Suggestions

The microelectronics industry is cyclical and characterized by high costs associated with developing marketable products and manufacturing technologies as well as very high levels of investment in production capabilities. The microelectronics industry has endured several boom-and-bust cycles over the last three decades including an unprecedented challenge from the COVID-19 pandemic to electronic components supplier's financial viability and their supply chains. Given the dynamic and ever-changing nature of the microelectronics industry, understanding the financial health and business viability of the electronic component supplier should also be a key factor in the decision-making process of developers' and customers' in the balancing of their mission assurance efforts.

There are several business factors that should be considered by government and developers when assessing advanced electronic components for mission assurance. The key attributes that can be extremely important in the decision-making process of business viability for mission assurance includes the following:

Industry Ranking and Reputation (IRR): How a supplier is viewed by its peers and competitors is a critical piece to understanding the long-term viability of the supplier. Is the supplier a market leader (i.e.

size of its production within its respective product category and breadth of product offerings) and recognized for its leadership and product positioning validated by industry and customer awards?

Financial Strength Metrics: includes the market capitalization of a company, annual revenue, and cash flow proxy.

- Market Capitalization - is called market cap and is the market value of a publicly traded company. The market capitalization of a company is calculated by multiplying the number of stock shares outstanding by the current stock price. The market cap of a company typically corresponds to a company's stage in its business development. A large cap company is more mature, established and well known while small cap companies are on the opposite end of that spectrum. Small cap companies are young companies or ones that serve niche markets and/or emerging industries.
- Revenue - is the value of all sales of goods and services recognized by a company over a period of time. If a company's year-over-year revenue is decreasing and declining at a rate greater than industry fundamentals and its peers, this is an indicator that there are underlying deficiencies in the business model.
- Cash Flow Proxy - cash flow is vital to the operation of the business. It helps the company keep up with short-term expenses along with debt payment obligations. A slowdown in cash flow can result from a variety of factors such as declining revenue, dividend payouts, insufficient accounts receivables, poor investments, or an underlying deficiency in the business model.

Domestic or Foreign ownership: The microelectronics industry has had significant consolidation over the last two decades with over 90 companies both public and private no longer existing as separate entities. This consolidation has resulted in companies that are headquartered in the United States, but through consolidation are now foreign owned. Foreign owned companies may have significant ramifications on the integrity of security in their products and supply chain that is not aligned with government and mission assurance.

The knowledge of these business viability factors will provide a transparent assessment on whether the government and the provider's business needs align well enough to conduct transactions. This knowledge will also help determine the likelihood of a consistent source of electronic products that meet program requirements and if the products are being produced by one or more providers that are either domestic or foreign.

In the context of this section, the following designations apply. Depending upon the scenario (*Constrained, Limited, Some, Many*) and the program risk posture, the following supplier types may be considered with IRR representing Industry Ranking and Reputation.

Industry Ranking and Reputation (IRR 1) - Supplier is viewed by its peers and competitors as a market leader being one of the largest producers with broadest product offerings and is recognized as leader in the industry which can be measured by having won awards from its customers or suppliers.

Industry Ranking and Reputation (IRR 2) - Supplier is viewed by its peers and competitors as a broad-based provider and recognized as a strong supplier in the industry which can be measured by having won awards from its customers or suppliers.

Industry Ranking and Reputation (IRR 3) - Supplier is viewed by its peers and competitors as a niche supplier with a limited product offering.

3.6.2 Specific Guidance by Taxonomy Level

3.6.2.1 Constrained

Industry Ranking and Reputation:

- IRR 1 - Supplier is viewed by its peers and competitors as a market leader being one of the largest producers with broadest product offerings and is recognized as leader in the industry which can be measured by having won awards from its customers or suppliers.

Financial Strength:

- Market Capitalization: Large-Cap >\$10 billion to Mid-Cap > \$5 billion
- Revenue: > \$2 billion.
- Cash Flow Proxy: Very profitable

Supply Chain Characteristics (Domestic or Foreign):

- Trusted Foundry, International Traffic in Arms Regulations (ITAR), Space Grade Products, Domestic ownership.

3.6.2.2 Limited

Industry Ranking / Industry Reputation:

- IRR 1 and IRR 2

Financial Strength for IRR 1:

- Market Capitalization: Large-Cap >\$10 billion to Mid-Cap > \$5 billion
- Revenue: > \$2 billion.
- Cash Flow Proxy: Very profitable

Financial Strength for IRR 2:

- Market Capitalization: Mid-Cap = > \$5 billion to Small-Cap = > \$2 billion
- Revenue: > \$100 million.
- Cash Flow Proxy: Profitable.

Supply Chain Characteristics (Domestic or Foreign):

- Trusted Foundry preferred, but not required, ITAR preferred, but not required, Space Grade Products preferred, but not required. Domestic ownership preferred, but not required.

3.6.2.3 Some

Industry Ranking / Industry Reputation:

- IRR 1 and IRR 2

Financial Strength for IRR 1:

- Market Capitalization: Large-Cap >\$10 billion to Mid-Cap > \$5 billion
- Revenue: > \$2 billion.
- Cash Flow Proxy: Very profitable

Financial Strength for IRR 2:

- Market Capitalization: Mid-Cap = > \$5 billion to Small-Cap = > \$2 billion
- Revenue: > \$100 million.
- Cash Flow Proxy: Profitable.

