Finding Answers to Space Industry's Top 10 Reliability Problems

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SUMMARY & CONCLUSIONS

This paper is the cornerstone for a Masters thesis that is to be published in 2002. It is the result of a cooperative effort between a 3rd year electrical engineering (EE) undergraduate, an EE college professor, and several reliability engineering experts that work for The Aerospace Corporation. The topic of this paper is an analytical process for identifying the top-10 problems that obstruct efforts to design high-reliability into modern space systems. The approach used to rate such problems is based on conjecture that the worst problem is one that is overlooked until it is too late. The chronological description of a process for uncovering these problems should prove helpful to domestic and international developers of reliability assessment tools, standards, and guides that seek insight as to where to focus their energies. Also, the developers of space systems should find this process helpful for planning reliability engineering programs that conform to "faster-better-cheaper" business practices, which are popular but sometimes lead to undesirable results (Ref. 1) when risk is not properly assessed.

1. INTRODUCTION

This paper describes the chronology of the industry survey that is currently being conducted by Al Jackson, a senior in the Electrical Engineering College of the California State University Long Beach. The survey's objective is to use the Delphi method (Ref. 2) to determine the top-10 "overlooked" problems that affect the operational reliability (Ro) of space systems. The idea to use the Delphi method to collect and correlate expert opinion originated from a Rome Laboratory report (Ref. 3) that describes the framework for a "high-quality" reliability engineering program. This frame-work was defined by surveying industry-wide practices, which, at the time, were based largely on military standards.

There is a problem with using this framework today because it is outdated. A year after publication of said Rome Laboratory report, DOD implemented the Acquisition Reform Initiative, which led to the cancellation of all military standards used for defining reliability engineering programs. Domestic and international standards organizations have since established working groups to try to fill the void left by the cancellation of military standards, but progress has been slow in developing "suitable" commercial standards and guides (Ref. 4, 5, and 6). As a result of this slow progress, and the relatively small and specialized customer base, only few notable advancements in commercial reliability assessment tools have been made since 1994 (Ref. 7), and virtually none that are specifically for use in the space industry.

Whether new and more powerful reliability assessment tools could have prevented the space system failures that are listed in Table 1 is unknown. However, what is known is that subsequent investigations of these failures (Ref. 8) uncovered "system killers" that were overlooked by the developers' reliability engineering programs. The perceived risk of these overlooked "system killers" varies from (1) they are simply isolated events that are unlikely to reoccur; to (2) they are systemic faults common to every developer's reliability engineering program. The individuals most qualified to assess that risk are the engineering experts familiar with the designed-in reliability of past and present space systems.

Table 1. Recent Space System Failures

Failed Space and Launch System Missions	Failure Date
Titan IV A-20/Centaur	08/12/98
Titan IV B-27/Inertial Upper Stage	04/09/99
Titan IV B-32/Centaur	04/30/99
Delta III 259/Galaxy-X	08/26/98
Delta III 269/Orion-3	05/04/99
Mars Climate Orbiter	09/23/99
Mars Polar Lander	12/03/99
STEX	04/15/99
Argos	02/20/99
PanAmSat Galaxy 4	05/19/98

2. CHRONOLOGY OF THE DELPHI METHOD SURVEY

The first step in developing the survey for determining the top-10 problems that are overlooked by reliability engineering programs in the space industry was to define the types and categories of questions that should be asked. Several reliability engineering experts that work for The Aerospace Corporation, which is a Federally Funded Research and Development Center (FFRDC), were asked for assistance.

They recommended that the questions address specific reliability engineering program activities and be categorized according to the product life cycle that each activity is most likely to apply. Implementing that recommendation required first defining a single system-engineering process that is applicable to all space system developers, i.e., a "standard" system-engineering template. After some research, a modified version of the IEEE standard definition for the product life cycle phases of the system engineering process (Ref. 9) was selected for categorizing the survey questions. The one modification made to the standard IEEE definition was to add the pre-system definition phase to address risk that may exist prior to initiation of the system definition phase. The resultant survey question categories are:

1. *Pre-System Definition*
2. *System Definition*
3. *Preliminary Design*
4. *Detailed Design*
5. *Fabrication, Assembly, Integration & Test (FAIT)*
6. *Production & Customer Support.*

The second step in developing the survey was to define a method of quantifying reliability risk based on the response to a particular question. Again, assistance was sought from The Aerospace Corp. reliability engineering experts. They recommended phrasing each question so that it requires a two-part response that qualifies the consequence and likelihood of risk separately. This approach is characteristic of the Delphi method for conducting a group risk assessment. Both published papers and experts' opinions were used to compose a set of questions that reveal how developers practice reliability engineering. The detailed reliability engineering program activities were identified using the Air Force Space and Missile Systems Center (SMC) Reliability Engineering Critical Process Assessment Tool (CPAT) (Ref. 10). Each survey question asks to postulate the consequence and likelihood of a specific activity leading to a problem with Ro. Both the consequence and likelihood of affecting Ro is rated as follows: 1=Low, 2=Minor, 3=Moderate, 4=Significant, or 5= High.

