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Mission Risk Planning and Acquisition Tailoring Guidelines for National Security Space Vehicles

September 13, 2010

Gail A. Johnson-Roth and William F. Tosney
Acquisition Risk and Reliability Engineering Department, Mission Assurance Subdivision;
Corporate Chief Engineering Office, Systems Planning and Engineering

Prepared for:

Space and Missile Systems Center
Air Force Space Command
483 N. Aviation Blvd.
El Segundo, CA 90245-2808

Contract No. FA8802-09-C-0001

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Approved by:

Michael L. Bolla, Principal Director
Mission Assurance Subdivision
Systems Engineering Division
Engineering and Technology Group

Rand H. Fisher, Senior Vice President
Systems Planning and Engineering

Christine L. Stevens, Principal Director
Engineering Directorate
Engineering and Integration Division
Space Systems Group

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Abstract

Acquisition planning for our national security space vehicles requires defining a set of contractual mission assurance requirements that represent the best balance between cost, performance, and risk. Much of the cost and complexity of any program occurs in development by the requirements imposed in specifications and standards for system design, manufacturing, and test. Program characteristics, such as the mission risk acceptance, influence the decisions made during the requirements tailoring process. Space vehicle mission risk classes with defined characteristics offer a more efficient communication of the risk acceptance to determine contractual requirements. Guidelines on the requirements tailoring consistent with defined mission risk classes is presented.

A process that addresses the tailoring process is defined, and is supplemented with appendix material that details the complete set of specifications and standards; including examples of the different mission risk classes to include top level descriptions of technical practices applied. Also included are examples of detailed tailoring of contract requirements and contract language for some standard technical areas.

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Daniel J. Byrne
John C. Cantrell
Roland J. Duphily
Suellen Eslinger
Larry I. Harzstark
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Malina M. Hills
David A. Hinkley
Leslie J. Holloway
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William S. Macaulay
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1. Introduction

This document describes a process to establish space vehicle and/or payload mission risk classes and an acquisition implementation strategy to define requirements for National Security Space (NSS) systems.[1] The early establishment of the risk acceptance provides the basis for government program and project managers to effectively communicate the acceptable level of risk to develop and implement appropriate contractual requirements and risk management strategies. Criteria are defined for four risk mission classification levels (i.e., A, B, C, and D) as a function of several parameters. This document references the recommended minimum set of specifications and standards that should be placed on contract for any NSS space vehicle acquisition. The development of tailored specifications and standards for a specific contract is intended to ensure a cost-effective space system acquisition consistent with the risk tolerance, policies, and constraints in the establishment of the contractual technical baseline requirements. In addition, guidelines are offered on typical technical practices commonly used by the different classes of space vehicles and payloads. The overarching principle behind all NSS programs is mission success. When acquiring space systems, mission success must be the first consideration when assessing the risks and trades among cost, schedule, and performance. Risk management, test planning, system engineering, and funding profiles must be driven by this objective.

1.1 Background

Acquisition planning requires defining requirements for contractual application to represent the best balance between cost, schedule, performance, and risk. Much of the cost and complexity of any program is imposed by the specifications and standards applied in developing system design, manufacturing, test, and safety requirements. Although every requirement in a specification or standard may be appropriate for some programs, every requirement does not make sense for every program. The set of applicable requirements for the identified applicable specifications and standards are established through an integrated and iterative approach based on the analysis of cost-technical drivers and risks, and serve as the baseline for that program. Program characteristics (i.e., risk classification level) are the primary influence on the decisions made during the requirements tailoring process. Tailoring the standards and specifications is the responsibility of the government in consideration of the mission risk and other program characteristics. The collective set of tailored requirements should be evaluated to ensure that the mission assurance profile is in concert with the risk posture and needs of the program.

Technical requirements link the user, the program manager, and the contractor(s), and should be defined during contract development in structuring the technical procurement package. In the initiation of any new development program, it is impractical to define and describe all technical requirements to the level of detail that will be required for production. However, a program must plan the initial contract with adequate assurance of an acceptable and feasible product. Resource and schedule constraints require that a program define overall contractual requirements that are tailored to program-specific needs and place emphasis on those aspects that the program considers most important for its success. The targeted breadth and depth of applied requirements will depend on several factors, including budget, schedule, state of maturity of the underlying technology, nature of the program (e.g., demonstration vs. operational), and more importantly, the criticality of the mission.

Once an acceptable mission risk classification level is established, the program can define and apply the appropriate management controls, systems engineering processes, contractual requirements, and risk management processes. The requirements serve as the technical baseline for the program. These

[1]This document does not include commercial or civil space vehicles as the contract requirements are derived from their own set of specifications, statistics, and policies that are markedly different from NSS.

requirements should be tailored to the needs of each acquisition in order to formulate and execute effective and efficient acquisition programs. The requirements are not intended to limit or constrain the flexibility of a program to deviate in order to create a technical baseline suitable to meet program needs. The intent is to implement a standard process to allow the program to make informed decisions in preparation of the request for proposal and subsequent contract actions. Regardless of the risk classification level designation, all programs should be developed using sound management, engineering, manufacturing, and verification practices.

2. Mission Risk Classifications

2.1 Basis for Mission Risk Classes

National security space (NSS) high-priority missions of high complexity are achieved by strict compliance to the specifications and standards, and the implementation of rigorous and proven best practices to achieve mission success over the desired life of the mission. All practical measures are taken to achieve minimum risk to mission success. Specifications and standards as compliance documents for these “Class A” space vehicle programs are required as an integral part of the acquisition process.

There are other classes of space programs that may require a single mission of short duration and the vehicle or payload may be relatively simple. When compared to high reliability, more complex programs, these one-of-a-kind technology demonstration or experimental space programs are developed with a higher level of risk with the goal to provide proof of concept within a limited budget and mission scope. Higher risk acceptance permits tailoring of the specification and standards requirements. These programs have considerably smaller budgets and usually shortened development schedules. In addition, there are other programs where medium risk is acceptable, and reduced mission assurance standards and provisions are permitted due to limited mission life and/or the mission may be experimental.

Successful acquisition and development of NSS systems requires identification of program risk factors early to ensure effective mitigation strategies are supported by adequate resources. Risk should be understood and agreed upon by the program manager, the management chain, the contractor(s), and the customer to achieve defined success criteria. The risk posture of the program should be determined as early in the formulation of the initial concept of operations and may evolve, but should be documented and approved as part of the program plan in defining requirements prior to the preliminary design review.

In order to be able to communicate the risk acceptance spectrum to the space community, space systems, space vehicles, and space experiments have been categorized into separate classes. By using the class definitions the concepts of risk acceptance for a mission can be communicated with management or the space community in general with defined terminology. Four risk classifications historically have been defined ranging from a Class A, lowest risk acceptance, to a Class D, highest risk acceptance. The definitions provided in this report build on the historical definitions and present risk classification levels based on current national security space missions.

Mission Risk Class can be applied to a space vehicle, or to individual payloads. For example, a Class A space vehicle may incorporate multiple instruments individually classified Class A through Class D, or a launch vehicle may have a primary mission (usually Class A or Class B) but may carry secondary mission payloads that are Class C or Class D to complete the manifest. Each part of the manifest is responsible for meeting the requirements of its own risk classification but, in addition, it may have to satisfy the requirements imposed by the co-travelers having different risk-tolerances.

The mission risk classes presented in this document are intended as guidelines to initiate discussions in identifying, developing, and adjusting requirements based on a specific mission’s design and environments in consideration of resource allocations, and to achieve a better understanding of risk acceptance and challenges with the goal of mission success.

2.2 Mission Risk Class Definitions

Four mission risk classes are defined. The mission risk classes and definition parameters provide a structured approach for defining a hierarchy of risk combinations for NSS space vehicles by considering such criteria as national significance, type of payload (operational or experimental), mission life, magnitude of investment and other relevant factors. Table 1 provides a summary of the risk classes and defining parameters. The Class types are historically defined in MIL-HDBK-343 and several NASA publications (Ref 1-6). The definitions in this document were further modified based on current acquisition experience. Appendix A includes additional detail on the descriptions below and provides examples of the various space vehicles that approximate the mission risk classes.

Class A. These high priority space vehicles risk acceptance is extremely low (minimized). If the mission were to fail or severely under-perform, the impact to national goals would be extremely critical. Payloads are characterized as operational. These missions generally have a design life exceeding 5 years, often with a goal of 8–10 years, or greater. For space systems, it implies design to long life performance requirements with imposition of all the intended specification and standard guidance items. Consequences of failure include an unacceptable combination of fiscal loss and impacts to national security space. All practical measures are taken to achieve minimum risk to mission success. Specification and standard requirements are fully incorporated in the program with no tailoring, to limited tailoring.

Class B. Risk acceptance for these missions is low. If the mission were to fail or severely under-perform, the impact to national goals would be critical. Payloads may be, or may become, operational, but often have limited scope or throughput. These missions usually have a more limited mission life than Class A. A compromise between minimum risk and minimum cost is determined in accordance with program unique requirements. For space vehicle systems, it implies design to long life performance requirements with the imposition of the majority of the specification and standard requirements recommended for Class A missions. Stringent application of the required specifications and standards with only minor tailoring in application are imposed to maintain a low risk to the mission.

Class C. Risk acceptance for these missions is moderate. If the mission were to fail or severely under-perform, the impact to national goals would not be critical. Payloads are usually experimental. These space vehicles generally have a mission design life of less than two years. Medium risk of achieving mission success may be acceptable with reduced requirements and a resultant tailored set of required specifications and standards.

Class D. Risk acceptance for these missions is high with the focus of keeping acquisition cost low. If the mission were to fail or severely under-perform, there would be little to no impact to national goals. Payloads are characterized as experimental. These space vehicles generally are research oriented vehicles and have a mission design life of one year or less. Higher risk acceptance of achieving mission success is permitted with a reduced set of imposed specification and standards requirements.

Table 1. Guideline of Space Vehicle Characteristics for Different Mission Risk Classes

	Class A	Class B	Class C	Class D
Mission Risk Acceptance	Lowest	Low	Moderate	Highest
National Significance	Extremely Critical	Critical	Not Critical	Not Critical
Payloads	Operational	Demonstrates Operational Utility May become Operational	Typically Experimental	Typically Experimental
Acquisition Cost	Highest	High	Medium	Lowest
Development Time	May take 4 or more years	May take 3 or more years	May take 2 or more years	May take 1 or more years
Mission Life	Long, Greater than 5 yrs (typically 8–10+ yrs)	Medium, Up to 5 years	Short, typically less than 2 years	Short, typically less than 1 year
Launch Constraints	Critical	Medium	Few	Few to none

3. Process to Identify Risk Posture and Contract Requirements

The goal of this document is to provide guidance on how to convert the risk that the government program manager is willing to accept in the acquisition and development of a space vehicle or payload to an accepted qualitative language that can be easily described to the rest of the space community.[2] After the acquisition strategy is defined, the process is to use the standard definitions of mission risk classes of space vehicles (Class A, Class B, Class C, Class D) to identify risk acceptance and be able to discuss it with management and contractors to select the applicable set of specifications and standards and then further tailor the requirements commensurate with the risk posture of the program. Cost and schedule drivers and technical risks should be explicitly identified with a strategy that maximizes the balance between programmatic constraints and mission success. Stakeholders must understand and accept the degree of risk to avoid disrupting the program as defined as the program development proceeds and some risk and uncertainties are realized. Early disclosure of known potential risks can sustain stakeholders support. Subject matter experts' inputs are incorporated collaboratively at this point to ensure appropriate best practices are applied as well as to identify possible risks incurred by the specific acquisition. Once the set of acquisition requirements (the set of contractual requirements) is defined, an independent assessment is recommended to assess the mission profile to assure the tailored requirements are consistent with the risk tolerance of the program.

Figure 1 illustrates the various process steps to identify, tailor, and document contractual requirements. The steps in the process are separately discussed in the sections that follow.

3.1 Identify Acquisition Risk Strategy—Programmatic and Technical

Concept development and refinement occurs before contract award where 75 percent (Ref 7) of the cost decisions are made.[2] Once the government program manager has identified the budget for a new space vehicle, the class of the vehicle is identified, initially primarily focused on cost. The program objectives, scope, constraints, and the environment in which the program is executed are characteristics considered in determining the risk classification.

A detailed examination of the program is required to determine the acquisition strategy of the space vehicle. Programmatic details such as the amount of government oversight and insight, the amount and detail of required contract deliverables, the number of program reviews, the extent of redundancy on subsystems, the types of parts used, the amount of material scavenged from other programs, and the level of testing at each of the stages of development all contribute to the risk associated with a space vehicle. A careful comparison of these, and the other characteristics on the various risk classifications, will determine the risk posture of the space vehicle program.

The bulleted list below indicates many of the fundamental acquisition strategy elements that should be considered before denoting the space vehicle risk class. The program implementation strategy includes identifying required leadership and talent to manage and execute throughout all phases of the program development.

- Key Performance Parameters
- Cost Goals
- Schedule
- Leadership and Resources

[2]This document focuses on the space vehicle only. For the government program manager, the space vehicle cost is only a portion of the system cost, which will include costs of the ground control system, the launch costs, and a cost of operations.

- Technology Readiness
- Testing & Integration Plan
- Concept Development/Refinement
- CONOPS
- Software Development Approach
- Alternatives to Mitigate Risk Areas
- Performance Assessment
- Architecture Development
- Supply Chain Management
- Contract Approach

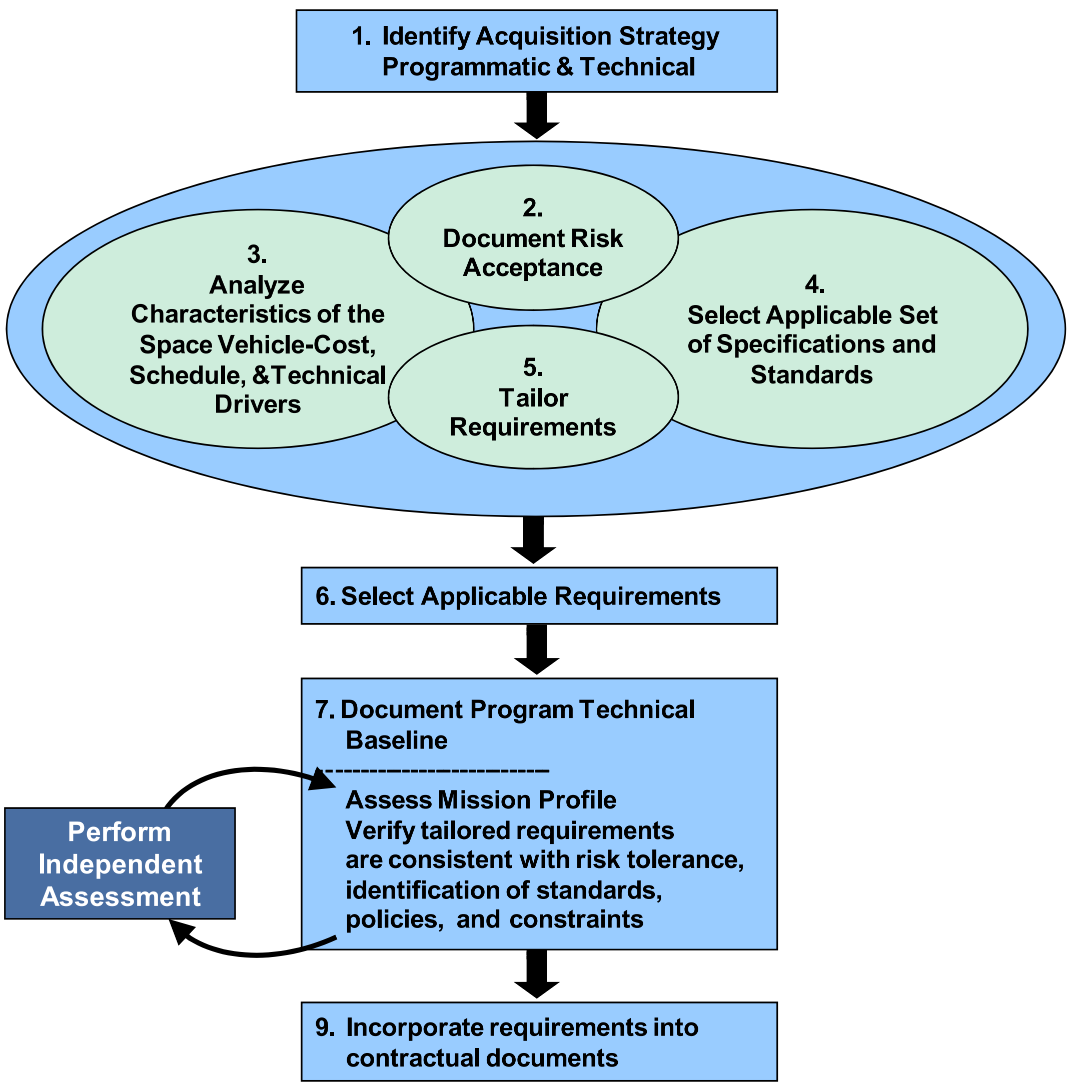

Figure 1. Risk classification and requirements tailoring process.

As a first approximation, the estimated cost of a mission is a significant contributing attribute as to its space vehicle Mission Class. In 2008 dollars, the following is a rough estimate of the cost of a space vehicle within each Class (e.g., A, B, C, or D).[3] These costs do not include the launch and launch vehicle integration costs.

Class A: above $660 million.
Class B: above $80 million
Class C: $5 to $140 million
Class D: below $10 million

There are some overlaps in the cost ranges to account for any cost savings due to multiple builds or other contractual variables. The associated risk that the government manager is willing to accept for the program is usually inversely proportional to cost. Most of this document refers to single builds since multiple builds are usually associated with considerable revision of the design for each build. The relationship of cost and performance is important. The functional requirements of the system will drive the design configuration balancing the user's needs, the range of system performance alternatives and their respective costs. The program office, the user of the data, and the contractor(s) should each participate in the process of determining this balance.

3.2 Document Risk Acceptance

The identification and quantification of major drivers and risk factors, together with mitigation strategies, provides the basis for the selection of program contractual requirements that should be detailed in the request for proposal as identified government risks. Risks should be identified early on that may impact cost, schedule, or performance along with measures and mitigations for keeping risk at acceptable levels. The program manager is responsible for documenting the risk factors that provide evidence of the accepted risk posture of the program.

3.3 Analyze Space Vehicle Characteristics

The program should be analyzed to identify significant cost and technical drivers, critical issues and specific constraints. The process should include results from similar, previous programs in different phases of development and experience in comparable context. The program manager is responsible for identifying key project characteristics. The purpose of this activity is to identify the program risks within the defined acquisition strategy and document, in consideration of the program life cycle and the various disciplines, the causes and consequences of the identified program risks which defines the probability of mission success. The output from this process should be a documented set of cost-technical drivers and risks, with roughly-estimated risk consequences to assess the overall risk tolerance of the program. Appendix A provides some examples of different mission risk classes and general characteristics of specific missions.

3.4 Select Applicable Specifications and Standards

In addition to the program characteristics and accepted risks, the set of applicable specifications and standards should be identified. This process should incorporate the acquiring agency's policies and constraints, and includes Aerospace's recommended minimum set of specifications and standards considered for every NSS space vehicle acquisition. Appendix B provides a list of specifications and standards that should be considered for every acquisition. This set represents current best practices

[3]These costs roughly align with DOD acquisition categories (ACAT) designations for implementation of mandatory procedures for major and non-major defense acquisition programs, and major and non-major

applied to space vehicle acquisition. The output from this process is a list of applicable specifications and standards to be considered in accordance with the program characteristics. New programs should consult with their relevant acquisition agency for applicable compliance standards and associated policies prior to the tailoring process. Space and Mission Systems Center (SMC) Instruction 63-106, Specifications and Standards, directs the development, use, and maintenance of specifications and standards as an integral element of the acquisition process and defines organizational roles and responsibilities. (10)

Government (to include FFRDC and SETA support) and contractors each require experience and competency in defining applicable set of requirements that best aligns with the documented acquisition strategy. The government focus should be on developing requirements and contractor compliance. Contractors play an important role in informing the government what is possible and where potential risks exist. Pre-RFP studies engaging the contractors with the government acquisition authority is a recommended practice for the more complex missions. Close coordination between the government and contractor is key to mission success.

3.5 Tailoring Requirements

The first phase of the tailoring process evaluates the complete list of specifications, standards, and other command media to assess applicability to the specific program. Some of the listed documents may not be pertinent to the specific acquisition or tailored due to the defined acquisition strategy. As a guideline, an average Class A acquisition typically has 35-40 compliance documents (specifications or standards) on contract with required deliverables to support compliance execution. A Class C acquisition typically has 20 compliance documents on contract with few deliverables. The Class C compliance documents are typically product focused, and the contract usually stipulates that the contractor use best practices as executed by their internal command media for processes (i.e., configuration management, cost accounting). The selected standards are then further assessed against the cost-technical drivers and quantified risks and mitigation strategies to determine modification or even addition of new requirements. There may be cases where requirements are called out in other contractual documents and the program must tailor to resolve redundant requirements that may create a precedence issue and configuration control concerns. All specifications and standards are tailorable, and often there are appendices or reference documents to provide tailoring guidance for a particular specification or standard.

The requirements in the accepted specifications and standards need to be tailored for the space vehicle as a function of mission risk class. What may be required for a Class A space vehicle will not be required for a Class C or a Class D.[4] A complete set of technical practices are presented as guidelines in Appendix C that will give the acquiring agency some insight into how the different mission risk classes are developed. A critical evaluation of a selected mission risk class "baseline" provides a "pre-tailored" starting point to further modify based on the specific acquisition constraints and mission needs. Typically, experimental missions require contractor best practices without specific required approved deliverables. Class D programs (payloads) may be funded through a proposal of a capability and may not have formal contract requirements other than interface or critical safety requirements. Risk is accepted by the developer with little to no technical oversight by the acquirer. The acquisition strategy for acquiring experimental missions is different as requirements are defined and adjusted to match resource constraints. This relationship is described in more detail in Appendix D.

[4]The Class A and B mission requirements and tailoring guidelines in this document were defined for a new program or block upgrade and not necessarily for new buy of a mature production program. For these types of acquisitions, the acquisition authority should consider contractor data to access if additional tailoring is warranted.

In addition to the specific mission requirements there may be additional requirements dictated by the launch base, the launch vehicle, or the accompanying primary payload that should be considered during development. Examples include range safety and other federally (OSHA) imposed requirements on all mission classes. Experimental space vehicles or payloads that usually have undergone a minimal set of qualifying tests, however, to gain access to space they fly as secondary payloads on a launch vehicle. These experimental missions must satisfy additional requirements to demonstrate integrity, cleanliness, and specific interface and safety requirements. More details on gaining access to space in these situations are provided in Appendix E.

Aerospace subject matter experts (SMEs) in several disciplines (EMI/EMC; Environmental Test; PMP; Risk Management; Reliability Engineering; and Software Development) have generated matrices and tailoring guidelines that identify the criteria that are to be used in the evaluation as the starting point in determining contractual requirements. See Appendices VI-XI. This selected set of standards tends to be applied across all space vehicles with tailoring commensurate with the stated risk posture of the program. The final language to be used in contractual documents will be written only after a thorough identification of all the mission boundary conditions with the contributions of the relevant SMEs. The overall objective is to determine the applicability of requirements to the specific acquisition. Modifications, i.e., tailoring, may be proposed if considered appropriate to the program characteristics and the cost-technical drivers and risks. In the development of the Request for Proposal (RFP) and/or other contractual documents the program office discusses the mission with the respective SMEs for a particular program. SMEs should be fully engaged in the technical requirements discussions as to the tailoring and/or elimination of requirements as to the wording to be used in contractual documentation. SMEs should be consulted based on their relevant expertise; inputs may come from customer technical personnel, FFRDC, SETA, or contractors. Ultimately, the customer who is the acquisition authority decides the final language and requirements used in the contractual documents.

Tailoring considerations are based on accrued experience, lessons learned, and best practices to assist in the iterative process to determine a complete set of requirements. The process of allocating and aggregating functions and requirements should follow a systems engineering approach that establishes a disciplined iterative process of definition, synthesis, analysis, design, test and evaluation, and leads to design requirements for the major subsystems.

3.6 Select Applicable Requirements

The complete set of tailored requirements should be fully documented and presented as the proposed program specific requirements for management, product assurance, and engineering. A comprehensive review should be directed by the program manager to ensure that specifications, standards and contract deliverables were selected and tailored appropriately. Specifications and standards should be selected and imposed based on contribution of requirements essential for the defined mission performance and operational effectiveness and suitability of the system. In some cases the program may elect not to have a specification listed as a compliance document and opt to include specific language which details requirements in the RFP and/or the contract.

3.7 Document Program Technical Baseline

Following the selection of program-specific specifications and standards requirements, together with the proposed requirements modifications, the collective set of space vehicle requirements should be reviewed by the program team. The program manager is responsible for verifying that the tailored requirements are consistent with the program risk tolerance, ensure all appropriate standards, requirements, policies, and constraints have been identified, and to eliminate the risk of conflict or misinterpretation. The requirements are based on a compromise between risk and cost that are determined appropriate by the government. The collective set represents program factors and goals, failure contingencies, maturity of the hardware, and the contractors involved.

3.8 Perform Independent Assessments

An independent assessment by an organization external to the program is recommended to ensure adherence to policies and practices, and to scrutinize exceptions. This mission assurance review requires detailed technical insight into the program by an independent organization with an independent reporting chain to measure the effectiveness and outcome of the core requirement analysis. The collective set of the program requirements should be assessed against the program development resources to ensure that the requirements are properly defined within the stated constraints of the program, meets the needs of the users, and the design is capable of being built in the projected time. The verified set of tailored requirements then serves as an input to the program requirements documents. The requirements should be incorporated into the RFP and eventually into the technical procurement package. An independent assessment can be accomplished even for a small-budget program in a cost-effective and cost-constrained manner. For example, a team of two to three senior Aerospace managers querying program leads and SMEs on their risk evaluations and the risk management processes of the program can be insightful for the program manager and his management.

3.9 Incorporating Requirements into Contractual Documents

The set of tailored specifications and standards is initially incorporated in the RFP and subject to offerors' proposals. The source selection process will often result in further tailoring based on clarification of mission requirements. The list of specifications and standards requirements along with specific contractual language is further negotiated before the final contract. The contract contains all the requirements for development and required documentation to include data acquisition items as well as deliverable products that may be subject to government approval. Figure 2 is a graphic representation of the process steps that take place to incorporate requirements into contractual documents.

The technical procurement package is defined as those portions of an acquisition or procurement request containing technical requirements: the system specification, the statement of work, the integrated management plan contract deliverables, and the contract data requirements list. Technical requirements are the link between the user, the acquirer, and the contractor(s). Each acquisition is unique but certainly generally characterized by the evolution of the technical requirements as a program progresses, cost/schedule/performance trade-offs considered in every phase of development, and the need for early government and industry participation. The evolution of the technical requirements is not requirements creep but a more detailed definition of the original requirements [7]. The Program Manager is responsible for review of the entire technical procurement to ensure consistency and accurate reflection of requirements with adequate time to develop. Once the contract is signed, the program office contract monitoring activities shift to mission assurance tasks associated with the oversight of those requirements to include review and approval of all contractual deliverables.

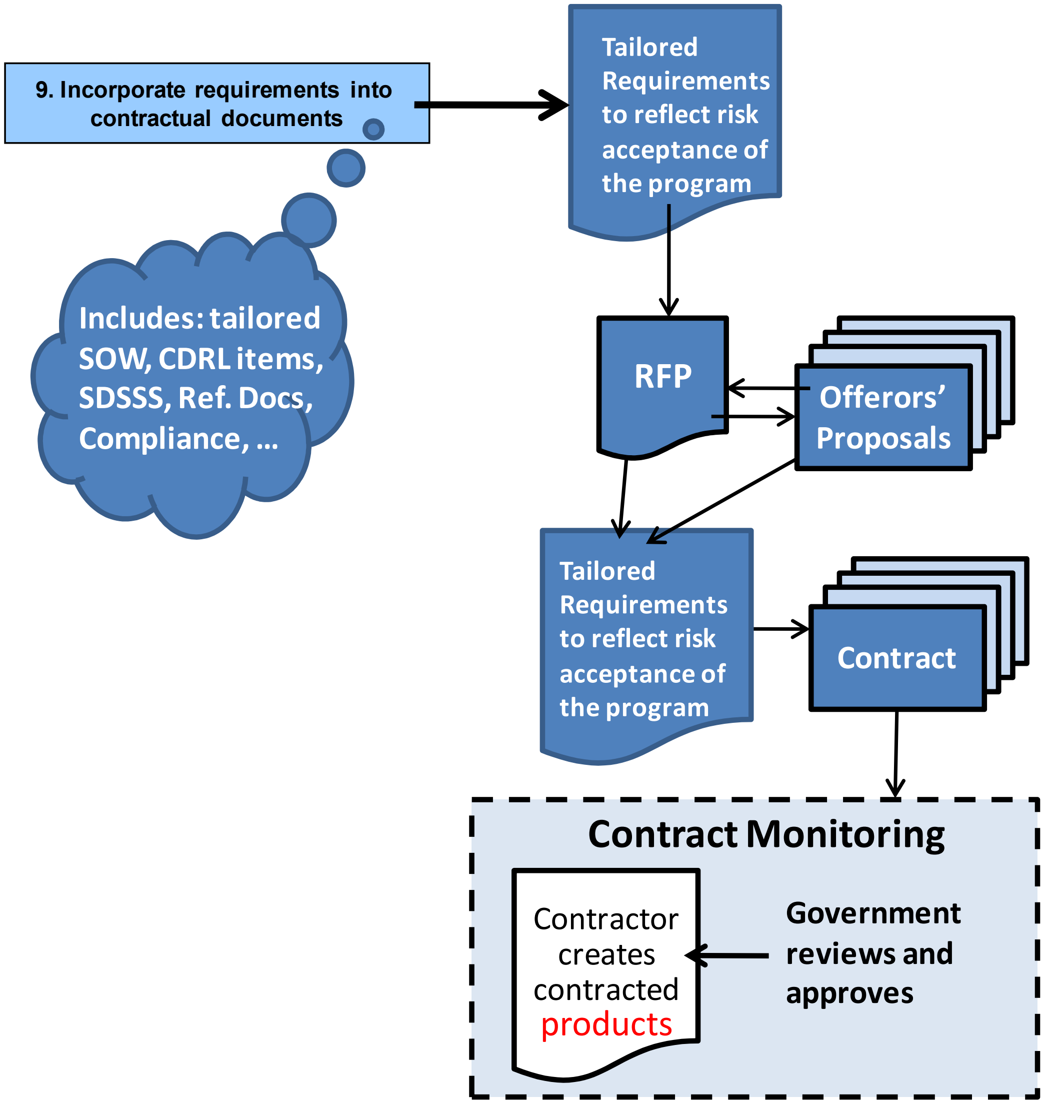

Figure 2. Incorporate requirements into contractual documents.

4. Specifications and Standards

Specifications and standards are an integral part of the acquisition process in RFPs, contracts, management practices, and compliance documents. Most government agencies have a mandated list of specifications and standards to be included in all solicitations, placed on contract as compliance documents, and implemented through the supplier chain. There are essentially two categories of documents: those needed for effective program implementation (process based); and those that provide detailed technical requirements for the design and development of the space vehicle system. The program is responsible for both the selection of the contractual command media and for the tailoring of each of those documents in accordance with the unique characteristics of their specific acquisition. Table B-1, Appendix B, provides a list of specifications, standards, and handbooks organized against a mission assurance baseline that should be adjusted for each specific program. Handbooks and other reference documents that are not recognized specifications or standards were included in the list for completeness. In some cases the requirements are derived from these references and written directly in the contract. Table B-2, Appendix B, provides recommendations on an implementation strategy in applying the specifications and standards per technical practice area across the different mission classes. The same mission assurance baseline is the basis of the technical practices implementation across risk classes in Appendix C and provides direct linkage to the mission assurance oversight conducted by the program office. [10]

4.1 Requirements Compared to Space Vehicle Class

The class of the space vehicle defines the risk tolerance that the government program manager is willing to accept. The goal is to balance the program requirements with the risk tolerance and program constraints. For example, to achieve cost savings, the government manager of a Class C satellite needs to identify a reduced set of requirements compared to those that are present for a Class A space vehicle. The contractor that is to build and test the space vehicle will insist on a reduced set of requirements if the costs are to be kept low. The requirements should be tailored in accordance to the program's needs considering budget and schedule constraints.

A generalized set of space vehicle characteristics is offered in Appendix A, created to assist the program manager in defining an acquisition strategy position that illustrates the differences among the different space vehicle or payload risk classes prior to negotiating the contract requirements. The program requirements codify the program classification, i.e., risk posture, by the contract provisions imposed, including the statement of work and the contract data requirements list.

The program manager is recommended to consult with relevant subject matter experts (SMEs) who have in-depth knowledge of the requirements prior to tailoring any requirements for the program. SMEs are experienced specialists in specific technical disciplines who can render authoritative and definitive judgment on technical processes and criteria during the tailoring process. They are often involved in analyzing failures, major anomalies, and major delays for use in prioritization and correlation with the specifications and standards.

Appendices F–K (EMI/EMC, Environmental Test, PMP, SW, Reliability, Risk Management) provide more detail on specific requirements for specific technical areas and how these would be tailored in accordance to mission risk class. These standards, or derived requirements from these, standards are applied to nearly every SV acquisition. Matrices in these appendices represent the top level requirements for the noted specification or standard; there are many more detailed requirements contained within each specification and standard to be considered when generating a full set of mission assurance requirements for a specific program. As the unique characteristics of each space vehicle are defined, the descriptions for the different risk classes in each cell of the technical matrix and recommended tailoring of the matrix requirements may change depending on the program needs and advice obtained from the SME. These appendices are not intended to replace the inputs and technical advice from subject matter experts, but were created as a baseline to initiate a learned discussion in the negotiation of requirements to specific areas.