Supply Chain Characteristics (Domestic or Foreign):

- Trusted Foundry preferred, but not required, ITAR preferred, but not required, Space Grade Products preferred, but not required. Domestic ownership preferred, but not required.

3.6.2.4 Many

Industry Ranking / Industry Reputation:

- IRR 3 - Use of IRR 1 and IRR 2 suppliers are also feasible if resources permit.

Financial Strength:

- Minimum Market Capitalization: Small Cap < \$1 billion to private
- Minimum Revenue: < \$100 million.
- Minimum Cash Flow Proxy: Break-even to unprofitable.

Supply Chain Characteristics (Domestic or Foreign):

- Domestic ownership preferred, but not required.

3.7 Cost and Schedule Estimating

3.7.1 General Considerations and Suggestions

Cost and schedule estimates are critical to any program's success and yield the most benefit when addressed early and often during the life cycle as events change. The purpose of cost and schedule analyses is to help define cost-effective systems that can be delivered in a timeframe that meets customer needs, inform program planning, develop schedule, budget and affordability estimates, and assist in contract negotiations. Cost and schedule are tightly coupled because with every cost comes an implied schedule.

The cost and schedule estimating process consists of the three phases of Preparation, Execution and Communication shown in Figure 3.7.1-1. The scope and depth of each phase can be scaled to match the program scenario (*Constrained, Limited, Some, Many*).

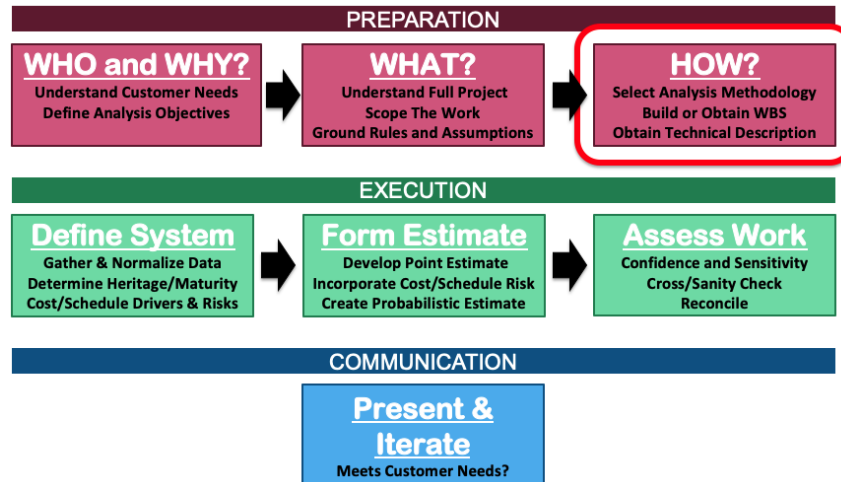


Figure 3.7.1-1. Generic cost and schedule analysis process.

3.7.2 Specific Guidance by Taxonomy Level

3.7.2.1 Constrained and Limited

The cost and schedule analysis recommendations are the same for the *Constrained* and *Limited* scenarios. The difference is that more detail and fidelity should be expected in the activities and products for the *Limited* scenario than the *Constrained* scenario. In other words, moving from the *Constrained* resource scenario to the *Many* resource scenario represents increased cost and schedule content. This results in higher quality cost and schedule products as tools to help balance the mission assurance resource trades and risks.

Very constrained schedule, cost, and resources available for alternate grade electronics mission assurance. IMS and cost do not allow significant confirmation of capability beyond *Constrained* case.

Recommended Schedule Related Activities and Products:

- Master Phasing Schedule showing the time relationship between launch, space, and ground segments
 - Disclose the plan for the respective acquisition strategies
- Sequencing and allocated time for performing schedule analyses
- Product/Process Flowchart for Integration & Test
- Primary and Secondary Critical Path Analysis
- Schedule Drivers Assessment
- Sensitivity Analysis
- Subcontractor Impact
- Schedule Risk Assessment (SRA) + SRA Report

Recommended Cost Related Activities and Products:

- Purpose of the cost analysis, including the scope and conditions for the estimate
- Secure a clear technical description of the target system for the cost analysis
- State any ground rules and assumptions, and bound the problem by limiting analysis or inference to the practical
- Clearly communicate and document the methodology to be used for the analysis and estimate
 - Methodologies may include using
 - Analogies to similar programs
 - Parametric statistical models that use system parameters or attributes
 - Grass Roots bottoms-up methodology that combines individual estimates for each element of the overall system
 - Extrapolation that predicts cost to complete based on performance to date
- State definitions (e.g., year dollars)
- Document the schedule (specified or implied), documenting the beginning, transition, and end of the program
- Develop a cost summary based on cost models or cost data available
- Assess the fidelity and quality of the estimate
- Review the realism of the cost estimate in light of the system's operations concept
- Document any potential impacts to the cost estimate due to market conditions
- Assess the feasibility of the cost estimate in light of the acquisition strategy

3.7.2.2 Some and Many

The cost and schedule analysis recommendations are the same for the *Some* and *Many* scenarios. The difference is that more detail and fidelity should be expected in the activities and products for the *Many* scenario than the *Some* scenario. In other words, moving from the *Constrained* to *Many* resources scenario represents increased cost and schedule content. This results in higher quality cost and schedule products as tools to help balance the mission assurance resource trades and risks.

