The Essential RAM
A guide to tailoring ESSENTIAL Reliability, Availability, and Maintainability Tasks

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Fall 2011
Systems Engineering Integrative Project
• Project Background – *Defining the Problem*

• Defining RAM: *Review of Reliability, Availability, and Maintainability*

• NGAS RAM: *Summary of the RAM process at NGAS*

• Commercial RAM: *Summary of Commercial Best Practices on Reliability*

• The Essential RAM: *Finding the best value on RAM*
This project does not include any Northrop Grumman Proprietary information, but does provide generalizations of the processes and procedures performed for Reliability, Availability, and Maintainability at NGAS.

This presentation shall not be distributed beyond the LMU project committee.
In 2008, NGST (now NGAS) bid on a palletized protection system to defend against small munitions (i.e. RPGs). Reliability and System Safety fell under the responsibility of Mission Assurance (Quality). NGST lost the bid due to the unreasonable cost of the bid. Reliability engineering alone was a key contributor to the high cost. The conjunction of NGST reliability processes and customer mandated reliability tasks made the cost of reliability unreasonable, resulting in a lost proposal.

Being in the era of “faster, better, cheaper”, it is evident that applying the rigorous reliability, availability, and maintainability (RAM) tasks cannot be done without tailoring when budget and time becomes a key customer driver.

**Project Goal:** Identify the Essential RAM tasks that will help meet the customers demands without jeopardizing mission success for smaller aerospace systems.
Assumptions and Ground Rules

➤ The focus for tailoring is for Aerospace systems.

➤ These principles can be applicable for all programs desiring high reliability, but the tailoring guide is geared towards Aerospace systems.

➤ Most of the data collected was on space based systems

➤ Based on NASA's Classification Guide, this study is primarily applicable to class A and class B programs, although the essential RAM can be applied all program classes.
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Current reliability methods were established after the first world war.

Due to the increase in complexity of systems and the addition of electrical components, military systems experience high levels of failures in the field.

It was estimated that nearly half of the electronic equipment were down at any given time.

Reliability through statistics became increasingly popular in the 50's and 60's, which lead to our current reliability methods used today.

- Missile systems, communication systems, space systems, airplanes, etc.

**Availability**

\[ \text{Availability} = \frac{\text{MTBF}}{\text{MTBF} + \text{MTTR}} \]

Ratio of time a system is in operation versus the total mission duration

**Maintainability (MTTR)**

The ability of an item to be restored into the original specified operating condition

**Reliability (MTBF)**

Probability of a system performing without failure under a given condition for a specific period of time
There are many RAM requirements documents that Aerospace system refers to

- The most popular RAM requirements document used at NGAS is MIL-STD-1543 "Reliability Program Requirements for Space and Launch Vehicles"

- All three requirements documents listed above provide consistent approaches to Reliability, Availability, and Maintainability
Defining RAM: Reliability Analysis - Allocations, Modeling and Predictions

- Reliability Allocations – assignment of RAM requirements down to subsystem and elements within a subsystem
  - Allocating RAM requirements allow design engineers to understand reliability margins for design trades.

- Reliability Modeling and Predictions are used to quantitatively estimate the systems ability to meet customer requirements
  - Parts failure information is the key input to the models and predictions.
    - MIL-HDBK-217F is the most common parts database used for aerospace applications. Although the database was last updated in 1991, it is still widely used for parts stress data

- Purpose of performing a reliability analysis:
  1. Provides reliability estimates for design trade-offs
  2. Assists in design development for redundancy and cross strapping
  3. Can indicate if design will meet reliability requirements at the end of life
  4. Key inputs to determining the maintenance activities
  5. Provides input to total life cycle costs – scheduled maintenance, determine spares population, crew staffing, expected failure time, etc

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FMEA is a qualitative analysis to determine the potential failure mechanisms and its effects on the system.

The purpose is to identify design issues early in the development cycle so that changes can be made to design out potential failures.

Various Types of FMEA:

<table>
<thead>
<tr>
<th>Functional</th>
<th>Detailed</th>
<th>Interface</th>
<th>Maintenance</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Top Down Approach</td>
<td>• Bottoms up Approach</td>
<td>• Focuses on interfaces between subsystems, units, and components</td>
<td>• Used to provide information on fault detection and isolation.</td>
</tr>
<tr>
<td>• System level failures.</td>
<td>• Investigates component level failures and their effects to the system</td>
<td>• Typically performed during the preliminary phase</td>
<td>• Provides early criteria for maintenance and logistics planning</td>
</tr>
<tr>
<td>• Performed early in the design phase</td>
<td>• Performed as early as possible when design has been developed</td>
<td>• Usually performed when new units are being included</td>
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<tr>
<td>• Used to identify how failures could occur and traces down to the lower units</td>
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FMEA Process:

1. System Definition
2. FMEA Worksheet
3. Determine Effects
4. Failure Detection
5. Severity Classification
6. Corrective Action

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Defining RAM: Summary of Reliability Tasks

- Management
  - Program Plans,
  - Design Reviews,
  - FRACAS,
  - Subcontractors

- Allocations

- Modeling

- Predictions

- FMEA / FMECA

- Part Stress and Derating

- Fault Tree Analysis

- Critical Items List

- Worst Case Analysis

RAM Requirements
MIL-STD-1543B

Quantitative

Qualitative

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A paper study was conducted on 16 NGAS reliability program plans

- Programs ranged from large to small, space and ground, and dated between 1972 to current programs
- 13 of the 16 programs were space based programs that heavily focused on reliability requirements
- 6 of the 16 programs were considered to be "Large"
  - Small: <$300 Million, medium: $300-$500 Million, large: > $500 Million
- 6 programs had specific maintainability requirements

There were no specific Reliability requirements or processes mandated by NGAS policy manuals.

- NGAS policy manual indicates that a reliability program shall be established according to program requirements.

- Majority of the program plans followed the requirements from MIL-STD-1543B
- Interviews with Key NGAS Senior Systems Engineers were conducted
Majority of NGAS maintainability requirements were specific to ground support equipment for the space asset.

- Common theme of the maintainability plan was to provide input to the Logistics Support Plan.
  - LSP includes information on preventative, predictive, and corrective actions for maintenance, spare parts count, manpower requirements, support equipment for maintenance, etc.

- Maintainability predictions was the common requirement found in the maintainability plans. The prediction provides the required analysis for the LSP.

Summary Of Maintainability Requirements

**Maintainability Allocation, Modeling, Predictions & FMEA:**
Follows similar process as reliability analysis.

**Availability Analysis:**
Quantitative analysis to determine the probability of a system being available. This is typically performed through modeling and simulation.

**Maintainability Design Criteria:**
Guidelines and criteria that influence the maintenance of the design. Example Criteria – Accessability, interchangeability, fault detection, testability, special tools.

**Logistical Support Plan (LSP):**
Provides the essential information required to initiate and maintain the system throughout its operating life.
The two major tasks performed at NGAS were Reliability Analysis and FMEA.

- Reliability Analysis encompasses the allocation, model, and prediction. They are all dependent on one another, serving the same purpose.
  - Part stress was the primary method for reliability predictions, which required a bottoms-up approach to estimating the reliability of the system.

- FMEAs were performed on all programs that were reviewed. Types of FMEAs varied, but nearly all performed some level of failure analysis.
  - Detailed FMEAs were the most common methods, which is a bottoms up approach to identifying failures.
  - Fault Tree Analysis was uncommon. Both serve similar objectives in identifying potential failure modes and effects, but typically a FTA was not performed when an FMEA was required.

- CIL were also considered to be an important task in reliability engineering. Great emphasis was placed on controlling and mitigating each critical item.

- Tasks that are not performed by the reliability engineer
  - Circuit and part Stress analysis, and WCA were performed by the RDE.
  - Parts, Material, and Processes (PM&P) department was responsible for acquiring and testing parts.
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Two approaches were used to assess current commercial reliability practices

- Paper studies of past assessment on commercial reliability
  - Reliability Information Analysis Center (RIAC): Past assessment on commercial industry
  - IEEE Publications – Medical, nuclear, and commercial reliability practices
  - Reliasoft - the leading reliability engineering training, software, and services performed a global survey of current reliability practices
- Interviews were a key contributor in understanding the reliability culture

<table>
<thead>
<tr>
<th>Data Collection Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Medical</strong></td>
</tr>
<tr>
<td>• FDA Requirements</td>
</tr>
<tr>
<td>• Interviews</td>
</tr>
<tr>
<td>• Journals</td>
</tr>
<tr>
<td><strong>Nuclear</strong></td>
</tr>
<tr>
<td>• NRC Requirements</td>
</tr>
<tr>
<td>• IEEE Procedures</td>
</tr>
<tr>
<td>• Journals</td>
</tr>
<tr>
<td><strong>General Commercial</strong></td>
</tr>
<tr>
<td>• Surveys</td>
</tr>
<tr>
<td>• Interviews</td>
</tr>
<tr>
<td>• Journals</td>
</tr>
</tbody>
</table>
## Commercial RAM: Differences in culture