The third step in developing the survey was to identify a minimum set of reliability engineering program risk mitigators, i.e., Ro problem-prevention activities, which singularly or in combination can facilitate successfully designing in high-reliability. Estimating the likelihood of failure of relevant risk mitigators for a specific type of problem provides rationale for estimating the "cumulative" likelihood of that problem. The 16 keywords in Table 2 were selected, with the help of The Aerospace Corp. reliability engineering experts, to represent that minimum set of process risk mitigators. The degree of failure of each mitigator is rated as follows: 1=Low, 2=Minor, 3=Moderate, 4=Significant, or 5= High. The complete survey is shown in Table 3.

Table 2. Reliability Engineering Program Risk Mitigators

Keyword Descriptors of Reliability Engineering Program Risk Mitigators			
Funding	Support	Planning	Requirements
Testing	Procedures	Data	Manpower
Coordination	Training	Standards	Guides
Tools	Rules	Knowledge	Experience

The fourth step is still ongoing. The objective here is to survey a large enough segment of the reliability engineering population of the space industry (including experts who do not hold reliability engineering job titles) to obtain a better than 50% confidence in the statistically ranked responses. The final results of the survey (e.g., risk charts, Pareto charts, bar charts, etc.) will be published in a future Masters thesis.

The fifth and final step will be to share the final results of the survey with space system developers and standards working groups, such as, the AIAA Collection of Preferred Space-Related Standards (CPSRS).

Table 3. Reliability Engineering Program Risk Survey

1.1	The affect on Ro is [ ] if documented reliability engineering practices are not cost-effective. The likelihood of this problem is [ ] due to the failure likelihood of key process risk mitigators: [ ] Funding [ ] Support [ ] Planning [ ] Requirements [ ] Testing [ ] Procedures [ ] Data [ ] Manpower [ ] Coordination [ ] Training [ ] Standards [ ] Guides [ ] Tools [ ] Rules [ ] Knowledge [ ] Experience
1.2	The affect on Ro is [ ] if the lead reliability engineer is not capable of coordinating a reliability engineering program with other system engineering functions. The likelihood of this problem is [ ] due to the failure likelihood of key process risk mitigators: [ ] Funding [ ] Support [ ] Planning [ ] Requirements [ ] Testing [ ] Procedures [ ] Data [ ] Manpower [ ] Coordination [ ] Training [ ] Standards [ ] Guides [ ] Tools [ ] Rules [ ] Knowledge [ ] Experience
1.3	The affect on Ro is [ ] if the subordinate reliability engineer is not capable of coordinating reliability engineering program activities with other system engineering functions. The likelihood of this problem is [ ] due to the failure likelihood of key process risk mitigators: [[ ] Funding [ ] Support [ ] Planning [ ] Requirements [ ] Testing [ ] Procedures [ ] Data [ ] Manpower [ ] Coordination [ ] Training [ ] Standards [ ] Guides [ ] Tools [ ] Rules [ ] Knowledge [ ] Experience
1.4	The affect on Ro is [ ] due to "overlooked" failure modes as a result of the likelihood of key failure assessment methods not being performed: [ ] FMECA; [ ] Parts Stress Analysis; [ ] Fault Tree Analysis; [ ] Fishbone Analysis; [ ] Worse Case Analysis; [ ] Thermal Analysis; [ ] EMI/EMC Analysis; [ ] Sneak Circuit Analysis; [ ] Event Tree Analysis; [ ] Physics of Failure Analysis; [ ] Finite Element Analysis. The likelihood of this problem is [ ] due to the failure likelihood of key process risk mitigators: [ ] Funding [ ] Support [ ] Planning [ ] Requirements [ ] Testing [ ] Procedures [ ] Data [ ] Manpower [ ] Coordination [ ] Training [ ] Standards [ ] Guides [ ] Tools [ ] Rules [ ] Knowledge [ ] Experience
1.5	The affect on Ro is [ ] if desired standards, guides, tools, or training are not obtained. The likelihood of this problem is [ ] due to the failure likelihood of key risk process mitigators: [ ] Funding [ ] Support [ ] Planning [ ] Requirements [ ] Testing [ ] Procedures [ ] Data [ ] Manpower [ ] Coordination [ ] Training [ ] Standards [ ] Guides [ ] Tools [ ] Rules [ ] Knowledge [ ] Experience