Recommended Schedule Related Activities and Products:

- Run schedule diagnostics
- Master Phasing Schedule showing the time relationship between launch, space, and ground segments
 - Disclose the plan for the respective acquisition strategies
- Sequencing and allocated time for performing schedule analyses
- Product/Process Flowchart (for Design, Development, Integration & Test)
- Critical Path Analysis (Primary, Secondary, Tertiary)
- Schedule Drivers Assessment
- Subcontractor Impact
- Sensitivity Analysis
- Duration Analysis
- Historical/Comparable Data Analysis
- Subcontractor Detailed Assessment
- SRA + SRA Report
- Develop Best/Worst Case Models and provide recommendations

Recommended Cost Related Activities and Products:

- Purpose of the cost analysis, including the scope and conditions for the estimate
- Secure a clear technical description of the target system for the cost analysis
- State any ground rules and assumptions, and bound the problem by limiting analysis or inference to the practical
- Clearly communicate and document the methodology to be used for the analysis and estimate
 - Methodologies may include using
 - Analogies to similar programs
 - Parametric statistical models that use system parameters or attributes
 - Grass Roots bottoms-up methodology that combines individual estimates for each element of the overall system
 - Extrapolation that predicts cost to complete based on performance to date
- State definitions (e.g., year dollars)
- Document the schedule (specified or implied), documenting the beginning, transition, and end of the program
- Develop a cost summary based on cost models or cost data available
- Assess the fidelity and quality of the estimate
- Review the realism of the cost estimate in light of the system's operations concept
- Document any potential impacts to the cost estimate due to market conditions
- Assess the feasibility of the cost estimate in light of the acquisition strategy

3.8 Acquisition and Contracting

3.8.1 Introduction

This section provides an overview of the Adaptive Acquisition Framework and the pathways for distinct types of acquisitions across the DoD. It also describe a set of potential contracting strategies and contract types available for program managers to use for acquiring systems that make use of alternate grade electronics.

3.8.2 Adaptive Acquisition Framework

The latest version of DoDI 5000.02 describes multiple adaptive acquisition pathways that enable streamlined delivery of capabilities to the warfighter. Under this framework, there are a set of acquisition pathways that a program can use to guide their acquisition. Figure 3.8.2-1 illustrates the Adaptive Acquisition Framework.

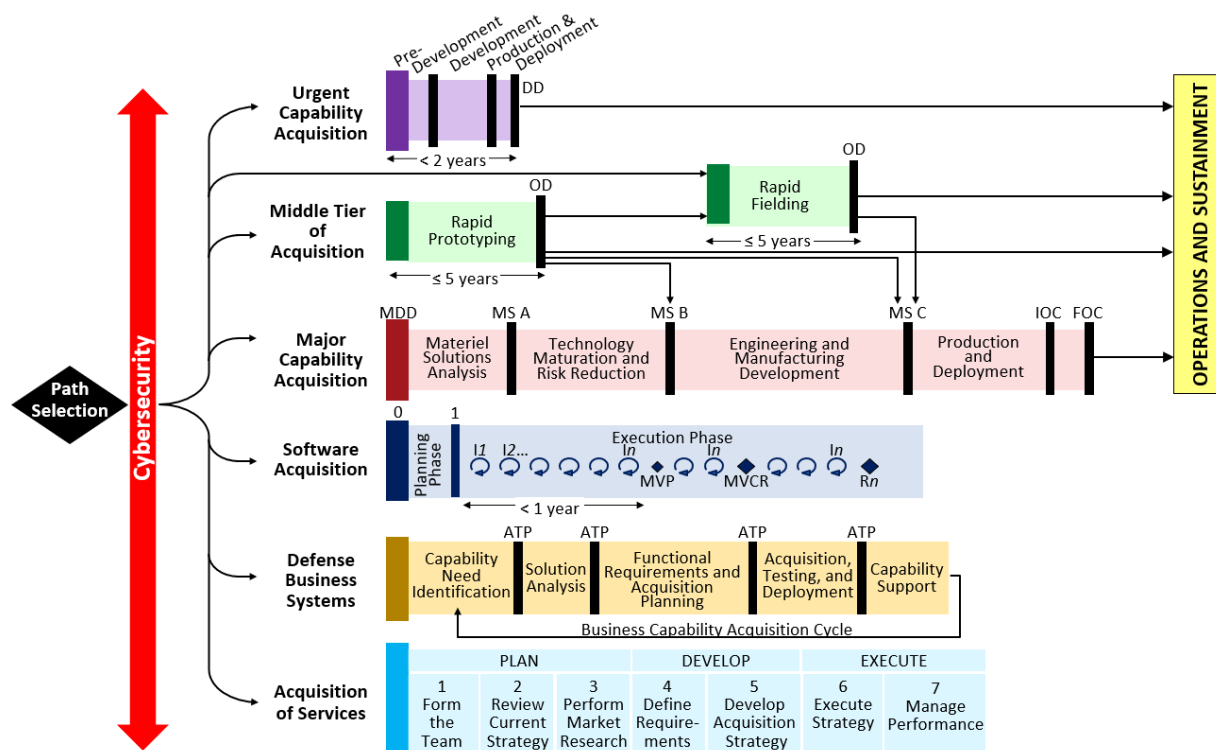


Figure 3.8.2-1. Adaptive acquisition framework.