<table>
<thead>
<tr>
<th>Aerospace</th>
<th>Commercial</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mandated by the customer</strong></td>
<td><strong>Reliability Requirements</strong></td>
</tr>
<tr>
<td><strong>Highly involved from the beginning. Attends reviews, requires evidence and documentation</strong></td>
<td><strong>No specific reliability requirement, but quality and reliability will result in greater customer satisfaction</strong></td>
</tr>
<tr>
<td><strong>Typically revolutionary, highly complex, new technology</strong></td>
<td><strong>Customer Involvement</strong></td>
</tr>
<tr>
<td><strong>Defined by the customer</strong></td>
<td><strong>Minimal involvement during the design phase. Only documentation expected is the users manual</strong></td>
</tr>
<tr>
<td><strong>Operating Environment</strong></td>
<td><strong>Product Design</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Typically evolutionary design changes</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Defined by the engineer or company.</strong></td>
</tr>
</tbody>
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Medical Devices do not have specific reliability requirements flowed down by the customer, but they do report to the FDA regarding quality and safety of their products.

- When a new product is being launched, a “501K Pre-Market Approval” is required before a medical device can be sold.
- These quality requirements are more geared towards product safety and eliminating any potential hazards.

Key challenges in Medical Device Industry

- Time to market is a key driver for the medical device industry, which can dilute the importance of quality and reliability.
- Culture of compliance testing and analysis does not always lead to design changes and improvements.
- Due to the competitive nature, there are no shared practices, processes or failure databases in regards to reliability in the medical device industry.

Below are a list of reliability specific deliverables required:

- System description and it’s intended environmental use
- Failure Modes and Effects Analysis
- Fault Tree Analysis
- Compliance Testing
- Environmental Testing
- Performance and functional testing
- EMC/Electrical Testing
The Nuclear Regulatory Commission (NRC) oversees the safety, security, licensing, and material handling of nuclear systems.

- 10 CFR 50 Appendix A provides nuclear design criterion for reliability to protect against system failures

According to these guidelines and requirements, the following are the suggested reliability analysis performed for Nuclear Reliability
- These tasks can be divided into qualitative and quantitative reliability analysis

- Closely Matches function FMEA per MIL-STD-1543B
- Added perspective of eliminating HAZARDS
- Maintainability FMEA is also performed. Maintenance is a key method to mitigate failure modes
- Also known as FTA, is another qualitative failure analysis required
- Equivalent to modeling and predictions. Used to provide quantitative reliability estimations
- There are many part failure databases used for Nuclear, but MIL-HDBK-217 is not used
- Component, unit, and subsystem level testing to confirm adequate system reliability margins.
- Regular scheduled testing to support high system availability

In summary, the quantitative and qualitative reliability analysis performed for Nuclear systems closely resembles the aerospace industry.

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Based on two recent surveys conducted by RIAC and Reliasoft (2010), suggested commercial best practices and lessons learned were developed:

<table>
<thead>
<tr>
<th>Most important task currently performed in Industry</th>
<th>Most important tasks that should be performed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perform FMEA for system, subsystems and critical components</td>
<td>15%</td>
</tr>
<tr>
<td>Define system, subsystem and component level reliability requirements</td>
<td>12.7%</td>
</tr>
<tr>
<td>Develop a system reliability model</td>
<td>9.7%</td>
</tr>
<tr>
<td>Generate/confirm operating use profiles</td>
<td>7.6%</td>
</tr>
<tr>
<td>Conduct Reliability demonstration testing</td>
<td>7.4%</td>
</tr>
<tr>
<td>Ensure reliability for critical components</td>
<td>7.0%</td>
</tr>
</tbody>
</table>

Reliasoft performed a survey with over 500 participants. 15 key reliability tasks were identified, but the top 6 are listed to the left.

The two most important reliability tasks to perform are FMEA and reliability allocations.

**General Lessons Learned:**

- Based on survey results presented during RAMS (Reliability and Maintainability Symposium), 70% commercial industry started reliability process to late in the design
  - Often times resulting in poor reliability or expensive design rework.
  - Ideally, the analysis should be performed during the concept phase so that critical items can be address early on, and failures can be designed out

- Reliability engineering has to deal with time-to-market and funding pressures
  - Without management support, proper reliability analysis is difficult. Reliability must be adopted by the whole program, and it starts with program management (Top-Down)
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The Essential RAM: The highest value tasks are Reliability Predictions and FMEA

- Based on interviews, NGAS reliability program plans, and commercial best practices, the two highest value tasks in regards to reliability are
  1. Failure Modes and Effects Analysis (qualitative analysis)
  2. Reliability Predictions (quantitative analysis)

