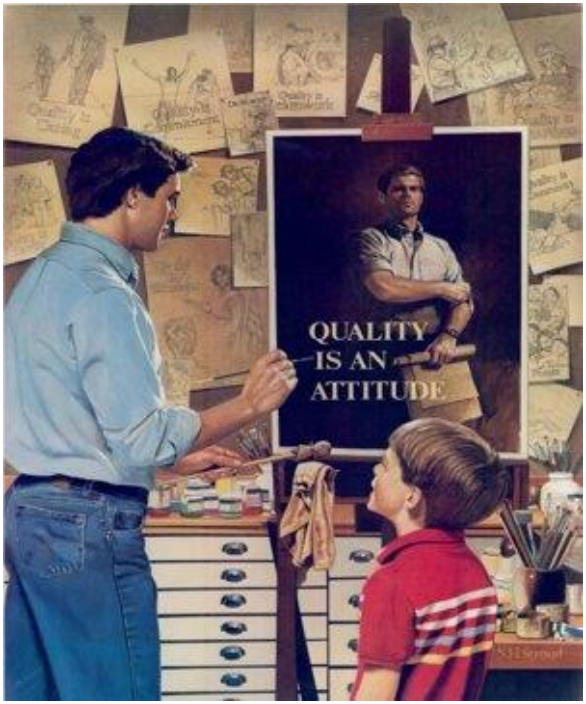
Reliability by Design

Asking the Right Questions at the Right Time!

Lessons Learned from Case Studies for Project, Program, and Portfolio Managers



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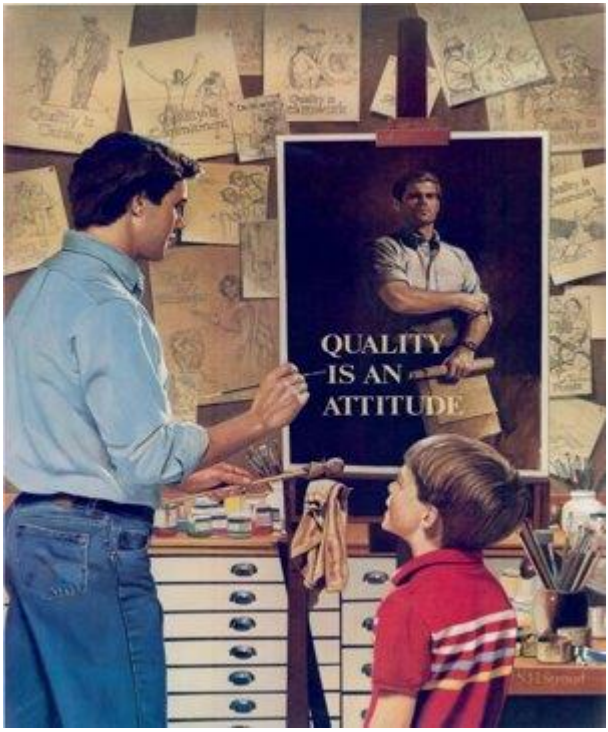

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"Understanding the Future Effects of Today's Decisions"

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Preface

You don't have to be an expert in every topic to know if an answer to a question shows that a topic is well understood … or not. Most times in weapons systems development all that is needed for success is asking the right question at the right time. This pamphlet will help program and portfolio managers do just that for reliability and supportability which is an often misunderstood key performance parameter for the Fleet. Properly applied reliability by design activities are key enablers to ensure the performance of our platforms and systems, and controlling cost so we have enough of these systems to meet force structure goals. Congress recognized this as well in GAO report 20-151 to which the Navy concurs.

This pamphlet is intended to highlight engineering design and support activities that need to be addressed by the program manager at critical points during the system life cycle. Although simple in presentation, the gravity of not paying attention to the lessons learned presented herein cannot be over-emphasized. Each activity is based on observed best practices and lessons learned throughout military and commercial programs.

The timing of each activity should be keyed to critical engineering decision points during the management of our programs. Start asking these questions early and often. Each question will help you identify a potential issue, and provides an opportunity to address it. Use each area discussed to spur your team's thinking of innovative solutions for your program.

"*In God we trust. All others must bring data."* by W. Edwards Deming

VADM Francis D. Morley, Principal Military Deputy Assistant Secretary of the Navy (Research, Development, and Acquisition)

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How to Use this Pamphlet

The intent of this document is to summarize lessons learned and best practices as a result of reviewing dozens of programs. These lessons learned are intended to assist Program Managers and their Engineering staffs with implementing best practices that have proven successful over the years to ensure that reliability, and supportability, are designed into programs early in the acquisition cycle. Many of the topics here are often overlooked, skipped, or short-changed in the interest of reducing cost or schedule without an understanding of the future effects of these decisions. Asking questions about these processes as you move through your design and support process has proven to be invaluable in helping programs through the major Milestones and when constructing reliability improvement programs. It is impossible to achieve the readiness levels (supportability) we need without good reliability.

To ensure systems performance is achieved, each reliability activity or topic should be thoroughly addressed during technical or program reviews. Program Managers are encouraged to engage the Program's engineering staff using the questions recommended for each reliability activity to ensure the Contractor has appropriately incorporated each activity into the design process. Work closely with your contracting staff to ensure they are addressed in your Statements of Work/Performance Work Statements (SOWs/PWSs) and specifications. There are numerous command and engineering activities standing ready to assist you when you ask the right question …

We have also included a simple scorecard to help you assess your program's supportability score. A spreadsheet is available to make assessment and tracking easy.

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History of the Reliability Challenge

In the '70s through early '90s DoD saw significant improvement in weapon system Reliability and Availability from addressing reliability and production quality issues; however, DoD took its eye off the ball in the latter part of the '90s losing significant institutional knowledge. The Government Accounting Office (GAO) pointed to this concern in its study (**GAO 20-151,** Ref. 1**)** entitled **"Senior Leaders Should Emphasize Key Practices to Improve Weapon System Reliability."** The study pointed out that DoD canceled Mil-Std-785B (Ref. 2) for reliability and reduced the total number of reliability test and evaluation personnel. Further degradation occurred in 2003 when DoD removed reliability language from the old DoD Instruction 5000.2, "Operation of the Adaptive Acquisition Framework," Ref. 3.

While some efforts to restore the importance of reliability began to occur over the next 10 years and resulted in the old 2015 DoD Instruction 5000.02 (Ref. 4) that mandated systems reliability in the "**planning stages for DoD weapon systems**" **… it wasn't until the National Defense Authorization Act (NDAA) for Fiscal Year (FY) 2018 (Ref. 5) that Congress required program managers to include certain reliability requirements in weapons systems. However, it stipulated this too late in the acquisition process.**

Finally, in 2019, DoD issued a memorandum implementing the NDAA for FY 2018 (Ref. 5) with Reliability-related requirements **for DEVELOPMENT and Production Contracts. This, while a great step forward, is late for the most effective Reliability by Design efforts** since first prototypes are being produced, many times, before E&MD.

The more effective efforts of "Reliability-by-Design" must begin much earlier in the "planning stages," ideally during the

development of the Draft Capabilities Development Document **(CDD)** being prepared for the Milestone-A (**MS-A**) decision. It is the activity during the Materiel Solution Analysis (**MSA**) phase and preparing the Draft CDD and MS-A Test and Evaluation Master Plan (**TEMP**) where we **examine and translate capability gaps into system-specific requirements designed to minimize failure**. The TEMP should address the flow down of relevant design requirements to subcontractors to include subcontractor testing.

Further, relevant design requirements must be flowed to the entire program team for clarity, including support personnel, testers, writers, customer support, sales, marketing & field support.

Poor reliability impacts our ability to use a capability when needed. Given its importance, Reliability is a mandatory Key System Attribute (**KSA**) according to the Joint Capabilities Integration and Development System (**JCIDS**) and is considered crucial in support of achieving the key performance attributes. As such, Reliability becomes an integral design criterion that critically impacts performance, cost, schedule, and supportability. The importance of proper Reliability by Design criteria, *not just calculating statistical prediction curves*, cannot be overstated; we must deterministically apply reliability requirements in designing and upgrading our system.

An up-front focus on Reliability is a focus on Performance! With today's highly complex systems, a small decrease in reliability can mean substantial, additional cost, but a small investment in "Reliability by Design" can significantly decrease Operations and Support (**O&S**) costs, as shown in Figure #1. We need to shift your mindset from a focus on acquisition to a focus on Sustainment; Reliability is what gets you there.

Systems engineering needs to be front-end oriented. Small investments upfront will have significant payoffs over the acquisition life cycle. The problem is that reliability, *mean time*

between failure (MTBF), is most often NOT considered early enough and is not always considered in the Research and Development

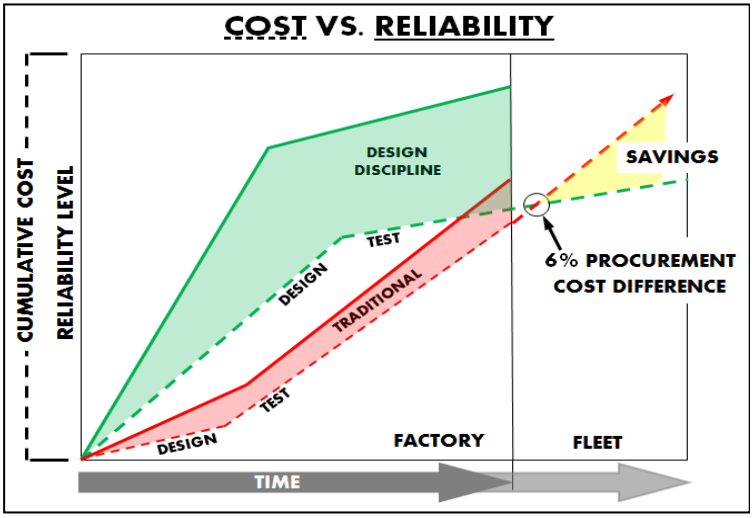

Figure #1 - Typical Cost to Address Reliability
Source: WILLCOR, adapted from SECNAV source

(R&D) budget (highlighted by GAO-20-151 Report, Ref. 1). Consequently, you need to **be prepared to fight for reliability requirements** from the beginning, ideally, it is best addressed for design during the Materiel Solution Analysis (MSA) phase before Milestone A (**MS-A**), where the **translation of capability gaps into system specific requirements** occur; like MTBF assignments in the early Work Breakdown Structure (**WBS**) or Reliability Block Diagram (**RBD**). Addressing reliability needs to start with the RFP process.

The contractor should demonstrate good design criteria as outlined in this pamphlet. Source Selection Criteria should quantify these reliability by design practices across all offerors. This will allow transparency for the understanding of need, overall cost, and how much risk will be taken on by the program management and contractor team.

Throughout the Government, its field activities, and contractors, there are reliability and process control engineers. **Seek them out and insert them** into the process **early** and often in the acquisitions. If the Reliability Team does not believe it is their job to address early design activities (*unfortunately many SYSCOM reliability leads do not see this upfront activity as traditionally their responsibility, and that it is the responsibility of Systems Engineering*). If so, the Program Manager needs to assign specific System Engineering leads to address these areas and **engage the team**. This guide will give you an understanding of the issues and an approach to implementing Reliability by Design as well as Reliability Growth, *which is typically applied later in the acquisition process once prototypes are being produced.*

Reliability by Design Fundamentals in the acquisition process cover an extensive array of topics throughout the defense acquisition process. Those topics generally fit within the below broad topical areas:

- **Contracting for** Reliability (a performance criterion) can be partially done by requiring physical parts to meet all performance criteria including but not limited to thermal expansion, junction temperature, glass transition temperature, thermal analysis, sizes, and weights.
- **Designing to** minimize failures
- **Testing to** verify design
- **Sustaining** Reliability **in production**
- **Preventing** failure recurrence
- **Sustaining** Reliability **in service**

In this guide, we touch on elements contained in the broad topical areas and provide warning traps and recommended practices.

Generally, once the design is robust and the reliability is designed in deterministically and as well as physics will allow, we next need to address a reliability growth program to capture any escapes in our

design and apply ***A_O type calculations***, to meet the mission. It must be understood Reliability is not a goal but must be a contractual requirement and a performance parameter.

For Mid-Tier acquisitions, this should be addressed in parallel with prototype development. Many Mid-Tier PMs erroneously think their job is to build a rapid prototype and will quote that "Reliability is not their concern." **Mid-Tier prototypes are meant to prove the system effectiveness of a solution and be EXPECTED to have a level of MATURITY to allow them to be rapidly prototyped.** System Effectiveness (Figure #2) is defined as availability, dependability, and capability. This material will highlight the importance of identifying capability gaps, constructing reliability block diagrams, tracing test requirements to the Design Reference Mission Profile (DRMP) and/or Operational Mode Summary/Mission Profile (OMS/MP).