Urgent Capability Acquisition and Middle Tier of Acquisition are the most appropriate acquisition pathways for EPIC Speed acquisitions of all types (*Constrained, Limited, Some, and Many*). We also identified Major Capability Acquisition as an alternative pathway that can be implemented for acquisitions of type *Many*. Next we provide an overview for each of these acquisition pathways.

3.8.2.1 Urgent Capability Acquisition

This pathway is for fielding capabilities to fulfill urgent existing and/or emerging operational needs or quick reactions in less than 2 years. Acquisition program offices employing this pathway fast-track their normal acquisition processes such as product support and sustainment, reviews, and documentation due to operational urgency. Research, development, and test and evaluation costs must not exceed \$525 million, or \$3.065 billion procurement in Fiscal Year 2020 constant dollars. The timelines for planning the capability is measured in weeks and for development and production measured in months, with a goal to quickly deliver useful capability to the warfighter in a timely fashion. Figure 3.8.2-2 illustrates the Urgent Capability Acquisition Pathway.

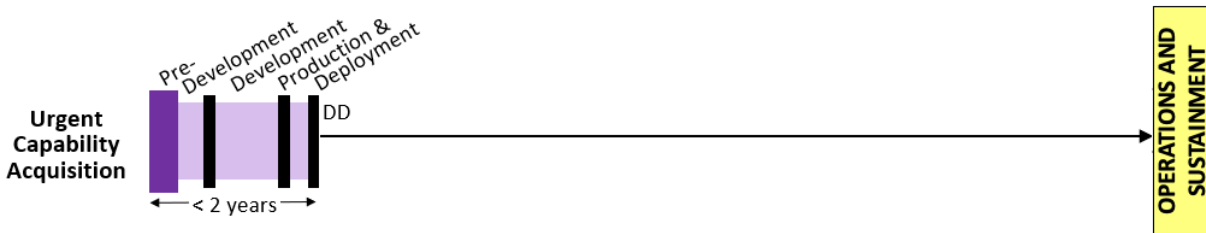


Figure 3.8.2-2. Urgent capability acquisition pathway.

3.8.2.2 Middle Tier of Acquisition (MTA) (Section 804)

The MTA pathway is intended for capabilities with a maturity level that allows them to be rapidly prototyped within an acquisition program or fielded within 5 years of MTA program start. This pathway may be used for accelerating capability maturation prior to transitioning to another acquisition pathway or may be used to minimally develop a capability before rapidly fielding. This approach was granted by Congress in the FY16 National Defense Authorization Act (NDAA) Section 804 and is not subject to the Joint Capabilities Integration Development System manual and DoD Directive 5000.01 “The Defense Acquisition System”. Figure 3.8.2-3 illustrates the Middle Tier of Acquisition Pathway.

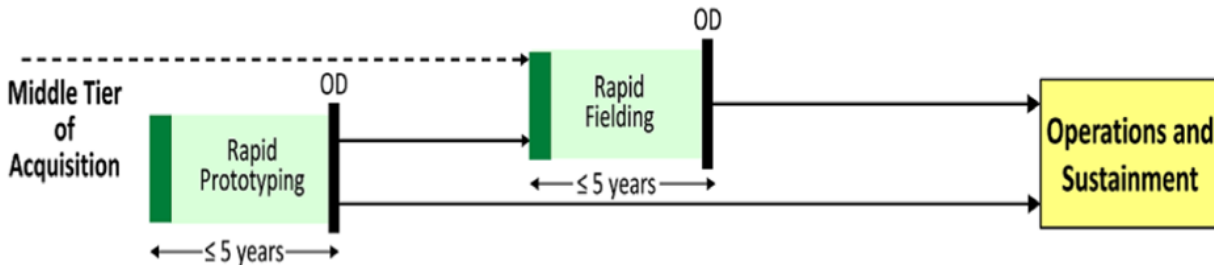


Figure 3.8.2-3. Middle tier of acquisition pathway.

The MTA pathway is comprised of 2 paths, Rapid Prototyping and Rapid Fielding. The rapid prototyping path allows for rapid development of fieldable prototypes using innovative technologies to demonstrate new capabilities and meet emerging military needs. Within this path, the acquisition program will field prototype meeting defined requirements that can be demonstrated in an operational environment and provide for a residual operational capability within 5 years of the MTA program start date. MTA programs may not be planned to exceed 5 years to completion and, in execution, will not exceed 5 years after MTA program start without Defense Acquisition Executive (DAE) waiver.

The rapid fielding path allows for the fielding of production quantities of new or upgraded systems using proven technologies which require minimal development. The acquisition program using this path will begin production within 6 months and complete fielding within 5 years of the MTA program start date. MTA program production start date will not exceed 6 months after MTA program start date without DAE waiver. MTA programs may not be planned to exceed 5 years to completion and, in execution, will not exceed 5 years after MTA program start without DAE waiver.

Not all programs are appropriate for the MTA pathway. Major systems intended to satisfy requirements that are critical to a major interagency requirement or are primarily focused on technology development or have significant international partner involvement should not use the MTA pathway.

3.8.2.3 Major Capability Acquisition

Major Capability Acquisition is the pathway used for acquiring and modernizing military unique programs that provide enduring capability. These acquisitions typically follow a structured approach for analyzing, designing, developing, integrating, testing, evaluating, producing, and supporting major defense acquisition programs. This process is designed to support major defense acquisition programs, major systems, and other complex acquisitions. Acquisition and product support processes, reviews, and documentation is tailored based on the program size, complexity, risk, urgency, and other factors. Figure 3.8.2-4 illustrates the Major Capability Acquisition Pathway.