5. Program Office Planning and Resourcing

The acquisition strategy approach for a space vehicle should consider the required program office staffing to ensure that the mission assurance (MA) oversight of contract execution is adequate and sufficient commensurate with the risk posture of the program. Some considerations regarding the acquisition strategy and best practices are offered in Appendix E. The success of any mission, regardless of risk class, is dependent on the identification of the program and system managers early to include identifying the FFRDC or SETA support needed. The program office staffing profile should reflect key roles, responsibilities, and accountabilities over the life cycle, all phases of the development, of the space vehicle and/or payload. A government plan that describes the MA methodology that will be applied to the program should be documented on contract award that codifies the earlier resource planning and allocation and should match the tailoring approach of the awarded contract. The tailored contract requirements will drive the program office activities to include approval of deliverables and required presence with review and approval at technical meetings and major milestones in the acquisition. Table 2 summarizes some of the differences in the way a program office may execute MA oversight in consideration of the space vehicle risk class.

Class A programs require full mission assurance oversight to include general systems engineering and integration roles and associated mission assurance functions. Independent technical assessment is the cornerstone of mission success for these complex systems and includes explicit MA tasks associated with the core processes and associated disciplines executed in the development of the system. A typical program office must be right sized and right resourced to ensure the government has access to the talent requirement to manage the program over the life of the program. A strategy should be developed that considers the life of the program and using the best people available in the government, the FFRDCs, and the professional service industry considering competency and required skills mix. The program should place “great emphasis on putting seasoned, domain-knowledgeable personnel in key positions—particularly the program manager, the chief system engineer, and the person in charge of requirements—and then empower them to tailor standardized processes and procedures as they feel is necessary.” [7] Depending on the complexity of the acquired system, the cost, and the development schedule, a Class A program office personnel (to include government, FFRDC allocation, and SETA) will often be in the hundreds. The program office size will vary depending on if there is accountability for ground and launch integration, and some system engineering functions.

Class B systems MA oversight varies balancing the cost of mission assurance against the risk tolerance of the specific mission. These typical demonstration missions may not require as many detailed document deliveries and opt for a more informal, but nearly as frequent, technical interchange with the contractor.

A large reduction in government oversight is realized in the Class C experimental missions where the program office size may range from just one or two personnel up to fifteen to include the support of subject matter expertise that is applied at critical points in the space vehicle development. In many cases, the Class C programs are executed as firm fixed price contracts. Mission assurance focuses on key, high value activities and the associated risks. Process/program management oriented standards are not typically put on contract and the requirements leverage the existing best practices of the contractor. Compliance documents (specifications and standards) that focus on the details of the design and testing require few deliverables that must be approved by the government, but are developed as an artifact of the contractor’s internal command media and process and are made available for review as evidence of their intent to meet the compliance documents on contract. The contractor must conform to the intent of the compliance documents listed and provide evidence or verification that specified analysis and tests are performed. Areas of mission assurance oversight by the government program office are typically in the areas of parts, materials, and processes; EMI/EMC; software; environmental and system test; and reliability. The government is typically invited to weekly/monthly technical interchange meetings, but does not chair or approve findings or minutes. The government does still chair major milestone reviews and provides resources to support interim design and test reviews.

Class D programs are typically developed with little to no government oversight with the exception of major milestone reviews (PDR, CDR, FRR) to ensure the program is developing as required and that the payload meets launch provider and interface requirements. The developer generally accepts the risk in a firm fixed contract. There are no compliance documents that are listed as requirements other than those requiring the payload to be compliant to the launch provider and/or relevant range; and includes requirements dictated by the Interface Compliance Document.

Table 2. Program Office Activities and Oversight as a Function of Mission Risk Class

	Class A	Class B	Class C	Class D
Specification and Standards Compliance	Specs/Stds fully incorporated as compliance documents with no to limited tailoring of requirements. All practical measures taken to minimize risk to mission success.	Specs/Stds required as compliance documents with minor tailoring in application to maintain a low risk to mission success.	Reduced set spec/stds required as compliance documents and tailoring acceptable for more informal structure. Medium risk of achieving mission success may be acceptable.	Reduced set of requirements acceptable; limited set of compliance documents focused on safety critical functions. Higher risk acceptance of achieving mission success permitted.
Government - Mission Assurance Oversight	Highest	High	Some- Allocated to highest risk areas	Limited
Program Reviews	Full formal	Full formal	Formal at major milestones	Not required. Informal and limited
Technical Reviews	Formal Monthly Reviews	Less formal—monthly reviews	Formal Quarterly Reviews, informal monthly reviews	Not required - Informal and limited
Inspections/Reviews	Formal inspections; peer reviews; independent assessments and analysis of design, requirements, and verification documentation. IRR, MRR, FRR required.	Formal inspections; peer reviews; independent assessments and analysis of design, requirements, and verification documents. IRR, MRR, FRR required.	Formal inspections on identified areas/high risk topics; some independent assessments and analysis conducted on design, requirements and verification documentation. Informal IRR. MRR and FRR required.	Informal inspections as required by experimenter. Peer review encouraged. IRR, MRR, and FRR only required for critical safety related functions.
Schedule and cost	Independent assessment required	Independent assessment required		
Contract Type	Cost plus with award fee incentives and shared cost savings	Cost plus with award fee incentives and shared cost savings	Often firm fixed price.	Firm Fixed Price
Contract Deliverables	High, Detailed	High, Detailed	Some, Less Detailed	None

6. Summary

Mission success for NSS systems is achieved by validating key program design specifications, effectively managing program requirements, and rigorously adhering to a practical set of mission assurance requirements. One goal of this document was to provide guidance on how to convert the risk that the government program manager is willing to take on a space vehicle acquisition to an accepted qualitative language that can be easily described to the rest of the space community. Definitions of classes of space vehicles (Class A, Class B, Class C, Class D) were used to identify the allowed risk and to enable discussion with management and contractors to identify a set of baseline requirements for a space vehicle acquisition as a function of the risk class.

A list of recommended specifications and standards for any space vehicle acquisition is provided for consideration for any new acquisition as a starting point to define requirements. To identify a set of requirements for the space vehicle as a function of class, the accepted standards need to be tailored. What may be required for a Class A space vehicle will not be required for a Class C or a Class D space vehicle. A process was described that includes tailoring guidelines for the recommended set of specifications and standards commensurate with the defined space vehicle risk class. As a general rule, higher risk programs typically have a reduced set of standards on contract, fewer requirements, and fewer deliverables with limited oversight of the development. The acquisition strategy may include incorporating some requirements directly into the contractual documentation or acceptance of the developer's process with little oversight. To aid the development of this documentation, additional matrices were generated that describe typical technical practices during the development, test, and deployment of the various space vehicle classes.

7. Definitions

Assembly: An assembly consists of structurally integrated and interconnecting hardware, forming a part of a system. Assemblies cross subsystem boundaries. A space vehicle example is a bus panel on which several electronic units belonging to different subsystems are mounted. [13]

Class (Mission): Space vehicle or payload designation based on the planned or desired program approach considering such criteria as national significance, type of payload (operational or experimental), mission life, magnitude of investment, and other relevant factors.

Critical Design Review: Evaluates the contractor's detailed system design and the detailed build-to-design for each configuration item to determine if each design meets the allocated functional, performance, and engineering specialty requirements. The CDR also evaluates whether the design can be produced and verified; interface compatibility; facilities and personnel; and that all risks have been identified, rated, and satisfactory mitigation plans established. [10]

Electronic Parts Stress Analysis: Comparison of actual stresses applied to each electrical/electronic part in a design with allowable rated or derated stresses for the purpose of identifying and correcting parts applications where actual stresses exceed design guidelines.

Failure Modes Effects and Criticality Analysis (FMECA): The objective of a FMECA is to identify the way failures could occur (failure modes) and the consequences of the failures modes on space vehicle performance (failure effect) and the severity of the effect on mission objectives (criticality). It is usually based on the case upon which failure effects at the system level are caused by failure modes at lower levels. Criticality is typically a qualitative measure (severity) and its assessment is normally accompanied by the failure mode's probability of occurrence. On space vehicles, FMECAs are used to help identify and limit critical failures/single point failures, prevent failure mode propagation and identify reliability critical items. For single-point failures that cannot be designed out or mitigated, critical-item control plans (CICP) are developed and executed to minimize failure mode probability.

Gated Reviews: Applied to assess the adequacy of the acquired system during the course of development. Gates imply a defined set of entrance and exit criteria to verify requirements established for the system at predetermined milestones.

Ground Control System (GCS): Provides the ability to upload data to and download data from a space vehicle. Upload data includes commands or software modifications; download data includes state of health, telemetry, and payload data.

Independent Readiness Review: An independent technical examination of the space vehicle and/or launch vehicle risks. Formal independent review teams are conducted by a core team, augmented as needed to provide a complete set of discipline and subsystem experts from Aerospace, system engineering and technical assistance (SETA), government, and contractor personnel. [10]

Mission Assurance: The disciplined application of general systems engineering, quality, and management principles towards the goal of achieving mission success, and, towards this goal, provides confidence in its achievement. Mission assurance focuses on the detailed engineering processes of the acquired system, and, towards this objective, uses independent technical assessments as a cornerstone throughout the entire concept and requirements definition, design, development, production, test, deployment, and operations phases.

Mission Readiness Review (MRR): Formal review to evaluate the readiness of the space vehicle before final launch integration activities are initiated. The mission director, launch vehicle program manager, and appropriate launch base detachment commander may choose to attend. Program and support organization personnel conduct the MRR, which is supported by the appropriate contractors. Findings and deficiencies should be corrected before the flight readiness review (FRR). [10]

Mission Success: The achievement by an acquired system (or system of systems) to singularly, or in combination, meet not only specified performance requirements but also the expectations of the users and operators in terms of safety, operability, suitability, and supportability.

Part: A part for space hardware applications refers to a physical item, or two or more joined pieces that are not normally subject to disassembly without destruction or impairment of the design use. Examples include diodes, capacitors, resistors, relays, connectors, and brackets. [13]

Payload (PL): A payload for a space vehicle is an assembly of subsystems and components capable of collecting data. The payload may be composed of sub-payloads (or experiments), each providing data for down-linking to the ground control system. (Note: There are some payloads that downlink directly and the space vehicle bus provides power and a stable platform.)

Preliminary Design Review: Evaluates the contractor's technical adequacy, progress, and risk resolution for the selected design-to approach for all configuration items, and establishes a configuration item design baseline down to the assembly level. PDR demonstrates design compatibility with the performance and engineering specialty requirements.

Pre-Ship Review: Formal review to assure that flight hardware and components, software, ground support equipment, and procedural documentation are ready to ship to the deployment site. This review identifies open issues affecting deployment and subsequent operations, verifies planning is in place to close-out remaining issues in a timely manner, and verifies supportability of the program's ensuring activities. [10]

Reliability Assurance Plan: Program document that defines the necessary measures and activities required to be implemented by the program and supportive elements to provide adequate assurance that the desired reliability objectives are achieved.

Space Vehicle (SV): A space vehicle is a complete, integrated set of subsystems and components capable of supporting an operational role in space. It is capable of performing functions that, when combined with a complete set of interfaces (e.g., ground support system) is able to collect a requested set of information. The SV is normally composed of a set of payloads and a space vehicle bus. An SV is sometimes called a satellite.

Space Vehicle Bus: The space vehicle bus is the set of structure, components, and subsystems that can support the collection of data from the payloads and transmit them to the ground when propitious. It is able to support the payloads through the life of the SV by providing them with structural support, power, communications, data storage, etc.

Specification: A document that prescribes, in a complete, precise, verifiable manner, the requirements, design, behavior, or characteristics of a system or system component. (9)

Standard: A document that is established by consensus and approved by an accredited standards development organization that provides for common and repeated use, rules, guidelines, or characteristics for activities or their results, aimed at the achievement of the optimum degree of order and consistency in a given context. [9]

Structural/Thermal Stress Analyses: Structural analyses compare actual stresses applied to a structural material to the material's property characteristics, to verify that design-applied stress does not exceed acceptable values identified in design criteria. Thermal analysis is used to verify that adequate heat transfer characteristics are present in system hardware element designs to ensure hardware elements will not exceed allowable temperature limits; this analysis is commonly applied to verify that adequate heat transfer mechanisms exist to prevent critical temperatures of electronic parts from being reached or exceeded.

Subsystem: A subsystem is an assembly of several functionally related units consisting of interconnections such as cables or tubing, the supporting structure to which they are mounted and any associated software. Typical space vehicle subsystems are attitude control; command and data handling; electrical power and distribution; fault management system; structures and mechanisms; thermal control; payloads; propulsion; and telemetry, tracking, and control. [13]

System: A system is a functionally complete assembly. A space vehicle (consisting of the bus and the payloads) is an example of a system. [13]

Tailoring: The process by which individual requirements of specifications, standards, and related documents are evaluated, and made applicable to a specific project by selection, and in some exceptional cases, modification of existing or addition of new requirements. [2]

Unit: A unit is treated as a physical and functional entity for purposes of analysis, manufacturing, maintenance, or recordkeeping. Example space vehicle units include a pyro controller box, a power control unit, an Earth sensor, a thruster, a solar array drive, or a fuel tank. Software configuration items are analogous deliverable products at the unit level. [13]

Worst Case Circuit Analysis: Verifies the performance of electronic circuits under worst case environmental conditions, voltages, frequencies, radiation effects, and various piece/part parametric tolerances to include shock and vibration.

8. Acronyms

AIAA	American Institute of Aeronautics and Astronautics
CAIV	Cost as an Independent Variable
CDR	Critical Design Review
CDRL	Contract Data Requirement List
CM	Configuration Management
CONOPS	Concept of Operations
COPV	Composite Overwrapped Pressure Vessel
EMC	Electromagnetic Compatibility
EMP	Electromagnetic Pulse
EMI	Electromagnetic Interference
ETG	Engineering and Technology Group
FFRDC	Federally Funded Research and Development Corporation
FMECA	Failure Modes and Criticality Effects Analysis
FRR	Flight Readiness Review
GFE	Government Furnished Equipment
GPO	Government Program Office
GPS	Global Positioning System
IEEE	Institute of Electrical and Electronics Engineers
IRR	Independent Readiness Review
ISO	International Organization for Standardization
MA	Mission Assurance
MIL-STD	Military Standard
MPE	Maximum Protected Environment
MRR	Mission Readiness Review
NSS	National Security Space
ORD	operational requirements document
PDR	Preliminary Design Review
PL	Payload
PMP	Parts, Materials, and Processes
PMPCB	Parts, Materials, and Processes Control Board
PMR	Program Management Review
RFP	Request for Proposal
RM	Risk Management
SDR	System Design Review
SE	Systems Engineering
SETA	System Engineering Technical Assistance
SME	Subject Matter Expert
SOO	Statement of Objectives
SPF	Single-point failure
SRR	System Requirements Review
SV	Space Vehicle
SW	Software
TLYF	Test Like You Fly

TOR	Technical Operating Report
TR	Technical Report
TRR	Test Readiness Review

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Appendix A. Descriptions and Examples of Different Space Vehicle Classes

Gail Johnson-Roth
Victor Matricardi

The definitions of the classes of space vehicles fall short of providing a simple, obvious way to differentiate between space vehicle mission classes. The requirements matrices, as an aid by topic area, do not provide insight into the developed space vehicle. A few examples and sample requirements are provided in this section to help the reader achieve a more intuitive view of the classes of space vehicles and the requirements appropriate to the documented program characteristics.

A.1 Description and Examples of Class A Space Vehicles

The space vehicle sponsor requires functionality of the payload in order to satisfy a critical national goal. The risk tolerance for Class A is the minimal practical risk, and because of the life expectancy, redundancy of subsystems is present. A Class A space vehicle program is usually integrated with other systems; large and complex; associated with a large acquisition agency; the size and demand dictates a large, reliable, proven launch vehicle; and the space vehicle must be highly reliable to provide a long term service commitment. In the early days of the space age these missions usually had a prototype qualification model built to allow for mechanical testing to qualification levels. Currently, Class A systems typically test to proto-qualification levels but have margins to full qualification levels and risk is mitigated by other testing. Qualification testing may be required to demonstrate that the design and manufacturing adherence to specifications and standards is expected with tailoring being heavily reviewed before acceptance.

The following represents a summary of attributes of Class A programs. Critical single-point failures are not permitted. Full formal program reviews are required. External independent technical and program reviews are managed at higher organizational levels that include independent inspections of software, requirements, design, and verification documents. Engineering model hardware is required for new or modified designs. Separate prototype and flight model hardware is also required. Full formal qualification and acceptance test programs are required with an integrated end-to-end testing of all hardware and software levels, i.e., Test-Like-You-Fly. Proto-qualification test strategy may be used in designing hardware to qualification levels; testing the first flight hardware to proto-qualification levels to verify design, and testing subsequent flight hardware to acceptance levels to screen workmanship defects. Verification of heritage of previously used materials and qualification of all new or changed material, applications, or configurations is required. All procured materials are subject to source controls and acceptance testing of each lot/batch. The following is required for all parts and circuits:

- Failure mode and effects analysis
- Critical items list
- Worst-case performance
- Parts electrical stress analysis

Mechanical reliability, human, and other reliability analyses, are required. A formal software assurance program is required with verification and validation determined by the software development plan. A formal quality assurance program is required including closed-loop problem reporting and corrective action, configuration management, performance trending, and stringent surveillance.

An example of a Class A space vehicle is the Global Positioning System (GPS) satellite. The Global Positioning System (GPS) is a U.S. space-based radio navigation system that provides reliable positioning, navigation, and timing services on a continuous worldwide basis. The GPS is also the world's largest military satellite constellation with the identified missions to include global navigation and time transfer. In addition to supporting military operations, the space vehicles orbiting the Earth have become a mainstay of transportation systems worldwide, providing navigation for aviation, ground, and maritime operations. Disaster relief and emergency services depend upon GPS for location and timing capabilities in their life-saving missions. Everyday activities such as banking, mobile phone operations, and even the control of power grids, are facilitated by the accurate timing provided by GPS. Farmers, surveyors, geologists, and countless others perform their work more efficiently, safely, economically, and accurately using the free and open GPS signal. Mission success for these space vehicles is not an option; 100% mission success is a requirement. The Air Force recently awarded Lockheed Martin a $1.5 billion contract to build the next generation of navigation satellites, crucial for the growing demand by the military, companies, and consumers for technology that pinpoints and tracks location. The contract was issued to develop and build two satellites, with an option for 10 more, the first batch of a constellation called the Global Positioning System III.

Other examples of Class A space vehicles include military communication satellite systems. Milstar is a joint service satellite communications system that provides secure jam-resistant, worldwide communications to meet essential wartime requirements for high priority military users. The multi-satellite constellation links command authorities with a wide variety of resources, including ships, submarines, aircraft, and ground stations. The Milstar system, like the GPS system, is composed of three segments: space (satellites), terminal (the users), and mission control. There are five satellites in the current constellation with an average unit cost of $880M.

A.2 Description and Examples of Class B Space Vehicles

This class occupies the risk spectrum between those of Class A and Class C space vehicles and is characterized as low. The sponsor usually views the payload as experimental but has semi-operational plans for the mission. Often a Class B mission will have requirements to collect data with average or limited bandwidth, thus demonstrating operational utility at a lower ops tempo. A compromise between minimum risk and minimum cost is determined in accordance with program unique requirements. For space vehicle systems, it implies design to medium life performance requirements with the imposition of the majority of the specification and standard requirements recommended for Class A missions. The qualification and acceptance program is more extensive than just functional or environmental testing. Proto-qualification testing may be acceptable whereby higher risk is acceptable dependent on program scope and budget or is mitigated by other testing. Stringent application of the required specifications and standards with only minor tailoring in application are imposed to maintain a low risk to the mission.

The following represents typical attributes of a Class B program. Critical single points of failure may be permitted by exception and are minimized and mitigated by the use of high reliability parts and additional testing. Essential space vehicle functions and key instruments are typically fully redundant. Other hardware has partial redundancy and/or provisions for graceful degradation. Full formal program reviews are required, and external independent reviews are conducted and managed by the customer and authority outside the immediate program office. Reviews include formal inspections of software requirements, design, verification documents, and peer reviews of code. Engineering model hardware is required for new or significantly modified designs. The program may use a combination of qualification and proto-flight hardware. Qualified software simulators may be used to verify software and system. The program may use previously tested/flown materials or qualify new materials in accordance with the configuration application. Acceptance tests are conducted for each lot of procured materials. Failure mode, effects, and criticality analysis and identification of articles for the critical items list are conducted as a minimum at the box level. Worst case circuit analysis (WCCA) to determine circuit performance under a worst case scenario are performed for all parts and circuits to ensure sufficient part stress derating to meet design requirements. WCCA is a cost-effective means of screening a design to ensure with a high degree of confidence that potential defects and deficiencies are identified and eliminated prior to test. WCCA are performed on all circuitry that is safety critical. Formal software assurance with independent verification and validation should be conducted in accordance with a software development plan. A formal quality assurance program should be applied to include close-loop problem reporting and corrective action, configuration management, and performance trending with moderate surveillance.

ARGOS is considered an example of a class B satellite being large with considerable redundancy and having undergone a thorough test regime with a design life of three years. The Advanced Research and Global Observation Satellite (ARGOS) with nine payloads addressing more than thirty research objectives was launched as a research and development program by the Space Test Program (STP) for the Air Force. The 6000 pound space vehicle had an average solar array that provided 1000 watts of power and up to 5 megabit/second data downlink. It was launched 23 February 1999 on a Delta II rocket to a sun-sync orbit of 456 nautical miles. It took 7.5 years between authority-to-proceed to the launch date. It contained considerable redundancy at a cost of $220 million (then dollars) that included the nine integrated payloads. The launch vehicle mission included two auxiliary NASA satellites: ORSTED and SUNSAT. It underwent two complete thermal vacuum cycle tests because of the extensive changes that were implemented (after the first thermal vacuum regime). The satellite met and sometimes exceeded its requirements even though some of the experiments suffered on orbit failures. The ARGOS mission was terminated on 31 July 2003.

Another example of a Class B space vehicle is the Combined Release & Radiation Effects Satellite (CRRES) which was launched 25 July 1990 into an initial low earth orbit and then into a highly elliptical orbit of 350 Km X 35,786 Km at an inclination of 18 degrees. It was a joint NASA/DOD mission having a mass of 3758 pounds and costing $88 million. It was a complex vehicle having multiple experiments including chemical release into the ionosphere, microelectronic radiation sensitivity experiments, and advanced solar cells. The CRRES included all the characteristics of a Class B satellite: important experiments, built and integrated by a reliable satellite developer, and a more thorough testing program than that usually applied for Class C space vehicles.

A.3 Description and Examples of Class C Space Vehicles

The usual purpose of a Class C space vehicle is to provide space testing for a new technology or sensor. Because the payload is usually experimental in nature, the sponsor wants the results in the shortest possible time and at minimum cost. The risk acceptance of the sponsor will determine the amount of redundancy that the space vehicle will have, the contractor that will build the satellite, the type of parts that are to be used, and the amount of tailoring of the space vehicle requirements that will be acceptable.

Typical attributes of a Class C program are as follows. Critical single points of failure may be permitted, but are mitigated by use of high reliability parts, additional testing, or by other means. Single string and selectively redundant design approaches may be used. Formal program reviews are conducted, and independent reviews managed and performed in accordance to customer requirements. Engineering model hardware is performed for new designs. Limited qualification testing for new aspects of the design and a full acceptance test program is usually required. Testing and failure analysis is required for verification of safety compliance and interface compatibility. For parts and materials, the use of previously tested/flown materials is acceptable. Acceptance testing is performed of sample lots of procured material. Failure mode, effects, and criticality analysis and identification of the critical items list is required at the system level. A formal quality assurance program includes problem reporting and corrective action, configuration management, and performance trending.

An example of the upper end of a Class C space vehicle is the Communications/Navigation Outages Forecasting System (CNOFS) which was launched on a Pegasus launch vehicle in 2008. This satellite has multiple sensors to identify, and potentially predict, instabilities in the ionosphere that could affect communication and the GPS data at low latitudes. This satellite was sponsored by the AF Space Test Program with the payload suite being provided by the Air Force Research Laboratory. Should the prediction of the communications outages prove successful, then the satellite will be operated in a quasi-operational mode after the first year in space. The satellite has some subsystem redundancy and the systems engineering tradeoffs were performed throughout the construction process.

Another example of a Class C satellite, one that had some of the characteristics of a Class B, is the Coriolis mission which was launched on 6 January 2003 aboard a Titan II launch vehicle. This satellite was built to support two experiments: Windsat and Solar Mass Ejection Imager. The Windsat payload was a risk reduction effort for one of the NPOESS payloads; therefore, it had a higher national importance than most experimental payloads. The satellite was relatively large for this class of satellite (1798 pounds) and, when fully deployed, had a height of 23 feet. It had some subsystem redundancy and had a 3-year design life. The mission cost was over $100M (including the payloads).

A.4 Description and Examples of Class D

The space vehicle in this class is most often created by an educational institution for the purpose of teaching students the concepts of systems engineering used in the design, construction, and testing of a space system. There is an inherent acceptance of risk—"If it works, great; if it does not, something was learned." A Class D satellite uses a single string philosophy; has a small and less complex design; can use a smaller, low cost, unproven launch vehicle; and has the goal to survive long enough to demonstrate the payload. The requirements imposed on such a mission are highly dependent on the project leader. Evaluation or testing is only required to ensure no deleterious impact with the launch vehicle or with other co-launched satellites as appropriate. The acceptance test program is usually limited to critical performance parameters, and formal verifications limited to those necessary for safety and compatibility. The launch vehicle mission integrator will require that the space vehicle be able to prove that it can sustain the launch loads without harming the other payloads or the launch vehicle, and that the space vehicle meets the fairing requirements for cleanliness and electromagnetic environment.

Typical attributes of a Class D program are as follows. Single string and selectively redundant design approaches may be used. Program reviews are informal, although should include the participation of all applicable domain areas. Peer reviews, particularly of software requirements and code, should be performed. Limited engineering modeling and flight spare hardware are performed due to budgetary constraints. Testing and failure mode analysis is required only for verification of safety compliance and interface compatibility. The acceptance test program is limited to critical performance parameters. Parts and materials requirements are based on applicable safety standards. Materials should be assessed for application and life limits. Quality assurance is less formal but should include problem reporting and corrective action, configuration management, and performance trending.

An example of a Class D space vehicle is the MidSTAR, a general purpose satellite bus capable of supporting a variety of space experiments and instruments. A project of the United States Naval Academy Small Satellite Program, MidSTAR-1, was launched in March 2007 as a secondary payload aboard an Atlas V launch vehicle. The space vehicle was commissioned to carry the Internet Communications Satellite Experiment and the Configurable Fault Tolerant Processor Experiment as well as the Nano Chem Sensor Unit for NASA Ames and Eclipse for NASA Goddard. MidSTAR was produced at a minimum cost with a correspondingly higher technical risk in production and operation. The simple design includes a rugged construction using commercial off-the-shelf plug-and-play components to the greatest extent possible. The space vehicle was unique in that the sponsor did not have the time or the funds to perform thermal vacuum cycling. However, MidSTAR was required to meet the structure, cleanliness, and electromagnetic requirements dictated by the mission integrator. Requirements included random vibration testing that would not have otherwise been a requirement for the MidSTAR mission. Even with these minimum development requirements, MidSTAR-1 fully supported all onboard experiments for two full years, fulfilling the 100% success criteria. (Contact with MidSTAR-1 was lost in April 2009 when the space vehicle ceased transmitting and failed to respond to ground command.)

Other examples of Class D space vehicles are the CubeSats. These are small (10-inch cubes), semi-standard, satellites that are produced and modified by universities and university-corporate partnerships. Students, through hands-on work, develop the necessary skills and experience needed to succeed in the aerospace industry. The CubeSat program strives to provide practical, reliable, and cost-effective launch opportunities for small satellites and their payloads. They are built with parts that are usually not space-qualified and they are very inexpensive. Space access is dependent on the imposed requirements for the safety of the total launch mission and will influence whether they have access to space. With their relatively small size, CubeSats can be made and launched for an estimated US$65,000–80,000 each (2004 US dollars).

A.5 Summary

The government program manager must determine the risk posture that the program is willing to accept. The goal is to define program characteristics as a balance of the program acquisition strategy with the risk tolerance and program constraints. The minimum set of specifications and standards recommended by The Aerospace Corporation that should be considered for any space vehicle acquisition is listed in Appendix B. This appendix also lists additional specifications and standards required for new SMC acquisitions as well as a number of best practices as references. Since acquisition strategy is more than just tailoring requirements from a standard set of specifications and standards, a generalized set of SV technical practices is provided in Appendix C, created to assist the program manager or developer in defining a position that illustrates the differences among the different space vehicle/payload classes prior to negotiating the contract requirements. The program requirements codify the program classification, i.e., risk posture, by the contract provisions imposed, including the statement of work and the contract data requirements list.

Appendix B. Space Vehicle Specifications and Standards

Brian E. Shaw
Gail A. Johnson-Roth
Joseph Meltzer

Table B-1 is the bibliography of compliance specifications and standards, as well as other useful reference reports and handbooks. The complete set of documents is organized and presented against a proposed mission assurance baseline that can be used to define the technical baseline of a program. The mission assurance baseline is divided into six main areas related to space vehicle acquisition:

- Program Planning and Management
- Systems Engineering (includes technical disciplines)
- Space Vehicle Integration and Test
- Space Vehicle Subsystems and Design
- Operations
- Launch Vehicle or Ground System Interfaces

Table B-1 further subdivides each of the mission assurance baseline areas into technical practice areas. Each technical practice area references a list of applicable specifications, standards, technical reports or handbooks and includes the official report number, the title of the document and the publication date. This set of references addresses known acquisition issues. Table B-1 includes the minimum essential government, industry, professional and international specifications and standards (highlighted in bold in the table) that should be considered for any space vehicle acquisition. The selected set of tailored specifications and standards of the documents placed on contract become part of the program's technical baseline. The program office is responsible for ensuring that requirements are enforced through their mission assurance oversight of the contract. For some of the technical practice areas there may be no specific standards; the contractual requirements for these areas are often written directly into the contract. Handbooks and other reports were included to provide a complete reference set against the proposed mission assurance baseline. Handbooks and guidelines are intended as reference only to offer best practices on approaches to define and derive compliance requirements. There are cases in Table B-1 where a particular reference may overlap different technical practice areas. This is often the case with many of the handbook references because of the broad scope of these technical guidelines.

Table B-2 recommends at a very top level the contractual implementation of the standards and specifications (and other requirements found in the referenced handbooks) against the proposed mission assurance baseline in consideration of the different mission risk classes. Recommendations for a general tailoring approach and general data delivery approach is offered in the first two rows followed by recommended practical implementation by technical practice area. This table is a guideline to initially establish the appropriate set of compliance documents. All specifications and standards tailorable; tailoring is the responsibility of the government in consideration of mission risk and other program characteristics. Further detail regarding the implementation of technical practices by mission risk class is found in Appendix C.