Achieving reliability requirements is an integral part of the design and system engineering process that is in full swing during the

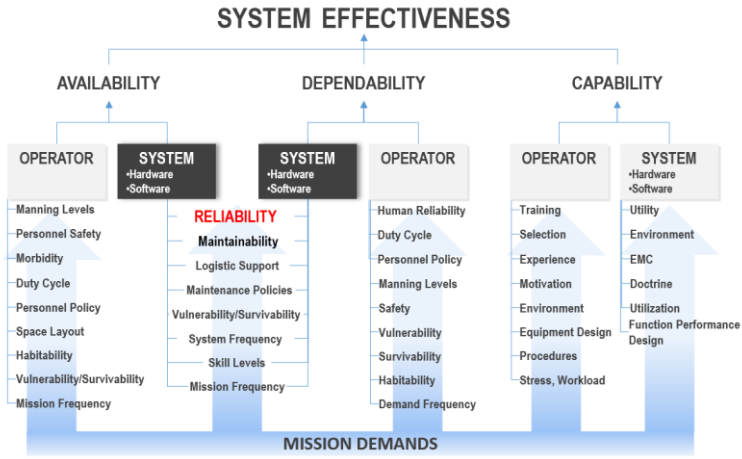

Figure #2 – System Effectiveness: Must be designed IN
Source: WILLCOR

Technology Maturation and Risk Reduction phase before Milestone B (MS-B). Even with the best design processes and focus on

reliability, issues may still be identified during testing. These remaining reliability issues must be addressed through a Reliability Growth Program. Reliability Growth planning and performance are needed throughout the program life cycle with parts and production variability requiring constant monitoring. These same techniques **apply to any in-service program** where improved sustainability can reduce cost and improve warfighter capability and effectiveness.

We must understand that Reliability is revenue positive over the acquisition lifecycle. A 6% increase in procurement cost is typically all that is needed to address reliability properly, Figure #1. PMs and others must understand the critical nature and timing required to influence a design's performance and how a metric like A_O can be manipulated before clearly defining the design's MTBF. While the FY16 National Defense Authorization Act (NDAA) (Ref. 6) Section 804 programs are focused on rapid prototyping and rapid fielding, adding an emphasis or review for Reliability by Design standards will prove revenue positive. Typically (based on a fixed cost of maintenance) a 1.5 times increase in reliability will cut O&S support costs by 25% (year after year).

The desired A_O must be clearly deconstructed into the usable reliability requirements needed for the design, re-design, and a reliability growth program; this means failure rate/MTBF and MTTR. A_O is not a physics-based Performance Parameter, but a statistic. Failure rate/MTBF and MTTR will drive Reliability by Design parameters, to include for example: junction temperatures, parts count, Mission Life, **software range checking**, protection for **Single Event Upset (SEU)**, etc., that contribute to effective system designs. Otherwise, the costs of addressing reliability downstream become untenable (Figure #1, Cost vs Reliability)!

Our DoD motivation for Reliability has gone dormant!

That motivation is **part Cost and part Human** (Figure #3). Imagine the **negative motivation** for our warfighter maintenance staff, having to repair something over and over just to see it fail again when it should just work, what kind of poor attitude are we creating with poor reliability. Is there a cost associated with that? Likely yes, but it may not be captured effectively.

Profit and loss are essential for Telecoms and Airlines; the equipment must work for long periods, like Telecom repeaters under the oceans for 40 years! With NASA & SpaceX, cost is certainly a motivation (perhaps more today than in the past 20yrs) because for manned space flight it is ***personal*** (like Figure #3) at NASA/SpaceX with the human element of friendships between designers and astronauts. This motivation should be the same with our warfighters. Each of us has at least one face in mind when we think of our warfighters.

Figure #3 – His Life …
Source: WWII Poster, Office for Emergency Management, Office of War Information - 1943

So, we must reawaken our DoD and Industry motivation for Reliability! While improved reliability will reduce cost, **reliability must be understood to be a performance criterion and hence a design parameter.**

It seems peculiar that so much of what is needed today is to re-learn what we learned 30 - 40 years ago but to apply it today with discipline. The Navy once had a slogan, **"*Big R & little m*" meaning focus on Reliability and also maintainability in order to:**

- **Improve Fleet Readiness and**
- **Minimize Life Cycle Costs!**

It is clear we must require equal footing for performance parameters, including Reliability, in all respects regardless of the Acquisition Pathway. **Drive it into our:**

- **Request for Proposals (RFPs),**
- **Source Selection Criteria, and**
- **Capability Development Documents (CDDs)!**

"We must not be interested in Cost unless the item is Reliable! And likewise, we must not be interested in Cost unless the item meets all Performance criteria!"

- *Willis J. Willoughby, Jr., Director Product Integrity, SECNAV (RD&A)*

Much of this can be summed up in a simple statement:

"We need an <u>Attitude change</u> that Reliability is a Performance Parameter and hence a Design Criterion."

As DoD is continually struggling for funding to meet current and emerging threats, we should not waste limited dollars on Operations and Support (O&S) **due to poor reliability**; these funds are needed to provide new capabilities.

Our greatest economic leverage for reliability improvement comes early in the Design Process; *as will be repeated through this guidebook.* **It must be understood that a vast majority of DoD money goes into spare parts and product support … unnecessarily**. We would spend less time and money changing a capacitor on a CAD drawing during design, than replacing it in the field after deployment. There is no such thing as a No-Cost Engineering Change Proposal (ECP) once an item is in the field. It cost millions after publications, training, standards, and test equipment changes. **Helping Reliability is the economic equation of the budget!**

The most important thing we must do is to **get the reliability decisions done early** and ENSURE it's going to be a reliable device early in the Materiel Solution Analysis (MSA) phase.

Infatuation with traditional performance parameters must be tempered with it also being a reliable device. We must reduce our reliance upon the logistics supply chain "umbilical cord to the beach." A plane that leaves and returns, but cannot do it again, does not meet our mission need. Consider what NASA/SpaceX are doing with its Falcon 9 Rocket Booster landings and how they are designing a Catch Tower so it can even more quickly land, refuel, add a new payload and relaunch! They can eliminate the Landing Leg **parts** and the inspection **steps** of those parts after landing on a hard landing pad! NASA/SpaceX clearly understands reliability, maintainability, and the mission.

"best part is no part, best step is no step"

- Elon Musk,
  12/30/2020 Ref. 7

Let's better understand Failure Rate (λ) and Mean Time Between Failure (MTBF) for a moment; and also recall that MTBF is the inverse of the Failure Rate (or 1/Failure Rate λ). Consider the **Figure #4** example where 1000 units *(lightbulbs, parts, really anything)* are fielded with a 100-hour MTBF*, which is a Failure Rate (Lambda λ) of 0.01. We see that* **only 367 will still be operating after 100 hours**.

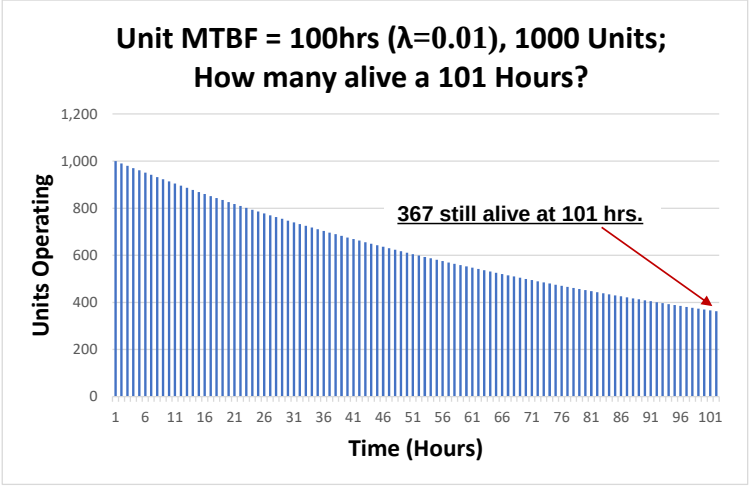

Figure #4 – Ways to Look at MTBF
Source: WILLCOR

To understand the math, consider that after 1-hr only 990 units remain operational (a loss of *1000 x 0.01=10 failed units*); only now repeat one hundred times that calculation with remaining *progressively smaller* populations to plot the above … we learn that only 367 units still function.

YES, we can see that with many parts, reliability is a critical performance parameter that must be understood. This example further means that every 100 hours of operation, the supply chain must work overtime to keep producing over 600 new parts every 100 hours! This drives up O&S costs. **You'll agree … This is unacceptable!**

Middle Tier of Acquisitions (MTAs) Goal in the Adaptive Acquisition Framework (AAF), DoDI 5000.02 "Operation of the Adaptive Acquisition Framework" (Ref. 4), is to provide a set of acquisition pathways to enable the tailored strategies to deliver solutions faster, the benefits of reliability to cost and schedule cannot be overlooked. Reliability by Design applies equally importantly to Middle Tier of Acquisition (**MTA**) and Urgent Capability Acquisition. It is important to understand that **the MTA pathway is intended to fill a gap in the Defense Acquisition System for those capabilities that are EXPECTED to have a level of MATURITY to allow them to be rapidly prototyped. Figure #5** Illustrates and contrasts a simplified view of some Major Capability Acquisition (**MCA)** program Phases, Milestones, and a couple of Reviews typically required to attain a

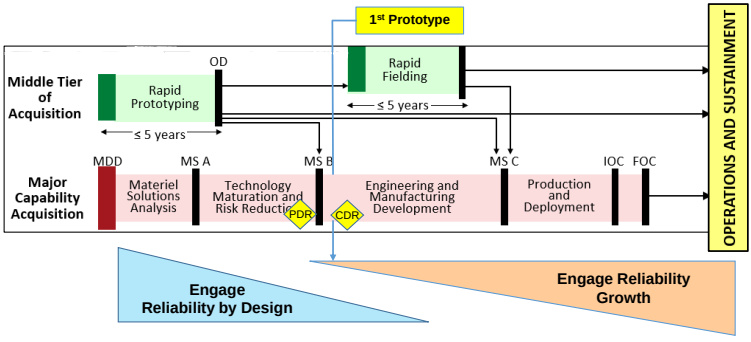

Figure #5 – Guidebook applies not only during early design but throughout life-cycle during all design changes, ECPs, and cost reduction and performance improvement activities.
Source: DAU & WILLCOR

level of **maturity** needed to achieve MS-B and MS-C successfully. This Guidebook applies not only during early design but throughout life-cycle during all design changes, ECPs, and cost reduction and performance improvement activities. **An MTA is expected to have the same level of Maturity!** A clear expectation of Reliability is equally essential if an MTA program is to transition effectively from the Rapid Prototyping to insertion at MS-B or the Rapid Fielding

insertion at MS-C **with expected Maturity**. Riskier is the Rapid Fielding insertion at MS-C, and more challenging yet those that survive the Operations and Support phase without excessive logistics implications. More information about the AAF and MTA can be found at Ref. 8.

- Reliability failure rate (λ) requirements (MTBF), must be in the mind of the designer!
- **Make it part of the Mission Profile and get it in the Request for Proposal (RFP).**

It is important to understand that the MTA pathway is **intended to fill a gap in the Defense Acquisition System and those capabilities that are EXPECTED to have a level of MATURITY to allow them to be rapidly prototyped.**

Assess the Maturity, consider either or both Manufacturing Readiness Level (MRL) assessment, Ref. 9, and Technology Readiness Level (TRL) assessment (See GAO-20-48G, Ref. 10). Another good risk-related document worth examination is: GAO-10-439, Ref. 11, "DoD Can Achieve Better Outcomes by Standardizing the way Manufacturing Risks are managed."

- An MTA **Rapid <u>Prototyping</u>** insertion at MS-B must have achieved at least an **MRL 6 and TRL 6**.
- Likewise, an MTA **Rapid <u>Fielding</u>** insertion at MS-C must have achieved at least an **MRL 8 and TRL 7**.

The reliability of MTA's must be well understood quantitatively to ensure that a system does not move forward that is unsupportable and hence cannot meet mission or be affordable; thus, complying with the stated purpose that MTAs "fill a gap in the Defense Acquisition System for those capabilities that are **EXPECTED to have a level of MATURITY to allow them to be rapidly prototyped**." These MTA attempt to field capabilities to fulfill urgent existing and/or emerging operational needs, or quick reactions as quickly as less than 2 years!

Parts Management and Selection

Narrative: Parts management as defined in Defense Standardization Program Office (DSPO) Standardization Document (SD)-19 titled "Parts Management Guide" (Ref. 12) focuses on selecting the best parts at the design phase of an acquisition program under an overarching systems engineering umbrella. Typically, the use of parts described by non-government standards or military standards or the use of commonly used parts already in the DoD supply system is preferred. The use of these types of parts provides the ultimate user, the Warfighter, returns that can be measured through the desired performance-based criteria of operational availability, operational reliability, cost per unit usage, logistics footprint, and logistics response time, as well as payback in terms of total ownership costs. Additional information on how parts management is an integral part of the systems engineering process can be found in the DoDI 5000.85 Appendix 3D Subparagraph 6, Ref. 13. A preferred parts list (**PPL**) should be used to maximize standardization during design by tailoring, streamlining, and minimizing the variety of types, grades, or classification of parts used in an acquisition.

Tailoring the PPL baseline requirements for a specific contract should be based on the following factors:

- Restrictions on the use of certain parts or part types
- Limitations in design imposed by part usage restrictions
- Reliability requirements
- Diminishing Manufacturing Sources and Material Shortages (DMSMS).