- Ground Rules for Essential RAM
  1. Define the operating environment and understand the reliability requirements and goals
     - Having a clear understanding of the reliability goals will help differentiate the necessary reliability analysis required to achieve the system goals
  2. Never compromise on Safety
  3. Perform reliability analysis as early as possible
     - Factor of ten rule applies to reliability. Design changes is ten times more expensive during production. Changes during operations can result in ten times more expensive than changes during production.
  4. Design Reuse
     - When proposing smaller and cheaper systems, design reuse is a key to minimizing reliability analysis, given that the analysis has already been performed on the reusable equipment.
     - Using proven and existing designs will help minimize the effort in reliability analysis.
The Essential RAM: Failure Modes and Effects Analysis

Tailoring Guide for Aerospace Programs

1. All programs shall perform a Functional FMEA as early as possible (during concept phase)
   - Identifying failures as early as possible will help drive design to mitigate these critical items

2. Based on the complexity of the program and the budget available, use the following tailoring guide:

<table>
<thead>
<tr>
<th>Simple Complexity - High design reuse, proven technology</th>
<th>Low Cost</th>
<th>Medium Cost</th>
<th>High Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Functional (unit level)</td>
<td>Functional (unit level) Interface for new equipment</td>
<td>Functional (component level) Interface for new equipment</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Medium Complexity - Design reuse with some new technology</th>
<th>Low Cost</th>
<th>Medium Cost</th>
<th>High Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Functional (unit level) Interface for new equipment</td>
<td>Functional (unit level) Interface for new equipment Detailed for new designs</td>
<td>Functional (component level) Interface for new equipment Detailed for new equipment</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>High Complexity - New system with little to no failure analysis available</th>
<th>Low Cost</th>
<th>Medium Cost</th>
<th>High Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Functional (unit level) Detailed for new designs</td>
<td>Functional (unit level) Detailed analysis on total system</td>
<td>Functional (component level) Detailed analysis on total system</td>
</tr>
</tbody>
</table>

3. Maintainability FMEA Analysis shall be performed if system is serviceable during operations

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If the system is maintainable, including ground support equipment, a Functional FMEA shall be performed and shall identify design concerns in regards to maintenance.

As a result of the FMEA, a CIL shall be created and managed through a Critical Items Control Plan.

- Reliability engineers shall work with design engineers to track and mitigate each critical item on the control plan.
- Criteria for CIL:
  - Failure modes categorized as a 1 or 2
  - Any items that leads to severe injury or death
  - State-of-art item with limited reliability data
  - Items known to have limitations or exceed derating criteria

Do not perform a criticality analysis.

- High effort is required to identify the failure probability, especially when failure rate data is not available.
- Ranking based on failure criticality does not negate the need mitigate the lower ranking failure modes that were identified by the FMEA.
- Criticality analysis has very little value for space systems where failure modes cannot be mitigated by maintenance. Therefore, all failures should have a mitigation, regardless of the criticality ranking.

Do not perform a FTA – a Functional FMEA performs the same function, just not in graphical form.
Instead of eliminating quantitative reliability analysis, the goal is to find essential methods to minimize the time spend on the detailed quantitative analysis.

Below lists the tailoring suggestions for reliability analysis:

- Reliability Allocations – Conduct higher level allocations.
  - Driving allocation requirements lower than the unit level restricts the flexibility of managing the requirements and can provide unreasonable expectations on design engineers

- Modeling and Predictions
  - For serviceable systems, maintainability predictions are crucial to understanding the total life cycle cost. Use the same part count method for maintainability predictions
  - See below for Reliability Predictions Tailoring Guide

<table>
<thead>
<tr>
<th>Complexity</th>
<th>Low Cost</th>
<th>Medium Cost</th>
<th>High Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple</td>
<td>Predictions are optional</td>
<td>Part Count only on new units</td>
<td>Part Count only on new units</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Part Stress when data is available</td>
</tr>
<tr>
<td>Medium</td>
<td>Part Count on new units</td>
<td>Part Count on new units</td>
<td>Part Stress on new units</td>
</tr>
<tr>
<td>High</td>
<td>Part Count</td>
<td>Part Count</td>
<td>Part Stress</td>
</tr>
<tr>
<td></td>
<td>Part Stress if data is available</td>
<td>Part Stress if data is available</td>
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For small aerospace programs, the reliability program can be summed up by three tasks

1. LOE Management Tasks (Plan, Design Reviews, FRACAS, etc)
2. Functional FMEA at the minimum, detailed FMEA for critical equipment, and interface FMEA for new equipment added to existing systems. Manage the CIL and provide a plan for closure.
3. Perform Reliability predictions using the part count method. Overly conservative predictions can be updated with part stress method if data is available.

Medical Device industry is trailing in their reliability practices, but initiatives to standardize and improve the process is underway.

Current NGAS RAM processes are effective for large systems, but tailoring must be performed for smaller aerospace systems to stay competitive.

Aerospace systems are heavily focused on Reliability, but basic tailoring guides are applicable to maintainability and availability.
QUESTIONS?

SPECIAL THANKS to

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