1.6	The affect on Ro is [ ] if reliability, safety, weight, and cost cannot be optimally balanced. The likelihood of this problem is [ ] due to the failure likelihood of key process risk mitigators: [ ] Funding [ ] Support [ ] Planning [ ] Requirements [ ] Testing [ ] Procedures [ ] Data [ ] Manpower [ ] Coordination [ ] Training [ ] Standards [ ] Guides [ ] Tools [ ] Rules [ ] Knowledge [ ] Experience
1.7	The affect on Ro is [ ] if the optimal set of reliability engineering program activities are not selected for a specific space system, mission, and budget. The likelihood of this problem is [ ] due to the failure likelihood of key process risk mitigators: [ ] Funding [ ] Support [ ] Planning [ ] Requirements [ ] Testing [ ] Procedures [ ] Data [ ] Manpower [ ] Coordination [ ] Training [ ] Standards [ ] Guides [ ] Tools [ ] Rules [ ] Knowledge [ ] Experience
1.8	The affect on Ro is [ ] due to "overlooked" functions as a result of the likelihood of key functional attributes not being represented in graphical or narrative system definitions: [ ] System indentured configuration; [ ] Modes of operation; [ ] Physical layout of components; [ ] Internal physical interfaces; [ ] Detailed functional relationships among components; [ ] Operating duty cycles; [ ] Fault tolerance features; [ ] Nomenclature of functions; [ ] Units of measure of functions. The likelihood of this problem is [ ] due to the failure likelihood of key process risk mitigators: [ ] Funding [ ] Support [ ] Planning [ ] Requirements [ ] Testing [ ] Procedures [ ] Data [ ] Manpower [ ] Coordination [ ] Training [ ] Standards [ ] Guides [ ] Tools [ ] Rules [ ] Knowledge [ ] Experience
1.9	The affect on Ro is [ ] if an evaluation is not made of the cost-effectiveness of proprietary reliability assessment methods in comparison to similar methods in the public domain. The likelihood of this problem is [ ] due to the failure likelihood of key process risk mitigators: [ ] Funding [ ] Support [ ] Planning [ ] Requirements [ ] Testing [ ] Procedures [ ] Data [ ] Manpower [ ] Coordination [ ] Training [ ] Standards [ ] Guides [ ] Tools [ ] Rules [ ] Knowledge [ ] Experience
1.10	The affect on Ro is [ ] if an evaluation is not made of the secret coefficients or parameters found in proprietary reliability assessment methods. The likelihood of this problem is [ ] due to the failure likelihood of key process risk mitigators: [ ] Funding [ ] Support [ ] Planning [ ] Requirements [ ] Testing [ ] Procedures [ ] Data [ ] Manpower [ ] Coordination [ ] Training [ ] Standards [ ] Guides [ ] Tools [ ] Rules [ ] Knowledge [ ] Experience
1.11	The affect on Ro is [ ] if reliability engineering lessons learned are not maintained in a company database. The likelihood of this problem is [ ] due to the failure likelihood of key process risk mitigators: [ ] Funding [ ] Support [ ] Planning [ ] Requirements [ ] Testing [ ] Procedures [ ] Data [ ] Manpower [ ] Coordination [ ] Training [ ] Standards [ ] Guides [ ] Tools [ ] Rules [ ] Knowledge [ ] Experience
1.12	The affect on Ro is [ ] if reliability data for items that are built in-house is not maintained in company databases or documents. The likelihood of this problem is [ ] due to the failure likelihood of key process risk mitigators: [ ] Funding [ ] Support [ ] Planning [ ] Requirements [ ] Testing [ ] Procedures [ ] Data [ ] Manpower [ ] Coordination [ ] Training [ ] Standards [ ] Guides [ ] Tools [ ] Rules [ ] Knowledge [ ] Experience
1.13	The affect on Ro is [ ] if reliability data for similar items and systems is not found in public domain databases or documents. The likelihood of this problem is [ ] due to the failure likelihood of key process risk mitigators: [ ] Funding [ ] Support [ ] Planning [ ] Requirements [ ] Testing [ ] Procedures [ ] Data [ ] Manpower [ ] Coordination [ ] Training [ ] Standards [ ] Guides [ ] Tools [ ] Rules [ ] Knowledge [ ] Experience
1.14	The affect on Ro is [ ] if insufficient funding is available to perform the selected reliability engineering program activities. The likelihood of this problem is [ ] due to the failure likelihood of key process risk mitigators: [ ] Funding [ ] Support [ ] Planning [ ] Requirements [ ] Testing [ ] Procedures [ ] Data [ ] Manpower [ ] Coordination [ ] Training [ ] Standards [ ] Guides [ ] Tools [ ] Rules [ ] Knowledge [ ] Experience
1.15	The affect on Ro is [ ] if the selected reliability engineering program activities cannot be seamlessly integrated into the system engineering process. The likelihood of this problem is [ ] due to the failure likelihood of key risk mitigators: [ ] Funding [ ] Support [ ] Planning [ ] Requirements [ ] Testing [ ] Procedures [ ] Data [ ] Manpower [ ] Coordination [ ] Training [ ] Standards [ ] Guides [ ] Tools [ ] Rules [ ] Knowledge [ ] Experience
1.16	The affect on Ro is [ ] if different reliability assessment tools cannot use common input data or exchange data between them. The likelihood of this problem is [ ] due to the failure likelihood of key process risk mitigators: [ ] Funding [ ] Support [ ] Planning [ ] Requirements [ ] Testing [ ] Procedures [ ] Data [ ] Manpower [ ] Coordination [ ] Training [ ] Standards [ ] Guides [ ] Tools [ ] Rules [ ] Knowledge [ ] Experience
1.17	The affect on Ro is [ ] if a previous reliability prediction or field reliability value for a similar item or system cannot be replicated or verified. The likelihood of this problem is [ ] due to the failure likelihood of key risk process mitigators: [ ] Funding [ ] Support [ ] Planning [ ] Requirements [ ] Testing [ ] Procedures [ ] Data [ ] Manpower [ ] Coordination [ ] Training [ ] Standards [ ] Guides [ ] Tools [ ] Rules [ ] Knowledge [ ] Experience
1.18	The affect on Ro is [ ] if the incremental progress of reliability engineering program activities cannot be measured. The likelihood of this problem is [ ] due to the failure likelihood of key process risk mitigators: [ ] Funding [ ] Support [ ] Planning [ ] Requirements [ ] Testing [ ] Procedures [ ] Data [ ] Manpower [ ] Coordination [ ] Training [ ] Standards [ ] Guides [ ] Tools [ ] Rules [ ] Knowledge [ ] Experience
1.19	The affect on Ro is [ ] if different reliability assessment methods cannot be performed simultaneously, e.g., perform reliability predictions, FMECA, and fault tree analysis simultaneously. The likelihood of this problem is [ ] due to the failure likelihood of key process risk mitigators: [ ] Funding [ ] Support [ ] Planning [ ] Requirements [ ] Testing [ ] Procedures [ ] Data [ ] Manpower [ ] Coordination [ ] Training [ ] Standards [ ] Guides [ ] Tools [ ] Rules [ ] Knowledge [ ] Experience
1.20	The affect on Ro is [ ] if the confidence limits of the predicted reliability values cannot be bounded. The likelihood of this problem is [ ] due to the failure likelihood of key process risk mitigators: [ ] Funding [ ] Support [ ] Planning [ ] Requirements [ ] Testing [ ] Procedures [ ] Data [ ] Manpower [ ] Coordination [ ] Training [ ] Standards [ ] Guides [ ] Tools [ ] Rules [ ] Knowledge [ ] Experience
1.21	The affect on Ro is [ ] if the scheduled milestones of the planned reliability engineering program cannot be met. The likelihood of this problem is [ ] due to the failure likelihood of key process risk mitigators: [ ] Funding [ ] Support [ ] Planning [ ] Requirements [ ] Testing [ ] Procedures [ ] Data [ ] Manpower [ ] Coordination [ ] Training [ ] Standards [ ] Guides [ ] Tools [ ] Rules [ ] Knowledge [ ] Experience
2.1	The affect on Ro is [ ] if the critical system reliability requirements are not properly specified. The likelihood of this problem is [ ] due to the failure likelihood of key process risk mitigators: [ ] Funding [ ] Support [ ] Planning [ ] Requirements [ ] Testing [ ] Procedures [ ] Data [ ] Manpower [ ] Coordination [ ] Training [ ] Standards [ ] Guides [ ] Tools [ ] Rules [ ] Knowledge [ ] Experience