To maximize standardization and reduce life cycle cost, parts should be selected based on the order of preference list in MIL-STD-3018, Ref. 14, as applicable. Figure #6 provides a typical parts selection

process. Depending on contractual requirements, the following part selection criteria should be taken into account:

- Availability (DMSMS concerns, aging technology, number of sources)
- Application (derating, operation, use of the part, type of environment in which the part will be used)
- Cost-benefit analysis
- Part screening
- Qualification test data or past performance data
- Supplier selection
- Part technology/ obsolescence (use of DMSMS databases, Government-Industry Data Exchange Program (GIDEP) Ref. 15
- Compliance with contract performance requirements
- Technical suitability

HOW DOES THE CONTRACTOR SELECT PARTS TO REDUCE LIFECYCLE COSTS?

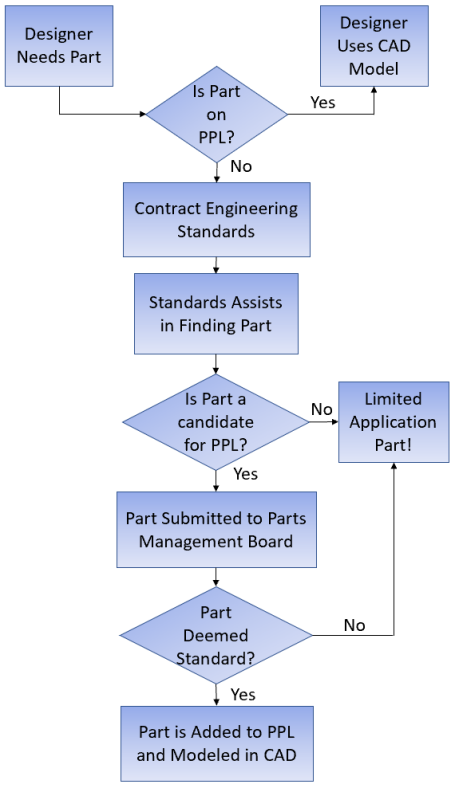

Figure #6 - Typical Parts Selection
Source: DSPO SD-19 "Parts Mngt. Guide"

Mistakes are often made in material selection as follows:

- No preferred parts list at the START of development.
- Obsolete parts are often selected.
- New technology parts are selected without a record of proven performance.
- Parts are unsuitable for their particular applications.
- Incomplete or inaccurate thermal analysis data on part operating temperature and vibration
- Risk of Counterfeit parts or materials increases

Failures to select the right suppliers will most certainly lead to high reject rates, failed delivery dates, and missed milestones. Printed circuit boards are most susceptible to aspects of poor quality and workmanship caused by bad parts.

PARTS Count and Quality: Figure #7 shows the benefit and criticality of using quality parts in manufacturing a printed wiring board (PWB)/printed circuit board (PCB) design. If you have a printed

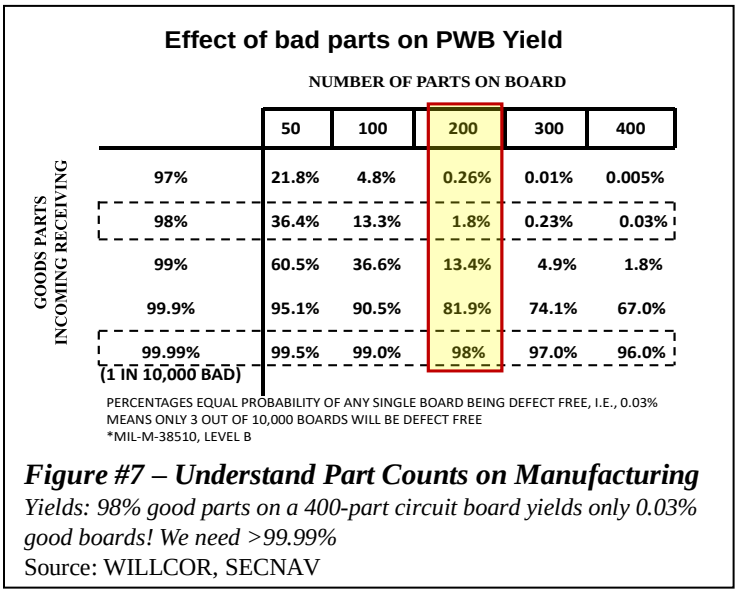

Figure #7 – Understand Part Counts on Manufacturing
Yields: 98% good parts on a 400-part circuit board yields only 0.03% good boards! We need >99.99%
Source: WILLCOR, SECNAV

circuit board with 200 parts, and with a parts quality of 98% good, you will only have a first-time yield of 1.8%. That means only 180 out of 10,000 boards will be defect-free! Now if you have a parts quality of 99.99% good, then you will then have a first-time yield of 98%. This means only 9,800 out of 10,000 boards will be defect-free; 200 boards are still bad! So, you can see that 99% good parts is NOT remotely good enough! An Approved Parts List (APL) should be issued at the start of Engineering & Manufacturing Development (E&MD) and consistently used and updated.

Major Questions That Need To Be Answered:

- What is the selection process for parts and material?
- Is there a parts management plan and strategy developed in accordance with MIL-STD-3018 (Ref. 14)?
- Does the contract require a moisture control plan for moisture-sensitive parts?
- Is there a Parts Failure Review Board?
- Do developers routinely provide feedback to parts designers and manufacturers?
- Has the program planned for obsolescence?
- Does the Statement of Work (SOW) require a DMSMS plan developed in accordance with Defense Standardization Program Office (DSPO) Standardization Document (SD)-22 titled "Diminishing Manufacturing Sources and Material Shortages – A Guidebook of Best Practices for Diminishing Manufacturing Sources and Material Shortages" (Ref. 16)?
- Is a formal parts control program required during Engineering & Manufacturing Development (E&MD)?
- Will there be a process in effect to control part variability?
- Does the contract explain how failure modes, degradations, and effects would be identified, prioritized, and addressed during design?
    - Does the government have a role in this as it should?

    - Does the contract provide the government management, test and technical data rights (e.g., Initial Capabilities Document) to support system understanding and RM&A data analysis and archival through the system life cycle?
- Will reliability predictions be calculated, deficiencies-to-requirements documented, and over-stressed parts identified?

Risk if you get it wrong:

- Production delays and unit cost increase due to part shortages.
- Either you won't be able to sustain your system causing operational impacts (See SD-22 DMSMS Guidebook for more information, Ref. 16), or it could be much more expensive to sustain your system than you planned and budgeted.
- Incorrect, costly, obsolete, counterfeit, or insufficient parts and material.
- Poor quality during production or poor reliability in the field
- Costly fixes to address/mitigate obsolete parts.

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Tin Whiskers/Lead-Free Solder/Industry Solder Standards

Narrative: Increased international concern about the environmental impact of lead has caused a shift by component vendors away from tin-lead surface finishes toward the use of pure tin. The result has been the formation of "tin whiskers" on the surface of tin coatings, a phenomenon that has been observed for many decades. Tin Whiskers can grow when RoHS (Reduction of Hazardous Substances) (lead-free) parts and or solder are used in a design. These whiskers are comprised of pure tin and are therefore electrically conductive. This has caused and continues to cause, reliability problems for electronic systems that employ components that are plated with tin. Tin whiskers can develop under typical operating conditions on any product type that uses lead-free pure tin coatings.

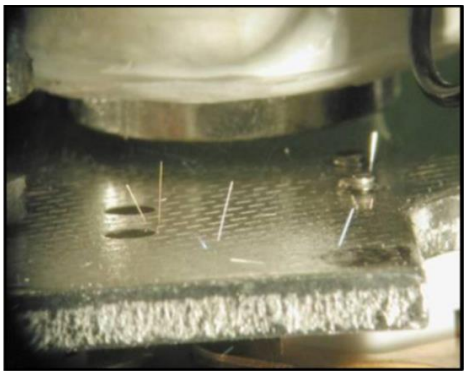

Figure #8 - Tin Whisker Growth
Source: NASA Electronic Part & Packaging

HOW DOES THE CONTRACTOR ENSURE THE QUALITY OF SOLDERING?

Tin Whiskers (Figure #8) are electrically conductive hair-like filaments that can cause short circuits in satellites, missiles, and other electronic equipment. To avoid this requires American National Standards Institute (ANSI)/IPC J-STD-001H, Level 3 (Ref. 17) for all soldering using leaded solder. Hot dipping of all RoHS tin-rich plated parts and re-balling of all RoHS Ball Grid Arrays (BGAs). As well

as provide objective evidence of board cleanliness. NASA has a great resource for further discussion of tin whiskers (Ref. 18).

Here are some suggestions for reducing the risk of tin whiskers:

1. **Do not use tin-rich or pure tin. Use a tin-lead alloy with at least 3% lead.**
2. **Use x-ray fluorescence (XRF) to verify the finish on all critical parts.**
3. **Refinish pure tin-finished part with a hot-solder dip.**
4. **Use some type of conformal coating encapsulation.** NASA has shown that Arathane 5750 (Ref. 18) can be effective in preventing tin-whisker shorting when applied with a nominal thickness of 2-3 mils on a tin-rich surface.

Military electronics suppliers will need to establish management processes to assure that the RoHS transition does not impact military equipment Reliability, Availability, and Maintainability. **The unintended inclusion of lead-free parts in military applications could result in significant reliability reduction due to tin whiskers and reduced solder joint life.** Military program contractors and program offices should implement proactive plans to manage these effects on the supply chain and system design.

While most aerospace and high-performance manufacturers and system integrators are attempting to prohibit the use of lead-free solders and finishes, the increasing cost of tin-lead products as their supplies diminish may, in cases, force at least a partial transition to lead-free products.

<u>Major Questions That Need To Be Answered:</u>

- If lead-free parts are used, does the parts management plan address the process to manage the risk associated with using lead-free parts?

- Does the Bill of Materials specify the use of parts with pure tin plating?
- How have tin whiskers failure mechanisms been accounted for in the design?
- Does your program include long-term dormant storage?
- Are the following soldering standards being used?
    - ANSI/IPC J-STD-001H, Level 3: Requirements for Soldered Electrical & Electronic Assemblies (Ref. 17)
    - IPC-A-610, Acceptability of Electronic Assemblies (Ref. 19)
- Has the supplier developed procedures to handle challenges using lead-free surface mount devices such as Micro-BGAs, BGAs, Quad Flat no-lead, Thin Small Outline Package, etc.?
- Given that the process to re-ball BGAs is not standard across re-balling facilities, has the supplier developed processes (i.e., incoming inspection and test) that evaluate the quality of the re-balled BGAs?

Risk if you get it wrong:

- Random failures whose root cause is not readily apparent.
- Poor reliability in the field or shorter time to failure
- Potential safety issues.

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Ionizing Radiation in Microelectronics

Narrative: Electronic components are susceptible to faults caused by terrestrial and space environment sources of ionizing radiation; space sources being the most serious change. Space environments naturally contain sub-atomic energetic particles (neutrons, protons & heavy ions) that may collide with our microelectronic components and can cause damage. These single energetic particles (radiation strikes) are called **Single-Event Effects** (**SEE**) on our microelectronics and may result in **Soft** (temporary) and **Hard** (permanent) events/faults. The resulting **effects** may be classified as:

- **Surface Charging -** where a dielectric effect from high energy electrons like that from triboelectric effects (or charging); *static electricity is triboelectric*;
- **Displacement Damage -** where damage is from collisions with energetic protons and electrons;
- **Total Ionizing Dose (TID) -** where there is a long-term effect from trapped protons and electrons; and
- **Single-Event Effects (SEEs) -** where the damage is not permanent and can appear as transient pulses in logic or support circuitry, or as flipped bits in memory cells or registers; Field Programmable Gate Arrays (FPGAs) being particularly susceptible.

Single Event Effects (SEEs) are incidents with heavy ions from cosmic rays and solar events and the primarily focuses on these **SEEs** which may be grouped into either **Soft or Hard Faults/Errors** and as briefly described below:

- **Soft Errors such as Single-Event Upset (SEU),** aka "Bit Flips" in memory cells or registers where a 1 or 0 are exchanged, and Single-Event Transient (**SET**). Damage is caused "when charged particles lose energy by ionizing in the medium through which they pass, leaving behind a wake of electron-hole pairs" (NASA

SEU Definition, Ref. 20). A memory register randomly changes a 1 to a 0, or a 0 to a 1. This is typically a soft error where the device was not damaged & could be reset. These Soft Errors become more tolerable when a design incorporates software solutions such as:

- **Software Range Checking** (**see content below**),
- **Error Correcting Code (ECC)** *with stored redundant data to catch and correct corrupted info in the memory*,
- **Software and Hardware Redundancy** (*Use Triple Modular Redundancy, Figure #9, so if one system suffers*

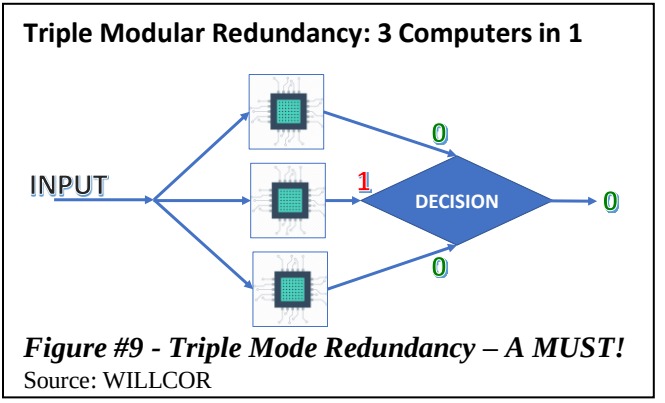

Figure #9 - Triple Mode Redundancy – A MUST!
Source: WILLCOR

*a **soft error** the other two will overrule in the Decision-making logic*) Resetting or rewriting a memory device restores proper operation.