Figure 3.8.2-4. Major capability acquisition pathway.

3.8.3 FAR and Non-FAR Based Contracting Solutions

Next we discuss the Contracting Cone, which represents the full spectrum of FAR and non-FAR based contracting solutions available. Figure 3.8.3-1 illustrates the Contracting Cone.

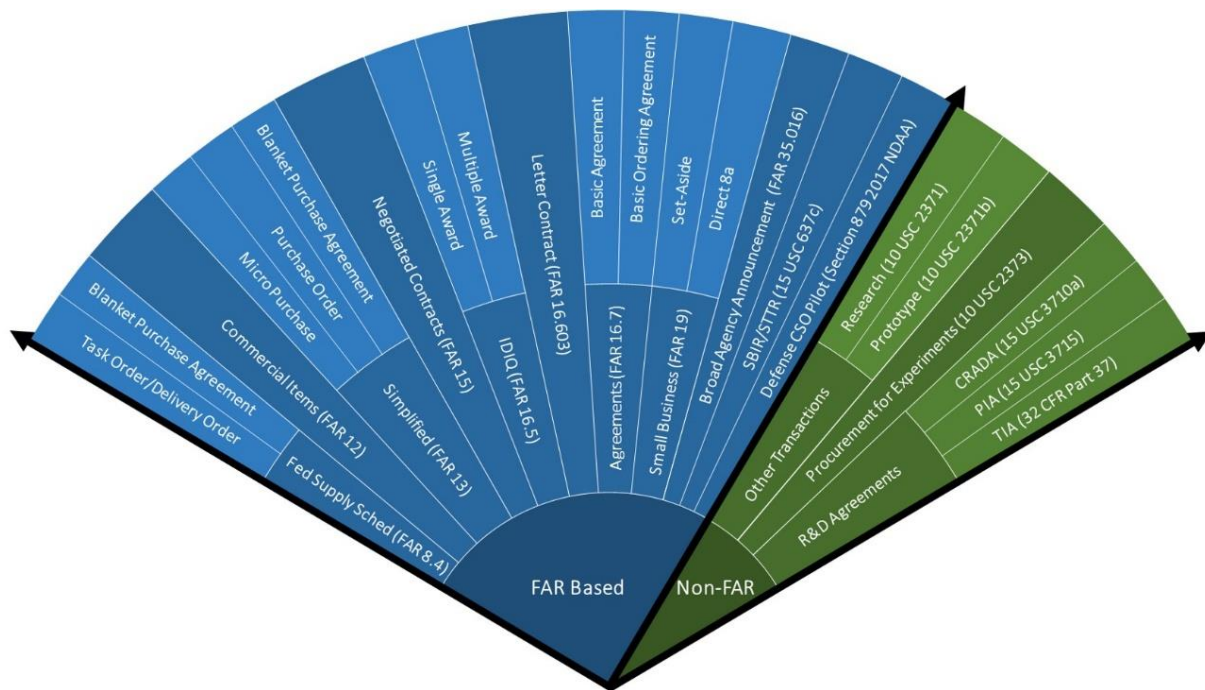


Figure 3.8.3-1. Contracting cone.

The Contracting Cone illustrates the vast array of contract strategy options available for the program office to use depending on the type of acquisition they are embarking on. For the purposes of this TOR we selected a set of these strategies that would be appropriate for the type of missions described herein.

3.8.4 Acquisition and Contracting Solution Descriptions

3.8.4.1 Commercial Items (Federal Acquisition Regulation (FAR) Part 12): Ideal for Constrained, Limited, Some

Supplies and services that meet the definition of a commercial item within the FAR Part 2.1 may be acquired using the streamlined procedures set forth in FAR Part 12. Non-Developmental Item (NDI) and COTS are considered subsets of commercial items. FAR Part 12 establishes acquisition procedures closely resembling those of the commercial marketplace to facilitate the acquisition of commercial items. Commercial items are any item or service customarily used by the general public or non-governmental entities for purposes other than governmental purposes, and:

- Has been sold, leased, or licensed to the general public; or
- Has been offered for sale, lease, or license to the general public.

Common Applications for FAR 12 contracts include COTS Defense Business Systems, COTS solutions and technologies, Commercial products and services, Products and services provided by non-traditional defense contractors, IT products and services, Health IT services and solutions, Cyber services and solutions, Cloud services and solutions, Software licenses, Telecommunications and wireless services, and Mobile solutions.

3.8.4.2 Simplified Acquisitions (FAR 13): Ideal for Constrained, Limited, Some

The procedures in FAR Part 13 provide streamlined processes to acquire supplies and services, including construction, research and development, and commercial items, for which the aggregate amount does not exceed the simplified acquisition threshold (\$250,000 in FY2020).

FAR Part 13.5 authorizes the use of simplified procedures for the acquisition of supplies and services in amounts greater than \$250,000 (in FY2020) and less than \$7 million (\$13 million for acquisitions as described in 13.500(c)), including options, if the contracting officer reasonably expects that offers will include only commercial items.

Simplified acquisition procedures allow contracting officers more procedural discretion and flexibility in soliciting, evaluating and awarding contracts for commercial items within this dollar range. This maximizes efficiency and reduces the burden and administrative costs for both industry and the Government.