2.2	The affect on Ro is [ ] if the design and manufacturing functions do not apply design reliability rules. The likelihood of this problem is [ ] due to the failure likelihood of key process risk mitigators: [ ] Funding [ ] Support [ ] Planning [ ] Requirements [ ] Testing [ ] Procedures [ ] Data [ ] Manpower [ ] Coordination [ ] Training [ ] Standards [ ] Guides [ ] Tools [ ] Rules [ ] Knowledge [ ] Experience
2.3	The affect on Ro is [ ] if the natural and induced environmental affects (e.g., EMI/EMC) are not improperly assessed. The likelihood of this problem is [ ] due to the failure likelihood of key process risk mitigators: [ ] Funding [ ] Support [ ] Planning [ ] Requirements [ ] Testing [ ] Procedures [ ] Data [ ] Manpower [ ] Coordination [ ] Training [ ] Standards [ ] Guides [ ] Tools [ ] Rules [ ] Knowledge [ ] Experience
2.4	The affect on Ro is [ ] if the design or manufacturing functions do not perform reliability assessments. The likelihood of this problem is [ ] due to the failure likelihood of key process risk mitigators: [ ] Funding [ ] Support [ ] Planning [ ] Requirements [ ] Testing [ ] Procedures [ ] Data [ ] Manpower [ ] Coordination [ ] Training [ ] Standards [ ] Guides [ ] Tools [ ] Rules [ ] Knowledge [ ] Experience
3.1	The affect on Ro is [ ] if the allocated reliability values that are generate for the system definition phase are grossly incorrect. The likelihood of this problem is [ ] due to the failure likelihood of key process risk mitigators: [ ] Funding [ ] Support [ ] Planning [ ] Requirements [ ] Testing [ ] Procedures [ ] Data [ ] Manpower [ ] Coordination [ ] Training [ ] Standards [ ] Guides [ ] Tools [ ] Rules [ ] Knowledge [ ] Experience
3.2	The affect on Ro is [ ] if reliability predictions are not adjusted with demonstrated reliability data. The likelihood of this problem is [ ] due to the failure likelihood of key process risk mitigators: [ ] Funding [ ] Support [ ] Planning [ ] Requirements [ ] Testing [ ] Procedures [ ] Data [ ] Manpower [ ] Coordination [ ] Training [ ] Standards [ ] Guides [ ] Tools [ ] Rules [ ] Knowledge [ ] Experience
3.3	The affect on Ro is [ ] if the reliability data that is requested from subcontractors and manufacturers is not received. The likelihood of this problem is [ ] due to the failure likelihood of key process risk mitigators: [ ] Funding [ ] Support [ ] Planning [ ] Requirements [ ] Testing [ ] Procedures [ ] Data [ ] Manpower [ ] Coordination [ ] Training [ ] Standards [ ] Guides [ ] Tools [ ] Rules [ ] Knowledge [ ] Experience
3.4	The affect on Ro is [ ] if the reliability data that is requested from in-house hardware and software designers, or manufacturing and test engineers is not received. The likelihood of this problem is [ ] due to the failure likelihood of key process risk mitigators: [ ] Funding [ ] Support [ ] Planning [ ] Requirements [ ] Testing [ ] Procedures [ ] Data [ ] Manpower [ ] Coordination [ ] Training [ ] Standards [ ] Guides [ ] Tools [ ] Rules [ ] Knowledge [ ] Experience
3.5	The affect on Ro is [ ] due to "overlooked" inherent or induced failure modes as a result of the likelihood of key failure characteristics not being assessed for all components and interfaces: [ ] Failure during normal operating modes; [ ] Failure during contingency operating modes; [ ] Failure to cease operation at a prescribed time; [ ] Premature operation; [ ] Delayed operation; [ ] Intermittent operation; [ ] Inadvertent operation; [ ] Operation above/below tolerance; [ ] Induced failure; [ ] Leakage; [ ] Cascading failures; [ ] Multiple failures; [ ] Sneak circuits. The likelihood of this problem is [ ] due to the failure likelihood of key process risk mitigators: [ ] Funding [ ] Support [ ] Planning [ ] Requirements [ ] Testing [ ] Procedures [ ] Data [ ] Manpower [ ] Coordination [ ] Training [ ] Standards [ ] Guides [ ] Tools [ ] Rules [ ] Knowledge [ ] Experience