- **Hard Errors such as Single-Event Latchup (SEL)** and Single-Event Burnout (**SEB**) where a burnout, gate rupture, frozen bits, and even noise on charge-coupled devices may occur. These are permanent and remain active permanently so mitigating design strategy must be considered; for example, Triple Modular Redundancy.

The ionizing radiation RISKS are growing! As DoD uses emerging commercial technologies where transistors on microchips double roughly every two years and have much tighter technology Node spacing, error opportunities are increasing. No longer does the commercial industry focus on SRAMs with 40 nanometer (nm)

spacing; far more common are Node technologies of 20, 16 & 7nm (Figure #10). These greater component densities and larger architectures provide **increasing risk opportunity** for SEEs.

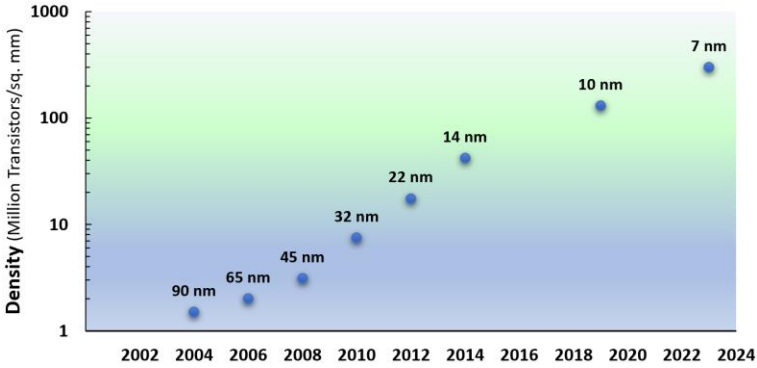

Figure #10 – Node Technology

Source: WILLCOR chart; Reference: Intel IEDM 2018 Presentation data

Additionally, these high-density microcircuits are no longer being attacked just in space (100+km altitude) but at non-space altitudes occupied by commercial and military aircraft as low as 30-40 km!

Fortunately, there are tactics available if designed in EARLY, to help mitigate these insidious risks. **A few tactics include:**

- Software "Range Checking" for Divide-By-Zero SEU errors - Make sure to conduct "Range Checking" for all Input/Outputs (I/O's) to avoid the Divide-by-Zero Problem. Divide-by-Zero is a well-known problem in software. Dividing by zero causes software and mathematical algorithms to lock up and crash as it produces a mathematically undefined result. The universe of all sensor Input/Output that can cause a divide by zero problem is unknown! What is needed is a "sanity check" table with a Range of expected values; a "Range Check." For example, on a Ballistic Missile test shot, the target was lost due to a divide-by-zero problem when the umbilical was cut and the "noise" generated an INPUT value that was not expected/allowed, resulting in a divide by zero operation. The solution was to do Range Checking

on all Input/Output so that ANY value gathered **is first "Range Checked"** to make sure the number is reasonable before forwarding for mathematical processing.

- **Error Correcting Code (ECC)** catches & corrects information in the memory. Such ECC code stores redundant data to recover & correct corrupted information. The central idea is the sender encodes the message with redundant information in the form of an ECC. The redundancy allows the receiver to detect a limited number of errors that may occur anywhere in the message and often corrects these errors without retransmission. Here are two common types of Coding Schemes:
    - Block Codes: Redundant bits are added as a block to the end of the initial message.
    - Continuous Codes: Redundant bits are added continuously into the structure of code word.

- **Radiation-Hardened by Design (Rad-Hard Chips) -** To benefit from modern chip cost and performance improvements, special and expensive radiation-hardened packaging (Rad-Hard chips) is another option. For Space application, we must have radiation-hardened chips that can withstand 40 times the radiation of a typical plastic encapsulated chips on earth. Such Chips must go through special and specific processes & packaging approaches to better survive the Space Environment radiation. Typically developed by a **Silicone on Insulator (SOI) Process**. In SOI Chip, an "Excite Layer" prevents the radiation-induced charge from getting into the Transistor layer; thus, making it more tolerant of radiation than ordinary silicon chips.

- **Ceramic Packages –** Another way to improve the radiation robustness of chips is the use of ceramic packages. This packaging reduces the Radiation Hardness (Rad-Hard) requirements to the chip itself. This might make possible the use of high-tech non-space grade chips. These expensive & ceramic package chips are typically 1-2 generations behind the equivalent Plastic Encapsulated parts!

Major Questions That Need To Be Answered:

- Do you understand the susceptibility of your system to ionizing radiation? For example, the TID failure rate can be described by a mean time to failure (MTTF), but SEE must be expressed in terms of a random failure rate.
- What is the potential for SEU in your system?
- Has there been analysis for single-point failures?
- Is there a fault detection, isolation, and identification strategy?
- Are you familiar with the mitigation techniques applied: error correction, failover, redundancy, etc., and the pros and cons of each?
- Has the fault protection scheme been independently verified?
- Will Electrostatic Discharge (ESD), radiation hardening, parts derating and corrosion resistance requirements be in place before final design analysis and testing?
- What is the potential for SEU in your system?

Risk if you get it wrong:

- Time consuming rework and possible reconfiguration with expensive long-lead-time components.
- Poor performance in the field and/or low reliability

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Reliability Growth

Ideally, once **Reliability-by-Design** initiatives have been completed and the program is producing prototypes during TM&RR or E&MD, it is time to execute the Reliability Growth initiatives planned during the earlier program phases.

Reliability growth is the positive change in reliability as a result of management strategy, actions taken, and effectiveness of actions during design, development, manufacturing, or field operations. The reliability growth process, when formalized and applied as part of the Reliability and Maintainability (R&M) engineering discipline, allows management to exercise control, allocate resources, and maintain visibility into those activities required to improve reliability and achieve a mature design. The R&M engineering program should incorporate the use of an appropriate reliability growth strategy.

The cost-effective application of reliability engineering disciplines and growth concepts during the design process reduces the frequency of reliability problems and forces early consideration of the methods for achieving and evaluating reliability progress.

While it is generally recognized that reliability will grow in the presence of a reliability program, reliability growth planning provides an objective measure of progress and resource allocation to achieve reliability thresholds in a timely and cost-effective manner.

Effective reliability growth planning improves the chances of achieving reliability targets for the program, while at the same time reducing cost and schedule.

Reliability Growth is dependent on 3 activities:

1. Data collection
2. Analysis and modeling

3. Corrective action

These activities need to be planned and resourced throughout the life cycle of a program. Reliability growth needs to be planned as a life cycle function. While issues and correlations vary by program, from a DoD standpoint, **it is clearly revenue positive to mandate reliability growth testing throughout the life cycle**.

The reliability growth curve (RGC) is a key component of both reliability growth planning and management and is essential for assessing progress. The RGC plots reliability against time (or life units) allocated for the program. Reliability values should represent threshold values expected at each specific evaluation point. Where time is not an appropriate measurement parameter, the other appropriate measurement parameters such as cycles, events, rounds, or miles can be used. Ultimately, the curve must lead to the final requirement.

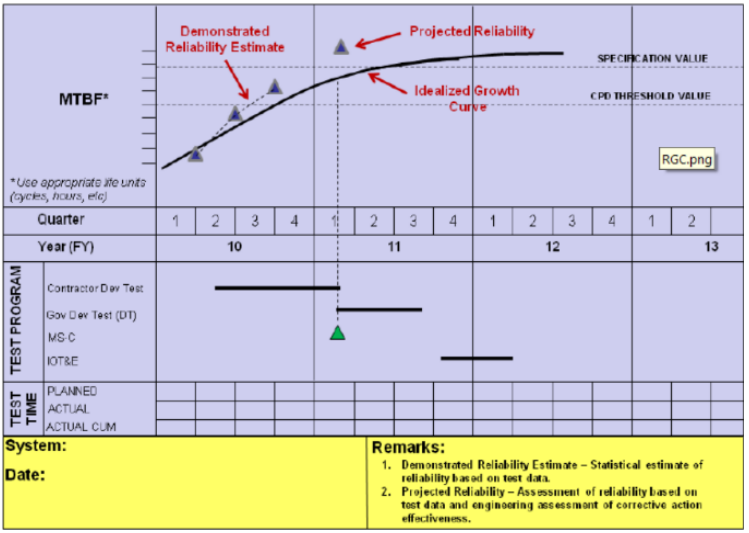

Figure #11 - Reliability Growth Process

Source: Office of the Assistant Secretary of Defense (OASD) Systems Engineering Plan Annotated Outline

Figure #11 is the sample reliability growth planning curve from the SEP outline that depicts the reliability expected at designated evaluation points.

The program should use this sample curve and test schedule as a guide; program reliability growth planning curves may also be a step curve or other shape that takes program specifics into account. MIL-HDBK-189C, Ref. 21, can be referenced for more information on reliability growth curve development.

Each test will provide reliability growth data that should be indicated with the total test time shown for each calendar or evaluation period. The rationale for the depicted rate of growth must be included in the total description of the RGC. The rate of growth, test time, program resources, management strategy, etc. will determine the level of risk to meeting the requirement inherent in the growth curve.

Reliability by Design is accomplished very early in the acquisition process (Material Solution Analysis and Technology Maturation and Risk Reduction Phases) **while Reliability Growth starts after the first production prototypes** are produced (Engineering and Manufacturing Development through Operations and Support phases).

Reliability Growth Projections

Reliability Predictions and allocation of requirements to sub-systems should emphasize with suppliers that requirements must be based in physics; failure rate (λ) versus A_O. Reliability starts as an Allocation, then to Prediction, and ultimately to Actuals. Again, the TEMP should address the flow down of design requirements to subcontractors.

Good systems engineering needs to be front-end oriented, where small investments will have significant payoffs over the acquisition life cycle.

The problem is, reliability (i.e., Failure Rate/MTBF) traditionally is not considered early enough and is not always considered in the Research and Development (R&D) budget.

Consequently, you need to be prepared to fight for reliability requirements from the beginning. Those initial allocations (Figure #12) at the system and sub-system Work Breakdown Structure

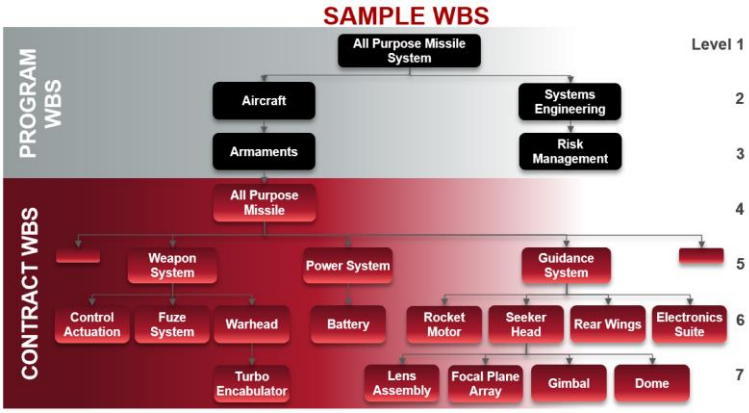

Figure #12 - Sample WBS
Source: WILLCOR

(**WBS**) levels are the starting point of a Reliability Block Diagram (**RBD**) which will include numerous allocated and predicted failure rates (λ) for the various blocks. This is where higher-level allocated and predicted reliability requirements are decomposed down through lower-level paths to represent the detailed design.

The key to success is to deterministically Design a reliable system; backed up by a reliability growth program, since we cannot catch all the unknown and will find these problems once in the field.

The Reliability Growth plan and program is to catch and fix early prototype problems and production issues. Additionally, toward success are establishing a growth plan, and tracking growth by comparing to the plan and the acquisition timeline. The reader should note that a vital component mentioned in each of these

handbooks is the implementation and use of a closed-loop Failure Reporting and Corrective Action System (FRACAS).

While "Planning Model based on Projection Methodology" (PM2) models have their place, they are not an effective tool for Reliability by Design. Unfortunately, the PM2 models only point to your unreliability as they are not deterministically designed nor change reliability at all.

The Duane Approximation is a good model and typically a better model to use during early development.

Reliability Growth Plots (Figure #13) are essentially a Plot of Reliability on Log-Log paper, allowing it to be presented as a straight line. Using Duane Growth plots which plot reliability growth on log-log paper allows examination of the slope as an indication of growth risk.