Table B-1. Bibliography of Standards and Reference Documents

		NOMENCLATURE	TOPIC AREA	PUBLICATION DATE
Program Planning & Management	Technical Contract Oversight	**ISO 14300-1**	**Space Systems - Program Management - Part 1: Structuring of a programme**	**2002**
		TOR-2004(8583)-3227	SE Contract Data Requirements Selection Guidelines for National Security Space Programs	2004
		ISBN 1-884989-15-2	Space Modeling and Simulation Roles and Applications Throughout the System Life Cycle	2004
	Cost Reporting	**ANSI/EIA 748B**	**Earned Value Management Systems**	**2007**
		DoD 5000.4-M	Cost Analysis Guidance & Procedures	1992
		DoD Instruction 5000.02	Enclosure 7 Resource Estimation	2008
	Risk Management	**ISO 17666**	**Space Systems - Risk Management**	**2003**
	Configuration Management	**TOR-2005(8583)-1** **also published as SMC-S-002 (2008)**	**Configuration Management**	**2005**
		EIA-649A	**National Consensus Standard for Configuration Management**	**2004**
	Subcontractor/ Supplier Management	**SMC-S-019, Rev A (2008)**	**Program and Subcontractor Management**	**2008**
	Manufacturing & Production Management	**MIL-STD-1528A**	**Production Management**	**1986**
	Reviews & Audits	**MIL STD 1521B, CN3**	**Technical Reviews and Audits for Systems, Equipment, and Computer Software**	**1992**
		TOR-2007(8583)-6414, Vol 1, Rev 1 **also published as SMC-S-021 (2010)**	**Technical Reviews and Audits for Systems, Equipment, and Computer Software**	**2009**
		TOR-2004(8583)-3360	System Engineer's Major Reviews for National Security Space Systems	2004
		TOR-2009(8583)-8545	Guidelines for Space Systems Critical events	2008
Systems Engineering	Systems Engineering Process	**TOR-2005(8583)-3, Rev B** **Also published as SMC-S-001 (2010)**	**Systems Engineering Requirements and Products** **Systems Engineering**	**2009**
		ANSI/EIA 632	**Processes for Engineering a System**	**1994**
		TOR-2004(8583)-3235	Systems Engineering Charter for National Security Space Systems	2004
		TOR-(8546)-6018	Mission Assurance Guide	2007
		TOR-2009(8546)-8604	Reuse of Hardware and Software products	2010
		TOR-2006(8506)-4494	Space Vehicle Systems Engineering Handbook	2005
	Requirements	Requirements derived from other standards	(see Systems Engineering Process topic area)	
	Requirements Verification	**TOR-2006(8506)-4732, Rev B**	**Space System Verification Program and Management Process**	**2006**

		NOMENCLATURE	TOPIC AREA	PUBLICATION DATE
		Additional requirements may be derived from other standards	(see Systems Engineering Process topic area)	
	Design Assurance	TOR-2009(8591)-11	Design Assurance Guide	2009
		Requirements may be derived from other standards	(See Reviews and Audits)	
	SV System Safety	**MIL-STD-882C**	**System Safety Program Requirements**	**1993**
	Reliability	**TOR-2007(8583)-6889** **also published as SMC-S-013 (2008)**	**Reliability Program Requirements for Space Systems**	**2007**
		MIL-STD-785B, CN 2&3	**Reliability Program for Systems and Equipment Development and Production**	**1988**
		MIL-STD-470B	**Maintainability Program for Systems and Equipment**	**1995**
		TOR-2009(8591)-13	Space Vehicle failure Modes, effects, and Criticality Analysis (FEMCA) Guide	2009
	Parts, Materials, Process	**TOR-2006(8583)-5235** **also published as SMC-S-009 (2009)**	**Parts, Materials & Processes Control Program for Space and Launch Vehicles**	**2009**
		TOR-2006(8583)-5236 **also published as SMC-S-010 (2009)**	**Technical Requirements for Electronic Parts, Materials & Processes used in Space and Launch Vehicles**	**2009**
		MIL-STD-883F	**Microcircuits (test methods)**	**TBA**
	Product and Quality Assurance	**ISO 9001**	**Quality Management Systems - Requirements**	**2008**
		SAE AS 9100	**Quality Systems - Aerospace - Model for Quality Assurance in Design, Development, Production, Installation and Servicing**	**Rev-C: 2010**
		TOR-2005(8583)-3859 **Also published as SMC-S-003 (2008)**	**Quality Systems**	**2005**
		ISO 14300-2	**Space Systems Programme Management - Part 2: Product Assurance…**	**2003**
	Mass Properties	**AIAA S-120-2006**	**Mass Properties Control for Space Systems**	**2006**
	EMI/EMC	**MIL-STD-461F**	**Electromagnetic Emissions and Susceptibility, Requirements for the Control of Electromagnetic Interference**	**2008**
		TOR-2005(8583)-1, Rev A **also published as SMC-S-008 (2008)**	**Electromagnetic Compatibility Requirements for Space Equipment and Systems**	**2008**
		MIL-STD-1541	Electromagnetic Compatibility Requirements for Space Systems	1987
	Contamination Control	**ASTM E 1548-**	**Standard Practice for Preparation of Aerospace Contamination Control Plans**	**2009**
	Electrical Design (Cable & Harness)	**TOR-2008(8583)-8492** **also published as SMC-S-020 (2009)**	**Wiring Harness, Space Vehicle, Design and Testing, General Specification for**	**2009**
	Mechanical Design	**AIAA-S-114-2005**	**Moving Mechanical Assemblies for Space and Launch Vehicles**	**2005**

		NOMENCLATURE	TOPIC AREA	PUBLICATION DATE
		Additional requirements may be derived from other standards	(See TOR-2006(8506)-4494, Space Vehicle Systems Engineering Handbook)	
	Software	**TOR-2004(3909)-3537, Rev B also published as SMC-S-012 (2008)**	**Software Development Standard for Space Systems**	**2005**
		ISO/IEC 15939-	Software Engineering - Software Measurement Process	2007
		IEEE 1012-2004	Standard for Software Verification and Validation	2004
		IEEE 1028-1997	Standard for Software Reviews	1997
		IEEE 1471	Recommended Practice for Architecture Description of Software-Intensive Systems	2000
		IEEE 828-2005	Standard for Software Reviews	2005
	Survivability	**TOR-2008(8583)-8164 Rev A** **also published as SMC-S-014 (2010)**	**Survivability Program Management for Space**	**2010**
		ASTM F 1892	**Standard Guide for Ionizing Radiation (Total Dose) Testing of Semiconductor Devices**	**2006**
		MIL-STD-1809	**Space Environment for USAF Space Vehicles**	**1991**
	Supportability	**MIL-PRF-49506**	**Logistics Management Information**	**1996**
		MIL-PRF-29612B	**Training Data Products**	**2001**
		TM-86-01/N	Air Force Technical Manual Contract Requirements	2010
		MIL-STD-1545	Optional Spare Parts, Maintenance and Inventory Support of Space and Missile Systems	1977 Reval: 1992
		MIL-STD-1538	Spare Parts and Support of Space and Missile Systems Undergoing RDT&E	1973 Reval: 1992
	Information Assurance	ANSI/GEIA 836-2002	Configuration Management - Data Exchange Interoperability	2002
		DISR Ver 10-02 [Updated 3x per annum]	**DOD Information Technology Standards Registry**	**2010**
		DoD Arch v2.0	**Department of Defense Architecture Framework**	**2009**
		IEEE 828-2005	Standard for Software Configuration Management	2005
		TOR-2007(8583)-6702	Guidance on Application of DoD 8500.1/8500.2 Controls	2007
		AFPAM 63-1701	Program Protection Planning	2003
		DoDI 8500.2	Information Assurance Implementation	2003
		DOD 8510.01	DoD Information Assurance Certification and Accreditation Process (DIACAP)	2007
		DODM 5200.39-M	Procedures for Critical Program Information (CPI) Protection Within the Department of Defense	2008
		DOD 5220-22M	National Industrial Security Program	2006
		AFPD 63-17	Technology and Acquisition Systems Safety Program Protection	2001

		NOMENCLATURE	TOPIC AREA	PUBLICATION DATE
		DCID 6/3 Manual	Protecting Sensitive Compartmented Information Within Information Systems	2003
		ICD 503	Intelligence Community Information Technology System Security Risk Management, Certification, & Accreditation	2005
		DOD C-5200.5	Communications Security	1990
	Frequency Management	NTIA Manual 2003	National Telecommunications and Information Administration (NTIA) Manual of Regulations and Procedures of Federal Radio Frequency Management	2003
	Human Factors Engineering	**MIL-STD-1472F**	**Department of Defense Design Criteria - Human Engineering**	**1999**
		EIA HEB-1A	**Electronic Industries Alliance Engineering Bulletin - Human Engineering - Principles and Practices**	**2005**
		ISO 9241	**Ergonomics of Human-Systems Interaction**	**2005**
		ANSI/HFES-100-2007	**Human Factors Engineering of Computer Workstations**	**2007**
		ISO 13407: 1999	Human-Centred Design Processes for Interactive Systems	1999
	Environmental, Safety and Health	**NAS 411**	**Hazardous Materials Management Program**	**1995**
		NASA STD 8719.14 (with SMC tailoring)	**Process for Limiting Orbital Debris**	**2009**
			OSHA	
			NEPA	
			PESHE	
Space Vehicle Integration and Test	External Interfaces	Requirements derived from other standards	(See TOR-2006(8506)-4494, Space Vehicle Systems Engineering Handbook) (See TOR-2006(8546)-4591, Space Vehicle Test & Evaluation Handbook)	
	SV to Payload Interfaces	Requirements derived from other standards	(See TOR-2006(8506)-4494, Space Vehicle Systems Engineering Handbook) (See TOR-2006(8546)-4591, Space Vehicle Test & Evaluation Handbook)	
	Space Vehicle Integration	Requirements derived from other standards	(See TOR-2006(8506)-4494, Space Vehicle Systems Engineering Handbook) (See TOR-2006(8546)-4591, Space Vehicle Test & Evaluation Handbook)	
	Subsystem Integration	Requirements derived from other standards	(See TOR-2006(8506)-4494, Space Vehicle Systems Engineering Handbook) (See TOR-2006(8546)-4591, Space Vehicle Test & Evaluation Handbook)	
	Space Unit Test	MIL-HDBK-340	Application Guidelines for MIL-STD-1540, Requirements for Space Vehicles; July 1, 1985	
		MIL-STD-810G	Environmental Test Methods and Engineering Guidelines, October 2008	
		MIL-HDBK-340	Application Guidelines for MIL-STD-1540; Test Requirements for Space Vehicles, July 1, 1985.	
		MIL-STD-810G	Environmental Test Methods and Engineering Guidelines, October 2008.	

		NOMENCLATURE	TOPIC AREA	PUBLICATION DATE
		SMC-TR-06-11/TR-2004(8583)-1, Rev A **also published as SMC-S-016 (2008)**	**Test Requirements for Launch, Upper-Stage, & Space Vehicles**	**2006**
		TOR-2006(8546)-4591	Space Vehicle Test and Evaluation Handbook	2006
		TOR-2009(8591)-12	Suggested Checklist to Improve Test Performance in the System Test Equipment Area	2009
		TOR-2009(8591)-15	Space Vehicle Checklist for Assuring Adherence to “Test-Like-You-Fly” Principles	2009
Space Vehicle Subsystems & Design	Structures & Mechanisms	**AIAA-S-110-2005**	**Space Systems - Structures, Structural Components, and Structural Assemblies**	**2005**
		TOR-2003(8583)-2894	Space Systems - Structures Design and Test Requirements	2003
	Electrical Power & Distribution	**AIAA-S-111-2005**	**Qualification and Quality Requirements for Space-Qualified Solar Cells**	**2005**
		AIAA-S-112-2005	**Qualification and Quality Requirements for Space-Qualified Solar Panels**	**2005**
		AIAA-S-122-2007	**Electrical Power Systems for Unmanned Spacecraft**	**2007**
		TOR-2004(8583)-5, Rev 1 **also published as SMC-S-007 (2008)**	**Space Battery**	**2005**
		TOR-2007(8583)-1 **also published as SMC-S-017 (2008)**	**Lithium Ion Batteries for Spacecraft Applications**	**2007**
	Thermal Control	ISBN 1-884989-11-X	Spacecraft Thermal Control Handbook Volume I Fundamental Technologies	2002
		ISBN 1-884989-14-4 (v.2)	Spacecraft Thermal Control Handbook Volume II Cryogenics	2000
	Attitude Control	Requirements derived from other standards	(See TOR-2006(8506)-4494, Space Vehicle Systems Engineering Handbook)	
	Propulsion	**AIAA S-081A-2006**	**Space Systems - Composite Overwrapped Pressure Vessels (COPVs)**	**2006**
	Pressurized Hardware	**TOR-2003(8583)-2896, Rev A** **also published as SMC-S-005 (2009)**	**Space Systems - Flight Pressurized Systems**	**2009**
		AIAA S-080-1998	**Space Systems - Metallic Pressure Vessels, Pressurized Structures, and Pressure Components**	**1998**
	Telemetry Tracking & Control	ISO 11754:2003 ISO 12171:2002 ISO 12172:2003 ISO 12173:2003 ISO 12174:2003 ISO 13419:2003 ISO 15396:1998	Space Data and Information Transfer Systems – etc.	1992 thru 2003

		NOMENCLATURE	TOPIC AREA	PUBLICATION DATE
		DTC/03-05-07	Telemetry and Telecommand Data Specification	2003
	Command & Data Handling	Requirements derived from other standards	(See TOR-2006(8506)-4494, Space Vehicle Systems Engineering Handbook)	
	Structural & Dynamic Loads	**TOR-2003(8583)-2886** **also published as SMC-S-004 (2008)**	**Independent Structural Loads Analysis of Integrated Spacecraft, Launch Vehicle Systems**	**2003**
	Ordnance & Pyrotechnics	**AIAA-S-113-2005**	**Criteria for Explosive Systems and Devices Used On Space Vehicles**	**2005**
	Fault Management	TOR-2009(8591)-14	Effective Fault Management Guidelines	2009
		Requirements may be derived from other standards	(See TOR-2006(8506)-4494, Space Vehicle Systems Engineering Handbook)	
	Payloads	Requirements derived from other standards	(See TOR-2006(8506)-4494, Space Vehicle Systems Engineering Handbook)	
Operations	LV Pre-launch Validation and Operational Testing	Requirements derived from other standards	(See TOR-2006(8546)-4591, Space Vehicle Test & Evaluation Handbook)	
	Space Operations	**MIL-STD-1367A**	**Packaging, handling, Storage and Transportation Program Requirements for Systems and Equipment**	**1989**
		MIL-STD-130N	**Identification Marking of U.S. Military Property**	**2008**
		MIL-STD 1366E	**Transportability Criteria**	**2003**
		MIL-STD-2073-1E	**Standard Practice for Military Packaging**	**2008**
	Range Safety	**EWR 127-1**	**Range Safety User Requirements Manual**	**1997**
		AFSPCMAN 91-710	**Range Safety User Requirements Manual**	**2004**
	End-of-life Disposal	**TOR-2006(8583)-4474** **also published as SMC-S-015 (2010)**	**End of Life Disposal of Satellites Operating at Geosynchronous Altitude**	**2010**
		TOR-2007(8506)-7164 **also published as SMC-S-022 (2010)**	**End of Life Disposal of Satellites Operating at Low Earth Orbits**	**2010**
Launch Vehicle or Ground System Interface	Launch Vehicle	**TOR-98(1412)-1, Rev A** **also published as SMC-S-011 (2008)**	**Parts, Materials and Processes Control Program for Expendable Launch Vehicles**	**1998**
		TOR-2003(8583)-2895, Rev 1 **also published as SMC-S-006 (2008)**	**Solid Rocket Motor Case Design & Test Requirements**	**2004**
		TOR-2007(8583)-1 **also published as SMC-S-018 (2008)**	**Lithium Ion Battery for Launch Vehicle Applications**	**2007**
	Ground System	**MIL-STD-1542B**	**EMC Grounding Requirements for Space System Facilities**	**1991**
		MIL-STD-1833	**Test Requirements for Ground Equipment and Associated Computer Software Supporting Space Vehicles**	**1989**
		ANSI/AIAA R-100A02001	Recommended Practice for Parts Management	2001

		NOMENCLATURE	TOPIC AREA	PUBLICATION DATE
		MIL-STD-810G	**Department of Defense Test Method for Environmental Engineering Considerations and Laboratory Tests**	**2008**
		COE UIS V 4.3 **also published as SMC-S-023, Vol 1**	**User Interface Standard**	**2003**
		HM-RB-2001-1 **also published as SMC-S-023, Vol 2**	**Space Operations Displays**	**2001**

Note: **Bolded** documents are formally-published government or industry standards that can be cited as compliance on contracts.

All others are guidance documents that may support of compliance standards or Statement Of Work (SOW) tasking.

Table B-2. Suggested Contractual Implementation of Standards with Technical Practices

		CLASS A	CLASS B	CLASS C	CLASS D
General tailoring approach		*All practical measures taken to achieve minimum risk to mission success; Standards fully incorporated with no to limited tailoring of requirements*	*Stringent assurance standards applied with only minor tailoring in application to maintain a low risk to mission success*	*Medium risk of achieving mission success may be acceptable; Reduce mission assurance requirements and limited set of compliance standards with tailoring acceptable*	*Higher risk acceptance to achieve mission success is permitted; Reduced set of mission assurance requirements acceptable; few compliance standards*
General data delivery approach		*Delivery of DIDs requiring formal government review/approval via CDRL and access of data via DAL*	*Delivery of select DIDs requiring formal government review/approval via CDRL and access of data via DAL*	*Limited delivery of DIDs via CDRLs; Government reviews contractor artifacts; Data accessed via informal data reviews or DAL*	*Informal data deliveries*
Program Planning & Management	Technical Contract Oversight	Compliance standard on contract	Compliance standard on contract	Standard is reference; contractor directed to meet intent of standard	Standard as reference where applicable
	Cost Reporting	Compliance standard on contract	Compliance standard on contract	Standard is reference; contractor directed to meet intent of standard	Standard as reference only
	Risk Management	Compliance standard on contract	Compliance standard on contract	Standard is reference; contractor directed to meet intent of standard	Standard as reference only
	Configuration Management	Compliance standard on contract	Compliance standard on contract	Standard is reference; contractor directed to meet intent of standard	Standard typically not applied
	Subcontractor/ Supplier Management	Compliance standard on contract	Compliance standard on contract	Standard as reference where applicable	Standard typically not applied
	Manufacturing & Production Management	Compliance standard on contract	Compliance standard on contract	Standard as reference where applicable	Standard typically not applied

		CLASS A	CLASS B	CLASS C	CLASS D
	Reviews & Audits	Compliance standard on contract	Compliance standard on contract	Standard is reference; contractor directed to meet intent of standard	Standard typically not applied
Systems Engineering	Systems Engineering Process	Compliance standard on contract	Compliance standard on contract	Standard is reference; contractor directed to meet intent of standard	Standard as reference only
	Requirements	See SE Process	See SE Process	See SE Process	See SE Process
	Requirements Verification	Compliance standard on contract; Also see SE Process	Compliance standard on contract; Also see SE Process	Standard is reference; contractor directed to meet intent of standard	Standard as reference only
	Design Assurance	Compliance standard on contract	Compliance standard on contract	Standard is reference; contractor directed to meet intent of standard	Standard as reference only
	SV System Safety	Compliance standard on contract	Compliance standard on contract	Compliance standard on contract	Compliance standard on contract
	Reliability	Compliance standard on contract; Additional requirements detailed in contract specific to mission	Compliance standard on contract; Additional requirements detailed in contract specific to mission	Tailored standard on contract; government review of products	Standard typically not applied
	Parts, Materials, Process	Compliance standard on contract	Compliance standard on contract	Tailored standard on contract or requirements specified in contract; government review of products	Standard typically not applied
	Quality Assurance	Compliance standard on contract	Compliance standard on contract	Standard is reference; contractor directed to meet intent of standard	Standard typically not applied
	Mass Properties	Compliance standard on contract	Compliance standard on contract	Require as Compliance Standard; LV/ride share provider may dictate requirements	Standard typically not applied; LV/ride share provider may dictate requirements
	EMI/EMC	Compliance standard on contract; tailored for specific mission environment	Compliance standard on contract; tailored for specific mission environment	Compliance standard on contract; tailored for specific mission environment	Standard typically not applied
	Contamination Control	Compliance standard on contract	Compliance standard on contract	Meet intent of standard; LV/ride share provider may dictate requirements	Standard typically not applied; LV/ride share provider may dictate requirements

		CLASS A	CLASS B	CLASS C	CLASS D
	Electrical Design (Cable & Harness)	Compliance standard on contract	Compliance standard on contract	Standard is reference; contractor directed to meet intent of standard	Standard as reference only
	Mechanical Design	Compliance standard on contract	Compliance standard on contract	Standard is reference; contractor directed to meet intent of standard	Standard typically not applied
	Software	Compliance standard on contract	Compliance standard on contract	Tailored standard on contract; government review of products	Standard typically not applied
	Survivability	Compliance standard on contract	Compliance standard on contract	Standard is reference; contractor directed to meet intent of standard	Standard typically not applied
	Supportability	Compliance standard on contract	Compliance standard on contract	Standard is reference; contractor directed to meet intent of standard	Standard typically not applied
	Information Assurance	Compliance standard on contract	Compliance standard on contract	Mission dependent- standard and/or requirements may be on contract	Standard typically not applied
	Frequency Management	Compliance standard on contract	Compliance standard on contract	Compliance standard on contract	Standard typically not applied
	Human Factors Engineering	Compliance standard on contract	Compliance standard on contract	Standard is reference; contractor directed to meet intent of standard	Standard typically not applied
	Environmental, Safety and Health	Compliance standard on contract	Compliance standard on contract	Compliance standard on contract	Compliance standard on contract
Space Vehicle Integration and Test	External Interfaces	Applicable requirements exist in a variety of other standards and/or ICDs	Applicable requirements exist in a variety of other standards and/or ICDs	Applicable requirements exist in a variety of other standards and/or ICDs	Applicable requirements exist in a variety of other standards and/or ICDs
	SV to Payload Interfaces	Applicable requirements exist in a variety of other standards and/or ICDs	Applicable requirements exist in a variety of other standards and/or ICDs	Applicable requirements exist in a variety of other standards and/or ICDs	Applicable requirements exist in a variety of other standards and/or ICDs
	Space Vehicle Integration	Applicable requirements exist in a variety of other standards.	Applicable requirements exist in a variety of other standards.	Applicable requirements exist in a variety of other standards.	No requirements
	Subsystem Integration	Applicable requirements exist in a variety of other standards.	Applicable requirements exist in a variety of other standards.	Applicable requirements exist in a variety of other standards.	No requirements

		CLASS A	CLASS B	CLASS C	CLASS D
	Space Environmental Test	Compliance standard on contract	Compliance standard on contract; tailoring as applicable to mission	Compliance standard on contract; tailoring as applicable mission type and risk posture	Standard as reference only
Space Vehicle Subsystems & Design	Structures & Mechanisms	Compliance standard on contract	Compliance standard on contract	Standard is reference; contractor directed to meet intent of standard	Standard as reference only
	Electrical Power & Distribution	Compliance standard on contract	Compliance standard on contract	Standard is reference; contractor directed to meet intent of standard	Standard typically not applied
	Thermal Control	Applicable requirements exist in a variety of other standards.	Applicable requirements exist in a variety of other standards.	Applicable requirements exist in a variety of other standards.	Applicable requirements exist in a variety of other standards.
	Attitude Control	Applicable requirements exist in a variety of other standards.	Applicable requirements exist in a variety of other standards.	Applicable requirements exist in a variety of other standards.	Applicable requirements exist in a variety of other standards.
	Propulsion	Compliance standard on contract	Compliance standard on contract	Standard is reference; contractor directed to meet intent of standard	Standard typically not applied
	Telemetry Tracking & Control	Compliance standard on contract	Compliance standard on contract	Standard is reference; contractor directed to meet intent of standard	Standard typically not applied
	Command & Data Handling	Applicable requirements exist in a variety of other standards.	Applicable requirements exist in a variety of other standards.	Applicable requirements exist in a variety of other standards.	Applicable requirements exist in a variety of other standards.
	Structural & Dynamic Loads	Compliance standard on contract	Compliance standard on contract	Standard is reference; contractor directed to meet intent of standard	Standard typically not applied
	Ordnance & Pyrotechnics	Compliance standard on contract	Compliance standard on contract	Standard is reference; contractor directed to meet intent of standard	Standard typically not applied
	Fault Management	Applicable requirements exist in a variety of other standards.	Applicable requirements exist in a variety of other standards.	Applicable requirements exist in a variety of other standards.	Requirements typically not applied
	Payloads	Applicable requirements exist in a variety of other standards.	Applicable requirements exist in a variety of other standards.	Applicable requirements exist in a variety of other standards.	Applicable requirements exist in a variety of other standards.
Operations	LV Pre-launch Validation and Operational Testing	Compliance standard on contract	Compliance standard on contract	Compliance standard on contract	Compliance standard on contract
	Space Operations	Compliance standard on contract	Compliance standard on contract	Standard is reference; contractor directed to meet intent of standard	Standard typically not applied
	Range Safety	Compliance standard on contract	Compliance standard on contract	Compliance standard on contract	Compliance standard on contract
	End-of-life Disposal	Compliance standard on contract	Compliance standard on contract	Require as Compliance Standard.	Require as Compliance Standard.

		CLASS A	CLASS B	CLASS C	CLASS D
Launch Vehicle or Ground System Design	Launch Vehicle	Compliance standard on contract	Compliance standard on contract	Standard is reference; contractor directed to meet intent of standard	Standard typically not applied
	Ground System	Compliance standard on contract	Compliance standard on contract	Standard is reference; contractor directed to meet intent of standard	Standard typically not applied

Appendix C. Technical Practices

Brian E. Shaw
Gail A. Johnson-Roth
Joseph Meltzer
Victor R. Matricardi

A complete set of technical practices are presented as guidelines that will give the acquiring agency some insight into how the different mission classes are developed. Typically, experimental missions require contractor best practices without specific required compliance to detailed specifications or standards with approved deliverables. Class D programs (payloads) may be funded through a proposal of a capability and may not have formal contract requirements other than interface requirements or critical safety requirements. Risk is accepted by the developer with little to no technical oversight by the acquirer. The acquisition strategy for acquiring experimental missions is different as requirements are defined and adjusted to match resource constraints.

This appendix provides technical practices organized around a mission assurance framework that should be adjusted for each specific program. This same framework is the basis of the organization of the list of specifications and standards presented in Appendix B. The technical practices implementation across risk classes provides direct linkage to mission assurance oversight conducted by the program office as detailed in the Mission Assurance Guide. [7]

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C.1 Program Planning and Management

Program planning and management encompasses a collection of organizational resources required to provide insight into how the program's products are delivered to meet the required capability within budget and schedule. Program management best practices apply systematic anticipation, assessment, balancing, and handling of program technical, schedule and cost risks and constraints to ensure that the program can be successfully executed.

Technical Focus Area	Class A	Class B	Class C	Class D
Technical Contract Oversight	• Formal inspections, peer reviews, independent assessments and analysis of design, requirements and verification documentation conducted • Formal monthly program management reviews (PMRs) required; informal ad-hoc technical interchanges with contractors on a regular basis • Contracts typically cost plus with award fee incentives and shared cost savings • Independent schedule and cost assessment required • Formal gated review processes required along with independent readiness review (IRR), mission readiness review (MRR), and flight readiness review (FRR)	• Formal inspections, peer reviews, independent assessments and analysis of design, requirements and verification documentation conducted • Formal PMRs on less frequent basis (bimonthly); Monthly technical/ management reviews conducted; informal ad-hoc technical interchanges with contractors on regular basis • Contracts typically cost plus with award fee incentives and shared cost savings • Independent cost and schedule assessment required • Formal gated review processes required along with IRR, MRR, and FRR	• Some independent assessments and analysis conducted on design, requirements and verification documentation; Inspections conducted on high risk areas • PMRs conducted at major milestones; Monthly technical /management reviews conducted with govt and contractor • Minimized administration of contract with a much smaller program office (3 -15 persons) • Contract type dependent on acquiring agency and mission • Inputs to IRR, MRR and FRR required	• Informal inspections as required by the developer; Peer review encouraged • Program and technical reviews not required; Programs typically provide status at standard milestone gates • Little or no contract support/government oversight (2-6 persons, government personnel not fully dedicated to project) • Funding likely firm fixed price • Inputs for IRR, MRR, and FRR required by LV provider for critical safety related functions
Cost Reporting	• Earned value management (EVM) system required • Formal Integrated Baseline Review (IBR) required • Independent cost assessment required	• EVM required • Formal IBR required • Independent cost assessment required	• EVM may be used • Routine cost reporting is performed	• Not required

Technical Focus Area	Class A	Class B	Class C	Class D
Risk Management	• Formal risk management (RM) plan as deliverable; validated/approved process and process documentation, formal risk management boards, integration of risk management process/databases throughout the subcontractor/supplier chain with full government participation • Program office develops separate risk management plan and integrates risks with those identified by the contractor to include handling plans as well as documents risk acceptance and evidences	• Formal RM plan as deliverable; validated/approved process and process documentation, formal risk management boards, integration of risk management process/databases throughout the subcontractor/supplier chain with full government participation • Program office participation in risk management board meetings	• Contractor RM best practices applied at inception of the program to the end; Risks reported on a monthly basis (as required) until risks are mitigated • RM focus on cost savings to ensure program delivered within budget constraints	• Risk is accepted by the developer • RM activities applied where practical; critical components/ subsystems (i.e., transponder) identified relative to critical or mission–essential services (i.e., command and data handling) • Safety and compatibility risks are required to be reported
Configuration Management	• Formal configuration management (CM) plans, processes and boards integrated throughout the sub/supplier chain with government approval for baseline/change control and configuration audits	• Same as Class A, perhaps with government insight at sub/supplier levels	• CM plan not a deliverable; Rely on contractor system • Formal configuration management is usually initiated once subsystems are integrated • Software CM is initiated earlier	• Not required • Applied at discretion of developer
Subcontractor/ Supplier Management	• Formal subcontractor/supplier management practices required; Includes validated/approved process and process documentation, integration of prime and sub/supplier activities • Assurance of proper requirements flow-down, monitoring/approval/ surveillance of sub/supplier processes, verification of supplied products required	• Same as Class A	• Monitored for critical items (such as command and data handling or momentum wheels) • Critical subcontracted items in development are presented at design and program reviews	• Usually no or little monitoring of subcontracts

Technical Focus Area	Class A	Class B	Class C	Class D
Manufacturing/ Production Management	• Formal manufacturing and production management programs with plans required • Includes early planning, manufacture readiness assessment, mfg process verification/validation, and government in-plant oversight at prime and throughout the sub/supplier chain	• Limited government oversight; focus on anomalies, waivers, parts alerts • Monthly reviews monitor production and expenditures with government insight • On site monitoring of critical integrations/system test	• Limited government oversight; focus on anomalies, waivers, parts alerts • Monthly reviews monitor production and expenditures with government insight • On site monitoring of critical integrations/system test	• Usually built in-house
Reviews and Audits	• Formal comprehensive design reviews required to component level at all major milestones (SDR, PDR, and CDR) • Government-approved entry-exit criteria and rigid enforcement of non-compliance status for design review liens • Government inclusion in contractor gate reviews • Formal Test Readiness Reviews (TRR), Independent Readiness Review (IRR), mission readiness review (MRR), and flight readiness review (FRR) required	• Same as Class A for major milestones and formal reviews required (IRR, MRR, FRR) with defined entrance/exit criteria • Government insight for contractor reviews and interim design reviews	• Four or five major reviews are performed (SRR, PDR, CDR, TRR, pre-ship review) • Monthly progress technical/management meetings • Topical reviews held as required • IRR usually conducted; MRR and FRR are required.	• Developer's discretion • Pre-ship review required by LV integrator where mass, safety, compatibility, cleanliness verified

C.2 System Engineering Processes and Disciplines

System engineering incorporates and integrates space vehicle development processes and technical disciplines to ensure that the customer's needs are satisfied throughout a system's entire life cycle. System engineering initially focuses on analyzing and capturing customer's needs and required functionality early in the development cycle, documenting the requirements, synthesizing a design, developing/building products, and validating the system considering the system lifecycle.