There are three main contracting solutions within FAR Part 13:

- Blanket Purchase Agreement: A BPA is a simplified method of filling anticipated repetitive needs for open market supplies and services below the Simplified Acquisition Threshold (SAT). Open market means items not available from required sources of supply, such as GSA schedule contracts, outlined in FAR Part 8.002. BPAs can be single award or multiple award, but multiple awards are preferred.
- Purchase Order: This is a method to acquire open market supplies and services below the Simplified Acquisition Threshold (SAT). Open market means items not available from required sources of supply, such as GSA schedule contracts, outlined in FAR Part 8.002.

- Micro-Purchase: This is a method for procurement of supplies and services below the micro-purchase threshold (\$10,000 in FY2020). Government Purchase Card (GPC) is the preferred method to acquire requirements below the micro-purchase threshold.

3.8.4.3 Defense Commercial Solutions Opening (CSO) Pilot Program: Ideal for Limited

The Defense Commercial Solutions Opening (CSO) Pilot is a competitive program authorized by Section 879 of the FY17 NDAA to obtain solutions or new capabilities that fulfill requirements, close capability gaps, or provide potential technological advances. CSO procedures are similar to those for Broad Agency Announcements (BAAs), with the exception that a CSO can be used to acquire innovative commercial items, technologies, or services that directly meet program requirements, whereas BAAs are restricted to basic and applied research. The CSO program may also be used to acquire R&D solutions from component development through operational systems development.

CSO procedures are also used to award non-FAR based agreements. Specific limitations and requirements apply when using the CSO evaluation procedures and is dependent upon the non-FAR based strategy selected.

Common Applications for Defense CSO include commercial products and services, Information Technology (IT) product and services, R&D studies for commercial technology, Commercial Technology maturation.

3.8.4.4 Indefinite Delivery Indefinite Quantity (IDIQ) (FAR 16.5): Ideal for Limited, Some

IDIQ contracts are designed for cases where the quantity to be purchased and actual delivery dates are unknown. Under this type of contract work is added to the contract via Task Orders (TO) or Delivery Orders (DO). IDIQ contracts provide a method to order from existing agency indefinite-delivery contracts as well as contracts awarded by another agency (i.e. Government-wide Acquisition Contracts (GWACs) and Multi-Agency Contracts).

A GWAC is a task-order or delivery-order contract for information technology established by one agency for Government-wide use. A Multi-Agency Contract (MAC) is a task-order or delivery-order contract established by one agency for use by Government agencies to obtain supplies and services.

New IDIQ contracts can be awarded to a single or multiple vendor.

- A new Single Award IDIQ contract containing the scope of products or services that can be ordered against it may be established and awarded to a single contractor. The base contract has no funding associated with it, and lays out the terms and conditions and pricing, applicable to any orders placed against the base contract.
- A new Multiple Award IDIQ contract containing the scope of products or services that can be ordered against it may be established and awarded to multiple vendors. When the need arises to place orders against the multiple award contract, all awardees holding a base contract are requested to submit a proposal to provide each contractor a fair opportunity to be considered for each order.

Common applications for IDIQ contracts include Defense Business Systems, Solutions and technologies, IT software and products, IT systems, Weapon systems, Aircraft, Ships, Space systems, Research and development, Advisory and assistance services, Engineering services, and Special studies.

3.8.4.5 Negotiated Contracts (FAR 15): Ideal for Some Many

A Negotiated Contracts is any contract awarded based on other than sealed bidding procedures. FAR Part 15 describes the procedures for competitive and non-competitive open market acquisitions exceeding the Simplified Acquisition Threshold (SAT). There are 2 types of negotiated acquisitions, Sole Source Acquisitions and Competitive Acquisitions.

Any combination of source selection approaches can be used to obtain best value in negotiated acquisitions. The relative importance of cost or price may be different for each type of acquisition. In certain acquisitions where the requirements are clearly definable and the performance risk is minimal, cost or price will be more important for source selection. Alternatively, when requirements are less definitive, more development work is required, or performance risk is greater, then technical or past performance considerations play a bigger role in source selection.

Common applications for negotiated contracts include all types of supplies and services (including construction), defense business systems and enterprise resource planning systems, solutions and technologies, IT software and products, to include Agile development, IT systems, weapon systems, aircraft, ships, space systems, research & development, advisory and assistance services, engineering services, and special studies.

3.8.4.6 Broad Agency Announcement (BAA) (FAR Part 35.016): Ideal for Many

BAAs are used for getting proposals for basic and applied research and development to advance or evaluate innovative technologies, not related to a specific system or hardware requirement. BAAs are typically “open,” and proposals accepted for a specified period of time. Proposals submitted in response to BAAs may or may not lead to contracts.

BAAs may be used for science and technology efforts for the following areas:

- Basic research
- Applied research
- Advanced technology development
- Advanced component development and prototypes

Common applications for BAAs include R&D studies, prototypes, Small Business Innovation Research (SBIR) efforts, Science and Technology initiatives, and technology maturation.