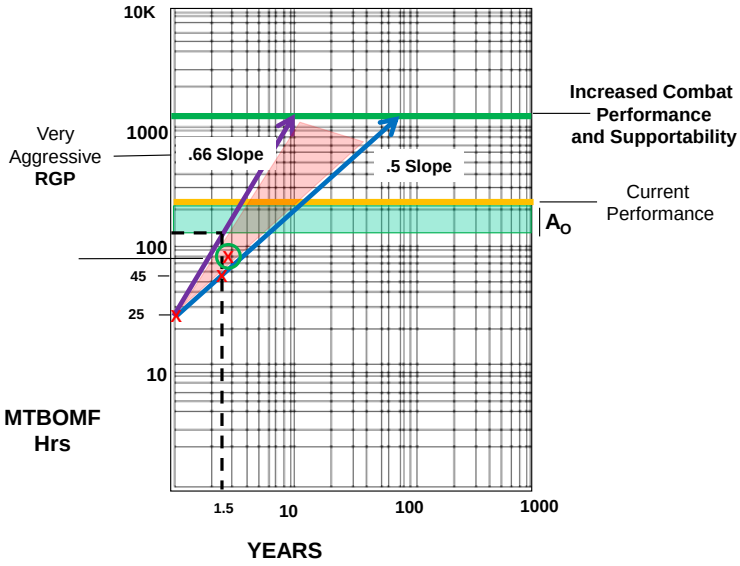

Figure #13 – Duane Approximation Plot & Rel. Growth
Source: WILLCOR

It provides an improved picture of growth, and what is needed to meet requirements. With the slope representing risk levels, it is easily understandable by analysts and senior decision-makers.

Consider the following slopes:

- 0.2 - 0.3 slopes indicate low to medium risk,
- 0.5 slopes indicate high risks and need management intervention (resources),
- Above 0.5 is typically not achievable without significant cost and schedule resources as well as management attention.

This "Duane Approximation Plot" (Figure #13) is a commonly accepted pattern for reliability growth and is reflected in both the "*Duane model*" and the "*Crow Army Material Systems Analysis Activity (AMSAA) model*" procedures for measuring reliability. The reliability of products should be continuously tracked into their use out in the field. This will provide source data for similarity analysis.

Reliability-Growth Programs

Historically, developers relied on Reliability Demonstration or Qualification testing to prove that the system **had** met its reliability requirement. **Reliability Demonstration testing** is a non-productive cost and schedule driver and is **not directed toward reliability improvement,** nor is it a Reliability-Growth Program.

Programs of **Reliability-Growth Testing can minimize risk**. If properly managed, such programs include time for performance monitoring, failure detection, failure analysis, and the verification that design corrections work as expected. Reliability-Growth Testing can be either "Integrated" or "Dedicated" or a mixture of these two types.

Dedicated Reliability-Growth Testing is reliability-growth testing that:

- Is run separately from other testing

- Occurs on equipment dedicated to this testing throughout the period of dedicated testing

Typically, dedicated reliability-growth testing occurs during an isolated phase of the development process. During this phase, the system is tested under controlled conditions solely to achieve reliability growth through failure detection and corrective modifications; have a good FRACAS program in place. FRACAS should be invoked in the Request for Proposal (RFP), if not actions must be taken early to remedy the oversight.

Integrated Reliability-Growth Testing is reliability-growth testing that:

- Is performed simultaneously with other development testing, such as:
  - safety testing,
  - environmental testing, or
  - functional testing of a prototype system.
- Usually starts earlier and often lasts longer than dedicated reliability-growth testing.

In order to accomplish the tasks necessary to support a reliability growth program, the program manager must ensure resources are available (*staff, funding, and schedule*) to get the work done. The task should reside within the program's systems engineering group. Challenges to resourcing a plan may include system complexity (*requiring a large workforce and effort*), acquisition category (*smaller programs may not have adequate funding for a dedicated reliability staff*), or lack of contractual tasking (*the contract must specify the need for and provide funding for reliability growth*.)
The elements of a structured growth program should be documented in a detailed reliability growth plan, which should describe a Test-Analyze-Fix-Test (TAFT) approach and how it is applied to the system under development. TAFT, *sometimes called Test Analyze and Fix (TAAF)*, is an engineering activity that is

incorporated into the Reliability Growth process. TAFT/TAAF allows for reliability growth through the repeated tests and correction of failures/errors revealed from those tests. This can be applied to a revised design process and fielded systems. Additionally, an active FRACAS program should be in place, having been invoked in the Request for Proposal (RFP). The prime contractor should be required to prepare an Integrated Test Plan. Design changes should be verified during reliability development testing.

Failure Modes Effects and Criticality Analysis (FMECA) is a great evaluation technique that identifies and analyzes possible failure modes, effects from those failure modes, and how to avoid or mitigate said failures.

Major Questions That Need To Be Answered:

- Is the reliability growth program an integral part of the program's strategy and is the amount of testing, test schedule, and test resources adequate to achieve the reliability requirement?
- Will newly designed and significantly modified equipment be subjected to Highly Accelerated Life Tests or accelerated tests before system-level testing?
- Is there a comprehensive failure reporting and corrective action system in place to identify the root cause and corrective action for all failures that occur during testing?
- Is reliability performance during testing being tracked as a program Technical Performance Measure (TPM), including the status of all corrective actions?
- For test hour calculations (test duration) will the predicted MTBF be >=1.25 times the required MTBF; growth slope on a Duane Log-Log Chart <=.5 for analog items and <=.7 for digital items; and 30% predicted MTBF as starting point?

Risk if you get it wrong:

- Significant increase in cost and schedule resulting from more corrective actions than planned.
- Production is initiated with unsatisfactory design.
- Major design changes are required during LRIP articles.
- Increased risk of being declared unsuitable during IOTE due to lower than expected reliability.
- Unacceptable impact to Availability and Ownership cost due to lower than expected reliability.
- Is a Failure Definition and Scoring Criteria (FD/SC) used to score all failures to assess compliance against the reliability KSA threshold and does the OTA participate in the scoring boards?
- What type of growth tracking and projection methodology will be used to monitor reliability growth during system-level tests (i.e., AMSAA-Crowe Extended, AMPM, etc.)?

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Parts Derating and Junction Temperatures

Narrative: Derating is the practice of reducing electrical, thermal, and mechanical stresses on devices to levels below their specified or proven capabilities to enhance reliability and prolong the expected part life. All parts must be de-rated from manufacturers' data sheets, which are typically aggressive, in accordance with Service or program-approved parts de-rating guidance. De-rating increases the margin of safety and allows for greater production variability between the operating stress level and the actual part failure level, providing added protection from unforeseen system anomalies. We must design such that our devices are operated at less than rated maximum power dissipation. For electrical circuits and electronic parts, designing in fans, heat sinks, along with good packaging will make a great difference. A good rule of thumb states that reliability doubles with each 10-degree decrease in junction temperature. Specific de-rating criteria supports low-risk design engineering.

To ensure parts will perform as required, designers use de-rating curves to ascertain the de-rating percentages. These curves are available for various parts types, and usually show sensitivities to changes in temperature, electrical transients, vibration, shock, altitude, and acceleration. Various techniques can be used depending on the parts in question.

WHAT ARE YOUR PARTS DERATING CRITERIA AND TESTS SCHEDULES?

The Figure #14 blue line is the de-rating curve in accordance with a notionally contracted standard. Note that the blue dot shows a resistors' **Working Ambient Temperature vs Percent Rated Wattage** (also could be - power stress factor or power ratio) for a

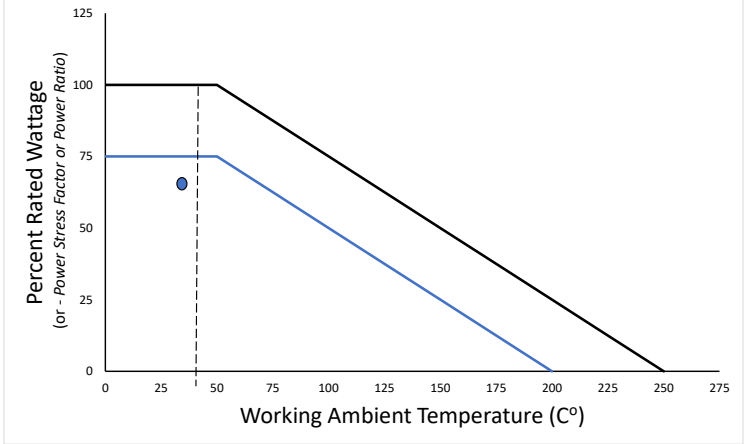

Figure #14 - Sample Derating Criteria
Source: WILLCOR, NAVSEA Resister Derating Sample

specific mission condition. For this example, that blue resistor dot is properly de-rated since the Working Ambient Temperature is below the blue de-rating line for this resistor's working ambient temperature. However, if the dot were above the blue derating line, the stress under this mission condition would exceed the required derating contracted standard; implying that the resistor is at risk for failure and would need to be changed to a higher-rated resistor or an adjustment was needed to the operating mission.

Most contractors have their own de-rating guides, so make sure they are used and manage by exception. The contractor's derating criteria should be approved by the buyer before the contract award. There are derating guidelines *like the NASA published MIL-STD-975M and the Navy published NAVSEA TE000-AB-GTP-010* (these two

documents are canceled but still worthy of viewing), issued by the military and other agencies, see Ref. 22.

Parts Temperatures:

Junction temperature is an important element of parts derating. With the myriad of electronic circuit boards, complex integrated circuits, processors, and harsh environments, Junction Temperatures are a special situation. A burned-out circuit could easily lead to system failure, severe electrical damage, and loss of mission.

No IC, transistor, etc. junction temperatures above 110 deg. C. Figure #15 shows gains from lowering junction temperatures. This is becoming far more critical as manufacturers, like Intel, put thermistors in their processor chips that will shut them down (to

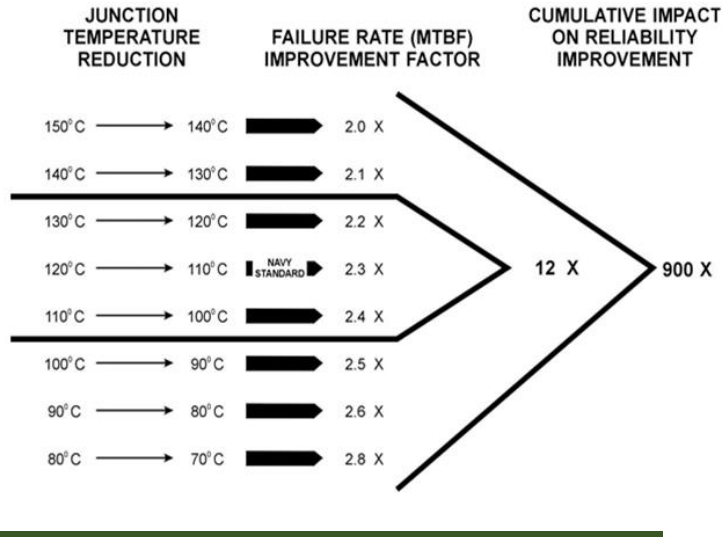

Figure #15 – Lower Junction Temps = Reliability
Source: WILLCOR, from SECNAV data

avoid erroneous operation) if temperatures exceed a specified level. Part operating temperatures should be verified by thermal survey measurements. The starting point is establishing Reliability as a performance criterion in the contract. This can be partially accomplished by requiring physical parts to meet all performance criteria including, but not limited to: *thermal expansion, junction temperature, glass transition temperature, thermal analysis*, sizes and weights.

Reliability is simply a function of stress; we must focus on figuring out how to solve destressing designs.
We're designing to minimize failure.

Major Questions That Need To Be Answered:

- Does the contract require a reliability prediction with stress analysis to evaluate part derating criteria and max allowable junction temperatures?
- By SRR, is there an established set of derating criteria and max allowable junction temperatures that all Engineers will use?
- Has the Government team reviewed derating criteria and max allowable junction temperatures? (Reference SD-18, Ref. 23)
- By CDR, have stress and thermal analysis been performed to identify parts that exceed derating criteria and max allowable junction temperatures?
- What actions will be taken to address parts that exceed established derating criteria and max allowable junction temps?
- Will the results of thermal testing be used to evaluate compliance with derating criteria?
- Is there an Approved Parts List? Alternatively, is there a prohibited parts list?
- Will part operating temperatures be determined by thermal survey measurement?

- Are the junction temps consistent with SD-18 based on the part type?
- Are the results of thermal analyses and thermal survey measurement being used in the design process?
- Are all T (thermal coefficients of expansion) mismatches understood?
- Will a thermal stress analysis be conducted (no junction temperatures should exceed 110 DEG. C.)?
    - What actions will be taken to address parts that exceed established derating criteria and max allowable junction temperatures?

Risk if you get it wrong:

- Higher operating temperatures resulting in increased failure rates.
- Thermal hotspots and overstressed components requiring unplanned engineering changes and increased logistics cost.
- Parts failure due to overheating and failure at junctions.
- Poor systems performance/field reliability.
- Destruction of circuit boards and other components by overheating.

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Finite Element Analysis

Finite Element Analysis (FEA) is a numerical method for solving engineering problems and mathematical physics, which include solving problems in structural analysis, heat transfer, fluid flow, mass transport, and electromagnetic potential. For physical systems involving complicated physical systems geometries, loadings, and material properties, it is generally not possible to obtain analytical mathematical solutions to simulate the response of the physical system. **FEA is an analysis tool** that provides a better understanding of the design and confidence in its ability to meet performance requirements, and allows the PM to examine what-ifs with materials and design changes. It can give the PM good early insight into the design's weaknesses. Use FEA to simulate and predict how the product will react during use in the real world.