Technical Practice	Class A	Class B	Class C	Class D
Systems Engineering Process	• System engineering (SE) processes/applicable deliverables required throughout the system lifecycle • Defined to include requirements definition, allocation, and verification; design; manufacturing; assembly; integration; test; launch; orbital checkout; and validation to ensure total system performance • Defined to include requirements for all supporting disciplines and applicable deliverables • Includes design attributes, final design, technology readiness, final design and integration planning • Scope encompasses the space vehicle and functional subsystems and appropriate interfaces	• Disciplined application SE processes with emphasis on risk assessment and cost trades over system lifecycle; possible less formal oversight • Defined to include all SE processes and supporting disciplines; tailoring as applicable in consideration of acceptance of specific design features (i.e., heritage hardware); flight history and level of verification may be tailored as appropriate • Scope encompasses the space vehicle and functional subsystems and appropriate interfaces	• SE principles applied to program but formality and deliverables are minimized; government evaluates contractor processes • Typically dependent on contractor processes with government insight; includes developing and maintaining an integrated management schedule, requirements verification matrix, system test plan, documented test plans and processes, software development plans, interface control documents, and ground operations plan • Exceptions where hardware has heritage flight history and level of verification may be tailored as appropriate	• Not required • Developer's discretion • Engineering, design, and test practices applied as best practices and lessons learned from previous missions • Experiments often are educational developments and processes may be followed as part of the teaching curriculum • Hardware (i.e., space vehicle bus components) may be purchased off-the-shelf
Requirements	• Rigorous requirements flow-down from system specification to unit level • Independent assessment conducted to assure completeness and system requirements traceability	• Similar to Class A, exception is limited independent assessment to spot check potential problem areas (mix of independent analysis and review of contractor analysis)	• Requirements derived from the Experiment Requirements Document (ERD), then vetted with space vehicle requirements and documented in the Mission Requirements Document (MRD) • Space vehicle ERD and MRD are contractual documents	• System/mission design guided by set of objectives that define but not limited to those objectives. • Minimally acceptable performance thresholds for mission performance defined

Technical Practice	Class A	Class B	Class C	Class D
Requirements Verification	• Comprehensive verification process with cross-reference matrix is deliverable to assure each requirement is properly verified at lowest level of integration • Govt oversight to include independent assessment of verification methods and results	Same as Class A.	• Requirements verification matrix provided by contractor is "bought-off" via test, analysis, demonstration or inspection • Performance verification required at system level	• Requirements allocation and verification at discretion of developer
Design Assurance	• Design reviews/deliverables include assessment of design process execution, change process, design changes, technology readiness level, and adequacy of technology demonstrations • Formal entrance/exit criteria defined by government for all design reviews • Independent assessment of system design effectiveness relative to key performance parameters and technical performance measures conducted	• Same as Class A in terms of scope • Standard design reviews required with formal entrance/exit criteria defined by government; criteria are typically tailored to focus on fewer items in high level matrices • Limited use of redundancy although single string approaches acceptable with applicable risk mitigation • Interim design reviews focus on new designs with independent assessment of effect of design info in system spec	• Dependent on contractor process with govt insight • Design reviews held to ensure the SV design, integration, test and operations plans are capable of meeting mission and technical requirements with required system level reliability and with budget/schedule constraints • Inputs often absorbed into the design because of technical merit and not contract direction	• No formal requirements • Design reviews may be held as part of the teaching of system engineering
Space Vehicle System Safety	• Formal systems safety program with plan required as deliverable • Includes direction for formal mishaps safety investigation boards in case of mission loss or major mission impact	• System safety program required • Assessed early on; contractor team has responsibility to work and resolve issues, and raise issues to independent government safety team	• System safety program required • Assessed early on and left to contractor identify/resolve issues	• Developer needs to prove space vehicle is safe to integrating/launch vehicle contractor(s)

Technical Practice	Class A	Class B	Class C	Class D
Reliability Analysis	• Reliability plan and analysis required • Failure mode and effect analysis (FMEA), critical items lists, worst-case performance, and parts electrical stress analysis for all parts and circuits required • No single-point failures allowed; Exceptions require justification based on risk analysis/mitigation measures. • Redundancy required for all essential SV functions and key instruments.	• Reliability plan and analysis required • FMEA and critical items lists at black box level as a minimum; Worst-case performance and parts electrical stress analysis for all parts and circuits. • Single-point failures accepted by exception, evaluated on case-by-case basis • Increased consideration of redundancy for all essential space vehicle functions and key instruments	• Reliability analysis required • FMEA scope and critical items lists determined by program • Analysis required at interfaces • Parts electrical stress analysis sometimes performed for parts and circuits. • Single-point failures permitted; Single string or selectively redundant design approaches may be used	• Reliability analysis requirements based on applicable safety requirements • Developer must prove to integrating contractor it meets Interface Control Document • Single-point failures permitted based on experiment requirements; Single string or selective redundant design approaches used
Parts, Materials and Processes	• High reliability, Class S, Grade 1 parts required. • Parts, Materials and Processes Control Board (PMPCB) with government approval integrated throughout the sub/supplier chain • Verification of heritage of previously used materials required • All new or changed materials and configurations must be qualified. • Source controls required on all procured materials and acceptance test each lot/batch	• High reliability, Class S, Grade 1 parts required • PMPCB with government approval at prime-level; Government may opt for insight at sub and supplier chain. • Program may use previously tested/flown materials or qualify new materials and configurations. • Acceptance test each lot of procured material • Quality and parts requirements should be flowed to sub-contractors, not always required	• Class B and/or commercial parts are used; Parts are rarely class S because of the short acquisition time and expense. • Adherence to a parts plan is maintained	• Class C parts, commercial parts usually used • Requirements based on safety and contamination standards
Quality Assurance	• Formal program with stringent surveillance-documented problem reporting, corrective action and performance trending • Formal failure reporting boards required; anomalies/failures worked to root cause	• Formal program should be required with moderate surveillance to include problem reporting, corrective action and performance trending • Formal failure reporting boards required; anomalies/failures worked to root cause	• Formal contractor program/process required with reporting of problems and corrective action • Govt attendance at critical test supplements contractor QA	• Informal program-problem and corrective actions should be tracked

Technical Practice	Class A	Class B	Class C	Class D
Mass Properties	• Management of mass considered at all levels of the design; Mass and mass growth, mass margins, and projection of launch mass is analyzed/modeled throughout development and integration • Mass model and mass growth analyses required	• Same as Class A	• Mass, mass margins, and projection of launch mass is actively monitored throughout development • Mass model may be required in case SV is delayed	• Developer tracks since must meet not-to-exceed mass requirement • Mass model may be required by LV provider
Electromagnetic Interference/ Electromagnetic compatibility	• EMI/EMC emissions and susceptibility considered at all levels of the design; power systems, antennas and radiated interfaces, and cables • Full consideration of passive intermediation and environmental impacts as well as power isolation	• Same as Class A	• Radiated and conductive emissions and susceptibilities are monitored by engineering support and usually tested to protoqual levels to ensure functionality	• Some electromagnetic self compatibility is usually performed • SV is required to be off during launch to ensure no emissions
Contamination Control	• Formal contamination control program throughout the sub/supplier chain required	• Formal contamination control program throughout the sub/supplier chain required • Contamination control levels/requirements dictated by the experiment having the highest contamination sensitivity or by ride share on the same launch vehicle	• Contamination control levels/requirements dictated by the experiment having the highest contamination sensitivity or by ride share on the same LV • Analysis/testing required demonstrating requirement satisfaction	• Must meet launch vehicle ICD contamination control requirements • Analysis or testing may be required to demonstrate requirement satisfaction
Electrical Design (Cable & Harness)	• Full design specification with prime oversight of sub/supplier processes and products conducted • Complete acceptance testing required prior to integration	• Same as Class A.	• Detailed ICDs dictate requirements by LV provider • Sizing, derating and individual hipot testing requirements applicable	• ICD to LV compliance required
Mechanical Design	• Full design specification with prime oversight of sub/supplier processes and products. • Complete acceptance testing required prior to integration.	• Same as Class A.	• Detailed ICDs dictate requirements by LV provider	• ICD to LV compliance required

Technical Practice	Class A	Class B	Class C	Class D
Software	• SW development plan (SDP), SW Test Plan (STP), contract deliverables and formal software reviews throughout design/integration required • Government approval of SW design and architecture • Implementation of defined methods for review and test to include TLYF; government may participate in inspection • Defined configuration management with government approval at configuration control boards	• SDP and STP required, some additional contract deliverables required and other data made available through Data Acquisition List (DAL) • Government insight at design reviews • Contractor processes applied with government review; formal problem resolution and risk management applied • Defined configuration management process required with government insight/participation at the configuration control boards	• SDP and STP usually required • Contractor manages design; Spot checks of SW design by government may occur • Contractor processes applied for development with government review • CM dependent on contractor processes	• Developer's discretion • Informal planning and design activities managed by developer • No CM requirements
Survivability	• Required mitigation of natural and man-made threats integrated into design/testing process	• Same as Class A, except may use high fidelity simulators/emulators for end-to-end testing	• Short mission duration drives selective parts testing for potentially susceptible devices; Testing required to proto-qualification margins	• Testing at developer's discretion
Supportability	• Required application of logistics support processes and products • TLYF methodologies for system-level and end-to-end testing required	• Same as Class A	• Testing with ground control performed during development; Testing to include commands sent from an operations-like system to provide confidence of execution • TLYF methodologies applied	• Usually operates own ground station • Testing at discretion of developer
Information Assurance	• System security and information assurance as mandated by all applicable government regulations. • Formal specification of IA requirements on DD254 (or equivalent) and certification. • Formal protection plan required as a deliverable	• Same as Class A	• Same as Class A	• Usually no requirements
Frequency Management	• Govt ensures coordination/approval for frequency usage with international agency	• Same as Class A	• Same as Class A • 1 yr missions given special compensation for R&D missions	• Approval for frequency usage is obtained by govt from international agency • Often uses CB frequencies

Technical Practice	Class A	Class B	Class C	Class D
Human Factors Engineering	• Integrated into design/testing of all ground support elements to ensure effective operability/maintainability characteristics and human error mitigation	• Same as A	• Performed as part of overall ground system development	• Not required
Environmental, Safety and Health	• Full National Environmental Protection Act (NEPA) and Programmatic Environmental Safety and Health Evaluation compliance required • Must comply with all OSHA and state regulated HAZMAT laws	• Same as Class A	• Compliance required as applicable to the program	• Compliance required as applicable to the experiment

C.3 Space Vehicle Integration and Test

The space vehicle integration process turns a large set of discrete parts and units into a fully functional space vehicle. The verification processes, to include test, alternates between several kinds of functional and performance testing with a variety of environmental tests at each level of integration. Each level of integration needs to address the testing of appropriate interfaces in addition to the total functionality and performance of the integrated item.

Technical Practice Area	Class A	Class B	Class C	Class D
External Interfaces	• Interface control process is managed by the program office; all external interfaces identified and documented to include ground test and mission ops functions • Detailed Interface Control Documents (ICDs) requirements • Validated ground segment used • Full Test-Like-You-Fly approach applied to ensure space-ground and mission compatibility • Independent review of contractor analysis for interface requirements verification and changes is conducted	• Same as Class A, but may use high-fidelity simulators/emulators for end-to-end testing	• Detailed ICD is developed with Launch Vehicle (LV) and ground control center • Several reviews address the ICD requirements between the ground system and the space vehicle • Testing includes Launch Base Compatibility Test	• Depends on ground system used • Needs to work with ground system which is usually home grown; testing deferred to satellite manufacturer
Space Vehicle to Payload Interfaces	• All interfaces defined and described by applicable ICDs • As a minimum all mechanical interfaces associated with telemetry, tracking and control; all internal electrical interfaces within the subsystems; all electrical interfaces with space vehicle and other ground test and mission ops functions defined	• Same as Class A	• Government and space vehicle contractor confirms experiment meets requirements in the Space Vehicle-to-Experiment ICD • Payloads usually developed in parallel with the space vehicle bus; ICDs may not be finalized until all payloads are mature • Possible government presence at prime contractor for integration efforts • Functional testing of payload is usually performed at payload's developer with a simulated space vehicle bus interface • Payloads first tested with non-flight	• Must comply with safety and other launch vehicle requirements and ICDs (i.e., contamination, launch environment) • Mechanical mating performed by developer and tested to their protocol

Technical Practice Area	Class A	Class B	Class C	Class D
			umbilical while external to space craft (electrical bench test)	
Space Vehicle Integration and Test	• Complete system to subsystem to unit requirement verification plan is developed and delivered; qualification method selected is documented with government approval • Qualification/Proto-qualification levels required • Government approval of system level test plans, procedures and results verify requirements at that level • Design life of requirements/verification summarized as result of worst-case analysis and tests	• Government review of contractor generated verification plan from system to subsystem to unit level • Qualification/Proto-qualification levels required; simulators may be used • Design life of requirements/verification summarized as result of worst-case analysis and tests	• System test plan required with government review/oversight • System functional test to proto-qualification levels required to include acoustic, random vibration, shock, thermal vacuum, deployment, EMI/EMC • Government usually present at system tests • Additional testing may include: solar array flash test, week-in-the-life, day-in-the-life, plugs-out, performance tests, factory compatibility, launch base compatibility and optical alignment	• Safety and compatibility testing required by the launch vehicle provider and/or launch base • Other testing at discretion of developer with an informal test program usually followed
Space Subsystem Integration and Test	• Subsystems functionally tested to environments plus margin at qualification /proto-qualification levels • Government approval at design reviews • Government involved when design changes or anomalies occur • Subcontractor/prime integration and test of units into subsystems	• Same as Class A, except with government insight/involvement at design reviews (review rather than approval authority)	• Subsystems functionally stress tested to margins exceeding what will be experienced during system testing • Limited government oversight and participation in design reviews • Subcontractor/prime performs integration and test of units into subsystems	• Discretion of developer
Space Unit Test	• Units functionally tested to environments plus margin at qualification/proto-qualification levels • Government approval at design reviews • Government approval when design changes or anomalies • Subcontractor/prime integration and test of units into subsystems	• Similar to Class A, except number of cycles, margins, and duration of test may be tailored based on program risk assessment and acceptance	• Component/box testing conducted to meet mission requirements, usually at proto-qualification levels • Limited government oversight • Government involved when design changes or anomalies occur	• Discretion of developer

C.4 Space Vehicle System Subsystems and Design

Space vehicle systems are comprised of subsystems, subordinate components, and software. The subsystems are the focus of extensive design and development in the process of configuring a system. Contractor teams are responsible for conducting necessary tradeoffs and design optimization to define a system that meets the government's requirements.

Technical Practice	Class A	Class B	Class C	Class D
Structures & Mechanisms	• Verification analysis/test must demonstrate structural integrity in a specified environment while exposed to a specified load (achieved through a series of tests tied with appropriate analysis to incrementally demonstrate integrity via determination of dynamic properties, loads, stresses, and structural margins of safety) • Must demonstrate/qualification flight structure to demonstrate positive margin of safety under all expected loading conditions and environments	• Similar to Class A, except proto-qualification margins are acceptable • Exceptions may be where structures have heritage flight history and level of testing may be tailored as appropriate	• Analysis/test with proto-qualification margins at the system level demonstrate survivability/integrity for launch and space environments. • Component qualification may not be required; engineering development unit may be used to do early testing at qualification levels. • Risks, both dynamic and static, elevated to government review	• Safety and compatibility requirements imposed by launch vehicle provider, ride sharers, and interface control documents

Technical Practice	Class A	Class B	Class C	Class D
Electrical Power and Distribution	• Verification analysis/test must demonstrate design meets allocated requirements over life of the space vehicle. • Demonstrate and perform analysis: solar array and battery sizing analyses given baseline load and charging profile; dead bus recovery capability; fusing scheme sizing appropriate and protects against failure propagation; battery cell bypassing, cell charge and battery reconditions; solar array design; power subsystem worse-case analysis; verification and test implementation; and identify any technology maturity issues • Testing must include stability and transient response in all op modes over the range of loading conditions	• Similar to Class A • Exceptions may be where power subsystem has heritage flight history and level of testing may be tailored as appropriate • Testing may be limited to key operational modes and loading conditions relating to overall mission success	• Comprehensive performance test performed by contractor • Design margin required to meet mission life (usually one year) under worse-case conditions • Typically 200 Watts orbit-average-power and no redundancy in its distribution (mission dependent) • Contractor required to document electrical and mechanical integrity of solar panels • Tested for transients • Assess test plan to ensure no hot mates (or de-mates) of batteries or external power during integration and test-functionally tested as a subsystem with government insight at reviews	• Simple subsystem with commercial batteries tested for space usage • Required safety and compatibility requirements imposed by launch vehicle provider, ride sharers or interface control documents

Technical Practice	Class A	Class B	Class C	Class D
Thermal Control	• Verification analysis/test must demonstrate design meets allocated requirements; overall design meets requirements under all mission conditions • Thermal balance modeling and testing required at all levels of design • Demonstrate and/or assess with thermal modeling: adequacy of thermal margins and acceptance limits; adequate control authority on all heaters in worse-case operation; blanket effectiveness; thermal protection of batteries; heater design; propellant lines; part temperature predictions within derated limits; bonding, interface and material assumptions; design of radiators, heat pipes, heat zones, thermal doublers; power dissipations; and weight allocations • Independent thermal assessments conducted	• Similar to Class A • Exceptions may be where thermal subsystem has heritage flight history and level of testing may be tailored as appropriate • Spot checks may be substituted for independent thermal analysis	• Designed to meet requirements under worse-case conditions plus proto-qualification margins; assumptions and analysis must demonstrate operation and recovery from safe mode ops with margin • Thermal balance test verifies the thermal model • Government does no independent thermal analysis of the space vehicle • Government may do analyses of areas of concern (e.g., solar arrays, heaters)	• Discretion of satellite manufacturer • Usually a simple thermal model is used

Technical Practice	Class A	Class B	Class C	Class D
Attitude Control	• Verification analysis/test must demonstrate design meets allocated requirements; overall design meets requirements under all mission conditions • Conduct hardware assurance reviews to assess inertial measurement units, guidance and control units, inertial navigation units, rate gyros, star trackers, gimbal controllers, space vehicle actuators, and sensor pointing platforms • Test cases must include mixed simulation testing of the HW/SW interfaces, polarity verification adequacy to sensor actuators and analytical transformations of components; polarity of all electrical connections (valve drivers, squib drivers, latch valve drivers) • Perform independent verification of final attitude control system performance parameters, sensor alignment and calibration, precision platform pointing, and inertial sensor error parameters	• Similar to Class A • Exceptions may be where attitude control subsystem has heritage flight history and level of testing may be tailored as appropriate • Spot checks may be substituted for independent attitude control system verification	• Comprehensive performance test performed by contractor • No detailed independent attitude control subsystem analysis required • Government reviews that subsystem meets requirements for pointing and pointing knowledge. • Typical required control to 0.1 degrees with 0.03 degree knowledge; dependent on experiments' requirements (mission dependent) • Control and attitude, and fault management software assessed by govt. • Safe modes for space vehicle fully analyzed/tested by contractor	• Discretion of satellite manufacturer • Typical gravity gradient or tumbling attitude control system

Technical Practice	Class A	Class B	Class C	Class D
Propulsion	• Verification analysis/test must demonstrate design meets allocated requirements under all mission conditions to include assessment of disposal requirements • Verify tank design (sizing, structural, thermal); propellant management system for all phases and modes; thruster sizing, lifetime throughput and duty cycle, maximum on-time and thermal conditions; and plumbing components to include regulators, valves, propellant lines are appropriate for design; plume impingement and contamination issues; worst-case analysis, component stress levels, failure modes and effects analysis, and reliability analysis; design life; and budget analysis for required mission	• Same as Class A • Exceptions may be where propulsion subsystem has heritage flight history and level of testing may be tailored as appropriate	• Not often present • Same as class B when applicable	• Rarely present • Needs to meet safety requirements
Telemetry Tracking & Control	• Verification analysis/test must demonstrate design meets allocated requirements under all mission conditions • Validated telemetry, tracking and control (TT&C) system with full redundancy; validate compatibility to external command and telemetry units • All interfaces identified and Interface Control Documents developed and delivered	• Same as Class A, with consideration of physical or functional redundancy for critical components	• Comprehensive performance test performed by contractor • Typically commercial subsystem purchased from vendor that may have some internal and antennae redundancy • TT&C should be powered by non-switched power; receiver always on. • Subsystem tested in day-in-the life, factory compatibility and launch base compatibility tests to ensure endurance and functionality; focus on initial commanding, commanding for a fault, and ground ops	• Typically a commercial TT&C or citizen band unit

Technical Practice	Class A	Class B	Class C	Class D
Command and Data Handling	• Verification analysis/test must demonstrate design meets allocated requirements under all mission conditions; includes flight hardware operation with software • Security and key management plans are deliverables; encryption requirements and accommodations verified • Validated subsystem with full redundancy; Demonstrate critical areas addressed to include processor throughput, data burst throughput, command latency, memory margin, board space, connector pins, data and/or control channels; interfaces all identified and tested • Command and telemetry lists generated and safe mode diagnostics telemetry storage requirements identified • Fault modes and detection planning defined and documented; Fault isolation addressed • Simulator test facility available to support launch and operations; independent simulation models built to support anomalies or launch training; • Independent audits as needed	• Similar to Class A • Verification analysis/test must demonstrate design meets allocated requirements under likely nominal and contingency mission conditions	• Comprehensive performance test performed by contractor • Usually off-the-shelf command and data handling system providing considerable margin for processor loading, data throughput, memory with some internal redundancy • Subsystem tested in day-in-the life, factory compatibility and launch base compatibility tests to ensure endurance and functionality	• Discretion of satellite manufacturer • Usually a commercial unit tested for space use

Technical Practice	Class A	Class B	Class C	Class D
Structural and Dynamic Loads Analysis	• Verification analysis/test must demonstrate design meets allocated requirements; overall design meets requirements under all mission conditions • Contractor load analysis plan delivered with defined roles and responsibilities in load cycle process; 3 load cycles required • Space vehicle design load cycle finite element model required as a delivered item • Space vehicle and launch vehicle dynamic models integrated to characterize coupled system • Independent loads analysis executed to include: analysis methods, models, forcing functions, response calculations, load transformation matrices, and all critical events (liftoff and liftoff abort, atmospheric flight, max dynamic pressure, times of flight, engine shutdown and ignitions, and separation/staging events)	• Similar to Class A • Exceptions may be where structures have heritage flight history and level of testing may be tailored as appropriate	• Verification analysis/test must demonstrate design meets allocated requirements; overall design meets requirements under all mission conditions • 3 load cycles required • Space vehicle design load cycle finite element model required as a delivered item • Space vehicle and launch vehicle dynamic models integrated to characterize coupled system • High level review of the results and oversight is performed by the govt.	• For safety only • Discretion of satellite manufacturer
Fault Management Subsystem	• Verification analysis/test must demonstrate design meets allocated requirements under all mission conditions • Full redundancy required	• Verification analysis/test must demonstrate design meets allocated requirements under all mission conditions • Where redundancy exists, all redundant modes of operations must be demonstrated	• Comprehensive performance test performed by contractor • Usually limited or no redundancy • If possible, all fault management paths are exercised by contractor.	• Discretion of satellite manufacturer • Usually no redundancy

Technical Practice	Class A	Class B	Class C	Class D
Ordnance Pyrotechnics	• Verification analysis/test must demonstrate design meets allocated requirements under all mission conditions • Qualification required; acceptance testing consisting of nondestructive and destructive tests on each production lot along with acceptable mfg records • Special attention to Electro-explosive Devices (EED); Worse-Case analysis; design of cleanout plug and seal; acceptance measurement tolerance	• Same as Class A	• Must meet safety requirements from LV/integrator/range. • Testing with flight-identical electro explosive devices units performed to ensure functionality under test-like-you-fly	• Must meet safety requirements from launch vehicle/integrator/ range
Payloads	• Verification analysis/test must demonstrate design meets allocated requirements; overall design meets requirements under all mission conditions • All payload design attributes assessed to include signal and data processing, and communications and antenna design • Government-furnished equipment payloads fully scrutinized during development and tested to ensure compliance with design criteria of the primary payload	• Similar to Class A • Exceptions may be less formal deliverables; may request data acquisition list access	• Pre-ship review and a compliance data package is usually required from the payloads to verify adherence to interface control documents	• Discretion of payload manufacturer

C.5 Space Vehicle Operations

Space vehicle capabilities and performance characteristics on-orbit are captured and analyzed to ensure the SV is operating as designed. SV capabilities and performance are ascertained and results formally captured for application to future designs. Compliance to applicable range safety requirements and respective launch vehicle providers is mandatory for all space vehicles.

	Class A	Class B	Class C	Class D
Space Operations	• Validated and documented operational process/procedures, including error and anomaly events, launch support, early-orbit checkout, and end-of-life/disposal ops required • Full application of logistics support processes and products required • Comprehensive anomaly resolution processes including on-site/factory support in all technical areas • Ability to sustain full operational capabilities at a rate that meets or exceeds the operational availability requirements • Provides mission products that meet or exceed product quality and timeliness requirements	• Similar to Class A • Mission not fully “operational:” manpower typically not available to accommodate 24/7 contingency operations with multiple shifts	• Usually 3 rehearsals plus dress rehearsal • Processes and operations are documented • Uses an operational center that services other space vehicles • Command and telemetry data bases are exercised and debugged • Factory compatibility and launch compatibility tests performed	• Up to developer’s discretion • May use citizen band
Range Safety	• Full compliance with range safety requirements, per launch range and vehicle being used. • Formal validation processes required	• Same as Class A	• Compliance required as applicable to the program and required per the launch vehicle and Range provider	• Compliance required as applicable to the program and required per the launch vehicle and Range provider
End of life/disposal	• No hardware is ejected into space unless absolutely essential • Low earth orbit have less than 25 years before re-entry, unless a waiver is granted	• Same as Class A	• Same as Class A	• Same as Class A

C.6 Launch Vehicle and Ground System Interfaces

Managing external interfaces is accomplished through the use of interface control working groups (ICWGs). The prime contractor or system integrator typically organizes the ICWGs. The government may chair these working groups, or co-chair with the contractor. Government leadership is required to resolve conflicts that may arise between associate contractors, as well as negotiate interactions with other government agencies. Interface control documents or drawings (ICDs) are products of the ICWGs or comparable integrated teams. The purpose is to establish and maintain compatibility between interfacing systems or components. All space vehicles must comply with applicable ICDs.

	Class A	Class B	Class C	Class D
Launch Vehicle Integration	• Identify and/or create applicable ICDs • Identify specific LV design constraints on the SV, such as the center of gravity • Provide early documentation of the interface requirements that dictate the launch processing that may include: dynamic loads, venting, contamination, thermal, electrostatic discharge, grounding and humidity • Document launch-processing issues addressed in SV configuration – integration of all elements of the launch stack (i.e., booster lower and upper stages, various elements of the SV- and testing of all equipment in the launch stack to extent possible • Integrated test and evaluation required to verify the structural integrity of the SV against the expected launch and ascent loads • Tests /analysis required include coupled loads analysis, independent loads analyses, mode survey testing, and structural qualification test	• Same as Class A	• Same as A for space vehicle • For payloads, identify LV ICDs that dictate structural, contamination, thermal, electrostatic discharge, grounding, humidity and other applicable requirements that would be above and beyond the payload mission requirements	• Identify LV ICDs that dictate structural, contamination, thermal, electrostatic discharge, grounding, humidity and other applicable requirements that would be above and beyond the payload mission requirements

	Class A	Class B	Class C	Class D
Ground Transportation	• Identify and/or create applicable ICDs • Early planning/coordination of ground or air transportation to launch facility required • Identify security requirements for space vehicle transport	• Same as Class A	• Same as A for space vehicle • For payloads, identify ICDs that require special considerations for ground or air transportation and be prepared to provide evidence of compliance prior to integration and at pre-ship review • Identify security requirements for transport	• Identify ICDs that require special considerations for ground or air transportation and be prepared to provide evidence of compliance prior to integration and at pre-ship review • Identify security requirements for transport
Ground Testing	• Identify and/or create applicable ICDs • Create required plans that document coordination/scheduling of special facilities at contractors and/or National testing resources like ranges and observatories booked more than a year in advance) • Assess need for special equipment needed to handle space vehicle subsystems or fully integrated system – design and build equipment	• Same as Class A	• Same as Class A for space vehicle • Identify applicable ICDs • For payloads, identify and/or create plans for special facilities and testing • Assess need for special equipment needed to integrate payload – design and build equipment	• Identify applicable ICDs • Identify or create plans for special equipment needs to test and/or handle payload
Ground System	• Identify and/or create applicable ICDs • Test-Like-You-Fly (TLYF) requires pre-flight configuration of actual ground system controlling the final SV (end-to end) through a set of mission –critical ops, according to a flight-like timeline. Mission HW, SE, processes, data production processes, and personnel should be exercised. Exceptions must be noted.	• Same as Class A	• Identify applicable ICDs • Provide evidence of ICD compliance prior to preship reviewe • Identify and create documentation detailing ground system interface • Create plan that details TLYF tests and exceptions to extent possible commensurate with mission risk	• Identify applicable ICDs • Identify and create documentation detailing ground system interface

Appendix D. Gaining Access to Space Pitfalls for Class C and D Space Vehicles

Victor Matricardi

Challenges for Class C and D Space Vehicles in Gaining Access to Space

D.1 Background on the Development of a Class C and D Space Vehicle (SV)

Space experiments are usually funded at very marginal levels. The experiment, to function in space, usually requires power, data storage, communication with the ground, etc. These necessities are provided by integrating the experiment, in possible combination with other experiments, onto a bus resulting in a space vehicle (SV). The amount of development, analysis, and testing performed on the SV is influenced by the accepted risk of failure and the amount of funding that is available.

The tradeoff between cost and risk is specific to the mission and difficult to efficiently communicate. To overcome this communication obstacle, the satellite community invented a classification for risk acceptance. SVs having the highest national importance and hence the lowest risk tolerance are Class A. Those SVs where high risk can be accepted are Class D, and are usually provided by universities and small laboratories. There are, however, SVs for which failure is not easily accepted but are developmental and/or do not have the funding required by Class A SVs. These are Class B and Class C (listed in increasing risk acceptance).

For Class D

A Class D SV is usually a low budget space vehicle with one or more experimental payloads. The sponsors are accepting of high risk since the experience gained in developing the payload and/or the space vehicle and learning how to control it are usually some of the principal goals. The subsystems and system have usually undergone a minimal set of qualifying tests. However, to gain access to space (a normally high cost enterprise) they must be willing to be secondary payloads on a launch vehicle and/or be payloads on a maiden flight of a new launch vehicle.

To be allowed on the launch manifest, the Class D satellite must satisfy certain requirements that are dictated by the launch base, the launch vehicle, or the accompanying primary payloads. These requirements are not only mechanical and electrical compatibility with interfaces but also safety and environmental compatibility.

To satisfy safety requirements, the satellite provider must be able to prove components will withstand storage, launch processing, and launch without causing danger to surrounding personnel, space vehicles, and other hardware. To satisfy environmental compatibility, the satellite provider must meet electromagnetic, contamination, and thermal requirements of its neighboring elements. These environmental requirements often force an item by item description of the components and processes used in assembling the satellite; a considerable undertaking beyond the means of a "garage type" assembly, especially if started after the assembly has been completed.

For Class C

A Class C satellite is a cost-constrained and medium risk enterprise. Sometimes the contractor for a Class C SV is still learning the processes used in developing an SV or is a division of a major contractor attempting the “low-cost” approach. For the government agency sponsoring a Class C venture, engineering and managerial judgment in trading cost vs. risk is paramount. Different organizations achieve these trade-offs in different ways. Thus there are no strict cookbook approaches. The extent to which specifications are tailored depends on mission characteristics and the amount of acceptable risk.

The number of CDRLs to be delivered by the contractor is minimized to be approximately a few dozen, and the number of people in the government and Aerospace program office is minimized to be approximately a half dozen. The contract is scrutinized by both the contractor and the government/Aerospace team to eliminate activity that adds little value.

Because independent validation and verification of design elements is reduced for Class C vehicles, testing becomes paramount, thus testing is a critical area where requirements from MIL-STD-1540 (currently SMC-S-016 [2008]) are minimally tailored. In addition, because Class C and D programs are often single string with little to no redundancy, a rigorous test program is critical to decreasing the program risk. Proof of the system’s ability to work in space is obtained through functional and environmental system level testing.

In the case of the AF Space Test Program, various aspects of “Test Like You Fly” (TLYF) are incorporated on a mission-by-mission basis (see Aerospace Corporation TOR-2010(1531)-1, e.g., Day-in-the-Life test, Week-in-the-Life test, Plugs-out test). Prior to the Air Force Mission Readiness Review, and sometimes also much earlier in the program for a preliminary perspective, the respective engineer (independent of the program manager) leads a Mission Risk Assessment where Aerospace SMEs evaluate the risk of the mission in their respective areas of expertise.

Potential Challenges for Class C and D SVs

In the course of finding a ride to space consistent with their low budgets, the sponsors of Class C and D space vehicles have to be very agile and enterprising. Sometimes decisions on the choice of a launch vehicle are made based on expediency and costs and lead to changes in launch vehicle interface requirements. However pitfalls may arise in meeting these new launch requirements.

This section will address representative examples of these potential pitfalls.

- Launch Vehicle (LV) requirements

  Usually the LV requirements are known well in advance and the SV developer has performed development and testing to address them. Sometimes, the developer of a class D SV has worked in isolation and starts focusing on the LV requirements late in the development cycle. Some pitfalls are discovered when the LV requirements are examined. Examples of requirements the developer may not have identified are list of parts, outgassing rates of components, rate of depressurization within the SV during ascent, number of inhibits before RF emission is enabled, and battery power for the length of time the SV is in the fairing prior to launch (this may be several months and is unpredictable).

  Sometimes, Class C and D SVs accept rides on newly developed LVs having appreciably higher launch risks. In addition they may not have mature environments specifications. Examples of LV changes that might affect SV environments are explosive bolts releasing the fairing, location of a LV transmitter, and unpredicted vibration modes. These changes may cause the SV to perform additional testing and development to reduce the risk of damage. The addition of shock absorbing structure between the LV and the SV may be required in extreme cases.

The LV provider will likely require a mass model of the SV should the secondary SV not be available when the rest of the manifest is ready to launch.

Once the fairing is released, surface temperatures of the SV may require may require the paint on an SV (or even a mass model) to be changed. This can lead to considerable expense when the low budget of a class C or D SV is used as a baseline.

- Changes in the SV

  If the SV is modified, even slightly, there may be additional testing or modifications. For example, if one of its antennae or booms is modified or changed due to a supply issue, the LV may require an analysis or a test to ensure the structural integrity of the modified unit so that any exposed LV components will not be at risk of damage from the unit. In the case of a Class D SV, the developer may not be able to perform the required analysis or have access to test facilities capable of proving their component's safety.

- Ridesharing and being a secondary SV

  A Class C or D SV will likely share a ride to space on an LV with one or more SVs of equal or higher priority in order to minimize costs. The higher-priority SVs usually share a comparatively larger portion of the launch costs placing the lower-priority SV in a "secondary" position. The requirements of the higher-priority (i.e., primary) SVs tend to be more restrictive which, in turn, will be dictated to the secondary SV. An example may be the cleanliness requirements of an optical instrument riding on a primary SV. This cleanliness requirement is imposed on the environment of the LV fairing. This, in turn, is imposed on the secondary SV, even though this requirement may not have been envisioned during its developmental phase. The secondary SV may have to undergo cleanliness, outgassing, and parts rescrub to meet this additional requirement.

  Another example may be a requirement on the electromagnetic compatibility of the secondary SV prior to separation from the LV. If possible, the secondary SV is placed into a dormant mode until separation. This change may require additional changes to the secondary SV startup modes.

- Change in the launch base

  Although the two military installations (Eastern and Western Range) have a common standard, NASA Wallops, European Space Agency (ESA) and other launch facilities have independent standards. The launch vehicle provider will accept these standards and pass them down to the SVs in its manifest. For example, if the required number of inhibits before a radio transmitter is allowed to turn on changes from one launch base to another, it might require a reengineering of SV power circuits or installation of expensive LV interrupts.

- Late on the manifest

  Because the Class C or D satellite sponsor is eager to get access to space in any way possible, the SV will often be the last to be manifested on a large LV. As a result, its launch interface requirements will be changed while it is in development or even after it is built. Meeting the requirements of new launch interfaces, environments, and safety is often an expensive and time-consuming task (as described earlier). Until the manifest and all the Interface Control Documents are final, the secondary SV is susceptible to changes in its requirements.

Ability to meet the schedule of the primary payloads is often a critical requirement. Should the secondary SV not be able to be ready when the rest of the launch manifest is, it will be responsible for having a mass model ready for the final testing phase.

D.2 Summary

Access to space for a Class C or D satellite can sometimes provide the unsuspecting program office with unforeseen challenges. This appendix provides a list of some of the challenges experienced that can affect both schedule and cost at various stages, often toward the end of the SV development.

Appendix E. DOD Space Test Program Acquisition Strategy and Practices Used for Class C Space Vehicles

Victor Matricardi

E.1 Mission Design

At the DOD Space Test Program (STP), a mission is usually conceived around one or two important technology or scientific payloads or experiments needing space flight. The source of these experiments is a prioritized list provided by the Space Experiments Review Board (SERB), a tri-service annual review of experiments that do not have the funding for space access.

A Government Program Office (GPO), comprised of government personnel and one or two Aerospace Program Office personnel, is organized to lead feasibility studies. The range of orbit parameters and estimated launch time is identified for the mission and the space community is canvassed looking for additional sponsors having payloads wanting a similar orbit at the same time. A preliminary list of requirements and capabilities is identified in the Mission Needs Statement. The available budget is identified and the rough mass of the space vehicle (SV) is estimated which is a primary driver for SV and LV costs. A "government" design and associated cost estimate for the mission (including launch and operations cost, if needed) is developed. The serious negotiations of the mission requirements begin when the available budget is compared to the estimated cost. The experiment and space vehicle requirements are scrubbed to identify any possible tradeoff space that can reduce a cost forcing function. As examples, are the 20 ground-contacts per day really required and does the attitude control need to be that stable? Various alternate SV concepts are identified with associated rough costs. Insufficient funding is the most frequent cause for mission cancellation.