3.8.4.7 Other Transactions (OT) (Non-FAR): Ideal for Constrained, Limited, Some

Other Transactions are contractual arrangements that fall outside of standard procurement contracts, grants, or cooperative agreements. OTs can be used for acquiring research and development activities to advance modern technologies, and prototypes or models to evaluate technical or manufacturing feasibility or military utility of new or existing technology. This type of arrangement may apply to processes, concepts, end items, and systems from non-traditional defense contractors allowing the government access to innovative solutions. OTs enable the Government to leverage commercial business practices and remove barriers to entry such as Cost Accounting System (CAS) compliance and intellectual property rights requirements, to encourage non-traditional defense contractors to do business with the Government.

OTs typically use RDT&E funding, but the statute does not prohibit use of other appropriations. OT agreements may be fixed-price, expenditure based, or hybrid.

3.8.4.7.1 Research OTS

Research OTs are used for basic, applied, and advanced research projects associated to weapons systems or other military needs. These OTs are intended to spur dual-use research and development (R&D), taking advantage of economies of scale without burdening companies with Government regulatory overhead, which would make them non-competitive in the commercial (non-defense) sector. Traditional defense contractors are also encouraged to engage in Research OTs, particularly if they seek to adopt commercial practices or standards, diversify into the commercial sector, or partner with NDCs. Research OTs may be used to pursue research and development of technology with dual-use application (commercial and government). Unlike Prototype OTs, Research OTs do not include authority for transition to follow-on production contracts or transactions.

3.8.4.7.2 Prototype OTs

Prototype OTs are appropriate for research and development and prototyping activities to enhance mission effectiveness of military personnel and supporting platforms, systems, components, or materials. Prototype OTs may be used to acquire a reasonable number of prototypes to test in the field before deciding to purchase in quantity.

Prototype OTs are authorized by law to acquire prototype capabilities and allow for those prototypes to transition into Production OTs. Per statute, successful Prototype OTs offer a streamlined method for transitioning into follow-on production without competition. The solicitation and original Prototype OT agreement shall include notice that a follow-on Production OT is possible to allow greater flexibility to those Government organizations planning to leverage production efforts without re-competing. This should also increase competition and reduce the risk of future protest.

3.8.4.8 Defense Innovation Unit (DIU) (Non-FAR): Ideal for Constrained, Limited, Some

The Defense Innovation Unit is a DoD organization under the Office of the Undersecretary of Defense for Research and Engineering (OUSD/R&E). Its purpose is to accelerate DoD adoption of commercial technology, transform military capacity and capability, and strengthen the national security innovation base. DIU works with organizations across the DoD, including the services and components to combatant commands and defense agencies, to rapidly prototype and field advanced commercial solutions to address national security challenges.

DIU's focus areas are Space, Cyber, Artificial Intelligence, Autonomy, and Human Systems. DIU established a process for awarding prototype contracts using OTA with an aim to move from problem identification to prototype contract award in 60-90 days. DIU's prototype projects run from 12-24 months and upon completion may transition to follow-on production-OT agreements or FAR-based contracts.

3.8.5 Contract Types for EPIC Speed

3.8.5.1 Firm Fixed Price: Ideal for Constrained, Limited, Some

This type of contract is used when the requirement is well-defined, contractors are experienced in meeting it, market conditions are stable and financial risks are otherwise insignificant. Under FFP contracts, the contractor assumes all cost risks and is obliged to provide an acceptable deliverable at the time, place and price specified in the contract. The contractor is incentivized by realizing an additional dollar of profit for every dollar that costs are reduced.

FFP Elements include a firm-fixed-price for each line item or one or more groupings of items. FFP contracts are typically used for commercial supplies and services. FFP contracts are not recommended for research and development efforts.

3.8.5.2 Fixed-Price Incentive Firm (FPIF) Target: Ideal for Constrained, Limited, Some

This type of contract is used when a ceiling price can be established that covers the most probable risks inherent in the nature of the work. The proposed profit-sharing formula would motivate the contractor to control costs and to meet other objectives. Under this contract type the contractor is required to provide an acceptable deliverable at the time and place specified in the contract at or below the ceiling price. The contractor's incentive is to realize profit on cost by completing work below the ceiling price. The contractor may also earn a higher profit by incurring costs below the target cost or by meeting objective performance targets.

FPIF elements include ceiling price; target cost; target profit; delivery, quality, or other performance targets; profit sharing formula; 120% ceiling and 50/50 share are points of departure.

FPIF contracts are typically used for production of major systems based on prototypes. FPIF contracts must be justified and negotiated and the contractor must have an adequate accounting system and their cost data must support targets.

3.8.5.3 Fixed Price Award Fee (FPAF): Ideal for Constrained, Limited, Some

FPAF contracts are used when judgmental standards can be fairly applied by the fee determining official. The potential fee is large enough to both provide a meaningful incentive and justify related administrative burdens. Under this contract type the contractor is required to perform at the time, place, and the price fixed in the contract. The contractor is incentivized by realizing an additional dollar of profit for every dollar that costs are reduced and earning an additional fee for satisfying the performance standards.

FPAF elements include fixed-price, award amount, award fee evaluation criteria, and procedures for measuring performance against the criteria. FPAF is typically well suited for performance-based contracts.

3.8.5.4 Cost-Plus-Incentive Fee (CPIF): Ideal for Some, Many

A cost-plus-incentive-fee contract is a cost-reimbursement contract that provides for an initially negotiated fee to be adjusted later by a formula based on the relationship of total allowable costs to total target costs. Under this contract type the Government assumes the risks inherent in the contract, benefiting if the actual cost is lower than the expected cost, or losing if the work cannot be completed within the expected cost of performance.