FEA divides complicated structures into small elements or pieces in relation to each other for analysis; it uses mathematical models to understand and quantify the effects of real-world conditions on a part or assembly. System complexity, design features, and available computer resources will affect any decision to employ FEA. It requires significant computing resources to support a fine enough mesh size in models to be effective. As a **simulation tool**, used principally during the analysis and design phase, FEA facilitates an understanding of the design and its ability to meet targeted performance requirements. Of course, FEA should be considered well before establishing the product baseline (*Pre-Milestone B during Technology Maturation and Risk Reduction (TMRR) phase if not during Materiel Solution Analysis (MSA) phase*). FEA can complement and expand traditional testing results. It can contribute to life prediction and failure analysis. The PM should trade-off the availability and cost of computational resources against the design complexity and innovation. From the start, the parameters specified in the FEA must be adequate to perform a

sufficiently In-depth analysis. FEA requires an early understanding and investment commitment.

The unit of measure (mesh size) is of vital importance as well as the method of mesh refinement. Figure #16 shows a typical FEA mesh.

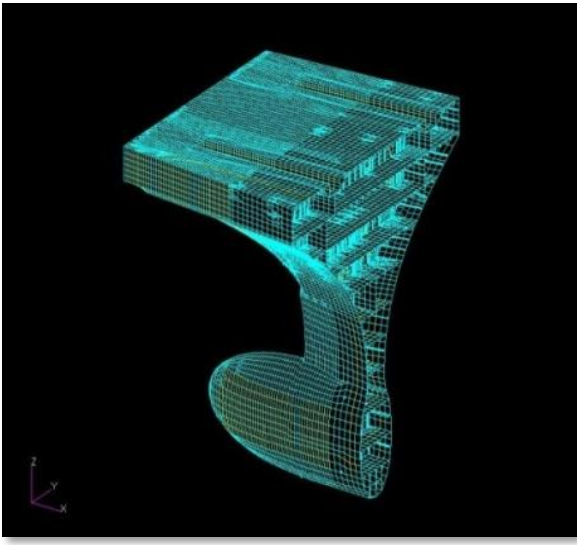

Figure #16 – FEA Mesh Example
Source: WILLCOR & US Navy

FEA also facilitates physics of failure analyses of electronic circuit cards *(shop replaceable units or shop replaceable assemblies)*. In the event the design is found to be marginal or unacceptable, being during the design phase adequate schedule must remain to perform a redesign.

After a design is fielded, having the FEA models archived allows engineering organizations to use the models to predict performance and make decisions for off-design conditions such as new operating environments **and the performance impact of damage**. When set up properly (i.e. - proper input conditions) FEA works and works very well.

FEA models for complex systems like an aircraft carrier hull can take weeks to run. To minimize this time and computing power, modelers will often increase the mesh size. The result can be the modeling of complex shapes as straight lines, which may be inappropriate. While in many cases this is acceptable, the PM should understand the modeling decision and how they affect program risks.

Major Questions That Need To Be Answered:

- Encouraging the use of FEA will reduce the amount of design and test time, how will that cost avoidance be used to determine the number of items that will be assessed?
- Is the analysis sufficient to accurately characterize the structure being examined?
- What method is being used to determine the mesh size?
- Are any non-linear structures being represented by a straight line?
- Will FEA be used to predict the response to environmental stimuli such as vibration, thermal loads, and shock (transient) loading?
- Has Modal Analysis been conducted, and are all modes well understood?

Risk if you get it wrong:

- Inherent design flaw(s) are detected after a product is produced.
- High cost to redesign once the product baseline has been established or if design flaw is discovered at or after MS C.
- Increased cost to re-test the product.

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Environmental Stress Screening (ESS)

Narrative: The objective of ESS is to ensure the manufacturing and quality process are in control to manufacture the product to meet its specifications. Environmental stressing is an effective technique to uncover defects for elimination. Stress level/stimulus must typically exceed part tolerances to be harsh enough to precipitate defects but not damage the useful life of the parts. Environmental Stress Screening verifies that production workmanship, manufacturing processes, quality control procedures, and the accumulation of design changes do not degrade the equipment reliability demonstrated during qualification and reliability testing.

During the Engineering and Manufacturing Development (E&MD) and Production and Deployment (P&D) phases, the establishment of tailored ESS stress profiles **facilitates the accelerated identification and removal of latent defects** ("weak actors") in the product which can yield significant improvements in field reliability and reductions in field maintenance cost. **Screening environments consist of temperature cycling and random vibration** applied either sequentially or concurrently to induce energy to precipitate latent defects. **Failures fall primarily into two defect categories:**

- **Poor Workmanship/Process/Assembly or**
- **Flawed Parts.**

The contractor's ESS profiles should be compared with the vibration and thermal stress profiles of MIL-HDBK-344A, Ref. 24, Figure #17, unless specific program or specification guidance is defined.

DESCRIBE YOUR EXPERIENCE, SPECS, PROCESS, AND TESTING TO EFFECTIVELY APPLY ESS

Alternatively, the contractor's ESS test environs should attain a minimum of 95% Precipitation Efficiency and 90% Detection

Efficiency using vibration and thermal stresses as defined by MIL-HDBK-344A.

The contractor should provide to the Government for review and approval:

1) An ESS procedure defining the thermal and vibration profiles to be applied, number of cycles, location of sensors, and functional test

SCREEN TYPE PARAMETERS AND CONDITIONS	ASSEMBLIES (PRINTED WIRING ASSEMBLIES) (SRU)	EQUIPMENT, OR UNIT (LRU/LRM)
THERMAL CYCLING SCREEN		
Temperature Range (Minimum) (See Note 1)	From -54°C To +85°C	From -54°C To +71°C
Temperature Rate Of Change (Minimum) (See Note 2)	30°C/Minute (Chamber Air Temp.)	5°C/Minute (Chamber Air Temp.)
Temperature Dwell Duration (See Note 3)	Until Stabilization	Until Stabilization
Temperature Cycles (Minimum)	25	10
Power On/Equipment Operating	No	(See Note 5)
Equipment Monitoring	No	(See Note 6)
Electrical Testing After Screen	Yes(At Ambient Temp)	Yes(At Ambient Temp)
QUAS-RANDOM VIBRATION (See Note 7)		
Spectral Density	(See Note 8)	6 Grms
Frequency Limits		100 -1000 HZ
Axes Stimulated Serially or Concurrently		3
Duration Of Vibration (Minimum) - Axes Stimulated Serially - Axes Stimulated Concurrently		 10 Minutes/Axis 10 Minutes
Power On/Equipment Operation		(See Note 5)
Equipment Monitoring		(See Note 6)

* SRU - Shop Replaceable Unit LRU - Line Replaceable Unit LRM - Line Replaceable Module

Notes:
1. Temperatures beyond stated minimums are acceptable.
2. Rapid transfers of the equipment between one chamber at maximum temperature and another chamber at minimum temperature are acceptable.
3. The temperature has stabilized when the temperature of the part of the test item considered to have the longest thermal lag is changing no more than 2 degrees Centigrade per hour.
4. A minimum of five thermal cycles must be completed after the random vibration screen.
5. Shall occur during the low to high temperature excursion of the chamber and during vibration. If operating, equipment shall be at maximum power loading. Power will be OFF on the high to low temperature excursion until stabilized at the low temperature. Power will be turned ON and OFF a minimum of three times at temperature extremes on each cycle.
6. Instantaneous go/no-go performance monitoring during the stress screen is essential to identify intermittent failures when power is on.
7. Specific level may be tailored to individual hardware specimen based on vibration response survey and operational requirements.
8. When random vibration is applied at the equipment- level, random vibration is not required at the subassembly-level. However, subassemblies purchased as spares are required to undergo the same random vibration required for the equipment-level. A "LRU mock-up" or equivalent approach is acceptable.

Figure #17 - ESS Initial Regimen
Source: MIL-HDBK-344A

and detection procedures for identifying intermittent and hard failures, and

2) Engineering documentation substantiating the methodology used to establish the ESS profiles (thermal survey for thermal stabilization/ dwell/soak times, vibration survey for resonant frequencies, temperature rate of change, etc.)

All electronics will go through 15 thermal cycles from +70 to -50 deg. C at no less than a 5-degree rate of change, while operating and running Built-In-Test (BIT), as well as random vibration cycling. For details, see among other documents, the Tri-Service Technical Brief 002-93-08 on ESS, Ref. 25, and MIL-HDBK-344A on ESS, Ref. 24. While this is a production screening process for latent manufacturing defects, it is also critical upfront to qualify the design especially when there are no parts restrictions on the designer. Another part of a good ESS program is the review of the need for Partial Impact Noise Detection (PIND) testing to detection of loose particles in electronic components. The effort to detect and resolve those particles will enhance the reliability of a system. BIT should be included in design reviews and utilize a fault tree to be developed and analyzed as input to BIT and other design efforts. BIT should detect 95% of all failures, and isolate replaceable modules 80% of the time. All BIT routines should be completed in 10 minutes or less and false alarms be specified at 0.1% or less.

Major Questions That Need To Be Answered:

- Is MIL-HDBK-344A (Ref. 24) used as guidance for ESS procedures or is another suitable ESS guidance provided?
- Do proposed ESS profiles perform both vibration and thermal stress sequentially or concurrently? Do stress profiles provide a minimum of 90% Precipitation Efficiency as specified by MIL-HDBK-344A if used as guidance?

- Are functional tests and/or equipment Built-In Test (BIT) performed while thermal and vibration stresses are applied?
- Do ESS procedures specify that for any failure and retest, the retested unit should have the last 3 to 5 stress cycles as failure-free?
- Does the contractor maintain a Failure Review Analysis and Corrective Action Process (FRACAS) to track failures and implement required design and process improvements?
- Is Environmental Stress Screening (ESS) considered a standard manufacturing practice (including for subcontractors)?

Risk if you get it wrong:

- **ESS development during E&MD**:
    - Use of non-tailored ESS profiles will likely result in low precipitation efficiency, during production failure-prone units will probably be sent to the field.
    - Lack of early ESS profile development may result in a missed opportunity to identify design weaknesses.

- **ESS during Production**:
    - Failure-prone units (with latent defects) are sent to the field.
    - For unpowered testing and/or testing with no stress, intermittent defects are not detected and failure-prone units are sent to the field.
    - High equipment return rate to the contractor.
    - Impact to operational and materiel availabilities.

Sneak Circuits and Analysis

A Sneak Circuit is an unexpected path or logic flow within a system. Under certain conditions, it can initiate an undesired function or inhibit a desired function. The path may consist of hardware, software, operator actions, or combinations of these elements. Sneak circuits are **not the result of hardware failure** but are latent conditions, inadvertently designed into the system, coded into the software program, or triggered by human error." Sneak circuits may exist in Hydraulic controls, Pneumatic Controls, Mechanical Systems, Operating Procedures, and Software … etc. One handy resource is the Department of the Navy, Sneak Circuit Analysis publication, NAVSO P-3634, August 1987, (Ref. 26) for more information.

Sneak Circuit Analysis (SCA) identifies latent (sneak) unexpected circuits and conditions, *which are a designed-in signal or current path and are present but not always active,* which inhibit desired function or cause an unwanted function in hardware or software system without a component having failed.

Ensure **Sneak Circuit Analysis (SCA)** is planned, funded, and conducted. Make certain there are no unintended consequences, for example, design mitigation for faults like the Divide by Zero faults in software by requiring **Range Checking** for all I/O (Input/Output). See also the Ionizing Radiation in Microelectronics fundamental for a brief description of some **Single Event Effects (SEEs)** which are incidents with heavy ions from cosmic rays and solar events which cause Soft or Hard Faults/Errors. Provided, there are some design phase considerations to mitigate several faults along with brief introductions of:

- **Single-Event Upset (SEU),** aka "Bit Flips" in memory registers;
- **Software Range Checking**, to mitigate divide by zero errors;
- **Error Correcting Code (ECC),** to store redundant data to catch and correct corrupted info in the memory;

- **Software and Hardware Redundancy,** like Triple Modular Redundancy so if one system suffers a soft error the other two will overrule in the decision-making logic;
- **Radiation Hardened Chips**, to take advantage of modern chip performance improvements; and
- **Ceramic Packaging,** to improve radiation hardness of chips.

Consider Figure #18's **common example of a sneak circuit.** The figure illustrates both the expected path of electrical flow and the sneak path. It illustrates graphically a sneak circuit that might exist in a 1960's automobile electrical system. In the situation

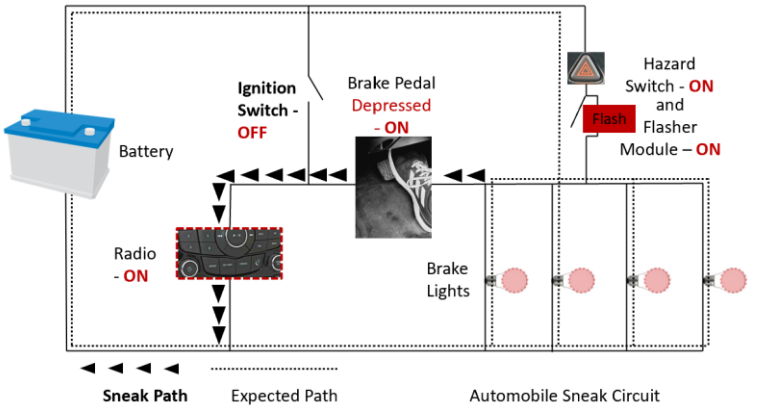


Figure #18 – 1960's Automobile Sneak Circuit
Source: NAVSO P-3634 (WILLCOR Images)

diagrammed - ***with the automobile ignition turned off, the radio switch left on, and the brake pedal depressed*** - the hazard switch can provide power that will turn the radio on with each flash of the brake lights.