Once the expensive requirements are minimized, the budget available determines the amount of redundancy and the amount of mission assurance that can be incorporated. The result is the risk tolerance for the mission; hence the class designation. Management approval is sought for the mission and its accompanying risk.

E.2 Contract Development

The GPO develops the initial conceptual design with the aid of a few critical engineering specialists. The detailed mission requirements are developed which include parameters such as:

- Vehicle mass
- Attitude control
- Power
- Computer and memory requirements
- Timing accuracy
- Radio frequency needs
- Ground stations and number of contacts per day
- Length of operations support (usually one year)
- Launch vehicle (LV) and launch base
- Any special needs for the mission

It is the thoroughness and technical detail available in this initial mission design that determines how well the requirements for the mission are identified in the RFP. These items are usually incorporated in the Technical Requirements Document. The GPO now determines if the acquisition is to proceed as a “cost plus” or “fixed price” contract and if the LV and the ops support are to be provided by the government (GFE) or as part of the contract. These decisions are related to the complexity and the number of unknowns of the mission.[5]

An expanded GPO develops criteria for evaluation of the proposals and relative weights are assigned to each criterion. The proposals are then evaluated.

Examples of the criteria used in the evaluation are listed below:

- Does the proposer show evidence that they understand the mission
- Are the cost estimates realistic and conservative or do they assume a “green-light” program
- Do the designs, the design margins, manufacturing processes, operating processes, and resulting data meet the requirements of the mission
- Is there a thorough requirements analysis and traceability matrix
- Is this a new design or a modification of a proven design
- Is the level of risk acceptable
- Is the proposed mission an improvement over the initial mission design developed by the GPO
- Is the experience of the contractor(s) consistent with the work they propose
- Is the government oversight clearly spelled out
- Is there evidence the contractor is willing to provide the GPO with insight
- Are potential workarounds identified in high risk development areas
- Are contractors’ “best practices” proposed, and if so, what are they
- Are the specs and standards listed in the RFP listed in the proposal

The government decides on the winning proposal and negotiates the contract. A short (less than two pages) initial mission risk assessment is developed by Aerospace for the government managers.

E.3 Managing the Contractor(s)

The GPO is now fully staffed. For a “typical” Class C Space Test Program mission (the word “typical” should not be taken too literally since these missions can be appreciably different from each other), the Air Force usually provides a Captain (the mission manager) to manage the mission, a Lieutenant to help manage SV development LV acquisition (if the LV is a GFE item), and the LV interface, and a Lieutenant to manage the experiment interfaces and on-orbit operations aspect of the mission. Time managing on-orbit operations will increase as the operations phase approaches. The Aerospace Corporation identifies one full time project lead to address the SV, roughly one third of a man-year of effort for the LV, and one third of a man-year of effort for operations support (again this

[5] Approval is obtained by the government to distribute a Request for Proposals that describes not only technical requirements for the mission but also the level of mission assurance and the specifications and standards that are to be followed (including the identification of the CDRLs). See “Space Development and Test Wing Aerospace Mission Assurance Process for Small Satellite Programs,” Aerospace Report No. TOR-2010(1531)-1.

will increase to full time). One half man-year of effort is sometimes used to address experiment interfaces. About three man-years of effort from a pool of about 15 to 20 individuals from the Engineering and Technology Group (ETG) are usually used on an as-needed basis to support technical reviews and to provide expertise in specific technical areas. The program office and its associated engineering support are miniscule compared with that associated with the higher class vehicles.

Previous “similar” Class C missions provide the GPO with the experience that is critical in guiding the technical and management decisions that are required throughout the program. In addition, collocation of the operations center and the LV acquisition arm with the GPO provides an efficient communication environment between the SV, LV, and operations parts of the mission.

An STP Class C space vehicle consists of several experiments integrated to a space vehicle, and its destination is usually a low earth orbit. The risk exposure for the experiments is independently determined by their individual sponsoring agency. STP, however, controls the risk accepted within the space vehicle and its interfaces. At times, the mission includes launch and operations which further complicates the number of entities that need to be controlled. Normally, the space vehicle does not have propulsion and its mass ranges between 300 and 500 pounds with an average of about 400 pounds. The SV usually generates about 200 watts of orbit average power that is usually split evenly between the payloads and the space vehicle. The pointing control is about 0.1 degree with a 0.03 degree knowledge requirement.

The main difference between the Class C approach and that associated with higher Classes (A & B) are the reduced number of personnel in the GPO, a smaller set of specifications and standards, a smaller number of CDRLs, a reduced amount or no redundancy, less stringent requirements on parts qualifications (often Class B parts), and a reduced level of component and subsystem testing (but thorough testing using the TLYF philosophy at the system level using protoqualification levels). Configuration management for hardware and software is usually required. For hardware, it is implemented after system build. Thereafter, configuration is controlled by a joint contractor-GPO review board. The launch vehicles are usually cheaper and smaller and sometimes conversions of decommissioned ICBMs. The ground stations are often shared with other programs and use personnel that may also support a variety of satellites.

System and subsystem level tests are spelled out in a detailed test plan (one of the CDRL components). The subsystem tests are usually functional in nature but the system tests adhere to SMC-S-016 list of tests with some limited tailoring allowed for each test. The system level tests are performed following the Test-Like-You-Fly philosophy and often include tests like a plugs-out test, a day-in-the-life and/or a week-in-the-life test. The contractor is usually required to provide a test plan for each of the system tests performed as well as a final report to indentify the results and anomalies encountered. An Aerospace or AF representative is usually present during each of the system tests.

E.4 Reviews and CDRLs

Different missions have different CDRLs and different management reviews.

Typically a Kick-off Meeting is called by the prime contractor where all the contributing entities are present. These will include the providers of the space vehicle, the payloads, the launch vehicle, the ground system, the launch base, the communication security, the GPO and the major subcontractors. The principal contacts from each contributing agency are introduced, the different Interface Control Documents (ICDs) are identified, and the “team” is organized. The rules of engagement are presented and usually a rough timeline is presented (usually three years with one year of operations). The accepted risk of the mission is clearly delineated by defining the things that will not be done (e.g., redundancy, requirements for space qualified parts, component and subsystem testing, bus reliability).

Monthly Management Meetings with the prime contractor are usually scheduled to review progress, expenditures, and technical issues. Any high risk items are identified and potential solutions suggested.

Technical Issues Meetings are scheduled as needed.

The requirements matrix is fully developed at the System Requirements Review.

Preliminary Design Review (or equivalent), Critical Design Review, Integration Readiness Review, Test Readiness Review, and Pre-Ship Review are additional reviews that are usually required for the SV.

A parallel but less extensive set of reviews are held for the LV, the launch base, and the operations area to ensure that these critical facets are ready and able when needed.

E.5 Readiness to Launch

While risk-tradeoffs have been addressed in real time throughout the development process, a Mission Risk Assessment (MRA) is prepared near the conclusion of the program. The MRA is developed by independent Aerospace ETG personnel that have supported the program and is presented to the Mission Director. The purpose of this independent assessment is to provide an *independent*, yet informed, and useful feedback loop to the mission director.

Roughly two months prior to launch, a Mission Readiness Review is held to get approval from the Mission Director for all the facets to assemble at the launch base. The operations team, having already performed an Operations Readiness Review, contributes to the review. The Flight Readiness Review and the Aerospace President's Review are provided to the SMC commander and to The Aerospace Corporation's president roughly two weeks prior to launch to ensure all issues have been closed, risks are understood, and the mission is ready for launch.

E.6 Summary

The DOD STP acquisition strategy for a Class C satellite accepts single-point failure design, but requires thorough system level tests to protoqualification levels. The government management team is limited to a small, essential number of personnel; close communication is maintained with the prime contractor. Engineering judgment is used throughout the program to make decisions on the cost/risk effectiveness of accepting or rejecting any decision. Most meaningful changes regarding risk decisions are made not by referring to a standard but by an open technical interchange between the contractor's engineer, the government engineering support team, the government program office, and the contractor's management. The teaming experience of the contractor, the government program office, and the associated engineering support with previous Class C missions is also essential in producing a cost-effective mission.

Appendix F. Tailoring EMI/EMC Requirements

Charles K. Jackson
Mark M. Simpson

F.1 Introduction

F.1.1 Overview

This appendix provides guidance to tailor Electromagnetic Interference/Electromagnetic Compatibility (EMI/EMC) requirements in order to place them on contract for any National Security Space (NSS) space vehicle (SV) acquisition. EMI/EMC requirements provide reasonable confidence that the units, subsystems, and systems will perform required functions within design tolerances in the intended electromagnetic environment.

The tailoring of EMI/EMC test requirements must consider:

- Electromagnetic self-compatibility between susceptible units and subsystems.
- Electromagnetic compatibility and validated margins in a complex (combined) electromagnetic environment containing various emitter sources in the SV-factory test configuration.
- Electromagnetic compatibility and validated margins within the complex (combined) electromagnetic environment containing the integrated SV-LV-Launch complex-Tracking Range configuration.

These complex multi-system configurations (including those used during the actual launch and SV deployment) contain the largest number of potential electromagnetic sources that may disrupt or damage susceptible flight equipment due to unwanted exposure to conducted or radiated emissions from those sources.

F.1.2 Definitions

Electromagnetic Environments are all the electromagnetic radiated and conducted environments to which the SV intentionally or unintentionally may encounter during assembly, test, storage, transportation, prelaunch preparation, launch, and operational phases. Consideration is also given to the operationally radiated environment from both friendly and hostile emitters which the SV may encounter during its life cycle.

Electromagnetic Interference (EMI) is unwanted radiated or conducted electromagnetic energy propagated from a source that temporarily interrupts, obstructs, or otherwise degrades or limits the effective performance of essential electrical, electronic, or electromechanical equipment. Radiated interference is any electromagnetic energy that is radiated from any unit, antenna, cable or interconnecting wiring.

Electromagnetic Compatibility (EMC) is a condition prevailing when essential electrical, electronic, or electromechanical equipment can collectively perform their individual design functions in a common electromagnetic environment without causing or suffering unacceptable degradation or damage due to electromagnetic interference to or from other equipment/systems in the same environment. At the system level all radiated and conducted interfaces between systems should be compatible whether the interfaces are intentional or not and whether the systems are related or not.

Conducted Emissions (CE) is electromagnetic energy that propagates along a signal or power conductor(s). In the context of this appendix, conducted emission are unwanted emissions from sources that may disrupt or damage essential electrical, electronic, or electromechanical hardware. Conducted emissions can come from external sources (e.g., ground support equipment) or internal sources (flight unit to flight unit).

Radiated Emissions (RE) is electromagnetic energy that propagates through free space. If it is unwanted, then it is known as radiated interference. In the context of this appendix, these unwanted radiated emissions must be prevented from occurring to avoid the potential disruption or damage to essential electrical, electronic, or electromechanical hardware. Radiated emissions can come from external sources or internal sources.

Susceptibility is the electrical, electronic, or electromechanical unit tolerance threshold when exposed to conducted, i.e., Conducted Susceptibility (CS) or radiated, i.e., Radiated Susceptibility (RS) electromagnetic energy causing unwanted responses. In the context of this Appendix, the susceptibility threshold for disruption or damage of essential flight equipment must be characterized and margins understood.

F.2 EMI/EMC Requirements

This section contains summarized requirements that should be considered when testing for EMI/EMC at unit, subsystem, and SV levels. Since the goal of this appendix is to summarize the key requirements and provide tailoring guidelines, there is an extensive use of tables. These tables summarize key EMI/EMC specification and standards, and then separate tables capture the key requirements that must be considered during the tailoring process:

- Tables F-1 and F-2 summarize relevant unit level test requirements.
- Tables F-3 and F-4 summarize key SV system level test requirements.

Application specific EMI/EMC environments and environmental success criteria may be derived from analysis or engineering tests. When requirements in these standards are shown not to be applicable then tailoring is acceptable and expected.

F.2.1 Applicable Specifications and Standards

Detailed EMI/EMC requirements for space programs are defined in the following military standards and form a complete set of standards and practices for EMI/EMC test requirements for unit level and SV system level test configurations, specific test requirements, and specific test techniques:

- MIL-STD-461F, “Military Standard, Requirements for Control of Electromagnetic Interference Characteristics of Subsystems and Equipment,” Department of Defense, 10 Dec 2007. This standard establishes EMI/EMC test requirements, test limits, and test procedures for electronic, electromechanical, and electrical unit level verification and margin determination.

- MIL-STD-1540E (or SMC Standard SMC-S-016), 13 June 2008, “Test Requirements for Launch, Upper-stage, and Space Vehicles,” Air Force Space Command. This document establishes the need for both unit and SV-LV system-level EMI/EMC testing. Specific unit level requirements are deferred to TOR-2005(8583)-1. MIL-STD-1540E mandates system (SV or LV) level testing for all operating modes, RF self-compatibility tests, radiated susceptibility tests, and radiated emissions tests.

- SMC Standard SMC-S-008, "Electromagnetic Compatibility Requirements for Space Equipment and Systems," 13 June 2008. SMC-S-008 is Aerospace TOR-2005(8583)-1, Revision A. SMC-S-008 is an update to MIL-STD-1541A and tailors MIL-STD-461F for space systems.

For further tutorial information see:

"Space Vehicle Test and Evaluation Handbook," TOR-2006(8546)-4591, of The Aerospace Corporation, and

"Electromagnetic Compatibility Requirements for Space Equipment and Systems," TOR-2005(8583)-1, Rev A, 13 June 2008, of The Aerospace Corporation. This TOR is also known as SMC-S-008.

The TOR titled, "Electromagnetic Compatibility Requirements for Space Equipment and Systems" was written to consolidate and update EMI/EMC test requirements applicable to space and launch vehicles at the unit, subsystem and system levels of assembly and their associated ground and space borne support and operational elements.

F.2.2 Unit Level EMI/EMC Test Requirements

SMC-S-008 provides the necessary generic tailoring of MIL-STD-461F. Mission specific tailoring is required in addition to the generic tailoring. Requirements analysis is mandatory for mission-specific tailoring to demonstrate margin across all the EMC/EMI interfaces. As the susceptibility margins are not against the corresponding emissions in all cases or are in different units, a subject matter expert should review the tailoring. Specific unit level EMI/EMC test Requirements are summarized in this section. Table F-1 table lists key test requirements from MIL-STD-461F. Specific test requirements are listed as a function of three broad categories: hardware interfaces (i.e., power cabling, bulk cables, antenna ports) to susceptible electronic, electrical, or electromechanical equipment; injected power variations (e.g., transients) that may stress susceptible equipment and; electric and magnetic fields produced by the units under test (UUT) or produced externally that can disrupt UUT functionality. The specific MIL-STD-461F test designators are shown for reference in the left column (e.g., CS 102 etc.) to aid the reader in finding the correct test description in the military standard. Test designators that are not in the 100 series are from MIL-STD-461C and were not included in MIL-STD-461F. Table F-2 summarizes key requirements in SMC-S-008, and enhances comprehensive unit level EMI/EMC testing by adding power quality and electrostatic discharge requirements.

Table F-1. Unit Level EMI/EMC Test Requirements (There are additional unit level requirements in SMC-S-008)

Requirement	Description
Power Leads	Power Lead testing: signals are injected in each wire (lead) of a multi-lead power cable supplying power to the UUT.
Conducted Emissions CE 101, CE 102	Conducted emissions for power and interconnecting leads, 30 Hz to 10 kHz/10 kHz to 10 MHz (50 MHz required by MIL-STD-461C): emissions from power supplies and pulsed loads may interfere with power supplies and power systems
Conducted Susceptibility CS 101, CS 02	Conducted Susceptibility for Power Leads: unit performance measured when each power lead is exposed to a voltage continuous wave swept or stepped from 30 Hz to 150 KHz and from 150 KHz to 50 MHz
Power Transients	Simulated power variations are injected onto the wires of each power cable supplying or producing power to/from the UUT, and the reaction of the UUT is measured
Conducted Emissions CE 07	Conducted emissions for power leads spikes, time domain: measures whether the power spikes from turning equipment on or off is between +50% and –150% steady state voltage
Conducted Susceptibility CS 06	Conducted susceptibility for spikes on power leads: measure unit performance when each power lead is exposed to 200-volt spikes of 10 μs and 0.15 μs pulse width
Antenna Ports	SV/LV antenna ports are specifically characterized by placing a sensor in the port to capture externally produced electromagnetic energy and or any signal leakage from anywhere but the antenna
Conducted Susceptibility CS 103, CS 104, CS 105	Conducted susceptibility measured at the antenna port: inter-modulation (15 kHz to 10 GHz), rejection of undesired signals (30 Hz to 40 GHz), cross-modulation (30 Hz to 40 GHz): establishes the minimum received signal (threshold) taking into account EMI impacts on the final acceptable bit error rate for that signal.
Conducted Emissions CE 106	Conducted emissions, antenna terminal, 10 kHz to 10 GHz (option to extend to 100 GHz).
Electric Field	The electric field is measured by placing an antenna one meter from front edge of test setup boundary.
Radiated Emissions RE 102	Radiated Emissions, Electric Field, 10 kHz to 100 GHz.
Radiated Susceptibility RS 103	Radiated susceptibility, electric field, 10 kHz to 40 GHz (MIL-STD-461C extends lower limit to 14 kHz).
Magnetic Field	The magnetic field is measured by placing a loop sensor 7 cm from the item face being probed.
Radiated Emissions RE 101	Radiated Emissions, Magnetic Field, 30 Hz to 100 kHz (tailoring required, MIL-STD-461C requires test).
Radiated Susceptibility RS 02	Radiated Susceptibility, Magnetic and Electric Field, power spikes and frequencies coupling into signal and power wiring and through the SV/LV chassis.
Bulk Cable Injection	Current injection probe injects the signal being monitored by a current probe 5 cm from the connector interface.
Conducted Susceptibility CS 114, CS 115	Conducted Susceptibility, Bulk Cable Injection: measures unit performance to a 1 kHz pulse modulated signal of 50% duty cycle being swept from 10 kHz to 200 MHz and a 30 nsec impulse signal.
Conducted Susceptibility CS 116	Conducted Susceptibility, Bulk Cable Injection, Damped Sinusoidal Transients, Cables and Power Leads, 10 kHz to 100 MHz.

Table F-2. Applicable SMC-S-008 Unit Level Power Quality and ESD Test Requirements

Power Quality	6.06 Conducted Emissions, ripple and periodic transients, power and command/control lines. This limits low bandwidth ripple and periodic transients of 0.1% of mean bus voltage as measured in the peak-to-peak time domain and high bandwidth ripple and periodic transients to 0.35% of mean bus voltage.
	6.08 Conducted Emissions, Inrush Current, Power and Command/Control Lines. This limits turn on inrush to 4 times the steady state current and normal operation to 1.5 times the steady state current.
	6.13 Conducted Susceptibility, Aperiodic Surges, Operate Through, Power and Command/Control Lines. This requires units to stay within specification with a 40 ms 20% step increase or decrease of the operating voltage.
	6.14 Conducted Susceptibility, Aperiodic Surges, Survival and Outrush Current, Power and Command/Control Lines. This requires units to survive both a transient that is twice the operating voltage and a transient that is dropped to zero volts.
Electrostatic Discharge	Proper equipment operation is verified while subjecting the unit to discharges. This effect includes space vehicle charging due to non-conductive materials collecting space-borne free electrons, atmospheric collisions with the LV structure during the launch event. Regardless of the source, currents flow from these charge distributions causing unwanted effects in susceptible equipment.
	Equipment Electrostatic Susceptibility: Equipment must operate properly when exposed to 8 kV contact and 15 kV air electrostatic discharges. The 8 kV contact discharge produces a 30 A discharge.
	Electrostatic Arc Discharge Susceptibility: Equipment must operate properly when exposed to 30 15 kV discharges at 1 pulse per second 30 centimeters for any exposed surface; 30 8 kV discharges at 1 pulse per second to each top corner of the unit, and; 30 8 kV discharges at 1 pulse per second through equipment mounting surfaces.

F.2.3 System Level EMI/EMC Test Requirements

System level EMI/EMC requirements are summarized in this section. For the purposes in this appendix, a “system” can be defined as a collection of units, that is a subsystem, or a collection of subsystems like a space vehicle. The intention is to apply requirements to verify compatibility at higher levels of assembly/integration. Table F-3 is a summary of applicable requirements in MIL-STD-1540E. Table F-4 summarizes those system test requirement considered critical to complement MIL-STD-1540E. In particular, SMC-S-008 specifies acceptable qualification and acceptance margins. If qualification test margins cannot be verified then SMC-S-008 requires acceptance level EMI/EMC test verification.

Table F-3. SV Electromagnetic Compatibility Requirements, MIL-STD-1540E

Test	Requirements
Radio frequency self-compatibility	With all the receivers and transmitters receiving and transmitting through flight antennas without antenna hats, the SV performance is measured to ensure that it is within specification. This partially verifies the correct tailoring and allocation of the EMC/EMI requirements.
Power quality	The power line ripple and transients are measured and compared to the requirements to establish margin between unit susceptibility power subsystem ripple and transients.
Radiated Emissions	The SV generated electric fields are measured and compared to the radiated external radiated emissions requirement to establish margin with receiver performance.
Radiated Susceptibility	The SV is exposed to the specified electric field requirement to show margin against the external transmitters, SV transmitters, and the intended capability.
Conducted emissions	The power line conducted emissions are verified to make sure they have the required margin against the unit level conducted susceptibility requirements.
Power transients	Prime power lines are monitored during SV level testing to verify the transients have the required margin against the unit power transient susceptibility.
Magnetic moments	The magnetic moment is measured to make sure it is within the control authority of the attitude control subsystem and does not affect the sensitivity of a flux gate magnetometer if present.
Critical Circuits	If critical circuits have been identified, then noise induced during SV operations is monitored at the circuit for comparison with vulnerability levels established at the unit/circuit level.
Umbilical Separation	Umbilical separation test must demonstrate that any equipment normally operating during the launch will continue to do so when the SV and or LV umbilical is abruptly removed during the first stages of LV lift-off.

*Required in all modes of operation with antenna hats off to show malfunction does not occur.

Table F-4. SMC-S-008 SV System Test Requirements*

7.1 d2. Self-compatibility	Requires the vehicle to be self-compatible in its full up configuration with antenna hats off, with minimal mission links, in all operational modes, at all frequencies. This verifies the derived requirements have at least 0 dB margin.
7.1 d3. Self-compatibility and EMISMS, conducted regime	Requires the power line time and frequency domain conducted emissions be measured to compare with unit susceptibility levels to establish margin.
7.3 d4. Self-compatibility and EMISMS, radiated emissions	Requires the radiated electric field and magnetic field emissions to be measured. This is what establishes margin against the unit level requirements. Note the radiated emissions levels are set at what will not cause receiver degradation in performance (typically bit-error-rate.) This is related to the receiver CS104 levels as well as the antenna gain and path loss.
7.3 d5. External RFI Compatibility (RS103) and EMISMs	Requires the SV be exposed to radiated susceptibility environment as defined in the requirements. The margin in this case is against the external transmitters and the desired capability.
7.3 d6. Ordnance EMISMs, with external RFI (RS103)	Requires the SV be exposed to radiated susceptibility environment as defined in the requirements. The ordnance simulators are used that will fail if the desired margin is not met which is 20 dB below the DC no-fire value and 6 dB below the RF no-fire value.
7.3 Vehicle Passive Intermodulation (PIM)	Requires that the RF transmissions from on-board transmitters and external transmitters, when incident on the vehicle, do not result in unintentional signals as a result of passive intermodulation (PIM), which can interfere with on-board receivers.
7.7 Vehicle Bonding c2 Cable, connector, ground reference system and related bonds	Requires that the electrical bonds are adequate to provide vehicle EMC and do not generate PIM.
7.7 Vehicle Bonding c3 ESD mitigation bonds	Requires that the equivalent resistances of equipment bonds be below what is likely to cause ESD from space vehicle charging.

*Required in all modes of operation with antenna hats off to show malfunction does not occur.

F.2.4 EMI/EMC Tailoring Considerations and Guidance

EMI/EMC requirement tailoring is a complex task best done face-to-face between EMI/EMC subject matter experts and unit and system designers. The majority of EMI/EMC requirements tailoring is done during the requirements allocation process from (1) the government to the prime contractor while finalizing prime contractor contract(s) and (2) between the prime contractor and their subcontractors defining requirements while finalizing subcontractor contracts.

The first goal in tailoring requirements is to technically refine applicable EMI/EMC requirements to suit the specific application/program and the available test infrastructure. For example, this means tailoring the test requirement to specific frequencies of interest. It also means allocating EMI/EMC test requirements appropriately to the unit, subsystem/payload or SV system level depending on the ground test capabilities for perceptive EMI/EMC testing. If, for example, an SV is large, EMI/EMC verification will have to be organized into a combination of unit level, subsystem level, and system level tests to address electromagnetic radiated and emission risks.

The second goal of tailoring is to eliminate requirements that provide little risk reduction for the time and expense incurred executing the test. In this second instance of tailoring, program risk acceptance drives the defined requirements.

Due to the complexity of combined electromagnetic environment and complex integrated SV/LV hardware configurations, many test compromises occur to approximate the final flight configuration system level in the real EMI/EMC internal and external environment. EMI/EMC testing may be preferentially biased towards subsystem and system levels of assembly because they will more closely approximate the true flight configuration; unit level risk is considered acceptable when the risk is managed. Typically, the smaller programs do more complete SV level EMC testing in a more flight-like configuration because risk has been deferred to the system level testing.

F.2.4.1 Key Requirements to Consider When Tailoring EMI/EMC Requirements

F.2.4.1.1 Mission Requirements and Constraints

Mission requirements determine orbit parameters, options for launch site, and launch vehicle configuration options. Given these considerations, radiated susceptibility requirements can be tailored for the vehicle-specific transmitters, on-orbit envelope distances from ground based RF sources, launch site RF sources, and the RF environment during ascent. Ground based RF sources considered include those in place today as well as those predicted to be in place during the mission duration. LV options allow consideration of RF antenna locations and sensitive frequencies. A certain minimum capability is recommended, otherwise, it would indicate that the units are close to failing with their internally generated EMI. Also a minimum capability will ease launch processing and hedge against risk against environment growth over the life of the mission. So a 20 V/m minimum capability is recommended.

F.2.4.1.2 Program Requirements and Constraints

Program requirements will establish the specific SV configuration(s) under consideration, which then determine specific subsystem/unit capabilities and layouts. Depending upon the specific mission addressed, emphasis on certain tests may be required. Program constraints will also influence consideration of schedule, facilities, and cost. Finally, this requirement also includes consideration of program heritage. For programs with successful flight heritage, it is often argued that heritage requirements are the low risk and the most cost effective alternative when considering EMI/EMC tailoring. Specifically, radiated emissions limits are tailored for on-board receivers and sensor bandwidths; conducted emissions and susceptibility limits are tailored for bus impedance and potential conducted noise sources. If heritage is used, the heritage still requires documentation and a gap analysis and delta qualification as necessary. If qualification by similarity is used, the similarity still requires documentation and delta qualification as necessary with an increased margin requirement to cover analysis uncertainty and a higher risk. Qualification by analysis when it is not similar should be rejected as EMI analysis has no consensus on the uncertainty.

F.2.4.1.3 Use of Qualification Units to Reduce Risk

Complete EMI/EMC verification includes unit level (design and workmanship), subsystem level (interfaces) and system level test verification. At the unit level, EMI/EMC design verification and margin assessment can occur on qualification units to reduce risk for susceptible equipment prior to the flight build. If sufficient margin exists, EMI/EMC acceptance testing to verify workmanship for each flight unit can be waived. If not, then a test program can be constructed to verify the EMI/EMC workmanship of each flight unit prior to integration at the next level of assembly.

F.2.4.1.4 Unit Level Self Compatibility

By definition, unit self compatibility is demonstrated at higher levels of integration and does not establish margin, and is limited by the fidelity in the mission and interface simulations.

F.2.4.1.5 Subsystem Level Self Compatibility

Internal unit-to-unit interfaces and external subsystem-to-subsystem interfaces should be verified. If resources are constrained, subsystem (e.g., payload) level testing is preferred to unit level testing since the configuration is more flight-like than the unit configuration. This should not be done without a risk assessment. If the risk is high, the risk should be retired at the first opportunity. Risk can also be schedule risk. Therefore, optical payload EMC is often verified un-integrated without the optics and surrounding structure to ease testing and troubleshooting and not to invalidate the integration, in case modifications are required.

F.2.4.1.6 Integrated SV Self Compatibility

Conducted emissions (ripple and transients) testing is performed on the SV power bus, and the measured levels are compared with unit susceptibility test limits to verify design margin. Receiver performance should be verified at 6 dB below the minimum required received power. If the receiver antenna hats cannot be removed, the radiated emissions over the receiver pass bands will have to be measured. Radiated susceptibility testing should be performed when on-board transmitters are not exercised during self compatibility testing. Radiated susceptibility testing should be performed when the vehicle structure is providing a Faraday cage to verify workmanship. Note, self compatibility is one of nine required tests in Table F-3, and is one of eight required tests in Table F-4.

F.2.4.1.7 Integrated SV/LV Self Compatibility

Radiated emissions tests are required at the integrated space vehicle level to verify that the noise is acceptable over the LV receiver bandwidth frequency ranges. Radiated susceptibility testing may also be required to show compatibility with LV depending on the LV contract.

F.2.5 Tailoring Guidance

EMI/EMC requirement tailoring is a complex task best done face-to-face between EMI/EMC subject matter experts and unit and system designers. Nothing in this discussion on tailoring is a substitute for that process. The scope and level of testing is a function of the amount of system and mission risk each program is willing to accept. Despite, the program's desire to accept higher risk, it is not always possible to test only at the highest level of integration for EMI/EMC, but in fact, lower level tests may still be required.

Table F-5 summarizes tailoring guidance for unit, subsystem, and system levels of integration for SV classes A through D. The payload (PL) and can be viewed like the Bus as a standalone subsystem or system in the application of EMI/EMC tailoring guidance. Table F-5 also provides priority guidance based on whether the SV is in Class A/B or in Class C/D. Whereas Class A or Class B would require all requirements being met at the unit, subsystem, and vehicle level, Class C and D allows, on a case-by-case basis, an assessment of existing test data and analysis. With that said, in practice, most undergo a rigorous unit, bus, payload, and space vehicle test program. The primary difference is Class C and D units may have some units with minor modifications that are qualified by similarity or with delta testing.

F.3 Suggested Guidance on Contract Language

F.3.1 Request for Proposal/Technical Requirements Document

Section M often references SMC-S-016 (aka MIL-STD-1540E) that in turn references MIL- SMC-S-008 and associated documents. The technical requirements document (TRD) contains the electromagnetic compatibility requirements, such as the conducted and radiated emissions and susceptibility requirement limits that will be satisfied at the unit, system, and vehicle level. Tailoring will be approved by the customer.

F.3.2 Contractor Statement of Work (CSOW)

"Electromagnetic Compatibility between components of the system and its intended environment shall be established using analysis and test verification consistent with the applicable document.

F.3.3 Integrated Management Plan/Integrated Master Schedule (IMP/IMS)

EMI/EMC test plans, test procedures, test readiness reviews, test periods (as part of unit qualification/acceptance or system environmental testing), and test reports should all have their milestones reflected in the IMP/IMS.

F.3.4 Data Item Descriptions (DIDs)

Aerospace TOR-2009(8591)-18 provides instructions and content for an EMC Control Plan, and can be used as a compliance document. Guidance is also provided for test documentation.

Table F-5. Summary of Risk Class and EMI/EMC Tailoring Guidance

	Class A	Class B	Class C	Class D
Unit EMI test	All units tested: SMC-S-008 unit level requirements addressed.	All units tested: SMC-S-008 unit level requirements addressed.	All units selectively qualified by test, similarity and/or analysis to SMC-S-008 unit level requirements.	All units selectively qualified by test, similarity and/or analysis to SMC-S-008 unit level requirements.
Integrated subsystem EMI test, or P/L, or Bus EMI test	SV P/L & Bus treated as separate subsystems. Subsystem tested to SMC-S-008 unit level requirements.	SV P/L & Bus treated as separate subsystems. Subsystem tested to SMC-S-008 unit level requirements.	SV P/L & Bus treated as separate subsystems. Testing to SMC-S-008 unit level requirements dependent on level of qualification of units (test, analysis, similarity and/or none), nature of P/L manifest, level of risk acceptable to program.	SV P/L & Bus treated as separate subsystems. Testing to SMC-S-008 unit level requirements dependent on level of qualification of units (test, analysis, similarity and/or none), nature of P/L manifest, level of risk acceptable to program.
Vehicle EMI test	Integrated SV. Tested in accordance with SMC-S-008 vehicle level requirements.	Integrated SV. Tested selective in accordance with SMC-S-008 vehicle level requirements.	Consideration given to relaxation of SMC-S-008 vehicle level requirements dependent on level of qualification of units, P/Ls and Bus (test, analysis, and similarity.)	Consideration given to relaxation of SMC-S-008 vehicle level requirements dependent on level of qualification of units, P/Ls and Bus (test, analysis, and similarity.)
LV/SV EMC	Integrated SV/LV. All tests and SV System level RE and RS and ESD requirements are addressed.	Integrated SV/LV. All tests and SV System level RE and RS and ESD requirements are addressed.	Integrated SV/LV. All tests and SV System level RE and RS and ESD requirements are addressed.	Integrated SV/LV. All tests and SV System level RE and RS and ESD requirements are addressed.