3.6	The affect on Ro is [ ] due to "overlooked" failure effects as a result of the likelihood of key system characteristics not being assessed: [ ] local effects; [ ] Next higher level effects; [ ] Effects at interfaces; [ ] Subsystem level effects; [ ] Effects that are dependant on the physical layout of components; [ ] Detectable effects; [ ] Ambiguity category of effects; [ ] Time to achieve effects; The likelihood of this problem is [ ] due to the failure likelihood of key process risk mitigators: [ ] Funding [ ] Support [ ] Planning [ ] Requirements [ ] Testing [ ] Procedures [ ] Data [ ] Manpower [ ] Coordination [ ] Training [ ] Standards [ ] Guides [ ] Tools [ ] Rules [ ] Knowledge [ ] Experience
3.7	The affect on Ro is [ ] due to "overlooked" failure causes as a result of the likelihood of key causal factors not being assessed: [ ] Electrical stress; [ ] Thermal stress; [ ] Vibration; [ ] Shock; [ ] Friction; [ ] Stress/strain; [ ] Radiation; [ ] Inadequate requirements; [ ] Inadequate procedures; [ ] Design errors; [ ] Parts management errors; [ ] Manufacturing errors; [ ] Testing errors; [ ] Assembly errors; [ ] Handling errors; [ ] Operator errors; [ ] Software errors. The likelihood of this problem is [ ] due to the failure likelihood of key process risk mitigators: [ ] Funding [ ] Support [ ] Planning [ ] Requirements [ ] Testing [ ] Procedures [ ] Data [ ] Manpower [ ] Coordination [ ] Training [ ] Standards [ ] Guides [ ] Tools [ ] Rules [ ] Knowledge [ ] Experience
3.8	The affect on Ro is [ ] due to critical failure modes that have a much higher probability of occurrence than assessed. The likelihood of this problem is [ ] due to the failure likelihood of key process risk mitigators: [ ] Funding [ ] Support [ ] Planning [ ] Requirements [ ] Testing [ ] Procedures [ ] Data [ ] Manpower [ ] Coordination [ ] Training [ ] Standards [ ] Guides [ ] Tools [ ] Rules [ ] Knowledge [ ] Experience
3.9	The affect on Ro is [ ] due to "overlooked" failure modes of software or firmware. The likelihood of this problem is [ ] due to the failure likelihood of key process risk mitigators: [ ] Funding [ ] Support [ ] Planning [ ] Requirements [ ] Testing [ ] Procedures [ ] Data [ ] Manpower [ ] Coordination [ ] Training [ ] Standards [ ] Guides [ ] Tools [ ] Rules [ ] Knowledge [ ] Experience
3.10	The affect on Ro is [ ] if failure rates of software or firmware are not estimated. The likelihood of this problem is [ ] due to the failure likelihood of key process risk mitigators: [ ] Funding [ ] Support [ ] Planning [ ] Requirements [ ] Testing [ ] Procedures [ ] Data [ ] Manpower [ ] Coordination [ ] Training [ ] Standards [ ] Guides [ ] Tools [ ] Rules [ ] Knowledge [ ] Experience
4.1	The affect on Ro is [ ] if all of the reverse current paths or timing faults in a space system are not assessed (i.e., perform Sneak Circuit Analysis). The likelihood of this problem is [ ] due to the failure likelihood of key process risk mitigators: [ ] Funding [ ] Support [ ] Planning [ ] Requirements [ ] Testing [ ] Procedures [ ] Data [ ] Manpower [ ] Coordination [ ] Training [ ] Standards [ ] Guides [ ] Tools [ ] Rules [ ] Knowledge [ ] Experience
4.2	The affect on Ro is [ ] if all of the human error modes associated with the manufacture, assembly, testing, handling, and operation of a space system are not assessed. The likelihood of this problem is [ ] due to the failure likelihood of key process risk mitigators: [ ] Funding [ ] Support [ ] Planning [ ] Requirements [ ] Testing [ ] Procedures [ ] Data [ ] Manpower [ ] Coordination [ ] Training [ ] Standards [ ] Guides [ ] Tools [ ] Rules [ ] Knowledge [ ] Experience
4.3	The affect on Ro is [ ] if the capability of fault management software to handle multiple failures is not assessed. The likelihood of this problem is [ ] due to the failure likelihood of key process risk mitigators: [ ] Funding [ ] Support [ ] Planning [ ] Requirements [ ] Testing [ ] Procedures [ ] Data [ ] Manpower [ ] Coordination [ ] Training [ ] Standards [ ] Guides [ ] Tools [ ] Rules [ ] Knowledge [ ] Experience