CPIF Elements include target cost, minimum, maximum and target fees, a formula for adjusting the fee based on actual costs and/or performance, and performance targets.

After contract performance, the fee payable to the contractor is determined in accordance with the formula. The formula provides for increases in fee above target fee when total allowable costs are less than target costs and decreases in fee below target fee when total allowable costs exceed target costs. This increase or decrease is intended to provide an incentive for the contractor to effectively manage the contract. When total allowable cost is greater than or less than the range of costs within which the fee-

adjustment formula operates, the contractor is paid total allowable costs, plus the minimum or maximum fee.

CPIF is typically well suited for services, or development and test programs. This type of contract must be justified and there are statutory and regulatory limits on the fees that may be negotiated. In addition, the contractor must have an adequate accounting system.

3.8.5.5 Cost-Plus Award Fee (CPAF): Ideal for Some, Many

CPAF is a cost-reimbursement contract that provides for a fee consisting of (1) a base amount fixed at inception of the contract, if applicable and at the discretion of the contracting officer, and (2) an award amount that the contractor may earn in whole or in part during performance and that is sufficient to provide motivation for excellence in the areas of cost, schedule, and technical performance. Under this contract type the Government assumes the risks inherent in the contract, benefiting if the actual cost is lower than the expected cost, or losing if the work cannot be completed within the expected cost of performance. CPAF is used when objective incentive targets are not feasible for critical aspects of performance, judgmental standards can be fairly applied, and potential fee would provide a meaningful incentive.

CPAF elements include estimated cost, base amount (if applicable), award amount, and the award fee evaluation criteria and procedures for measuring performance against the criteria.

Under CPAF, the contractor is incentivized by realizing a higher fee by meeting judgmental performance standards. This type of contract is typically well suited for large scale research studies.

3.8.5.6 References

1. Department of Defense Instruction 5000.02 Operation of the Adaptive Acquisition Framework
2. DAU - Comparison of Major Contract Types Feb 2020
3. www.Acquisition.gov/FAR

4. Conclusion

Historically, the high-reliability space systems ecosystem has focused on minimizing risk, delivering performance, maintaining cost and schedule, and protecting resiliency—in this order. The drive to outpace the threat in today’s complex environment is rapidly and drastically re-ordering these priorities. Going forward, resiliency will become a top objective, along with schedule, performance, cost, agility, and risk, in a still-unclear order of priority. In order to maintain US dominance across the space domain, decision-makers demand a wider range of innovative options within the trade space. Among these options are new architectures that leverage the commercial space industrial base, agile technology development, and diverse mission types that serve as force multipliers across the integrated enterprise.

The work presented here has identified options for balancing mission assurance effort based on the use of alternate grade electronics from the commercial industrial base. The guidance has been offered across four notional levels of mission assurance available to reduce risk to mission success. These levels span the range of *Constrained*, *Limited*, *Some* and *Many* resources accessible to a program. In each case, several critical inter-related dimensions of the decision space were discussed. These include specific guidance for Electronic Products Assessment and Control, Environmental Test and Analysis, Natural Space Radiation Testing, and Reliability and Sustainment. In addition, actionable recommendations have been offered for Mission Capabilities Definition and Planning, Design Assurance, Provider Business Models and Key Attributes, Cost and Schedule Estimating, and Acquisition Approaches and Contracting Mechanisms. When applied in the context of program constraints, the integrated guidance and corresponding risk considerations provide decision-makers with greater flexibility in specifying systems that outpace the threat. This flexibility is a key enabler for balancing mission assurance with increased risk to deploy new capabilities on orbit more quickly.

5. Acronyms

AEC	Automotive Electronics Council
AoA	Analysis of Alternatives
ATP:	Acceptance Test Program
COTS:	Commercial Off the Shelf
DD:	Displacement Damage
DITL:	Day in the Life
DTIC:	Defense Technical Information Center
EDAC	Error Detection and Correction
EOL	End of Life
FA	Functional Availability
FMEA	Failure Modes and Effects Analysis
FMECA	Failure Modes, Effects, and Criticality Analysis
FP	Flight Proof
GCR	Galactic Cosmic Ray
ICD	Interface Control Document
I&T	Integration and Test
ITAR	International Traffic in Arms Regulations
IMS	Integrated Master Schedule
KPP	Key Performance Parameter
LEO	Low Earth Orbit
LET	Linear Energy Transfer
MPE	Maximum Predicted Environment
MPT	Maximum Predicted Temperature
MTBF	Mean Time Between Failures

OEM	Original Equipment Manufacturer
PQ	Proto Qualification
QCI	Quality Conformance Inspection
QML	Qualified Manufacturer Listing
QPL	Qualified Products List
RAC	Reliability Analysis Center
RIAC	Reliability Information Analysis Center
RLAT	Radiation Lot Acceptance Test
RPP	Reliability Program Plan
SMC	Space and Missile Systems Center
SPF	Single Point Failure
SRA	Schedule Risk Analysis
TCI	Technology Conformance Inspection
TID	Total Ionizing Dose
TMR	Triple Modular Redundancy
WCCA	Worst Case Circuit Analysis

E.P.I.C. (Enterprise, Partnerships, Innovation, Culture) Speed Electronics: A Pre-RFP Application Guide for Alternate-Grade Electronics in Small Satellites and Resilient Systems

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