Appendix G. Tailoring Environmental Test Requirements

Alan Peterson
Irwin Perl

G.1 Introduction

G.1.1 Overview

Launching a space-vehicle is a very dynamic event. Space vehicles experience severe shock and vibration environments during various stages of their missions. At liftoff and for the next several seconds, the intense sound field generated by the engine firing exerts significant acoustic pressure on the entire space vehicle. The intense acoustic pressure continues throughout the stages that are referred to as liftoff and transonic/maximum dynamic pressure events. These acoustic pressures induce vibration, externally and internally, in the space vehicle structures. In addition, the vehicle experiences intense transient impulses or "shocks" at various stages of the mission, such as those generated by engine ignition and shutdown, solid rocket motor jettison, staging, and fairing and space vehicle separation. The acoustic-induced vibration and shocks have the potential to damage delicate space vehicle components. The space vehicle also must endure a wide range of thermal environments over the course of the mission. Pre-launch thermal control must consider how conditioned air blown through the fairing enclosure ensures that items such as batteries do not overheat. Following launch and fairing jettison, ram-facing surfaces are exposed to free-molecular heating during ascent. Throughout the entire mission, the space vehicle must accommodate environmental heating from three primary sources: direct solar from the sun, reflected solar from the earth (albedo), and infrared heating from the earth. This heat, and all internally generated heat from electronics, must be radiated to space through radiator surfaces. Shadowing, eclipses, and safe mode orientations result in variations in the heating that need to be accounted for in the thermal design.

Ensuring the survivability of the hardware poses challenges that can be met only by extensive pre-flight acoustic, shock, and vibration and thermal testing. The primary purposes of ground testing include environmental stress screening, operating and performance verification, demonstration of survival and turn-on requirements, and achieving confirmation in analysis predictions. Part and unit testing imposes stresses on flight hardware more severe than expected in flight for the purpose of environmental stress screening to detect latent defects early in the development process. Subsystem and vehicle testing impose more flight-like test environments with a primary purpose of demonstrating performance requirements and proving flightworthiness.

G.1.2 Key practices and Activities

The process for acoustic, shock, vibration, and thermal environments definition involves using both analytical tools and test data bases. Design and workmanship verification is accomplished using various dynamic and thermal test processes.

G.1.2.1 Acoustics

The dominant dynamic concern for most space vehicles is the intense acoustic pressure generated by turbulent mixing of exhaust gases from the main engines and rocket motors with the ambient atmosphere during liftoff. This event typically begins when the main engine is ignited and lasts approximately 3 to 6 seconds. Ignition produces an exhaust plume that exerts acoustic pressure on the launch pad and reflects back to the space vehicle to induce vibration in its structures. The magnitude of the exhaust plume and the amount of pressure it exerts depends on factors such as engine thrust, exit velocity, engine nozzle diameter, location of structures, and duct configuration. The sound pressure and its induced vibration are random in character. The spectra that are used to assess damage potential are expressed in terms of mass per unit area or converted into the more common units of decibels and power spectral density for acoustic pressure and vibration, respectively. These spectra usually span the range of frequencies from 10 to 10,000 hertz.

Acoustic tests of space vehicle equipment or major subsystems are usually performed by simulating the acoustic pressure expected during liftoff and subsequent mission phases. Space vehicles also contain complex components that are susceptible to acoustic noise, and these must be tested to ensure all potential failure modes and workmanship defects are properly screened out prior to system integration.

In a typical acoustic test, the test specimen is positioned in an acoustic chamber on a foam pad or suspended from bungee cords. In some cases, the test item may be attached to larger metal plates to simulate actual mounting on the space vehicle structure, thereby creating a more realistic profile of the interface vibration. The chamber is a large room with thick walls and a smooth interior surface that permits high reverberation. Loud speakers or horns supply the acoustic energy, with four or more microphones strategically placed to control and record the sound level within the room. Numerous acceleration transducers are installed on the test item to measure the motion induced by the acoustic pressure into the critical components of the test item. Many of these critical components are also functionally monitored during the test. The measurements are compared with the appropriate design specifications for the components to assess their qualification acceptability for flight.

The maximum protected environment acoustic test levels for a particular space vehicle or subsystem are usually derived from measurements of similar structures on past flights and ground tests. Analytical tools such as statistical energy analysis for frequencies above 100 hertz and finite-element and boundary-element methods for frequencies below 100 hertz are sometimes used to derive the test levels in the absence of measurements. The predicted acoustic environment is scaled up using statistical methods to derive a maximum predicted flight environment. Margin is added to ensure that the hardware is sufficiently robust and to account for uncertainties in the derivation of the environment and design of the hardware. A typical margin is 6 decibels, which is 4 times the energy of the maximum predicted environment. The test usually lasts from 1 to 3 minutes, depending upon the program requirements. Hardware that is susceptible to the acoustic pressure loading are those with large surfaces with low mass density such as composite material solar arrays and antenna reflectors. These composite structures may have design or workmanship deficiencies which result in bond and/or material failures.

G.1.2.2 Vibration

As a launch vehicle accelerates through the atmosphere, the relative velocity between the vehicle and the ambient atmosphere generates fluctuating pressures in a turbulent boundary layer between the exterior surface and the atmosphere. As the vehicle moves at a speed near or above the speed of sound (the so-called transonic or maximum-dynamic-pressure region), the fluctuating pressures are convected along with the flow and cause the vehicle’s skin to vibrate.

Vibration testing helps demonstrate that hardware can withstand these conditions. Random vibration tests are conducted on an electrodynamic vibration machine or “shaker,” which consists of a mounting table for the test item rigidly attached to a drive-coil armature. A control system energizes the shaker to the desired vibration level. Feedback for the control system is provided by a series of accelerometers, which are mounted at the base of the test item at locations that correspond to where the launch vehicle adapter would be attached. Two control approaches can be used to provide realistic structural responses. Most space vehicle vibration tests use response-limiting major-appendage accelerations to reduce input at discrete frequencies so as not to cause unrealistic failures. For test structures that exhibit distinct, lightly damped resonances on a shaker, force limiting is used in conjunction with input vibration to control the shaker. In the force-limiting approach, transducers that measure the input force are mounted between the test item and the shaker. The goal is to reduce the response of the test item at its resonant frequencies on the shaker to replicate the response at the combined system at the resonant frequencies that would exist in the flight-mounting configuration.

As in the case of acoustic testing, heritage flight and test data are used to predict vibration test levels, and analytical methods are sometimes used to develop transfer functions to scale heritage data to new hardware configurations. In most cases, the predicted maximum protected environments (MPEs) are verified later with system-level acoustic tests and rocket engine static fire tests. As with acoustic testing, a 6-decibel margin is typically added to the maximum predicted environment. Structural failures of piece parts, unit assemblies, secondary and primary space vehicle structures can and do occur from vibration induced high stresses and material fatigue. Failures of inadequately designed or poorly manufactured or assembled structural interfaces are commonly revealed.

Aerospace personnel using predictive software provide analysis conformation for optimal instrumentation for vibration testing. Aerospace confirms hardware test perceptiveness and effectiveness with analysis, testing experience, and consideration of interface constraints.

G.1.2.3 Shock

Stage, fairing, and vehicle separations are often accomplished by means of pyrotechnic devices such as explosive bolts, separation nuts, bolt cutters, expanding-tube separation systems, clamp bands, ordnance thrusters, and pressurized bellows. When activated, these devices produce powerful shocks that can damage equipment and structures. The characteristics of these shocks depend on the particular separation mechanism, but the energy spectrum is usually concentrated at or above 500 hertz and is measured in a frequency range of 100 to10,000 hertz. A typical shock response spectrum plot is used to gauge the damage potential of a given separation event.

Separations or deployments will generate brief impulsive loads even if no pyrotechnic devices are used. Nonexplosive initiators will still produce significant shock levels from structural strain release alone. Experience has shown that shock can induce a hard or intermittent failure or exacerbate a latent defect. Commonly encountered hardware failures include relay transfer, cracking of parts, dislodging of contaminants, and cracking of solder at circuit board interfaces.

Unit-level shock tests are accomplished using one of several methods, which generally entail securing the component to a fixture that is then subjected to impact. This “ringing plate” approach has provided the best practicable simulation of unit exposure to shock. In addition, vibration shakers are used in some applications to impart a transient shock. Shock testing is typically not performed as a unit workmanship screen, but is deferred to the system level for greater detection of functional defects. System-level shock tests usually involve activating the separation or deployment systems, providing a direct simulation of the mission event. Thus, they do not include any amplitude margin. Test fixtures are frequently needed to support hardware that has been deployed or separated to prevent subsequent contact or damage. System-level shock tests provide an excellent opportunity to measure shocks incident on components throughout the space vehicle.

Accurate prediction of high-frequency shock levels, such as those associated with explosive ordnance, remains an elusive goal. Therefore, it is important that the shock environment be assessed during the development phase of the program through both analysis and test simulations. Shock analysis includes consideration of the source amplitudes, durations, transmission paths, path materials, and path discontinuities. Development tests employ an accurate replica of the flight structure with all significant constituents simulated. Deployed hardware is permitted to physically separate at least a small amount to provide realistic shock transmission paths. When practical, a shock-producing event is repeated several times to permit meaningful statistical evaluation of the resulting data. Qualification margins at the unit level are typically 6 decibels on amplitude and twice the number of flight activations. At the system level, it is generally impractical to impose an amplitude qualification margin; however, a duration margin of 2 or 3 activations is imposed. Aerospace SMEs provide expertise for the prediction of test levels and the configuration of the hardware interfaces to achieve an effective test.

G.1.2.4 Thermal

Thermal tests demonstrate that hardware can survive, operate and perform to mission requirements in thermal environments expected over the vehicle life and mission. These thermal environments include hot and cold temperature extremes, thermal gradients, and temperature rates of change. Thermal tests subject the test article to hot and cold temperature extremes that are either derived from predicted flight environments or set for the test article as an acceptable operating and performance range. At hot and cold test temperature extremes and during the transitions between temperature extremes, performance and functional tests are conducted to demonstrate operation and specified mission requirements.

The four common thermal tests are thermal cycle, thermal vacuum, thermal balance, and burn-in testing. Thermal cycle testing subjects the test article to a number of cycles at hot and cold temperatures in an ambient-air or gaseous-nitrogen environment. Thermal vacuum testing does the same, but in a vacuum chamber. In thermal balance testing, also conducted in vacuum, dedicated test phases that simulate flight conditions are used to verify the thermal control subsystem design and hardware and to obtain temperature data for thermal model correlation. Burn-in tests are typically part of unit thermal cycle tests with additional unit operation at elevated temperature or while cycling hot and cold. The thermal cycle test at the unit level is recognized as one of the most effective screening environments in ground testing. The thermal vacuum test at the unit level is used for demonstrating unit performance and additional defect screening (particularly vacuum-related defects). The thermal vacuum test at the vehicle level is the most flight-like ground test that the space vehicle will experience, combining both temperature and vacuum environments. A significant aspect of this test is the high level of performance testing conducted at hot and cold extremes.

Unlike dynamics testing, thermal testing is very time-consuming, requiring 24-hour operation. Thermal cycle testing of a typical large electronic unit to 14 cycles (acceptance) can take 10 days to complete and a thermal vacuum test of only four cycles can take just as long. A large Class A space vehicle thermal vacuum test will require about 45 to 60 days of round-the-clock testing. Smaller Class B and C space vehicles will typically spend 30 to 45 days in a thermal vacuum test. A vehicle-level thermal vacuum test will also include typically another 40 days split between vehicle test preparation and vehicle removal.

G.1.3 Definitions

G.1.3.1 Maximum Predicted Environment (MPE)

The MPE is a basis for the acceptance-level test spectrum. The MPE is statistically the P95/50 acoustic, random vibration or shock spectrum. The MPE +6 dB equates to the P99/90 qualification level.

G.1.3.2 Maximum and Minimum Predicted Temperatures (MPT)

The maximum and minimum predicted temperatures (MPT) are the highest and lowest temperatures that an item can experience during its service life, including all test and operational modes. The MPT are established by adding thermal uncertainty margins to the maximum and minimum model temperature predictions.

G.1.3.3 Maximum and Minimum Model Temperature Predictions

The maximum and minimum model temperature predictions are the hottest and coldest temperatures predicted from models using applicable effects of worst-case combinations of equipment operation, internal heating, vehicle orientation, solar radiation eclipse conditions, ascent heating, descent heating, and degradation of thermal surfaces during service life.

G.2 Requirements

G.2.1 Applicable Specifications/Standards

G.2.1.1 MIL-STD-1540E "Test Requirements for Launch, Upper-Stage, and Space Vehicle

This Standard establishes the environmental and structural ground testing requirements for launch vehicles, upper-stage vehicles, space vehicles, and their subsystems and units. In addition, a uniform set of definitions of related terms is established. This requirements document is expected to be tailored for specific programs with specific customer defined test strategies.

G.2.1.2 MIL-HDBK-343, "Application Guidelines for MIL-STD-1540; Test Requirements for Space Vehicles"

The 340B Handbook was written to provide explanations and guidance to the users of 1540E. The information presented herein is intended to aid in the formulation and review of detailed test requirements for launch, upper stage, and space vehicles including the tailoring of requirements for specific program specifications or contracts.

G.2.1.3 MIL-STD-810H, "Environmental Test Methods and Engineering Guidelines"

This standard contains materiel acquisition program planning and engineering direction for considering the influences that environmental stresses have on materiel throughout all phases of its service life. It is important to note that this document does not impose design or test specifications. Rather, it describes the environmental tailoring process that results in realistic materiel designs and test methods based on materiel system performance requirements.

G.2.1.4 Discussion of Matrix or Matrices

The matrices shown in Table 4A for satellite procurement quantities of three and greater and Table 4B for quantities of one or two satellites provides the environmental test requirements based on the buyers procurement strategy selected in MIL-STD-1540E. The environmental test parameters are defined for each of the four risk classes (A, B, C, D).

G.2.1.4.1 Qualification

The qualification testing baseline defined in MIL-STD 1540E provides a demonstration that the design, manufacturing, and acceptance testing produces subsequent flight items that meet specification requirements for a minimum-risk program denoted as risk Class A. In Class B and Class C programs where it is necessary to demonstrate the flightworthiness of tested hardware the protoqualification strategy and flightproof strategies are alternatives that may be used at the system, subsystem, and unit levels. A combination of various applications of qualification and protoqualification strategies may also be considered to meet the needs for particular items, as deemed necessary. As in the case for protoqualification, the higher risk of deviating from qualification may be partially mitigated by enhanced development testing and by increasing the design margin. These strategies are particularly intended for use in space vehicle programs that have a very limited number of vehicles, typically one to three. Care must be exercised to ensure that an acceptable balance of demonstrated design margin, workmanship screening, and remaining life for flight is achieved for programs pursuing these options.

G.2.1.4.2 Protoqualification Strategy

The protoqualification test strategy (Risk Class B) consists of designing hardware to qualification levels, testing the first flight hardware to protoqualification levels to verify design, and testing subsequent flight hardware to acceptance levels to screen workmanship defects.

G.2.1.4.3 Acceptance

Regardless of the program strategy used all units need to be acceptance tested. Acceptance tests are conducted on each deliverable item to demonstrate quality of unit workmanship and performance to specifications. Acceptance testing is intended to stress screen items to precipitate failures due to latent defects in parts, processes, materials, and workmanship. The purpose of stress screening is to reveal defects related to workmanship or materials. Enhanced test conditions may be required to achieve perceptive screening.

If the equipment is to be used by more than one program or in different vehicle locations, the acceptance test conditions are developed to envelop a composite of the worst-case applications. The test baseline can be tailored for each program, considering both the required and other directed tests (e.g., mass properties testing) not covered in this standard. For certain items the specified acceptance test environments could result in physical deterioration of materials or other damage. In those cases, less severe acceptance test environments that still satisfy the system operational requirements may be used.

G.2.1.4.4 Flightproof Strategy

The flightproof test strategy, denoted as Class C, subjects each flight item to a flightproof test that is an enhanced acceptance test using the protoqualification level, while retaining the acceptance duration. Repeated acceptance testing may or may not be enhanced depending on the significance of hardware modifications during the acceptance program. The risk taken is that there has been no formal demonstration of remaining life for flight. This is a lesser risk than accepted for flight of a protoqualification item since the flightproof test duration is less than that for protoqualification. However, this risk is accepted in the flightproof strategy for all flight items. This risk may be traded against the additional confidence gained that each flightproof item will meet performance requirements in flight after having successfully passed testing beyond the maximum expected flight environments (MPE or MPT). Thus, flightproof testing is a check on the adequacy of the capability of each flight item, considering build variability or defects introduced due to handling or testing. This strategy may be the most reasonable for a program anticipating the procurement of fewer than five vehicles and where the design is expected to evolve such that each of the vehicles may be somewhat different than its predecessor(s).

G.2.1.4.5 Combination Strategy

Various combinations of strategy may be considered, depending on specific program considerations and the degree of risk deemed acceptable. For example, the protoqualification strategy for units (MIL-STD 1540E 4.3.3) may be combined with the flightproof strategy for the vehicle. In other cases, the flightproof strategy would be applied to some units, subsystem, or system peculiar to a single mission, while the protoqualification strategy may be applied to some units, subsystem, or system. In such cases, the provisions of each method would apply and the resultant risk would be increased correspondingly and program risk (Class B, C, or D) evaluated.

G.2.1.5 Tailoring

It is intended that MIL-STD-1540E test requirements be tailored to each specific program class after considering the design complexity, design margins, vulnerabilities, technology state of the art, in-process controls, mission criticality, life cycle cost, number of vehicles involved, prior usage, and acceptable risk. The tailored requirements shall achieve a level of verification equivalent to the baseline requirements described herein. However, when the procuring agency selects a design and verification strategy level (Reference MIL-HDBK-343) resulting in variation (Protoqualification, Flightproof, Combinations, etc.) from the baseline level the requirements, MIL-STD-1540E shall be tailored to accomplish that risk strategy. Because testing represents such a large expense, good management requires optimum tailoring of the test program to assure that a cost effective program is achieved for any procurement strategy. On one hand, any excessive testing clearly represents a waste of money and time. On the other hand, an undetected deficiency or failure can result in an unsuccessful launch or shortened orbital life. The preponderance of evidence is, as expected, that the use of extensive testing and other quality assurance provisions that are based upon those used for previously successful programs is the most cost effective approach. For high reliability space programs, testing costs represent a significant percentage of the cost of each vehicle.

G.2.1.5.1 Tailoring Guidelines

Specific tailoring may generally be based on the Contracting Agency choice of Risk Classes defined as A, B, C, or D.

G.2.1.5.2 Tailoring for Class A

- High, (A) value program using Table 4A or 4B test matrix A column with tailoring only when there is proof of insignificant risk (Qualification approach)

- The qualification at unit and system levels is the A standard

- The use of protoqualification at unit and/or system levels may be considered a B+ program

- National value criticality: use of maximum integration and test performance and design verification

- Schedule high criticality: Extensive test verification

- Launch Vehicle: Extensive evaluation of new units and new environments (less if LV requirements well known)

- Launch Facility: Requirements are well known and highly controlled

- Heritage unit/subsystem: Test verification is well documented

- Requalification of modifications of heritage designs with new or old heritage vendors/parts

- Full qualification to Table 4A or 4B test matrix A for new hardware including engineering model development testing test for highly complex designs

- Use of established contractors with positive previous performance:
  - High level of conformance to Table 4A or 4B matrix A encompassing Best Practices, COTS, and oversight, reviews
  - Established processes based on Lesson Learned for design, fabrication, integration, and test.

- Verification Process Documentation
  - Complete parts/module screening
  - Complete 100% unit level screening

G.2.1.5.3 Tailoring for Class B

- High to Nominal, (AB) value program using Table 4A or 4B matrix B (Protoqualification approach)

- National value criticality: use of maximum integration and test performance and design verification

- Schedule high criticality: reduced test verification Protoqualification margins

- Launch Vehicle: Evaluate new environments (less if LV requirements well known)

- Launch Facility: Requirements known

- Heritage unit/subsystem: deletion of margin testing 100% screening (Acceptance level)

- Modifications of heritage designs with new or old heritage vendors/parts

- New hardware complexity/state of art design: margin testing and engineering model development test

- Contractor capability and previous performance, well proven:
  - Best Practices, COTS, Level of oversight, reviews
  - Lesson Learned, design, fabrication, integration and test.

- Repeat vehicle: delay some verification to vehicle and/or no margin testing (Acceptance only)
  - Reduction in parts/module screening
  - 100% unit screening (Acceptance level)
- Verification Process Full Documentation

G.2.1.5.4 Tailoring for Class C

- Nominal to Low (C) value program using Table 4A or 4B matrix C (Flightproof or partial Protoqualification approach)
- National value low criticality: use of minimum to nominal integration and test performance and design verification
- Schedule low criticality: reduced test verification
- Launch Vehicle: evaluate new environments (less if LV requirements well known)
- Launch Facility: Requirements known
- Heritage unit/subsystem: deletion of margin testing or partial screening
- Modifications of heritage designs with new or old heritage vendors/parts
- New hardware complexity/state of art design: selected protoqualification, selected engineering model dev. test
- Contractor capability and previous performance proven:
  - Best Practices, COTS, Level of oversight, reviews
  - Lesson Learned, design, fabrication, integration and test.
- Repeat vehicle: delay selected verification to vehicle and/or no margin testing
  - Reduction in parts/module screening
  - Reduction in unit screening, selected next level screen
- Limited Verification Documentation

G.2.1.5.5 Tailoring for Class D

- Low (D) value program using Table 4A or 4B matrix D
- National value low criticality: use of minimum integration and test performance and design verification
- Schedule low criticality: reduced test verification

- Launch Vehicle: evaluate new environments (less if LV requirements well known)

- Launch Facility: Requirements known

- High use of Heritage unit/subsystem: deletion of margin testing or screening, selected flightproof and/or selected acceptance

- Some modifications of heritage designs with new or old heritage vendors/parts, selected flightproof

- Little new hardware : some engineering model dev. test

- Contractor capability and previous performance:
  - Best Practices, COTS
  - Potential new unproven vendors

- Repeat vehicle: delay verification to vehicle and/or no margin testing
  - Considerable reduction in parts/module screening
  - Considerable reduction in unit screening

- Minimum Verification Documentation

G.2.1.6 Government Policies/Practices

MIL-STD-1540E is applicable to the procurement of space system hardware as a compliance document for the establishment of baseline test requirements for the strategy selected. The test requirements therein focus on design verification and the elimination of latent defects to help ensure a high level of confidence in achieving successful space missions.

G.2.2 Implementation over the Life Cycle of the Acquisition

G.2.2.1 Strategy of Requirements Application by Program Phase

The complete test program for launch vehicles, upper-stage vehicles, and space vehicles encompasses development, qualification, acceptance, system, pre-launch validation, and post-launch validation tests. Test methods, environments, and measured parameters shall be selected to permit the collection of empirical design or performance data for correlation or trending throughout the test program.

A satisfactory test program requires the completion of specific test objectives in a specified sequence. The test program encompasses the testing of progressively more complex assemblies of hardware and computer software. Design suitability should be demonstrated in the earlier development tests prior to formal qualification testing. All qualification testing for an item should be completed, and design improvements incorporated, prior to the initiation of flight hardware acceptance testing. In general, hardware items subjected to qualification may be eligible for flight, provided suitable analyses, refurbishment, and verification are completed. The test plan for verification follows the pyramid test philosophy. That is, the requirements and hardware/software function are verified at the lowest level possible, where test perceptivity and environmental stress is usually greatest.

G.3 Contract Products Containing Test Specifications

G.3.1 Requests for Proposal (RFP)

During the proposal phase, instructions and explanations are generated for the bidders in order to obtain the appropriate data to evaluate source selection. Sections dealing with environmental verification compliance and reference documents provide the instructions for tailoring based on the buyers desired procurement class. The expected environmental testing for the four classes is given Tables 4A and 4B.

G.3.2 Contractor Statement of Work (CSOW)

The CSOW contains several locations of environmental verification tasks including a verification matrix for engineering requirements. Also, relevant CDRLs for environmental verification such as test plans, procedures, reports, and supporting analysis are specified.

G.3.3 Technical Requirements Document

For the environmental test phases, a verification plan based on the contract class is generated to reflect which of the four methods to be used to accomplish requirements verification. This plan represents requirement verification flow-down and -up, and is used for requirements verification sell-off.

G.3.4 Integrated Master Plan

The IMP is the central management plan that becomes a binding part of the contract. IMP

Narrative is provided for environmental verification of requirements that include all major tailored test compliance documents.

G.3.4.1 Deliverables

- Tailored MIL-STD-1540E and any tailored supporting compliance documents
- Launch Vehicle ICD
- SV, Bus PL Integration and Test Plans
- SV, Bus PL individual specification verification ledgers (at CDR)
- Unit, subsystem, SV Environmental Requirements Specification
- Test Verification ledger with substantiation documentation of requirements compliance including subsystem and SV environmental test reports (At related sell offs)

G.4 Lessons Learned

- Properly maintain and check test facilities.
- Implement overtest protection (such as accelerometer stop circuits on hardware).

- Take risks of overtesting during vibration tests into account. In particular, large satellites should typically be acoustically tested.

- Step up vibration tests from one-third to one-half of the full level so that the required force can be evaluated before proceeding. Test procedures, set up, and data should be thoroughly checked to account for operator mistakes and avoid damage.

- Cables and connectors must be designed to withstand vibration-induced stresses.

- Margins must be reserved both in dynamic input estimation and in design.

- The interfaces among different organizations, particularly between the space vehicle side and the launcher side, frequently lead to problems. Independent analysis is often necessary.

G.5 References

[1] TOR-2006(8586)-4591 Space Vehicle Test and Evaluation Handbook

[2] NASA-HDBK-7005, “Dynamic Environmental Criteria”

[3] NASA GEVS-SE, “General Environmental Verification Specification for STS & ELV Payloads, Subsystems and Components”

[4] GSFC NAS5-15208, “Aerospace Systems Pyrotechnic Shock Data”

[5] Harry Himelblau and Allan G. Piersol, IES-RP-DTE012.1, “Handbook for Dynamic Data Acquisition and Analysis”

[6] Dave S. Steinberg, Vibration Analysis for Electronic Equipment

[7] Leo L. Beranek, “Noise and Vibration Control Engineering”

[8] NASA TN D-1836, “Techniques for Predicting Localized Vibratory Environments of Rocket Vehicles”

[9] NASA SP-8072, “Acoustic Loads Generated by the Propulsion System”

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Table 4A Test Requirements for Space Vehicles					
Procurement of 3 Satellites and up		**Program Risk Classification**			
Vehicle Level		**A**	**B**	**C**	**D**
	1st S/V non-flight (Qual)	Qualification	Not applicable	Not applicable	Not applicable
	Thermal margin	10^{0}C MPT/8cyc.	Not applicable	Not applicable	Not applicable
	Vibration margin	6dB MPE*/3 Min	Not applicable	Not applicable	Not applicable
	Acoustic margin	6dB MPE*/3 Min	Not applicable	Not applicable	Not applicable
	Shock margin***	6dB/3 Exposures	Not applicable	Not applicable	Not applicable
	1st S/V flight	ProtoQual	ProtoQual	FlightProof	**
	Thermal margin	5^{0}C MPT/4cyc.	5^{0}C MPT/4cyc.	5^{0}C MPT/4cyc.	
	Vibration margin	3dB MPE*/2Min	3dB MPE*/2Min	3dB MPE*/1Min	
	Acoustic margin	3dB MPE*/2 Min	3dB MPE*/2 Min	3dB MPE*/1 Min	
	Shock margin***	3dB/2 Exposures	3dB/2 Exposures	3dB/1 Exposure	
	All subsequent flight S/V	Acceptance	Acceptance	Acceptance**	**
	Thermal margin	0^{0}C MPT/4cyc.	0^{0}C MPT/4cyc.	0^{0}C MPT/4cyc.	
	Vibration margin	0dB MPE*/1Min	0dB MPE*/1Min	0dB MPE*/1Min	
	Acoustic margin	0dB MPE*/1Min	0dB MPE*/1Min	0dB MPE*/1Min	
	Shock margin	0dB/1 Exposure	0dB/1 Exposure	0dB/1 Exposure	
Payload Level (Same as Vehicle)					
Unit Level		**A**	**B**	**C**	**D**
	1st Unit non-flight	Qualification	Not applicable	Not applicable	Not applicable
	Thermal margin	10^{0}C MPT*/27cyc.	Not applicable	Not applicable	Not applicable
	Vibration margin	6dB MPE*/3 Min	Not applicable	Not applicable	Not applicable
	Acoustic margin	6dB MPE*/3 Min	Not applicable	Not applicable	Not applicable
	Shock margin	6dB MPE*/3 Exposures	Not applicable	Not applicable	Not applicable
	1st Unit flight	ProtoQual	ProtoQual	FlightProof	**
	Thermal margin	5^{0}C MPT*/27cyc.	5^{0}C MPT*/27cyc.	5^{0}C MPT*/14cyc.	
	Vibration margin	3dB MPE*/2Min	3dB MPE*/2Min	3dB MPE*/1Min	
	Acoustic margin	3dB MPE*/2 Min	3dB MPE*/2 Min	3dB MPE*/1 Min	
	Shock margin	3dB MPE*/2 Exposures	3dB MPE*/2 Exposures	3dB MPE*/1 Exposure	
	All subsequent units	Acceptance	Acceptance	FlightProof**	**
	Thermal margin	0^{0}C MPT*/14cyc.	0^{0}C MPT*/14cyc.	5^{0}C MPT*/14cyc.	
	Vibration margin	0dB MPE*/1Min	0dB MPE*/1Min	3dB MPE*/1Min	
	Acoustic margin	0dB MPE*/1Min	0dB MPE*/1Min	3dB MPE*/1 Min	
	Shock margin	0dB MPE*/1 Exposure	0dB MPE*/1 Exposure	3dB MPE*/1 Exposure	
		*Envelope of MPE or MPT and 1540 Minimum Grms or delta T.			
		**FlightProof or Acceptance or None or Combinations depending on verification tailoring			

***Shock device methodology provides margin over flight may be utilized for unique verifications. Typical testing performed with actuation of flight release devices is 0dB for qual and protoqual.

Note: Tailoring to each program class is not straight forward and requires input from subject matter experts (SME) based on specific program details.

Table 4B Test Requirements for Space Vehicles

Procurement of 1 or 2 Satellites		Program Risk Classification			
Vehicle Level		**A**	**B**	**C**	**D**
	1st S/V non-flight (Qual)	Not applicable	Not applicable	Not applicable	Not applicable
	Thermal margin	Not applicable	Not applicable	Not applicable	Not applicable
	Vibration margin	Not applicable	Not applicable	Not applicable	Not applicable
	Acoustic margin	Not applicable	Not applicable	Not applicable	Not applicable
	Shock margin	Not applicable	Not applicable	Not applicable	Not applicable
	1st S/V flight	ProtoQual	FlightProof	FlightProof	**
	Thermal margin	5^0C MPT/4cyc.	5^0C MPT/4cyc.	5^0C MPT/4cyc.	
	Vibration margin	3dB MPE*/2Min	3dB MPE*/1Min	3dB MPE*/1Min	
	Acoustic margin	3dB MPE*/2 Min	3dB MPE*/1 Min	3dB MPE*/1 Min	
	Shock margin	3dB/2 Exposures	3dB/ Exposure	3dB/1 Exposure	
	Subsequent flight S/V	Acceptance	FlightProof	FlightProof	**
	Thermal margin	**0**^{0}C MPT/4cyc.	5^0C MPT/4cyc.	5^0C MPT/4cyc.	.
	Vibration margin	0dB MPE*/1Min	3dB MPE*/1Min	3dB MPE*/1Min	
	Acoustic margin	0dB MPE*/1Min	3dB MPE*/1 Min	3dB MPE*/1 Min	
	Shock margin	0dB/1 Exposure	3dB/ Exposure	3dB/1 Exposure	
Payload Level (Same as Vehicle)					
Unit Level		**A**	**B**	**C**	**D**
	1st Unit non-flight (Qual)	Qualification	Not applicable	Not applicable	Not applicable
	Thermal margin	10^0C MPT*/27cyc.	Not applicable	Not applicable	Not applicable
	Vibration margin	6dB MPE*/3 Min	Not applicable	Not applicable	Not applicable
	Acoustic margin	6dB MPE*/3 Min	Not applicable	Not applicable	Not applicable
	Shock margin	6dB MPE*/3 Exposures	Not applicable	Not applicable	Not applicable
	1st Unit flight	ProtoQual	FlightProof	FlightProof	**
	Thermal margin	5^0C MPT*/27cyc.	5^0C MPT*/14cyc.	5^0C MPT*/14cyc.	.
	Vibration margin	3dB MPE*/2Min	3dB MPE*/1Min	3dB MPE*/1Min	
	Acoustic margin	3dB MPE*/2 Min	3dB MPE*/1 Min	3dB MPE*/1 Min	
	Shock margin	3dB MPE*/2 Exposures	3dB MPE*/1 Exposure	3dB MPE*/1 Exposure	
	All subsequent units	Acceptance	FlightProof	FlightProof	**
	Thermal margin	**0**^{0}C MPT*/14cyc.	5^0C MPT*/14cyc.	5^0C MPT*/14cyc.	.
	Vibration margin	0dB MPE*/1Min	3dB MPE*/1Min	3dB MPE*/1Min	
	Acoustic margin	0dB MPE*/1Min	3dB MPE*/1 Min	3dB MPE*/1 Min	
	Shock margin	0dB MPE*/1 Exposure			
		*Envelope of MPE or MPT and 1540 Minimum Grms or delta T.			
		**FlightProof or Acceptance or None or Combinations depending on verification ta loring			

Note: Tailoring to each program class is not straight forward and requires input from subject matter experts (SME) based on specific program details.