4.4	The affect on Ro is [ ] if the cyclic failure rates for mechanical and structural hardware are not assessed. The likelihood of this problem is [ ] due to the failure likelihood of key process risk mitigators: [ ] Funding [ ] Support [ ] Planning [ ] Requirements [ ] Testing [ ] Procedures [ ] Data [ ] Manpower [ ] Coordination [ ] Training [ ] Standards [ ] Guides [ ] Tools [ ] Rules [ ] Knowledge [ ] Experience
4.5	The affect on Ro is [ ] if the dormant hazard rates for electronic and mechanical hardware are not accurately estimated. The likelihood of this problem is [ ] due to the failure likelihood of key process risk mitigators: [ ] Funding [ ] Support [ ] Planning [ ] Requirements [ ] Testing [ ] Procedures [ ] Data [ ] Manpower [ ] Coordination [ ] Training [ ] Standards [ ] Guides [ ] Tools [ ] Rules [ ] Knowledge [ ] Experience
4.6	The affect on Ro is [ ] if the wearout hazard rates for electronic and mechanical hardware are not accurately estimated. The likelihood of this problem is [ ] due to the failure likelihood of key process risk mitigators: [ ] Funding [ ] Support [ ] Planning [ ] Requirements [ ] Testing [ ] Procedures [ ] Data [ ] Manpower [ ] Coordination [ ] Training [ ] Standards [ ] Guides [ ] Tools [ ] Rules [ ] Knowledge [ ] Experience
4.7	The affect on Ro is [ ] if the demonstrated reliability of equipment is estimated using very limited test and flight history. The likelihood of this problem is [ ] due to the failure likelihood of key process risk mitigators: [ ] Funding [ ] Support [ ] Planning [ ] Requirements [ ] Testing [ ] Procedures [ ] Data [ ] Manpower [ ] Coordination [ ] Training [ ] Standards [ ] Guides [ ] Tools [ ] Rules [ ] Knowledge [ ] Experience
4.8	The affect on Ro is [ ] if items that have non-constant failure rates are assumed to have exponential (i.e., constant) failure rates. The likelihood of this problem is [ ] due to the failure likelihood of key process risk mitigators: [ ] Funding [ ] Support [ ] Planning [ ] Requirements [ ] Testing [ ] Procedures [ ] Data [ ] Manpower [ ] Coordination [ ] Training [ ] Standards [ ] Guides [ ] Tools [ ] Rules [ ] Knowledge [ ] Experience
4.9	The affect on Ro is [ ] if the probability of occurrence of system-critical electrical transients (e.g., in-rush currents and voltage spikes) is not assessed. The likelihood of this problem is [ ] due to the failure likelihood of key process risk mitigators: [ ] Funding [ ] Support [ ] Planning [ ] Requirements [ ] Testing [ ] Procedures [ ] Data [ ] Manpower [ ] Coordination [ ] Training [ ] Standards [ ] Guides [ ] Tools [ ] Rules [ ] Knowledge [ ] Experience
4.10	The affect on Ro is [ ] if the system is designed to met a probability of success threshold for hardware and software operation instead of a minimum probability of mission success. The likelihood of this problem is [ ] due to the failure likelihood of key process risk mitigators: [ ] Funding [ ] Support [ ] Planning [ ] Requirements [ ] Testing [ ] Procedures [ ] Data [ ] Manpower [ ] Coordination [ ] Training [ ] Standards [ ] Guides [ ] Tools [ ] Rules [ ] Knowledge [ ] Experience
4.11	The affect on Ro is [ ] if the reliability assessment does not include the affects of storage, transportation, and handling. The likelihood of this problem is [ ] due to the failure likelihood of key process risk mitigators: [ ] Funding [ ] Support [ ] Planning [ ] Requirements [ ] Testing [ ] Procedures [ ] Data [ ] Manpower [ ] Coordination [ ] Training [ ] Standards [ ] Guides [ ] Tools [ ] Rules [ ] Knowledge [ ] Experience
4.12	The affect on Ro is [ ] if the system design is based on predictions that do not include margin. The likelihood of this problem is [ ] due to the failure likelihood of key process risk mitigators: [ ] Funding [ ] Support [ ] Planning [ ] Requirements [ ] Testing [ ] Procedures [ ] Data [ ] Manpower [ ] Coordination [ ] Training [ ] Standards [ ] Guides [ ] Tools [ ] Rules [ ] Knowledge [ ] Experience