Particular attributes of systems have been identified that can cause these latent or "sneak" conditions to be unintentionally introduced into a system design. Designers must be aware of these attributes and conduct SCA when appropriate. **Sneak Circuit Analysis should be conducted on**:

- highly **complex** system designs
- system designs experiencing a **high rate of change**
- systems with a **large number of interfaces** to other systems
- systems with **complicated operating procedures**, and
- systems when a **safety** issue is involved.

Common applications of SCA are seen in electronics, power supply, and control systems. The benefits of an SCA are not limited to these areas. This technique can be successfully conducted on the hardware, software, and manual procedures used to operate the system or any combination of these three. For example, the types of problems to examine in the sneak circuit analysis ***of the operator's procedures*** include:

- **Errors Of Omission:** the failure of the operator to perform a task or part of a task indicated in the procedures
  Errors Of Commission: the operator performs a task or step incorrectly
- **Extraneous Acts:** the operator introduces some task or step that should not have been performed.
- **Sequential Errors:** the failure of the operator to perform the tasks in the correct order.
- **Timing Errors:** a task or step is performed too early or too late, i.e., not performed within an allotted time interval.

<u>Major Questions That Need To Be Answered:</u>

- Do you understand the susceptibility of your system to ionizing radiation? For example, Total Ionizing Dose (TID) failure rate can be described by a mean time to failure (MTTF), but SEE must be expressed in terms of a random failure rate.
- What is the potential for SEU in your system?
- Has there been analysis for single-point failures?
- Is there a fault detection, isolation, and identification strategy?

- Are you familiar with the mitigation techniques applied: error correction, failover, redundancy, etc., and the pros and cons of each?
- Has the fault protection scheme been independently verified?

Risk if you get it wrong:

- Time consuming rework and possible reconfiguration with expensive long-lead-time components.
- Poor performance in the field and/or low reliability

Process Oriented Technical Risk Assessment and Management

Narrative: The Risk Management process is the overarching process that encompasses identification, analysis, mitigation planning, mitigation plan implementation, and tracking of program risks. **Risk management is the primary method of mitigating program uncertainties** and is therefore critical to achieving cost, schedule, and performance goals at every stage of the life cycle. Effectively managing risks helps the Program Manager and Systems Engineer develop and maintain a system's technical performance, and ensure realistic life cycle cost and schedule estimates.

DoDI 5000.02 (Ref. 4) requires that technical and programmatic risks be managed in all life cycle phases. A program's Technology Development Strategy or Acquisition Strategy, and Systems Engineering Plan (SEP) should address risks and should describe the program's risk management process. The scope of this activity is proportional to the complexity of the program.

Risk analysis (Figure #19) is an iterative process that attempts to identify potential problem areas, probability of occurrence of the risk, assess the effects of the risks, and generate alternative solutions to reduce the risks (i.e., mitigation). Risk modeling should initially be done in the Materiel Solution Analysis (MSA) phase or certainly by the Technology Maturation and Risk Reduction (**TMRR**) phase to detect and minimize risks early. It is easier and less costly to make changes and correct errors when the system is being designed and developed than when prototypes or actual systems are being tested.

PREDICTIVE RISK MANAGEMENT, NOT REACTIVE PROBLEM MANAGEMENT

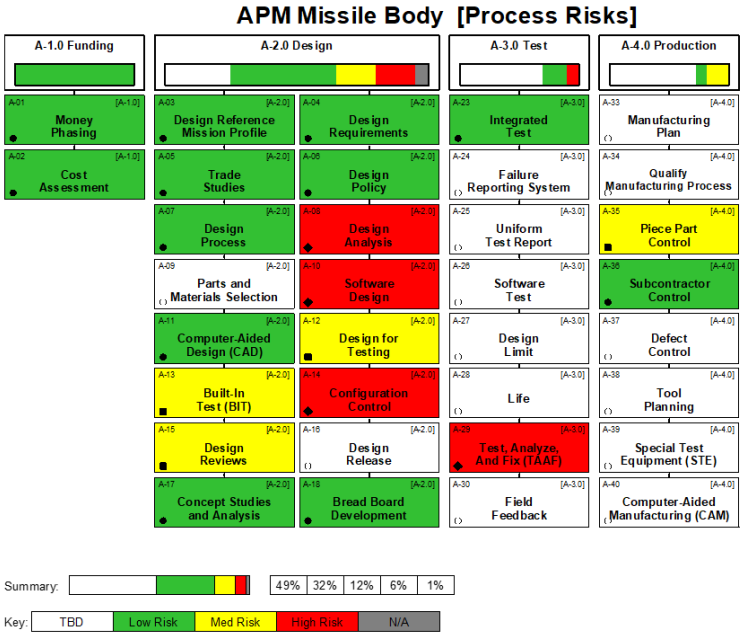


Figure #19 - Technical Risk Identification and Mitigation System (TRIMS) Process Risk Template (Ref. 27)
Source: WILLCOR – TRIMS

Major Questions That Need To Be Answered:

- Following the Risk Management Guide for DoD Acquisition? (Also see Defense Acquisition Guidebook (DAG) (Ref. 28) Chapter 1 Program Management Activities for more information on the Program Manager's role in Risk Management and Chapter 3 Systems Engineering.) This is not enough, you need to track key process risks as well (see DOD 4245.7-M, Ref.29, NAVSO P-6071, TRIMS tool, Ref. 27).
- Have technical risk indicators been generated for design, test, manufacturing, facilities, logistics, cost, and management processes?

- Are all levels of management provided periodic risk tracking reports of the technical status, problem corrective actions, and subsequent project impact?
- Does each technical risk indicator have a program approach for addressing the potential root cause or unfavorable consequence?
- Is Reliability addressed in the contract as an MTBF?
- Does the detailed program schedule show that the results of the RM&A activities will be available in sufficient time to be considered as part of the design and trade studies and reviewed at Preliminary Design Reviews (PDR)? This should be clearly visible in the Integrated Program Schedule.
- Is reliability a TRADE-STUDY factor?
- Beyond PDR, does the program office conduct periodic design reviews (continue Manufacturing Readiness Assessments)?
- Will Manufacturing and Producibility personnel be involved in the design process?
- Do the mission profiles (Design Reference Mission Profile (DRMP) and/or Operational Mode Summary/Mission Profile (OMS/MP)) make clear that designing to minimize failure must include Environment and Life conditions?
- Is the design reference mission profile included in the RFP?
- Will environmental testing be conducted based on the Mission Profile (including transport and storage)?
- Will Reliability and Maintainability (R&M) design requirements, processes, and practices include efforts such as stress analysis, derating, physics of failure analysis, test & evaluation, and FRACAS to realistically achieve desired fielded system R&M attributes?
- Will reliability be treated as a performance parameter and weighted equally during design trade-offs?
- Will a stress analysis be conducted based on all Design Reference Mission Profile (both functional and environmental) extremes?

Risk if you get it wrong:

- Program delays in recognizing technical factors will likely drive cost and schedule.
- Technical mitigation of problems may not be included in the configuration baseline.
- Significant cost and schedule impact may result from unrecognized technical risk.

Appendix A: Reliability-By-Design

Scorecard:
Measures of Effectiveness (MOE)

Source: Image is Open source

Scorecard Spreadsheet Available at:

https://www.bmpcoe-trims.org/

Measuring Product Maturity against a Process-Based Best Practices Technical Baseline

This scorecard is a pro-active process-based risk assessment tool that can identify weaknesses that affect our warfighters. Figure #'s 1a & 1b shows a *notional* sample excerpt from an assessment using the scorecard. This appendix provides details on how to use the scorecard (with an accompanying spreadsheet) and score the assessment as well as a discussion on the key reliability by design activities to improve your score.

A Simple Maturity Index Concept & Definitions

Reliability By Design - Measure Of Effectiveness (RBD-MOE) Maturity Index (MI)

NOTE: Maturity Index (MI) Scoring covers the *Individual Templete -level MOE's* (TMI) as well as rolling those measures up to both *Discipline* -level (DMI) (i.e. Design, Test, Production,...) and the entire *Program* -level (PMI) MOE's.

EXAMPLE: RBD-MOE MI for the notional "All-Purpose Missle Program" and Compliance Value (CV) Metrics

Milestone Decision Points	Milestone 1				Milestone 2				Milestone 3			
Templates / Discipline / PROGRAM	CV	RBD-MOE	MI	%	CV	RBD-MOE	MI	%	CV	RBD-MOE	MI	%
Design												
Template D1-Design Mission Profile	21	21	1.00	33%	53	21	2.52	84%	60	21	2.86	95%
Template D2-Design Requirements	51	21	2.43	81%	40	21	1.90	63%	55	21	2.62	87%
Template D3-Design Analysis	11	6	1.83	61%	18	6	3.00	100%	18	6	3.00	100%
Design Roll-up - DMI	83	48	1.73	58%	111	48	2.31	77%	133	48	2.77	92%
Test												
Template T1-Integrated Test Plan	13	12	1.08	36%	24	12	2.00	67%	34	12	2.83	94%
Template T2-Failure Reporting System	3	3	1.00	33%	4	3	1.33	44%	5	3	1.67	56%
Template T3-Design Limit	47	22	2.14	71%	57	22	2.59	86%	66	22	3.00	100%
Test Roll-Up - DMI	63	37	1.70	57%	85	37	2.30	77%	105	37	2.84	95%
Production												
Template P1-Manufacturing Plan	21	8	2.63	88%	16	8	2.00	67%	22	8	2.75	92%
Template P2-Piece Part Control	24	9	2.67	89%	25	9	2.78	93%	27	9	3.00	100%
Template P3-Subcontractor Control	24	16	1.50	50%	35	16	2.19	73%	37	16	2.31	77%
Production Roll-Up - DMI	69	33	2.09	70%	76	33	2.30	77%	86	33	2.61	87%
ALL PURPOSE MISSLE PROGRAM - PMI	215	118	1.82	61%	272	118	2.31	77%	324	118	2.75	92%

Figure #1a - Maturity Index Scorecard – Sample Calculations
Source: WILLCOR

The below Figure #1b - **Maturity Index Definitions** and Rules are embedded in the colored ASN RDA – Simple Maturity Index Scorecard.

Assign a **Compliance Value (CV)** measure, according to the scale, for each bulleted **Measure Of Effectiveness (MOE)** in each process (**Template**) being assessed in your program. **Compliance review starts with a score of 1, which is shown in the Database spreadsheet until scoring questions reflect some compliance improvement.*	**Compliance Value SCALE** **1 = NO Compliance** 2 = PARTIAL Compliance **3 = TOTAL Compliance**
Sum the **CV**s **for a single *Template*** and divide by the **number of MOE's** in that Template for the ***Template*** Maturity Index (**TMI**)	**TMI** = ∑ CVs / nMOE's
Sum the **CV**s for ***all* Templates *within a* Discipline** and divide by the number of ***all* MOE**'s in that Discipline for the **Discipline** Maturity Index (**DMI**).	**DMI** = ∑ CVs / nMOE's
Sum the **CV**s for ***all* Templates *being assessed in the* PROGRAM** and divide by the number of **MOE**'s in these Templates to determine the **PROGRAM** Maturity Index (**PMI**).	**PMI** = ∑ CVs / nMOE's
Each Maturity Index (TMI, DMI, and PMI) is color-coded according to the scale on the right for ease of presenting a summary report.	**Maturity Index Scale** **Red** = 1.00 - 1.79 **Yellow** = 1.80 - 2.49 **Green** = 2.50 - 3.00