Appendix H. Tailoring Parts, Materials, and Process Requirements

Dr. Steven Robertson
Mr. Larry Harzstark

H.1 Introduction

H.1.1 Overview

The design selection, application, procurement, and operation of Parts, Materials and Processes (PMP) throughout the life cycle of Space and Launch vehicles are critical to mission success. The requirements that drive the need for robust designs are dependent on robust PMP that are carefully selected, fully qualified, and have a demonstrated long life and tolerance to the harsh environmental conditions of space. Program Managers often try to achieve savings in the procurement of PMP, and this may be acceptable for certain classes of space vehicles where the risk is calculated and planned.

PMP specifications and standards are designed to meet space system requirements, and any tailoring would entail a risk (possibly compounded by actions or lack of actions during the overall system acquisition process) that must be weighed against mission criticality, performance, and life expectancy.

H.1.2 Definitions

PMP are those basic elements that are required to manufacture the desired end product.

A **part** is defined as one piece, or two or more pieces joined together, which are not normally subjected to disassembly without destruction or impairment of its designed use.

A **material** is a metallic or nonmetallic element, alloy, mixture, or compound used in a manufacturing operation, which becomes either a temporary or a permanent portion of the manufactured item.

A **process** is an operation, treatment, or procedure used during a step in the manufacture of a material, part, or assembly.

PMP engineering is a critical engineering discipline comprising a set of skills and knowledge used to select, apply, design, and manage PMP to manufacture an end product.

H.2 Requirements

H.2.1 Applicable Specifications and Standards

Detailed PMP requirements for space programs are defined in two Aerospace technical operating reports (TOR); together they form a complete set of standards and requirements.

TOR-2006(8583)-5235 Rev A [Also published as SMC-S-09(2009)]	"Parts Materials and Processes Control Program for Space and Launch Vehicles"	Establishes the management requirements for the preparation, implementation, and operation of a parts, materials, and processes control program for use during the design, development, manufacture, assembly, integration and test of space and launch vehicle systems.
TOR-2006(8583)-5236, Rev A [Also published as SMC-S-10(2009)]	"Technical Requirements for Electronic Parts, Materials and Processes Used in Space and Launch Vehicles"	Establishes the minimum technical requirements for electronic parts, materials, and processes used in the design, development, and fabrication of space and launch vehicles.

Key to a successful acquisition strategy is the identification of the PMP requirements for the program as to parts selection, screening, qualification, quality conformance inspection (QCI), space quality baseline, approvals for non-standard parts, use of heritage parts and designs, radiation, new technology insertion and lot acceptance data. Typically a contractor prepares a PMP plan that defines exactly how the program will function and how the program PMP requirements will be implemented. The plan will include flowdown of PMP requirements to subcontractors and how these subcontractors will be managed, the requirements for screening, qualification, QCI and data, non-conforming items and the responsibilities and make-up of the PMP Control-Board (PMPCB). Typically at the beginning of the contract, it is established that the customer has approval/disapproval authority over all PMPCB actions.

While it is recognized that developers' current procurement practices tend to select many of their parts and materials from the qualified product list (QPL) and qualified manufacturing line (QML), certified by the Defense Logistics Agency (DLA) Land & Maritime (formerly Defense Supply Center Columbus), it remains the responsibility of the developers and procuring agency to assure that the requirements of the program have been imposed and are being met. Where QPL/QML-specified parts are not available or where parts do not meet program requirements, the developer must either upgrade the devices or prepare a procurement source control drawing (SCD) to impose those specific requirements. Program approved selection and as-designed PMP lists should be reviewed to verify that the parts selection and the source control drawings reflect program requirements, including screening, qualification, and quality conformance inspection.

The equipment specification for a satellite/payload defines the specific performance requirements when deployed in a particular orbit and calls for a reliable, dependable, and within-specification performance during the mission. The estimated operating life requirement defines the performance during the mission. For long duration and high importance national security missions (Class A) it is necessary to select suppliers and part types that offer assured high reliability and performance as verified by in-process controls, screening, qualification and quality control inspections. Reliable operation in space must be addressed by selecting components having the highest (available) reliability and assurance levels. The PMP specifications should be put on contract as compliance documents with all applicable deliverable items. Contractors must supply a PMP plan that incorporates a government certified program or self-certification program that meets the intent of the government program. For short duration lower cost missions, other procurement strategies may be applied with the implication of greater risk acceptance.

H.2.2 Tailoring

The top-level minimum PMP technical requirements are listed in the first column of Table H-1 with recommended compliance to these requirements listed for each class of program.

Class A space systems should apply all the technical requirements listed as contractual requirements with minimum tailoring consideration in the acquisition. The PMP plan should detail how requirements will be met and tailored and modified in accordance with requirements definition through the major milestone reviews. PMP entrance/exit criteria should be imposed for the system requirements review (SRR), the system design review (SDR), and the preliminary design review (PDR) to include government review and approval of the PMP plan at each major milestone. New technology insertion, radiation assurance, counterfeit, and prohibited parts should be specifically addressed in detail during the early phases of the program. Entrance and exit criteria for the PDR includes details on the PMP characterization data, program approved parts list, approved PMP selection lists, preliminary parts lists, and PMP approval requests. The contractor should deliver preliminary stress/derating analysis and reliability models/analysis. All internal Technology Readiness Assessments for new technology insertion should be completed by PDR.

The critical design review (CDR) should include delivery of the designed parts lists; screen, qualification, radiation, and DPA data; Material Review Board (MRB) decision reports on non-conforming PMP; and final stress/derating analysis and reliability models including input assumptions and exceptions for PMP. As the space vehicle is being developed the contractor should deliver end item data packages; failure analysis reports and mitigation/corrective actions; deviations and waivers; as-built parts lists; and build/manufacturing discrepancy reports and failure review board decisions.

Similarly, Class B systems should apply all the requirements that may be tailored slightly to meet the unique needs of the Class B system.

Class C system requirements should incorporate tailored requirements commensurate with the risk posture of the program and there will be many differences, i.e., allowing lower grade, lower cost EEE parts, and less rigor in implementation of program requirements. Parts are rarely Class S because of the short acquisition time and expense and in consideration that the life time of operation is usually only one year. However, the basic tenets of the PMP requirements are still executed but usually to a lesser extent than for Class A/B systems, allowing more tailoring to the detailed requirements. For example, smaller sample sizes may be selected for lot sample testing such as for DPA. Adherence to a parts plan is maintained and actively supported by PMP engineers as needed and the basic requirements still form an important part of the PMP management practices, though the plan and detailed requirements will have less rigor. Programs generally use previously tested/flown materials or characterize new materials. Acceptance test of sample lots of procured materials is required. The contract should include requirements that a PMP plan be developed and delivered by the contractor with government involvement in the PMP management tasks such as the PMPCB.

Class D programs, for the most part, are acquired through study proposals and less formal contract agreements. Class D programs rarely have specific contractual requirements other than those imparted by applicable safety standards or interface requirements. PMP management is left to the experimenter/developer. Commercial parts are usually used and it is strongly recommended that materials and parts be assessed for application and life limits.

Table H-1. PMP Requirements for Different Space Vehicle Risk Classes

PMP Requirements	Class A	Class B	Class C	Class D
Part, Materials, and Processes Control as part of the Overall System Acquisition Process	Yes - Rigorous	Yes - Rigorous	Yes - General	Recommended
Part, Materials, and Processes Control Plan	Yes - Detailed	Yes - Detailed	Yes - General	Recommended
Parts, Materials, and Processes Control Board	Yes	Yes	Yes	Optional
PMP Selection Process	Yes Space Quality Baseline	Yes Space Quality Baseline	Yes Planned order of precedence	Best Commercial Practice
PMP Procurement From OEM/Authorized Distributor	Yes	Yes	Yes	Optional
Part and Circuit Stress Analysis	Yes All circuits	Yes All circuits	Yes Critical circuits minimum	Optional
Worst Case Analysis	Yes	Yes	Yes	Optional
Parts Derating Criteria	Yes	Yes	Yes	Optional
Prohibited Materials	Yes - include validation	Yes - include validation	Yes - less validation rigor	Optional
EEE Part Quality	Per Space Quality Baseline Class SV Grade 1	Per Space Quality Baseline Class SV Grade 1	Class B/Q Grade 2	Class C - commercial
PMP Subcontractor and Procurement Management	Yes	Yes	Yes - less rigor	Optional
Electrostatic Discharge Prevention and Control	Yes	Yes	Yes	Recommended - Safety and interfaces minimum
PMP Destructive Physical Analysis	Yes - all part types	Yes - all part types	Yes - critical part types, small sample sizes	Optional
P&M Radiation Hardness Assurance Control	Yes - with testing and verification	Yes - with testing and verification	Yes - critical risk areas	Optional
PMP Failure Analysis	Yes - all failures	Yes - all failures	Yes - Limited verification	Yes-Limited verification
Approved PMP Selection List	Yes	Yes	Yes	Optional
As-Designed PMP List	Yes - full system, electronically searchable	Yes - full system, electronically searchable	Yes - full system	Optional
As-Built PMP List Highlighted by Contractor	Yes - full system, electronically searchable	Yes - full system, electronically searchable	Yes - full system	Optional but Recommended
Parts, Materials or Processes Approval Request	Yes	Yes	Recommended	Optional
Counterfeit PMP Control	Yes	Yes	Yes - less rigorous	Optional but Recommended
Corrosion Prevention and Control	Yes	Yes	Yes - less rigorous	Optional
Government Oversight and Right of Approval	Yes	Yes	Optional	Optional

H.3 Contract Language

H.3.1 SOW/RFP

Requirements for PMP are usually included in the Systems Engineering, Mission Assurance, or Specialty Engineering Sections of the RFP or SOW. The basic PMP requirements flow down document should be identified as well as specific requirements of interest for the class of the program, e.g., requirements listed per Table H-1.

SOW Program Task Language Examples

PMP requirements language for an SOW or RFP may include (but is not limited to) the following tasks, tailored for the program class, Table H-1:

The contractor shall implement a Parts, Materials, and Processes Control Program in accordance with the following documents: TOR-2006(8583)-5235 Rev A (or SMC Standard SMC-S-009 (2009)) Parts, Materials and Processes Control Program for Space and Launch Vehicles and TOR-2006(8583)-5236 Rev A (or SMC Standard SMC-S-010 (2009)) Parts, Materials and Processes Technical Requirements for Space and Launch Vehicles (see Table A-1).

Details of the proposed PMP Control Program and requirements shall be documented into a plan and delivered to the government for review and approval. If the contractor takes exceptions to these requirements or any part therein then the contractor shall identify the differences between these PMP requirement documents and the proposed requirements for PMP and provide those differences to the government for review.

Prime contractor shall establish a PMPCB (Parts, Materials, and Processes Control Board) to ensure all aspects of the PMP requirements are met across the program. The contractor shall work with the government to develop a process and mutual agreement for notice of PMPCB meetings/activities and delivery of supporting data prior to the meetings. The contractor shall record and deliver the attendance list and minutes of the meetings.

Prime contractor shall ensure an approved Program Preferred Parts Selection List is available and shall develop an electronically searchable As-Designed PMP list and As-Built PMP List. The As-Designed and As-Built PMP lists shall include all subcontractors' data.

Prime contractor shall ensure all PMP selected for use on the program have been approved by the PMPCB. The contractor shall select PMP used to fabricate the contract end item by considering the operational requirements including temperature limits, humidity, radiation, contamination, and life expectancy. The contractor shall consider the following properties in selecting proper parts and materials: flammability and outgassing (ambient and vacuum) characteristics, thermal and mechanical fatigue properties, Electrostatic Discharge (ESD), dissimilar metals, corrosion including stress corrosion, and hazardous materials.

Prime contractor shall ensure all Source Control Documents have been reviewed and approved by the PMPCB including subcontractor documents and that all PMP have been qualified in accordance with the requirements established for the program.

Prime contractor shall ensure all applicable PMP requirements have been flowed down contractually to the subcontractors and suppliers/vendors. The prime contractor shall develop a methodology to monitor/manage the subcontractors and suppliers/vendors compliance to the PMP requirements.

Prime contractor shall ensure procurements of long lead material and parts are properly implemented across the program.

Prime contractor shall require a review by the PMPCB of any lot, DPA or radiation test failures for procured PMP.

The contractor shall notify the government upon disposition of any Government-Industry Data Exchange Program (GIDEP) alert that affects this program.

The prime contractor shall require the PMPCB to review and approve any residual PMP that is planned to be utilized on this program. This review and approval shall include any waivers or deviations and GIDEP alerts or advisories.

The prime contractor shall ensure that a Prohibited PMP List is available and updated.

The prime contractor shall require notification of any technical/administrative issues on procurements to help resolve the concerns. This includes impacts from GIDEP.

The prime contractor shall develop a counterfeit parts plan and flow down to all subcontractors. The prime contractor shall perform audits of the subcontractors' compliance to the counterfeit plan.

The prime contractor shall require an obsolescence plan from all subcontractors with the identification of all known or potential obsolete parts and materials.

The prime contractor and subcontractor's supplier material review records for use-as-is or repair/rework dispositions shall be available on the prime contractor's discrepancy reporting system.

The prime contractor shall ensure the PMPCB is made aware of all failures and nonconforming PMP and the PMPCB shall provide inputs and recommended dispositions to the MRB for all nonconforming PMP product.

The contractor shall perform Manufacturing/Producibility tasks such as performing manufacturing trades, analyses, and plans as needed to define, evaluate, and select manufacturing methods, processes and process controls to meet functional and performance requirements.

The following list of CDRLs are possible contract delivery items:

- PMP Program Plan
- Evaluation of differences between PMP requirements from SMC documents versus proposed PMP requirements
- Program Preferred Parts Selection List
- As-Designed PMP List
- As-Built PMP List
- Radiation Assurance Plan
- Counterfeit Plan
- Obsolescence List of Parts and Materials

H.3.2 IMP/IMS

The Integrated Master Plan (IMP) and Integrated Master Schedule (IMS) shall fully integrate and incorporate the Parts, Materials and Processes program management tasks, defining completion time periods within the program plan/schedule, including entrance/exit criteria at each appropriate major program milestone such as SSR, PDR and CDR. For example, as discussed earlier, PDR should include such items as the approved PMP selection lists, PMP approval requests, long lead items schedules, preliminary stress/derating analysis, reliability models/analysis, and internal Technology Readiness Assessments for new technology insertion. CDR should include delivery of the as-designed parts lists, procurement schedule issues, screen, qualification, radiation and DPA data, MRB decision reports on non-conforming PMP; and final stress/derating analysis and reliability models.

The time period in each program phase to which these analyses/items should be completed/delivered remain basically the same between the various classes of programs. What changes is the requirements for said analyses/items such that some of the tasks that are performed for Class A programs will not be performed for Class C or D programs, or may not be a contractual deliverable, and therefore will not be available for review.

H.4 Lessons Learned

Prohibited Materials (Pure Tin Escapes): Prohibited materials if not properly managed and prevented from use in space systems can cause on-orbit failures and large impacts to cost and schedule following discovery late in the acquisition cycle. For example, pure tin finishes in electronic hardware can cause tin whisker growth and short circuit failure risk. Many contractors have relied on the supplier's certification of compliance that states no pure tin is used. This is totally insufficient as a prohibited materials prevention practice where, in many cases, it has been found that the parts may actually contain the prohibited material. It is important that a more proactive method be employed such as evaluating every lot for prohibited materials by non-destructive analysis techniques such as x-ray fluorescence (XRF) or energy dispersive spectroscopy (EDS) using a scanning electron microscope. For Class C and D programs where reliance of more commercial practices/parts increases, the risk of prohibited material impact will increase, therefore additional rigor may be warranted and should be part of the program risk decision process.

Counterfeit: Many examples of "Counterfeit" parts have been observed when procuring from an independent distributor or broker and not from the Original Equipment Manufacturer (OEM) or authorized/franchised distributor. All procurements must be made through the OEM or authorized/franchised distributor to mitigate the risks of counterfeit parts. Inspection and DPA should also be performed as part of counterfeit prevention practices. For Class C and D programs where reliance of more commercial practices/parts increases, the risk of procurement practices that rely on independent distributors/brokers may increase, resulting in a greater risk of counterfeit parts.

Qualification: Regardless of the parts selection philosophy, the parts and technology should be qualified at minimum for the application to show margin over mission regardless of the class of program. For Class A and B programs, a great deal of rigor is exercised in all aspects of the PMP management program, including in-process controls, screening, qualification and quality conformance inspection (QCI) as well as in-application derating, to ensure a highly reliable product. Though tailoring may be employed to reduce the requirements rigor for shorter mission programs and programs that can assume greater risk, a balance of requirements including derating is still important to meet the minimum mission goals. For Class C missions, where single string designs are commonly used, parts quality is an important risk mediator. If any requirement area is reduced dramatically, such as elimination of QCI, then rigor in the other areas may need to improve as compensation.

Qualification of the PMP is one of the critical management aspects that should never be eliminated completely.

GIDEP: Regardless of the class of program, it is important to receive and review GIDEP alerts and advisories, as well as other PMP issue information from other forums such that a risk impact review of PMP used on the program can be performed. Addressing these potential issues as early as possible in the acquisition phase has the greatest impact in reducing potential risk at the lowest cost/schedule impact. The capability to know the PMP used in the space system, such as through PMP lists, is essential for timely resolution risk reduction.

H.5 References

Policy-related

Specifications and Standards

Aerospace TOR-2006(8583)-5235 Revision A [Also published as SMC-S-09(2009)]	Parts, Materials, and Processes Control Program for Space and Launch Vehicles, 30 September, 2008
Aerospace TOR-2006(8583)-5236 Revision A [Also published as SMC-S-10(2009)]	Technical Requirements for Electronic Parts, Materials, and Processes Used in Space and Launch Vehicles, 30 September 2008
Aerospace TOR-98(1412)-1 Revision A	Electronic Parts, Materials, and Processes Control Program for Expendable Launch Vehicles, 01 January 2004
MIL-STD-1556B	Government/Industry Data Exchange Program (GIDEP) Contractor Participation Requirements, 24 February 1986

Technical Handbooks

MIL-HDBK-965	Acquisition Practices for Parts Management (for GIDEP Application Guidance Manual), 30 September 1996
Aerospace TOR-2007(8546)-6018 Revision A	Mission Assurance Guide
Aerospace TOR-2006(8506)-4494	Space Vehicle Systems Engineering Handbook, 31 January 2006
Aerospace TOR-2006 (8546)-4591	Space Vehicle Test and Evaluation Handbook, 06 November 2006

Deliverables

The following is a list of Data Item Description (DID) documents that form the typical instructions for deliverable PMP products through Contract Data Requirements Lists (CDRLs). These DIDs are older documents that would need to be tailored to appropriately reference the requirements of Aerospace TOR-2006(8583)-5235 Revision A and/or Aerospace TOR-2006(8583)-5236 Revision A.

DI-MISC-80526D 05 August 1998	Parts Management Plan
DI-MISC-80071E 05 August 1998	Parts Approval Request
DI-MISC-81277	Parts, Materials, and Processes Selection List, 27 July 1992
DI-RELI-80255	Failure Summary and Analysis Report, 17 October 1996
DI-RELI-80253 17 October 17 1986	Failed Item Analysis Report
DI-QCIC-80125B 05 May 2003	Government Industry Data Exchange Program (GIDEP) Alert/Safe-Alert Report
DI-MGMT-81453 23 January 1995	Data Accession List (DAL)
DI-MGMT-81334 01 February 2005	Contract Work Breakdown Structure (CWBS)
DI-MISC-81276A Date Unknown	As-Designed Parts, Materials and Processes List
DI-CMAN-81516 Date Unknown	As- Built Parts, Materials and Processes List

Appendix I. Tailoring Reliability Engineering Requirements

Roland J. Duphily
Gail A. Johnson-Roth
Acquisition Risk and Reliability Engineering Department

I.1 Introduction

I.1.1 Overview

Reliability engineering encompasses a set of analytical activities that include:

- Development of probabilistic system reliability requirements
- Analysis of failure modes and effects
- Identification and control of critical/limited life items, the development of probabilistic reliability models
- Determination of component/part failure rates
- Use of worst-case and parts stress analyses
- Analysis of accelerated life test data
- Implementation of a failure recurrence prevention system, which ensures that all failures are adequately driven to closure

A reliability plan that defines the process is prepared and submitted as a program contract data requirements list (CDRL) item with periodic updates. Contractors are responsible for planning and implementing a reliability program that is consistent with the program's risk tolerance posture and the contract requirements.

Reliability engineering is integral to the system design process and works closely with:

- Subsystem designers
- Risk management
- Parts, materials, and processes
- System safety
- Subcontractors
- Quality assurance
- Integration and test engineering
- Configuration management

Reliability engineering also tracks the design's ability to meet or exceed the product's reliability requirements. System reliability requirements are developed and included in system requirements documents. Reliability assessments of the hardware design characteristics against allocated requirements are performed by contractors to detect design deficiencies and functional performance risks, as well as ways to mitigate those risks early in the design process. The process begins during conceptual design and continues through the remaining program life cycle, which includes detail design, assembly, integration and test, and on-orbit problem resolution.

Reliability engineering requirements for Class A systems are designed to achieve 100 percent mission success for the mission life. Any tailoring of requirements entails a risk (which may be compounded by actions or lack of actions during the overall system acquisition process) that has to be weighed against mission criticality, performance, and life expectancy.

I.1.2 Definitions

System or device **reliability** is defined as the probability that the system or device will perform its intended functions for a specified period of time, under specified operating conditions.

Reliability engineering is a combination of engineering techniques and practices aimed at ensuring that the reliability level specified (numeric value) for a system or device will be achieved in its actual operation by the user.

I.2 Reliability Engineering Requirements

I.2.1 Applicable Specifications and Standards

Detailed reliability engineering requirements for a space program are defined in the following Aerospace technical operating report, TOR-2007(8583)-6889, "Reliability Program Requirements for Space Systems," 10 July 2007. This document prescribes general reliability requirements for space contracts involving:

- Design
- Development (both hardware and software)
- Fabrication
- Test and/or operation of space vehicles
- Space vehicle bus
- Payloads (including those supplied as government-furnished equipment and launch vehicles

This document specifies required contractor reliability data items to include the elements and attributes of a Reliability Program Plan and is the recommended standard to be put on contract as a compliance document. This appendix focuses on the tailoring of this specific standard. Reliability engineering directly draws on design development, and test results so therefore overlap with all aspects of the technical baseline.

Detailed descriptions of core reliability engineering processes and practices can be found in the following documents:

Aerospace TOR-2007(8546)-6018	"Mission Assurance Guide," 1 July 2007

Aerospace TOR-2006(8506)-4494	"Space Vehicle Systems Engineering Handbook," 30 November 2005 chapter 21 "Reliability Engineering"
Aerospace TOR-2009(8583)-8929	"Space Vehicle Reliability Engineering Tutorial for SMC-University," 13 January 2009
Aerospace TOR-2009(8591)-13	"Space Vehicle Failure Modes, Effects, and Criticality Analysis (FMECA) Guide," 15 June 2009
Aerospace TOR-2006(8583)-5236 (Also published as SMC-S-010)	"Parts, Materials, and Processes Technical Requirements for Space and Launch Vehicles," 2008

I.2.2 Requirements Lifecycle Application

Contractors are responsible for planning and implementing a reliability program that is consistent with the program's risk tolerance posture and the contract requirements. Most contractors have corporate manuals that describe their reliability engineering process. They also use commercial or home grown software tools to manage their reliability prediction, FMECA, and Failure Reporting and Corrective Action System (FRACAS) activities. All requirements are subject to tailoring to achieve an optimal reliability program that takes into account the programmatic and mission requirements.

The reliability engineering plan should detail how requirements will be met and tailored and modified in accordance with requirements definition through the major milestone reviews. Reliability engineering entrance/exit criteria should be imposed for the system requirements review (SRR), the system design review (SDR), and the preliminary design review (PDR) to include government review and approval of the reliability engineering plan at each major milestone.

The SRR demonstrates that mission and system level requirements are understood and adequately defined to meet mission /program objectives. Reliability engineering requirements should be defined at SRR and formally assessed for optimization, allocation and completeness by SDR to include evaluation of system analysis evaluation of adequacy of system design to accomplish mission objectives within constraints and acceptable risk. A draft reliability engineering plan should be provided at SDR that details reliability analysis, critical items list, and a description of the failure review and corrective action activities.

Entrance/Exit criteria for the PDR should include completion of reliability analysis and demonstration that results have been factored into the design. Analyses reviewed at that time could include:

- Probabilistic risk assessment
- Event tree/fault tree system analysis
- Failure mode and effects analysis
- Single-point failure assessment
- Reliability risk drivers (design issues)
- Worst-case analysis

All analyses should be further updated with appropriate results factored into the design by CDR. The reliability plan is formally delivered and baselined at CDR. The analyses products, particularly the FMECA and reliability predictions, are continually referenced and assessed against contractor manufactured component/builds through system integration and test and validated after product turnover. All system level test discrepancies must be fully addressed by the Failure Review Board and FRACAS processes. The reliability models and assessments continue to be referenced, assessed and updated through the life of the mission and are important tools in the course of any on-orbit anomaly investigations.

I.2.3 Tailoring

The reliability engineering requirements are applied at the discretion of the acquirer and are tailored to the specific requirements of a particular program or program phase beginning early in the Request For Proposal (RFP) development through issue of the contract. The tailoring may add additional requirements (tailor in/up) to satisfy program requirements or delete (tailor out) activities that may not be applicable to the program's needs taking into account cost, schedule, performance, or other constraints. The reliability requirements are specified in the Statement of Work (SOW) and/or compliance documents section of the RFP or contract. Class A programs nearly always require the contractor to deliver a Reliability Engineering Plan with government approval.

TOR-2007(8583)-6889, "Reliability Program Requirements for Space Systems," 10 July 2007 is the recommended compliance document for any Class A acquisition. The top level reliability engineering technical requirements from this document are listed in the first column of Table I-1 and should be applied as contractual requirements with minimum tailoring consideration in the acquisition of Class A space missions. Recommended tailoring approaches for the different space vehicle classes is provided in the table.

Table I-1. Reliability Engineering – Reliability Program Requirements (Space and Launch Vehicles)

Engineering Specialties – Reliability: TOR-2007(8583)-6889	Class A	Class B	Class C	Class D
Implement Formal Reliability Program Plan	Mandatory	Mandatory	Tailored	Optional
Reliability Requirements and Allocations	Mandatory	Mandatory	Mandatory	Optional
Monitor and Control Subcontractors and Suppliers	Mandatory	Mandatory	Mandatory	Optional
Program Reviews and Audits	Down to slice level	Down to unit level	System level	Optional
Failure Reporting, Analysis, and Corrective Action System (FRACAS)	Mandatory	Mandatory	Tailored	Optional
Failure Review Board (FRB)	Mandatory	Mandatory	Tailored	Optional
Reliability Predictions	High fidelity	High fidelity	Fidelity as appropriate	Optional
EEE Part Quality	Class S Grade 1	Class S Grade 1	Class B Grade 2	Class C
Failure Modes, Effects, and Criticality Analysis (FMECA)	All levels	All levels	All levels	As appropriate for safety and interface
Sneak Circuit Analysis	As needed	As needed	As needed	As needed
Parts, Materials, and Processes (PM&P) Program Interface	Mandatory	Mandatory	Mandatory	Mandatory for safety as required by launch provided
Critical Items	Mandatory	Mandatory	Tailored	Optional
Reliability Support to Trade Studies	Mandatory	Mandatory	Tailored	Optional
Manufacturing Reliability	Mandatory	Mandatory	Optional	Optional
Worst Case Analysis	Mandatory	Mandatory	Tailored	Optional
Human Reliability Analysis	Mandatory	Mandatory	Optional	Optional
Fault Tree Analysis	Mandatory	Mandatory	Optional	Optional
Part Stress Analysis	Mandatory	Mandatory	Tailored	Optional
Environmental Stress Screening	Mandatory	Mandatory	Tailored	Optional
Developmental Testing Reliability Input	Mandatory	Mandatory	Tailored	Optional
Reliability Life Testing	Mandatory	Mandatory	Tailored	Optional

Class A system requirements dictate the implementation of a formal reliability program plan (sometimes combined with availability and maintainability); the plan is a formal contract deliverable with government review and approval. Reliability requirements are allocated from the system level down to the parts level. Requirements flow to the subcontractors and suppliers, and are monitored by the contractor and government to ensure full compliance with the reliability requirements. Specific reliability activities and analyses include:

- FRACAS
- FMECA (to parts level)
- FRB
- Reliability predictions
- Part quality
- Critical items lists
- Worst case performance
- Reliability life testing
- Parts electrical stress analysis for all parts and circuits

Class A reliability requirements dictate that no single-point failures are allowed; exceptions require justification based on risk analysis and mitigation measures. Redundancy is required for all space vehicle functions and key instruments. The contractor's reliability organization will be a major factor in the effectiveness of the implementation of the reliability requirements and is responsible for the definition of major reliability tasks as an integral part of the design, development, and verification process.

Class B systems similarly should apply all the requirements that may be tailored to meet the unique needs of the Class B system. Exceptions may be where structures have heritage flight history and the level of analyses may be tailored as appropriate. Deliverables with government approval should include a reliability plan and analyses to include: FRACAS, FRB, FMECA; critical items lists at the black box level as a minimum; worst-case performance; and parts electrical stress analyses for all parts and circuits. Class B reliability requirements dictate single-point failures acceptance by exception with appropriate justification. Redundancy is required for all essential space vehicle functions and key instruments. The contractor's reliability organization and processes are heavily leveraged to define the major reliability tasks as an integral part of the design, development, and verification process.

Class C system requirements should incorporate tailored requirements commensurate with the risk posture of the program. The contract may require a reliability plan to be developed and heavily depends on the contractor's internal reliability engineering function, processes, and analyses. The plan is usually available for government review (not usually a specified contract deliverable). The scope of the FMECA and the detail of the critical items list are determined by the program. Parts electrical stress analysis is sometimes performed for parts and circuits. Analysis is required at interfaces and to meet safety standard requirements. Single-point failures are permitted; single string or selectively redundant design approaches may be used. The reliability tasks are determined by the contractor and the reliability program specification is used as a reference document.

Class D programs for the most part are acquired through study proposals and less formal contract agreements. Class D programs rarely have specific contractual requirements other than those imparted by applicable safety standards or interface requirements. Reliability assessment is left to the discretion of the experimenter/developer. Single-point failures are permitted based on the experiment requirements; single string or selective redundant design approaches are often used due to the small size and limited life and budgets of these missions.

I.3 Contract Language

At this time, standard templates or language does not exist to be used to generate the Statement of Work (SOW) or sections related to reliability engineering within the Request For Proposal (RFP). The subsections below provide extracted *example* words that have been used during the acquisition of a Category A space system.

I.3.1 Request for Proposal

During the proposal phase of the program, appropriate instructions and explanations are generated for the bidders in order to obtain the appropriate data to complete source selection. There is no standard text to generate the reliability related sections of the RFP as these are unique to the specific solicitation. In many cases, reliability is integrated as characteristics for the design of different system elements. Sections H, J, L, and M usually contain requirements pertaining to reliability requirements, analyses, or data deliverables for Class A system acquisitions.

Sections H, J, L, and M, highlighted below, usually contain requirements pertaining to reliability requirements, analyses, or data deliverables for Class A system acquisitions.

Request for Proposal Format:

Part I—The Schedule

- A. Solicitation/Contract Form
- B. Supplies or Services & Prices or Costs
- C. Specification
- D. Packaging & Marking
- E. Inspection & Acceptance
- F. Deliveries or Performance
- G. Contract Administration Data
- H. Special Contract Requirements

Part II—Clauses

- I. Contract Clauses

Part III—List of Documents, Exhibits, & Other Attachments

- J. List of Attachments
  - CSOW
  - Past Performance Questions
  - Compliance and Reference Documents List

Part IV—Representations & Instructions

- K. Representations, Certifications, & Other Statements
- L. Instructions, Conditions, & Notices to Offerors
- M. Evaluation Factors for Award

I.3.1.1 Section H – Special Contract Requirements

Section H provides requirements such as the contract type, terms and value; tax related information; requirements for electronic access; citizen requirements; and award fee information. There is an area within Section H that focuses on electronic and physical access to contractor and subcontractor information and facilities throughout the contract, usually through access of the contractor's electronic data interchange network (EDI). The EDI is implemented and maintained by the contractor and provides the government with electronic, secure access to all the contractor and subcontractor information produced as artifacts of the contract. Section H clauses may call out access for specific data needed by the government to do their own reliability analyses. An example is provided below:

> *In the performance of this contract, the contractor shall provide to the government the results of and data associated with tracking problems and failure reports. The government shall have access to copies of the contractor's problem and failure data in a format such as Excel, to which the government has agreed, in order to conduct reliability analysis, system safety analysis and space mishap event reporting.*

Section H also contains the Federally Funded and Research Development Corporation (FFRDC) and System Engineering Technical Assistance (SETA) contractor enabling clauses that require the contractor and subcontractors to provide physical access and information to FFRDC and SETA personnel for the purpose of performing independent analysis. The enabling clauses are specific in terms of requiring access to general systems engineering and integration information to include system definition, integration, analysis of design, design trade-offs, interface definitions; quality control test data, and technical alternatives which are required for system reliability assessments.

I.3.1.2 Section J – List of Attachments: Contractor Statement of Work

There are several locations in the CSOW attachment that references reliability engineering tasks. Requirements are usually distributed in different subheadings within the Systems Engineering and Mission Assurance sections under the Space Segment. Often reliability is coupled with maintainability in the RFP text and is just one of the many specialty engineering or mission assurance functions stipulated.

Systems Engineering

Specialty Engineering

- Contractor shall plan a reliability program and perform reliability (and maintainability) tasks as required. Contractor shall plan reliability (and maintainability) analyses and studies, and document the assessments and decisions they support in the appropriate verification reports; and those reports shall be provided to the government.