4.13	The affect on Ro is [ ] due to "escaped" inherent or induced failures as a result of the likelihood of key provisions not being implemented to eliminate or reduce the likelihood of operational failures: [ ] Requirements changes; [ ] Design changes; [ ] Parts management changes; [ ] Manufacturing process changes; [ ] Test procedure changes; [ ] Assembly procedure changes; [ ] Handling procedure changes. The likelihood of this problem is [ ] due to the failure likelihood of key process risk mitigators: [ ] Funding [ ] Support [ ] Planning [ ] Requirements [ ] Testing [ ] Procedures [ ] Data [ ] Manpower [ ] Coordination [ ] Training [ ] Standards [ ] Guides [ ] Tools [ ] Rules [ ] Knowledge [ ] Experience
4.14	The affect on Ro is [ ] if the status of design, manufacturing, test, or procedural changes that are intended for eliminating or reducing the likelihood of critical failures is not properly tracked. The likelihood of this problem is [ ] due to the failure likelihood of key process risk mitigators: [ ] Funding [ ] Support [ ] Planning [ ] Requirements [ ] Testing [ ] Procedures [ ] Data [ ] Manpower [ ] Coordination [ ] Training [ ] Standards [ ] Guides [ ] Tools [ ] Rules [ ] Knowledge [ ] Experience
4.15	The affect on Ro is [ ] if the fault coverage of built-in test functions in repairable or re-configurable devices is not assessed. The likelihood of this problem is [ ] due to the failure likelihood of key process risk mitigators: [ ] Funding [ ] Support [ ] Planning [ ] Requirements [ ] Testing [ ] Procedures [ ] Data [ ] Manpower [ ] Coordination [ ] Training [ ] Standards [ ] Guides [ ] Tools [ ] Rules [ ] Knowledge [ ] Experience
5.1	The affect on Ro is [ ] if the reliability assessment does not include the affects of manufacturing, assembly, testing, rework, and maintenance. The likelihood of this problem is [ ] due to the failure likelihood of key process risk mitigators: [ ] Funding [ ] Support [ ] Planning [ ] Requirements [ ] Testing [ ] Procedures [ ] Data [ ] Manpower [ ] Coordination [ ] Training [ ] Standards [ ] Guides [ ] Tools [ ] Rules [ ] Knowledge [ ] Experience
5.2	The affect on Ro is [ ] if the reliability assessment does not include the affects of the software life-cycle process. The likelihood of this problem is [ ] due to the failure likelihood of key process risk mitigators: [ ] Funding [ ] Support [ ] Planning [ ] Requirements [ ] Testing [ ] Procedures [ ] Data [ ] Manpower [ ] Coordination [ ] Training [ ] Standards [ ] Guides [ ] Tools [ ] Rules [ ] Knowledge [ ] Experience
5.3	The affect on Ro is [ ] if the failure rate adjustment factors for different types of accelerated life tests are not accurately estimated. The likelihood of this problem is [ ] due to the failure likelihood of key process risk mitigators: [ ] Funding [ ] Support [ ] Planning [ ] Requirements [ ] Testing [ ] Procedures [ ] Data [ ] Manpower [ ] Coordination [ ] Training [ ] Standards [ ] Guides [ ] Tools [ ] Rules [ ] Knowledge [ ] Experience
5.4	The affect on Ro is [ ] if the downtime for repairable or re-configurable devices is not accurately estimated. The likelihood of this problem is [ ] due to the failure likelihood of key process risk mitigators: [ ] Funding [ ] Support [ ] Planning [ ] Requirements [ ] Testing [ ] Procedures [ ] Data [ ] Manpower [ ] Coordination [ ] Training [ ] Standards [ ] Guides [ ] Tools [ ] Rules [ ] Knowledge [ ] Experience
5.5	The affect on Ro is [ ] if a reliability life test of a part, equipment, or system is not properly planned. The likelihood of this problem is [ ] due to the failure likelihood of key process risk mitigators: [ ] Funding [ ] Support [ ] Planning [ ] Requirements [ ] Testing [ ] Procedures [ ] Data [ ] Manpower [ ] Coordination [ ] Training [ ] Standards [ ] Guides [ ] Tools [ ] Rules [ ] Knowledge [ ] Experience