Figure #1b - Maturity Index Definitions and Rules
Source: WILLCOR

Table 1 - Simple Maturity Index

Reliability by Design MOE Maturity Index (MI) for: YOUR PROGRAM NAME HERE								
Milestone Decision Points	Milestone 1				Milestone 2			
Templates Discipline PROGRAM	Compliance Value (CV)	RBD-MOE	MI	%	Compliance Value (CV)	RBD-MOE	MI	%
Design								
Design Reference Mission Profile	5	5	1.00	33%	5	5	1.00	33%
Design Requirements	16	16	1.00	33%	16	16	1.00	33%
Trade Studies	4	4	1.00	33%	4	4	1.00	33%
Design Process for Reliability	5	5	1.00	33%	5	5	1.00	33%
Design Analysis	12	12	1.00	33%	12	12	1.00	33%
Parts & Materials Selection	5	5	1.00	33%	5	5	1.00	33%
Software Design	15	15	1.00	33%	15	15	1.00	33%
Built-in Test	5	5	1.00	33%	5	5	1.00	33%
Design Reviews	15	15	1.00	33%	15	15	1.00	33%
Spec Development Allocation/Validation	12	12	1.00	33%	12	12	1.00	33%
Prototype Development and Review	2	2	1.00	33%	2	2	1.00	33%
Prepare Design Requirements Documents	11	11	1.00	33%	11	11	1.00	33%
Quality Assurance (QA)	7	7	1.00	33%	7	7	1.00	33%
New Template								
Design Roll-up - DMI	**114**	**114**	**1.00**	**33%**	**114**	**114**	**1.00**	**33%**
Test								
Integrated Test Plan	5	5	1.00	33%	5	5	1.00	33%
Failure Definition Scoring (and FMEA/FMECA)	7	7	1.00	33%	7	7	1.00	33%
Software Test	8	8	1.00	33%	8	8	1.00	33%
Design Limit	4	4	1.00	33%	4	4	1.00	33%
Life	4	4	1.00	33%	4	4	1.00	33%
Test, Analyze, & Fix (TAAF/TAFT)	9	9	1.00	33%	9	9	1.00	33%
TEMP Development/Execution	6	6	1.00	33%	6	6	1.00	33%
New Template								
Test Roll-Up - DMI	**43**	**43**	**1.00**	**33%**	**43**	**43**	**1.00**	**33%**
Production								
Piece Part Control	10	10	1.00	33%	10	10	1.00	33%
Requirements Flow Down - Subcontractor Control	10	10	1.00	33%	10	10	1.00	33%
Defect Control	5	5	1.00	33%	5	5	1.00	33%
Manufacturing Screening (ESS)	12	12	1.00	33%	12	12	1.00	33%
Diminishing Mfg. Sources & Material Shortages (DMSMS)	9	9	1.00	33%	9	9	1.00	33%
New Template								
Production Roll-Up - DMI	46	46	1.00	33%	46	46	1.00	33%
Sustainability/Supportability								
Sustainment/Provisioning Analysis	3	3	1.00	33%	3	3	1.00	33%
Maintainance/Manpower Ratio	4	4	1.00	33%	4	4	1.00	33%
Support and Test Equipment	7	7	1.00	33%	7	7	1.00	33%
Training Materals and Equipment	6	6	1.00	33%	6	6	1.00	33%
Spares	4	4	1.00	33%	4	4	1.00	33%
Technical Manuals	5	5	1.00	33%	5	5	1.00	33%
Logistics Analysis/Documentation	7	7	1.00	33%	7	7	1.00	33%
New Template								
Supportability-Logistics Roll-Up - DMI	36	36	1.00	33%	36	36	1.00	33%
ALL PURPOSE MISSLE PROGRAM – PMI	**239**	**239**	**1.00**	**33%**	**239**	**239**	**1.00**	**33%**

Reliability by Design Measures of Effectiveness: The Lessons Learned Questions Database

The following process-based risk assessment question ***samples*** help identify weaknesses early before they become problems. You will note the major column headings reflect a notional Milestone. For simplicity and clarity in this booklet, only one Milestone sis shown. Milestones may reflect any of the overall Defense Acquisition Framework with an MS-A, MS-B, MS-C… or may reflect any review need the user desires like ASR, SRR, SFR, PDR, CDR, TRR. The actual MS Excel Spreadsheet being provided has three Milestones; while a knowledgeable MS Excel user may modify the spreadsheet and data roll-up. Further, as you will see with the various blank yellow cells, new knowledge questions may be added to supplement the existing Process-Based question based on best practices from many programs. A great degree of tailoring is afforded with this simple MS Excel spreadsheet format. However, it does not contain the breadth of program management features afforded by the full TRIMS tool, Ref. 27!

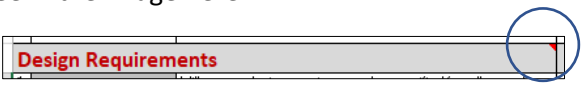
When making use of this RBD-MOE Maturity Index assessment Scorecard tool, the user simply goes to each of the Category Database tabs (Design, Test, Production, & Logistics) as appropriate to perform an assessment. The evaluator(s) will make a judgment about the level of risk in those overall categories based on the relative number of questions coded with a compliance score of 1, 2, or 3 (discussed above) to represent the individual question compliance scores (1=No Compliance, 2=Partial Compliance, & 3=Total Compliance). This is quick, high-level, and simple.

As program compliance improves over time, the actual Maturity Index chart will change color as displayed on the above sample concept - maturity index chart. When progressing to the second and following milestone reviews, you will note that the question has changed in tense. The Milestone 1 questions speak to a preparation

or planning like: *will something be done*. Follow-on Milestone questions are phrased to determine if the planned action has been accomplished and ask a question like: *has something been done*.

The best and proper time for Reliability by Design planning to be accomplished is … EARLY. Early in initial design and early in redesigns. With initial designs, early typically mean pre-MS-A, or at the earliest program entry point, like inclusion in foundational documents like the draft Capabilities Development Document (CDD), MS-A Test and Evaluation Master Plan (TEMP). Prudent and rigorous use of this simple Maturity Index Scorecard occurs in the build-up to MS-A, and of course during the Technology Maturation & Risk Reduction (TM&RR) phase. Often, programs sense cost and/or schedule challenges at or following MS-B in the Engineering & Manufacturing Development (E&MD) phase as they struggle to achieve a successful Critical Design Review (CDR). In such E&MD cases, use of this Scorecard can help a program get back on track by identifying risk areas that may have been overlooked.

Additionally, the **Category Questions Database spreadsheet** (like Design Questions, Test Questions, Production Questions, & Logistics/Supportability Question) **contains a very brief description of why the scorecard topic is important!** It is contained within *the individual* Template Headings Cell (like Design Requirements, Trade Studies, Design Analysis …). This MS Excel spreadsheet CELL COMMENT is indicated by a small red triangle in the Cell's top Right Corner as you can see in the image here.



Take for example the Design Category Template entitled "Design Requirements" it contains the following helpful reminder:

> *The designation of detailed **design requirements** is singularly important in the discussion of design activities. An iterative requirement setting process starts with concept formulation and with trade studies using refined*

mission/environmental profiles. This results in firm requirements necessary for the Engineering and Manufacturing Development (E&MD) Request for Proposals (RFP's).

The following 2 pages are a sample of the question sets contained in the actual scorecard spreadsheet database, and TRIMS.

These sample tables below only show one Milestone column for fitment to this document, the downloadable spreadsheet contains three columns. Milestones need not be limited to just three Major Milestones like A, B & C, they could be almost anything a program chooses like MS-A, SFR, PDR, MS-B, CDR, TRR, DT&E Event, MS-C, OTRR, IOT&E, …

Scorecard Spreadsheet download available at:

https://www.bmpcoe-trims.org/

Design Database Questions (*Sample*)

	Reliability By Design - Measures of Effectiveness (RBD-MOE)		
		DESIGN (Milestone 1)	
		QUESTIONS	**SCORE**
Design Reference Mission Profile			
1		Will mission functional and environmental profiles be prepared by the government and included in the Request For Proposals (RFP)?	1
2		Will the contractor use detailed mission functional and environmental profiles to establish requirements and design margins for the system and its component parts?	1
3		Will mission functional and environmental profiles be updated as test data warrants?	1
4		Will environmental profiles cover all functional modes of operation including combat, transport, storage, handling, training, maintenance, and production?	1
5		Will all functional profiles be defined in terms of time (duration), level of severity, and duty cycle including peacetime and wartime missions?	1
10			
11			
	Compliance Value	CV	**5**
	Questions Counter	RBD-MOE	**5**
Design Requirements			
1		Will system design requirements be specified for, allocated to, and understood by each responsible design engineer and tester for each of the three pillars of System Effectiveness (Availiability, Dependability, and Capability)?	1
2		Will relevant design requirements be flowed down to subcontractors?	1
3		Will detailed design requirements be specified in the Request for Proposal (RFP)?	1
4		Will Inherent Availability (Ai) be used as a design requirement?	1
5		Will design requirements be frozen at Milestone II?	1
6		Will a clear definition of firmware for this project be established?	1
7		Are all mandatory requirements stated in a testable fashion?	1
8		Will, at the conceptual level, a review of any possible environmental hazards be conducted?	1
9		If alternatives to environmental hazards do not exist, are the hazards acceptable?	1
10		Will a traceability plan be developed showing how all requirements are based on the Design Reference Mission Profile and that specifications are traceable to requirements?	1
11		Will a specification tree be developed and maintained?	1
12		Will a story board of the full life cycle be communicated to the entire team to further clarify requirements?	1
13		Will relevant design requirements be flowed down to support personnel including testers, writers, customer support, sales, marketing & field support?	1
14		Will the architecture address external software interfaces, user interfaces, database organization, key algorithms, memory management, data and string storage, concurrency of threads, security, networking, portability and error handling?	1
15		Will program management (PM) team decompose Sustainment KPPs/KSAs as early as possible (Draft CDD & CDD) into affordable, testable & tracable Physics of Failure requirements, such as Failure Rate/MTBF?	1
16		Will Availability metrics focus on Design-Controllable metrics like Inherent Availability (A_i) in requirements generation, decomposition, and design process verses the common Operational Availability (A_O) which can disguises performance by including the Mean Logistics Delay Time (MLDT)?	1
17		Will Reliability and Maintainability (R&M) design requirements and practices include efforts such as stress analysis, derating, physics of failure analysis, test & evaluation, and FRACAS to realistically achieve desired fielded system R&M attributes?	1
18			
19			
	Compliance Value	CV	**17**
	Questions Counter	RBD-MOE	**17**

Test Database Questions (*Sample*)

	Reliability by Design - Measures of Effectiveness (RBD-MOE)		
		TEST (Milestone 1)	
		QUESTIONS	**SCORE**
Integrated Test Plan			
1		Is the prime contractor required to prepare an Integrated Test Plan (ITP)?	1
		Will contingency resources be available for unforeseen test problems?	1
		Will contractual arrangements be made for buyer participation in contractor systems tests?	1
		Will software development testing be conducted prior to system integration testing?	1
		Will the ITP identify all developmental tests at the system and subsystem levels?	1
		Will the integrated test plan identify all tests, screens, etc. done by parts vendors, subcontractors, suppliers, prime, and buyer (i.e. Government)?	1
2		Will a requirements verification matrix be developed and distributed showing which tests verify which requirements?	1
3		Will test selects for the system test be kept to a minimum?	1
4			
6			
	Compliance Value	CV	**8**
	Questions Counter	RBD-MOE	**8**
Failure Reporting System			
1		Will all failures be reported (including but not limited to test, production, facilities, shipping and field failures)?	1
2		Will all failure analysis reports be closed out within 30 days of failure occurrence or rationale provided for any extensions?	1
3		Will corporate management be automatically alerted to failures exceeding closeout criteria?	1
4		Will Failure Review Board (FRB) membership be reviewed and approved by both contractor and government?	1
5		Will failure data be stored electronically and is it available to ALL design team members?	1
6		Will all pattern (pattern is >=3) failures be analyzed and categorized?	1
7		Will 85% of all failures be closed out within 30 days?	1
8		Will the ratio of closed failures to all failures be > 0.5 at CDR?	1
9		Will the ratio of closed failures to all failures be >= 0.9 at design release?	1
10		Will subcontractors issue monthly (and weekly for critical) Corrective Action (CA) summaries to the prime based on flowed down Failure Reporting Analysis and Corrective Action System (FRACAS) requirements?	1
11		Will the Failure reporting and corrective action system be shared with the entire team including production, designers and field support?	1
12		Will a white paper be written to explain the root cause of each failure, alternative approaches considered and corrective actions taken?	1
13		Will process improvements be made, based on trend data, to prevent reoccurrence?	1
14			
16			
	Compliance Value	CV	**13**
	Questions Counter	RBD-MOE	**13**

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Closing Thoughts

GAO has reported that Operations and Support (O&S) costs are driven by the system's Reliability and Maintainability qualities, and are approximately 80% of a system's Life Cycle Cost. Critical is that these Reliability and Maintainability influences cannot be added in during later phases of a program, but MUST be Designed-In from the onset of the program and certainly not later than during the Materiel Solution Analysis and Technology Maturation and Risk Reduction Phases. This provides a basis for SECNAV to emphasize rigorous and disciplined Reliability, Supportability, and Affordability efforts focused on a systems design, not prediction curves.

So, if there is a single aligning theme or metric for what we need to do, it is:

Reliability Is A Performance Parameter and Hence A Design Criterion.

To improve Reliability: Early in the acquisition lifecycle, address Design Stress … not reliability predictions curves.

For a full copy of the Scorecard and related database,
Contact ASN (RDA):
Phone - 703-695-6315

End Quotes:

"All failures are mechanical or chemical … electrons don't fail"
- Dr. Halpern, WPAFB

"With time and stress all joints fail"
– Mr. Jim Raby, US Navy EMPF

"The best part is No Part, the best step is No Step!"
- Mr. Elon Musk, CEO SpaceX

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Additional Reliability-by-Design Terms

Failure modes and effects analysis - Identifies potential failures and their impact on system reliability; used to prioritize failures and take actions based on how serious the consequences are, how frequently they occur, and how easily they can be detected

Failure reporting, analysis, and corrective action system - Identifies and captures information about failures, which can be used to prioritize corrective and preventative actions, avoid recurrence of failures in future designs, and provide a centralized location for failure data that can be used for reliability analysis

Physics of failure - Involves modeling and simulation of the root causes of failure, such as fatigue, fracture, wear, and corrosion; used to design reliability into a product, perform reliability assessments, and focus reliability tests where they will be most effective.

Reliability block diagrams - Illustrates relationships between components and subsystems graphically, using blocks to represent individual items; can be used to identify critical components and how the failure of a component or subsystem can impact the reliability of the overall system.

Reliability growth curves - Depicts management strategy to increase reliability and are useful in determining appropriate test time and number of test units for a given reliability target; can be used to illustrate and report reliability growth.

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Reliability is a performance parameter and hence, a design criterion.

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