Table 3. Reliability Engineering Program Risk Survey (contd)

5.6	The affect on Ro is [ ] if assessments are not conducted to verify there are no erroneous or ambiguous manufacturing, test, assembly, handling, or operating procedures that will induce hardware or software failure modes. The likelihood of this problem is [ ] due to the failure likelihood of key process risk mitigators: [ ] Funding [ ] Support [ ] Planning [ ] Requirements [ ] Testing [ ] Procedures [ ] Data [ ] Manpower [ ] Coordination [ ] Training [ ] Standards [ ] Guides [ ] Tools [ ] Rules [ ] Knowledge [ ] Experience
6.1	The affect on Ro is [ ] if the collection of field reliability data is not properly coordinated. The likelihood of this problem is [ ] due to the failure likelihood of key process risk mitigators: [ ] Funding [ ] Support [ ] Planning [ ] Requirements [ ] Testing [ ] Procedures [ ] Data [ ] Manpower [ ] Coordination [ ] Training [ ] Standards [ ] Guides [ ] Tools [ ] Rules [ ] Knowledge [ ] Experience

3. SAMPLING THE SURVEY

At the time this paper was written, only 12 reliability engineering experts had responded to the survey. The average time that was reported to complete the survey was 2.5 hours. The median results of these first responses are summarized in the risk chart in Figure 1. The numbers in the blocks correspond to the numbered questions in the survey. Based on this small sampling of the survey, the consensus opinion is that the problems described in questions 1.4, 3.5, and 5.1 present the greatest risk to Ro. These initial results may change as more responses are received, but there appears to be three tale-telling characteristics of the kinds of reliability engineering programs that are likely to cause Ro problems:

1. Many unresolved reliability engineering program problems exist prior to initiation of the system definition phase.
2. All inherent or induced failure modes are unidentified.
3. Potential effects of the developer's processes on Ro are not properly assessed.

Likelihood \ Consequence	1	2	3	4	5
5	4.12		3.10	2.4	1.4, 3.5, 5.1
4	4.5, 4.6, 4.8	1.3, 1.9, 1.10, 1.15, 1.20	1.8, 1.9	1.13, 1.17, 3.2, 4.10	1.11 3.7, 3.8, 4.2, 4.4, 5.6, 6.1
3	1.6, 1.7	1.2, 1.18	1.16, 4.15	3.1,4.3	2.1, 3.6, 3.9, 4.7 4.13
2		1.5, 1.21, 5.3, 5.4		2.2, 4.11, 5.2	1.12, 1.14, 2.3, 3.3, 3.4, 4.1, 5.5
1			1.1	4.14	4.9

Legend:
1 = Low 3 = Moderate 5 = High
2 = Minor 4 = Significant

Figure 1. Risk chart showing result of survey using Delphi method.

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