- Contractor shall manage the contributions to system reliability (and maintainability) made by system elements.

Mission Assurance

- Contractor shall provide supporting technical information on reliability as requested by the government

- Contractor shall report component and system reliability updates at program updates at program management reviews, PDR, and CDR based on qualification test results and models.

- Contractor shall provide FMECA reports for hardware and software development items.

- Contractor shall set up and operate a failure review board (FRB) to review and approve appropriate actions to investigate and resolve failures with government participation.

- Contractor shall set up and operate a corrective action board (CAB) to review and approve appropriate corrective actions to resolve failures identified at the FRB; and provide government full insight into the processes.

- Contractor shall provide a failure reporting and corrective action system to support SFP, FRB, and CAB processes at prime and subcontractors. Contractor shall identify and provide the appropriate processes to support these activities for both hardware and software development and production; and provide government insight into the processes as well as government coordination on the results.

I.3.1.3 Section J – List of Attachments: Past Performance

Contractors may be evaluated on past performance as part of the proposal submission. The past performance questionnaire is included in the RFP along with rating definitions. Factors related to reliability engineering fall under the systems engineering category. Below is an example of such a question.

- *How well did the contractor continuously assess, maintain, and improve reliability throughout the contract (development, test, operation, maintenance)?*

I.3.1.4 Section J – List of Attachments: Compliance, Reference, and CDRL Documents List

I.3.1.4.1 Compliance Documents

TOR-2006(8506)-4494 Reliability Program for Space Systems, 13 June 2008

This is a compliance document sometimes tailored by the contractor that is listed in this section of the RFP TOR with a required delivery of a Reliability Program Plan (RPP).

I.3.1.4.2 Reference Documents

Aerospace TOR-2006(8506)-4494	Space Vehicle Systems Engineering Handbook, Chapter 21, 30 November 2005
Aerospace TOR-2009(8591)-13	Space Vehicle Failure Modes, Effects, and Criticality Analysis (FMECA) Guide, 15 June 2009
Aerospace TOR-2007(8546)-6018	Mission Assurance Guide
MIL-STD-785B	Reliability Program for Systems and Equipment Development and Production (for ground systems)
MIL-STD-1543B	Reliability Program requirements for Space and Launch Vehicles
MIL-HDBK-217F	Reliability Prediction of Electronic Equipment
MIL-HDBK-338B	Electronic Reliability Design Handbook
MIL-STD-756B	Reliability Modeling and Prediction, November 1981
MIL-STD-1629A	Procedures for Performing a Failure Modes, Effects & Criticality Analysis, November 1980
IEEE STD 1413.1-2002	IEEE Guide for Selecting and Using Reliability Predictions Based on IEEE 1413
MIL-STD-1556	Government/Industry Data Exchange program, Contractor Participation Requirements
Critical Process Assessment Tool (CPAT)	Reliability Engineering (contains guidance on RFP preparations)
Air Force Instruction 10-602	Determining Mission Capability and Supportability Requirements, 20 September 2000 (contains reliability metrics definitions)

I.3.1.4.4 Required Reliability Engineering Contract Data Requirements List (CDRL)

- Reliability Program Plan (RPP)
- Reliability Prediction Report
- FMECA Report
- Failure Analysis and Corrective Action Reports

I.3.1.4.5 Data Item Descriptions

- DI-RELI-80685 Critical Items List, 30 September 1998
- DI-SESS-81613 Reliability & Maintainability (R&M) Program Plan, October 2001
- DI-RELI-81497 Reliability Prediction, April 1989
- DI-RELI-81496 Reliability Block Diagrams, April 1989
- DI-RELI-80687 Failure Modes Effects & Criticality Analysis (FMECA), June 1986
- DI-RELI-81315 Failure Reporting and Corrective Action System (FRACAS), 1989
- DI-RELI-80255 Failure Summary Report, June 1986

I.3.1.4.6 Additional CDRLs which may contain relevant reliability engineering information may be required for updating reliability assessments and analysis. If the design or performance is impacted, then the reliability assessment and analysis should be revisited to ensure it accurately reflects the as-built article.

- Integrated Master plan
- Engineering Change Proposal
- Design Reviews
- Product Drawings and Associated Lists
- System Safety Plan
- Parts Materials, and Processes Program Plan and Lists
- Software Test Report
- Risk Management Plan
- Mission Assurance Plan
- Test Reports and Tech Maturity Demonstration Results
- System Engineering Management Plan
- Test Procedures
- Test and Evaluation Program Plan
- Test Plan
- Software Development Plan
- Subcontractor Management Plan
- Critical Items List/Critical Item Control Plans
- Government Industry Data Exchange Program (GIDEP) Alerts

I.3.1.5 Section M – Evaluation Factors for Award

Section M identifies all the significant factors and any significant subfactors that are to be considered in awarding the contract and their relative importance. Sections L and M of the RFPs have a matching structure, as Section M provides criteria for assessment of proposal.

I.3.2 Technical Requirements Document (TRD)

I.3.2.1 Class A – Sample Language

Example requirements typically found in the top specifications documents (specification, TRD, etc.) for a program follow (for a mission with a design life of three years):

Reliability. The reliability allocations will ensure that the overall mission reliability requirements are met under worst case allowable conditions of storage, transportation, testing, and operations. As a goal, the Space Vehicle (SV) design shall be such that a failure in one component does not propagate to other devices, components, or configuration items (CIs). To the extent practical, the SV will be capable of detecting malfunctions and automatically initiating protective measures to avoid catastrophic loss of its mission. Reliability predictions shall be in accordance with SMC-S-013 and shall use part failure rates as specified in MIL-HDBK- 217F. Failure rates for parts not specified therein shall be submitted to the System Program Office (SPO) for concurrence with identification of source data and applicability to Program.

Single Event Reliability. The space vehicle shall be designed to perform the required functions during—and to withstand the effects of—pre-launch, launch, ascent, separation from the launch vehicle (LV), earth orientation, transfer, orbit insertion, mission orbit, and operations through the first primary data acquisition with a probability of success (PS) of 0.95. This number does not include the reliability factor applicable to LV launch, ascent, and satellite separation operations.

Space Vehicle On-Orbit Reliability. The space vehicle shall be designed to have an on-orbit Mean Mission Duration (MMD) of not less than 33 months. MMD is defined by the following equation for a reliability function R(t) and a time (t) from zero to end of design life (T_D) of 36 months.

$$MMD = \int_{0}^{T_D} R(t)dt$$

The minimum acceptable on-orbit probability of success for the space vehicle shall be 0.8 for a 36-month mission in accordance with the following:

- This reliability value is based on the probability of 100% successful completion of the mission for 36 months. The probability for partial success, such as operation with degraded attitude accuracies, shall not be included in the specified value.

- The reliability value does not include GFE such as the sensor payloads or the Communications Security (COMSEC) equipment.

Single-Point Failures. Credible single-point failures of the space vehicle shall be treated as follows:

- Shall be eliminated, where practical, on designs if they cause critical or catastrophic hazards.

- Shall be eliminated, where practical, for new designs if they cause loss or serious degradation of satellite on-orbit mission.

- If unavoidable in the design, provisions shall be made to enable monitoring of all credible single-point failure modes, which could give rise to critical or catastrophic hazards or to mission loss on the telemetry subsystem. All credible single-point failures shall be identified on the Critical Items List with critical item control plans (CICP).

Redundancy. Redundancy shall be provided to eliminate credible single-point failures and to ensure that the 33-months MMD requirement is satisfied. For all cases where a credible single-point failure on-orbit would cause loss of mission, a catastrophic or a critical hazard, automatic switchover to the backup component and/or circuit shall be provided for. Commanded switchover is acceptable where a single-point failure causes degraded performance without increasing the risk of mission loss. In the design of redundancy, care shall be taken not to reduce overall reliability due to added complexity.

For designs that switch redundant units, components, or subassemblies autonomously, or by command, the failure rates for the switching circuits, and for the redundant equipment while in the off-line mode, shall be included appropriately in the reliability determination. Provisions to enable verification of the operation of all switchable redundant paths, without disassembly, shall be incorporated to the maximum extent practical.

Maintainability and Availability. The space vehicle shall be designed so as not to require any scheduled maintenance or repair during its design life. The design of the space vehicle shall incorporate test and telemetry points to allow verification of functional performance and failure identification to the box level. It shall accommodate installation and replacement of individual components in the space vehicle and GFE during factory assembly, test, and at the launch site prior to encapsulation in the fairing and installation on the launch vehicle. Access shall be provided to those external umbilical connections, safe and arm devices, explosive ordnance devices, pressurant and propellant fill and drain valves, and other devices required for maintenance, alignment, and servicing. As a goal, the use of test plugs and breakout boxes shall be minimized after the vehicle has been assembled.

Alignment. References for critically aligned components shall be visible directly or through windows or access doors in fairings.

Maintainability

Design for Maintainability. The design shall be based on the principle that component failures during ground tests, checkout, and storage can be repaired without degrading the performance or reliability characteristics of other components.

Maintainability Operations. Maintainability operations shall include the following:

- Cleaning and inspection of the space vehicle prior to delivery to the launch preparation facility.
- Servicing, installation, and replacement of batteries, solar panels, etc.
- Inspection of all thermally sensitive surfaces, cleaning, and repair as required.
- Loading, servicing, and monitoring the status of the liquid propellant subsystem.
- Complete space vehicle validation to include a demonstration of command and telemetry compatibility.
- Ordnance installation.
- Inspection and maintenance during storage.

Availability

Launch Availability. The space vehicle shall remain in a readiness condition following integration and system performance verification so that the space vehicle shall be available for launch 60 calendar days after call-up.

Space Vehicle On-Orbit Availability. The space vehicle shall be available for operations 100 percent of the total time for three years subsequent to achieving an operational condition.

I.3.2.2 Class C – Sample Language

Class C systems define reliability analysis/assessments in terms of the expected mission life. Reliability requirements are defined in the technical requirements document (TRD) as they pertain to the design and construction of the space vehicle. The reliability standard may be listed as a compliance document; however, the requirements for the reliability standard are tailored commensurate with the risk posture of the program. The contractor is required to have a reliability program and required to report on the program and reliability assessments at all design reviews. However, a reliability plan is not usually a required deliverable. Results from reliability assessments and analysis are required to be presented at all design reviews. Below is example TRD language that might be reflected for an experimental mission.

> *The contractor shall design a space vehicle to optimize the probability that it will successfully separate from the launch vehicle and complete a one-year mission. The contractor shall calculate, through analysis and comparative examples, the probability for success that the space vehicle bus will operate successfully for one year. The probability of success calculation shall include the methodology used. The probability of success represented should satisfy the government that the reliability risk is realistic and acceptable. Over the life of the program, iterative reliability predictions shall be expected to reflect system engineering decisions and trade-offs that improve reliability and/or mitigate possible failures. A one-year mission is defined as 365 days from successful orbital insertion and completion of system checkout. The space vehicle design shall not preclude operations beyond the first year at normally degrading power levels, and functional capabilities consistent with the reliability of the one-year design.*
>
> *The reliability program shall address all mission hardware. The contractor shall provide an analysis that predicts overall system reliability and addresses reliability allocations and assessments. The contractor shall emphasize simple, proven designs; appropriate testing; backup and alternative processes, design decisions and tradeoffs; and mitigation of single-point failure modes. When appropriate and cost effective, redundancy may be the selected approach. However, approaches to operation at degraded levels or in alternate modes shall be considered and included in the overall reliability program. The reliability program and reliability assessments shall be reported at all design reviews.*

I.3.3 Integrated Master Plan

The IMP is the central management plan that becomes a binding part of the contract. IMP narratives provide high level objectives, compliance documents, and processes for specific topics in Section L, including such areas as systems engineering, software development and maintenance, specialty engineering, configuration management and logistics. The IMP is the primary tool for tracking the program's status and covers the entire program, including the prime and all subcontractors. The award and incentive fees are generally tied to completion of program events and functionality.

These IMP sections may contain or reference reliability engineering activities, products, and associated work products as required per the Reliability Program Plan. The integrated master schedule outlines the program plan in sufficient detail to define resource requirements, material timing, and integration requirements with existing plans and schedules.

Appendix J. Tailoring Risk Management Requirements

Gail Johnson-Roth

J.1 Introduction

J.1.1 Overview

Risk Management (RM) is the overarching process that encompasses identification, analysis, mitigation planning, mitigation plan implementation, and tracking of potential failures or anomalies, possible root causes and consequence. RM applies a systematic and structured approach to identifying, analyzing, and controlling areas or events with a potential for causing unwanted change; risks to the program are assessed and systematically managed to reduce risk to an acceptable level. RM has a key program function in identifying and communicating threats to mission success to all decision makers and program stakeholders at all levels. Risk is considered tradable against the program resources within the programmatic (e.g., cost, schedule), and technical (e.g., PL performance, mass, power, reliability) domains. RM is an iterative process throughout the program life cycle, with iterations being determined by the program's progress through the different phases, and by changes to a given program baseline influenced by the program's resources.

J.1.2 Definitions

Risk is the possibility and impact of all events and conditions that are believed to carry negative consequences for a specific program. The term is used to refer to events that are possible, but not realized at the time of consideration. Risk is usually characterized by the identification of the risk events that pertain to a specific program or mission, by their probability of occurrence, and by the magnitude of the possible impacts as measured in some appropriate scale of assessable consequences.

Risk Assessment relates to the technical activities applied to identify risk, to understand its nature in terms of possible sources, mechanisms, and consequences, and to evaluate the magnitude, in relation to a specific program or mission.

Risk Acceptance is the decision to cope with consequences, should a risk scenario materialize. In the context of RM, acceptance can mean that even though a risk is not eliminated, its existence and magnitude are acknowledged and tolerated.

Risk Scenario is the sequence or combination of events leading from the initial cause to the unwanted consequence. The cause can be a single event or the result of a dormant problem being activated.

J.2 Risk Management Requirements

Risk Management (RM) seeks, via an organized and formalized flow of processes and activities, the systematic identification, evaluation, and control, of the "risk items" that may affect the execution of a program. The formalization of the RM objectives and the definition of the RM process and activities are expressed, for any given program, in a top-level document approved and endorsed by the Program Manager. This document is the programmatic Risk Management Plan (RMP). The RM process documented in the RMP is tailored for the specific program for which the plan is developed and seeks to maximize the effectiveness and efficiency of the RM activities (i.e., to achieve the maximum possible risk control results while keeping any added programmatic burden at a reasonable level).

General considerations for RM implementation include the following:

- RM is performed within the normal program management structure, ensuring a systematic risk identification, assessment, and follow-up of risks.

- RM is implemented as a team effort, with tasks and responsibilities assigned to the functions and individual with the program with the most relevant expertise in the areas concerned by a given risk.

- The results of RM are considered in the routine program management process and in the decisions (documented) relative to the baseline evolution.

J.2.1 Applicable Specifications, Standards and Guides

- ISO 17666, Space Systems Risk Management, 01 April 2003. Explains what is needed to implement a program-integrated risk management policy by any program actor, at any level. Contains a summary of the general risk management process and implementation. This standard is listed as a compliance document for Class A and Class B acquisitions.

- Aerospace TOR-2005(8583)-4019, Risk Management Plan Guide for Space Acquisition Programs, 29 April 2005.

- Risk Management Guide for DoD Acquisition, Sixth Edition, Version 1.0.

J.2.2 Requirements Lifecycle Application

The programmatic risk perspective changes as programs evolve from concept definition to system acquisition and operation. Pre-award risk mostly concerns the procuring organization's ability to define system requirements clearly and in a way that is commensurate with the technology and the funding resources available to develop such technology further by prospective bidders, and apply it successfully for system fabrication and assembly. As the program progresses to post-award phases, risk shifts from design to manufacturing, reliability, maintainability, and safety issues.

J.2.3 Tailoring

The top level requirements for a space systems risk management process are listed in Table K-1 in the first column. The table provides the tailoring and implementation guidance for the four different risk classes.

Table J-1. Risk Management – Program Requirements

	Class A	**Class B**	**Class C**	**Class D**
Define the Risk Management Policy	Mandatory; may be defined by acquirer. Establishment of risk index scheme to define magnitude of risk in terms of severity and likelihood. Establishment of criteria to determine actions required on risks of various risk magnitudes and associated risk decision levels in the program structure.	Same as Class A.	Mandatory; usually dependent on best practices of contractor, but submitted for customer review.	Recommended
Prepare the Risk Management Plan	Mandatory in accordance to compliance standard on contract. Plan developed by contractor and delivered to customer for approval. Customer develops/maintains separate plan for comprehensive assessment of program risk. Risk process applies to sub-contractors and critical vendors.	Same as Class A.	Required by contract; typically follows the contractors internal risk management processes but should meet intent of standard. Plan developed and submitted for customer review. Risk process identifies risks at sub-contractors and critical vendors. Training as required in accordance to contractor best practices. Risks reported at customer meetings and major milestone reviews.	Recommended, but not required by contract developed by the contractor; typically follows the contractor's internal risk management processes or a tailored version of contractor's best practices. Risks reported at informal customer meetings and major milestone reviews.
Identify Risk Scenarios	Mandatory identification of risk scenarios to include causes and consequences	Mandatory, although maybe executed less formally.	Dependent on mission and contractor best practices.	Optional

	Class A	Class B	Class C	Class D
Assess the Risks	Mandatory to determine the severity and likelihood of each risk. Risks identified by contractor; customer provides inputs and initiates new risks through participation in formal risk management boards. All personnel responsible to identify risks; construct includes many layers from working groups and integrated product teams that are responsible for continuous risk management to include risk handling and mitigation activities. Independent assessment typical/required for all critical mission impacting risks and prior to major milestone reviews.	Same as Class A.	Risks, severity, and consequence, identified by contractor and reviewed by customer. Independent assessment usually conducted for critical mission impacting risks.	Risks assessed by the contractor. Independent assessment may be conducted for critical risk assessment- mission impacting risks.
Analyze Acceptability of Risks and Risk Reduction Options	Risk reduction measures and decision on priorities for implementation at appropriate decision making level in the program according to risk management plan. Documentation of all risk reduction options, resolved and unresolved risks submitted for customer approval and or/further action. Risks tracked at weekly technical meetings and reported at monthly risk management boards and major milestone reviews.	Same as Class A.	Risk reduction measures and decision on priorities for implementation at appropriate decision making level in the program according to risk management plan. Risks decisions presented for customer review.	Risk acceptability and risk reduction options at discretion of contractor. Residual risks communicated to customer at major milestone reviews.
Reduce and or Recommend Acceptance of the Risks	All practical measures taken to achieve minimum risk to mission success.	Stringent risk reduction applied to maintain a low risk to mission success.	Medium risk of achieving mission success may be acceptable; must address risk balance in consideration of risk posture to keep appropriate balance within cost/schedule constraints.	Higher residual risk acceptable. Contractor addresses risk balance in consideration of risk posture to keep appropriate balance within cost/schedule constraints.

	Class A	Class B	Class C	Class D
Monitor and Communicate risks	Risks formally tracked at weekly technical meetings and reported at required monthly risk management boards and major milestone reviews. Common access server and standardized format usually dictated by contractor for visibility by all personnel- contractor and customer teams.	Same as Class A, although risks may be communicated in less formal structure as stipulated by customer.	Contractor responsible for monitoring and communicating risks at customer meetings and major miles stone reviews. Common access server may be required by customer with recommended visibility by all personnel.	Recommended, but not required by contract. At the discretion of and handled by the contractor. Risks communicated to customer informally.
Define Risk Management Implementation Requirements	All personnel responsible to identify risks; construct includes many layers from working groups and integrated product teams that are responsible for continuous risk management to include risk handling and mitigation activities. Contractor and customer personnel training required.	Same as Class A.	Contractor responsible to identify risks in accordance to best practices. Training as required in accordance to contractor best practices.	Recommended
Implement Risk Management at each Level of the Customer-Supplier Network	Risk management requirements apply to sub-contractors and critical vendors.	Same as Class A.	Per contractor's best practices.	Optional

Class A system requirements dictate the implementation of a formal risk management (RM) plan (sometimes combined with availability and maintainability plans). The plan is a formal contract deliverable with government review and approval. The formal RM plan includes a summary description of risk management policy with defined measures of risk in terms of severity and likelihood; the process to identify and assess the risks; criteria for acceptability and handling of risks; monitoring and communication of risks; and implementation details to include organizational responsibilities and flow of risk management requirements to sub-contractors and critical vendors. Technical, cost, and schedule risks are addressed and handled by the Plan. The government and contractor are responsible for identifying potential risks on the program and submitting appropriate potential risk information like cause, likelihood, and impact. The monthly risk management board (RMB) is chaired by the contractor with the government in attendance and actively participating as a board member.

All practical measures are taken to achieve minimum risk to mission success. The RM plan should address how residual risk will be managed and kept to a minimum. The government program office should maintain a separate risk management process that identifies risks and handling plans as well as documents risk acceptance and evidences. All personnel are responsible for identifying potential risks on the program and submitting appropriate potential risk information like cause, likelihood, and impact. All personnel are required to undergo training for the purpose of properly identifying risk and communicating those risks effectively. Key to RM success is the identification of resources required to implement the developed risk-handling options. Risks affecting mission success and their mitigation plans must be approved by the government.

Class B systems similarly should apply all the standard risk management process requirements to include flow of risk management requirements to sub-contractors and critical vendors. The reporting format may be less formal and formal communication less frequent to meet the unique needs of the Class B system. The risk planning process is a joint effort between the contractor and the government. The risk plan must be approved by the government for cost plus projects, and at a minimum, reviewed by the government for Fixed Price projects. Risks are identified by all stakeholders. Risk review boards are conducted at various levels within the project, and all risks affecting mission success must be approved by the government. Risk handling plans are jointly developed by the contractor and the government, with the contractor taking the lead. The government will monitor the status of the risk handling through reports from the contractor. The contractor is responsible for maintaining the risk management tool which will document the risks, the associated handling plans, and progress against those plans.

Class C system requirements should incorporate tailored requirements commensurate with the risk posture of the program. A risk management plan is required by contract but usually will stipulate use of contractor’s best practices to meet the intent of the compliance standard. The developed risk management plan is submitted for government review. Medium risk of achieving mission success may be acceptable, and the program must address risk balance in consideration of risk posture to keep appropriate balance and focus on the allocated resources and constraints. The contractor is responsible for monitoring and communicating risks at meetings with the government. All personnel—both contractor and government—are encouraged to identify risks.

Class D programs for the most part are acquired through study proposals and less formal contract agreements. Class D programs rarely have specific contractual requirements other than those imparted by applicable safety standards or interface requirements. Risk management—identification, assessment, handling—is left to the discretion of the experimenter/developer. Risk management processes and mitigation activities are recommended where practical. Risks are informally communicated at customer meetings and at major milestone reviews. Higher residual mission risk is acceptable as the contractor addresses the risk balance in consideration of risk posture to keep appropriate balance of allocated budget and inflexible schedule demands.

J.3 Contract Language

At this time, standard templates or language does not exist to be used to generate the Statement of Work (SOW) or sections related to reliability engineering within the Request For Proposal (RFP). The subsections below provide extracted *example* words that have been used during the acquisition of a Category A space system.

J.3.1 Request for Proposal

During the proposal phase of the program, appropriate instructions and explanations are generated for the bidders in order to obtain the appropriate data to complete source selection. In many cases, reliability is integrated as government identified risks for the design of different system elements. Sections L and M contain requirements pertaining to the delivery of a risk management plan that incorporates the requirements of the referenced standard.

Section L – Instructions, Conditions, and Notices to Offerors

Section L provides instructions to the Offerors including requirements for proposal delivery, content by volume, and instructions about attachments. Section L specifies the contract volumes and proposal volumes, e.g., executive overview volume, volumes and attachments for each factor and subfactor; and provides specific instructions for the minimum information required with the proposal for each factor and subfactor. Section L includes the proposal requirement to generate a risk management plan in accordance to referenced compliance documents and directly incorporates details to the delivery of the plan. In addition, the government may choose to identify specific known technical risks that may be included in other areas of the proposal but stipulate inclusion in the risk management plan. Section L also includes a number of attachments where risk management requirements and activities are further detailed; i.e., the Contractor Statement of Work (CSOW), the Integrated Master Plan (IMP), and the Compliance/Reference Documents List. The Contractor Statement of Work (CSOW) usually identifies specific technical risks that are required to be incorporated and addressed in the risk management plan.

J.3.2 Class A – Sample Language

RFP Section L Requirement for a Risk Management Plan

Describe in a separate attachment the Risk Management Plan, the integrated risk management process that will be used to manage performance, cost, and reduce schedule risks for the program and explain the approach to defining responsible organizations (government, contractor, and subcontractors) for risks. Describe the approach to identifying, assessing, handling, and monitoring the quantified acceptable risk levels that need to be achieved prior to transition to deployment. Provide a description of the processes, tools, and criteria that will be used to improve the risk-management process. Propose a detailed description of the critical management and systems engineering risk areas with associated rationale. Provide a prioritized list of all significant performance, cost, and schedule risks. For system engineering, program management, and integration risks, provide a mitigation strategy with detailed impact assessments and a rationale for each likelihood and consequence. For key risk areas describe specific engineering activities that will resolve these risks. Discuss areas for which technologies, design, interfaces, or implementation alternatives are immature, and present an approach and schedule for maturing these areas. Describe the means to achieve schedule confidence as a part of the IMS and appropriate resources in the Basis of Estimate (BOE) with supporting-experience data.

Details for Delivery of Risk Management Plan

Section I: Risk Management Approach

1. Describe the integrated risk-management approach that will be used to manage and reduce performance, cost, and schedule risks.
2. Describe the approach to identifying, assessing, handling, and monitoring the quantified acceptable risk levels that need to be achieved prior to transition to deployment. Include definitions of the criteria used to determine the acceptability of the risk levels and justification for the selection of those criteria.
3. Include on- and off-ramps or critical decision points, along with the plans for reaching those points.

Section II: Risk Identification

1. Describe overall design. Use detailed risk assessments from the component to the subsystem levels. Provide a prioritized list of all significant performance, cost, and schedule risks.
2. Each risk assessment should include, at a minimum, a risk description, associated root causes, and impact descriptions to performance, cost, and schedule.
3. The individual risk mitigation plans should detail, at a minimum, the overall mitigation activities, key mitigation milestones, risk handling plans, and demonstrations in relevant environments.
4. Describe any risk mitigation plans that address natural and self-generated environments on or created by critical or new technologies.

Narratives in the IMP

Define the processes used across the project team to identify, assess, handle, and monitor performance, cost, and schedule risks. Define the process to identify most likely critical paths and effective measures to mitigate risks. Describe procedures for contingency planning, and the methods to be used in tracking the various risk factors, evaluating changes in the levels of risk factors, and the responses to those changes. Describe the development and maintenance of the Risk Management plan, and the reporting of risk status updates on a basis that will allow appropriate and timely government insight and action. Risk factors that should be considered include risks in the acquirer-supplier relationship, contractual risks, technological risks, risks caused by the size and complexity of the product, risks in the development and target environments, risks in personnel acquisition, skill levels and retention, risks to schedule and budget, and risks in achieving acquirer acceptance of the product.

Compliance Document List

ISO 17666	Risk Management Space Systems - Risk Management 1-Apr-03 Compliance

J.3.3 Class C

Class C systems define risks in the technical requirements document (TRD) as they pertain to the design and construction of the space vehicle. The contractor is usually required to deliver a risk management plan as a "Technical Report" that meets in accordance to their best practices. The risk management standard may be listed as a reference document.

J.4 Additional References

Aerospace TOR-2007(8546)-6018	"Mission Assurance Guide," 1 July 2007
Aerospace TOR-2006(8506)-4494	Space Vehicle Systems Engineering Handbook, 31 January 2006
	SMC Systems Engineering Primer & Handbook, Space & Missile Systems Center, USAF, 3rd Edition, 29 April 2005

Appendix K. Tailoring Software Development Requirements

Software Development
Martha Johnson
Steven Meyers
Rey Rojo

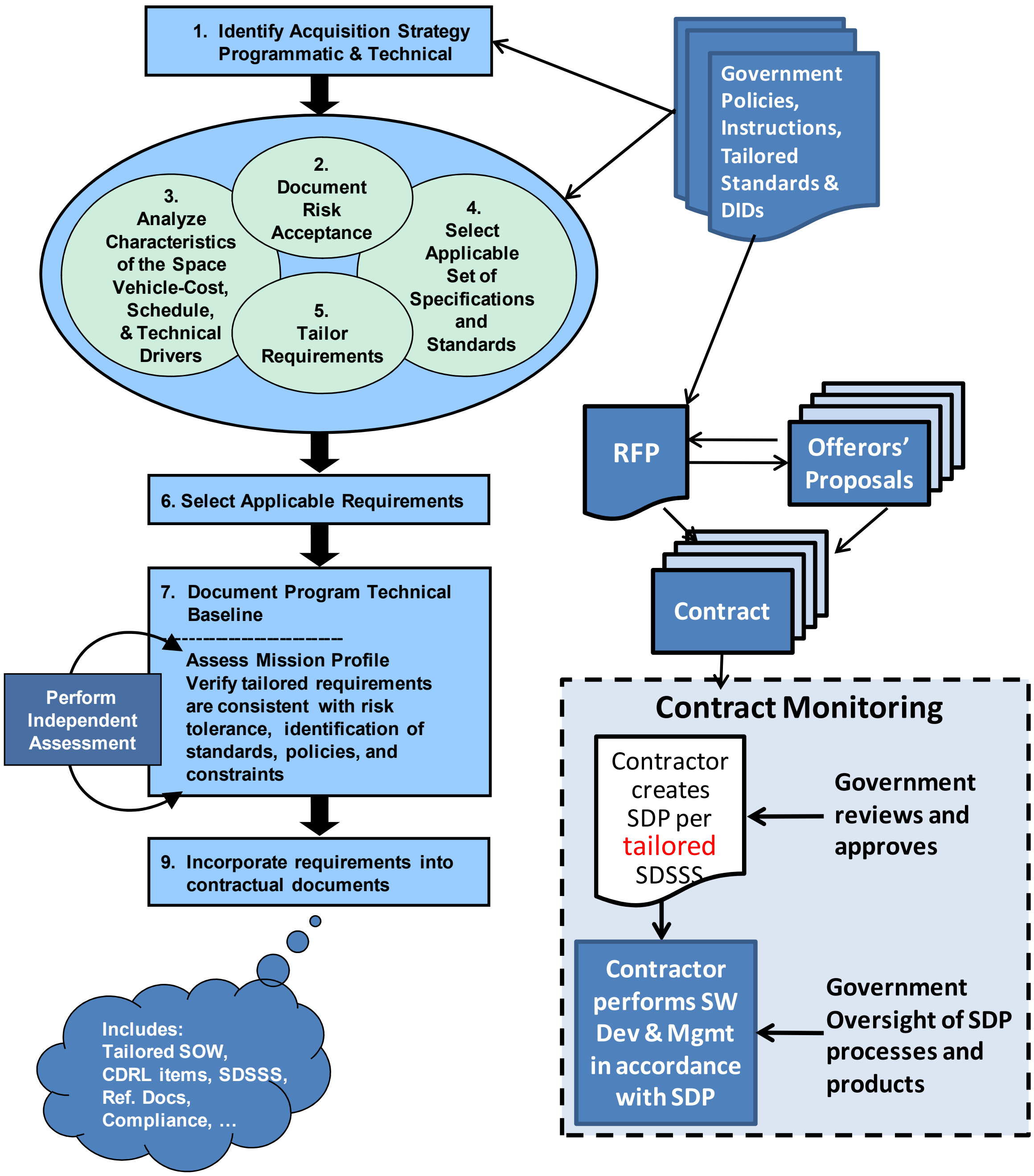
K.1 Introduction

K.1.1 Topic Area Overview

This appendix provides guidance on the tailoring of the Software Development Standard for Space Systems (SDSSS) (Table K-1 [1]) for the development of software for the various risk classes of space vehicles for National Security Space (NSS). This appendix is intended for government personnel who tailor the SDSSS in support of software acquisition planning activities. The SDSSS provides the standard for what a program must address in terms of processes and work products as a part of software development and management. It does not provide a “how to” for software development. As such, this guidance is high level and reference to the SDSSS is required to ensure appropriate implementation. Building on Figure 1 of the tailoring process defined in the main part of this handbook, Figure L-1 provides a high level overview of the government’s involvement in establishing software development contract requirements and the resulting oversight.

Software mission assurance (MA) is the disciplined application of software engineering, acquisition, and management processes and standards to achieve mission success. Since software has a major role in space systems, the SDSSS is applied in accordance with the mission assurance objectives as defined of the specified space system.

The tailoring guidance contained in this appendix is provided for Space Flight Software development. Flight software consists of all the software on the space vehicle while on orbit. This appendix is not intended to provide the complete approach to tailoring the SDSSS. As a high level guide, it is necessary for the user to involve the Subject Matter Experts (SMEs) in defining the details of any tailoring. Section K.5 provides a list of resources for software development standards and their application.


1. Identify Acquisition Strategy Programmatic & Technical
2. Document Risk Acceptance
3. Analyze Characteristics of the Space Vehicle-Cost, Schedule, & Technical Drivers
4. Select Applicable Set of Specifications and Standards
5. Tailor Requirements
Government Policies, Instructions, Tailored Standards & DIDs
6. Select Applicable Requirements
RFP
Offerors' Proposals
7. Document Program Technical Baseline
Assess Mission Profile
Verify tailored requirements are consistent with risk tolerance, identification of standards, policies, and constraints
Perform Independent Assessment
Contract
Contract Monitoring
Contractor creates SDP per tailored SDSSS
Government reviews and approves
9. Incorporate requirements into contractual documents
Contractor performs SW Dev & Mgmt in accordance with SDP
Government Oversight of SDP processes and products
Includes:
Tailored SOW,
CDRL items, SDSSS,
Ref. Docs,
Compliance, …

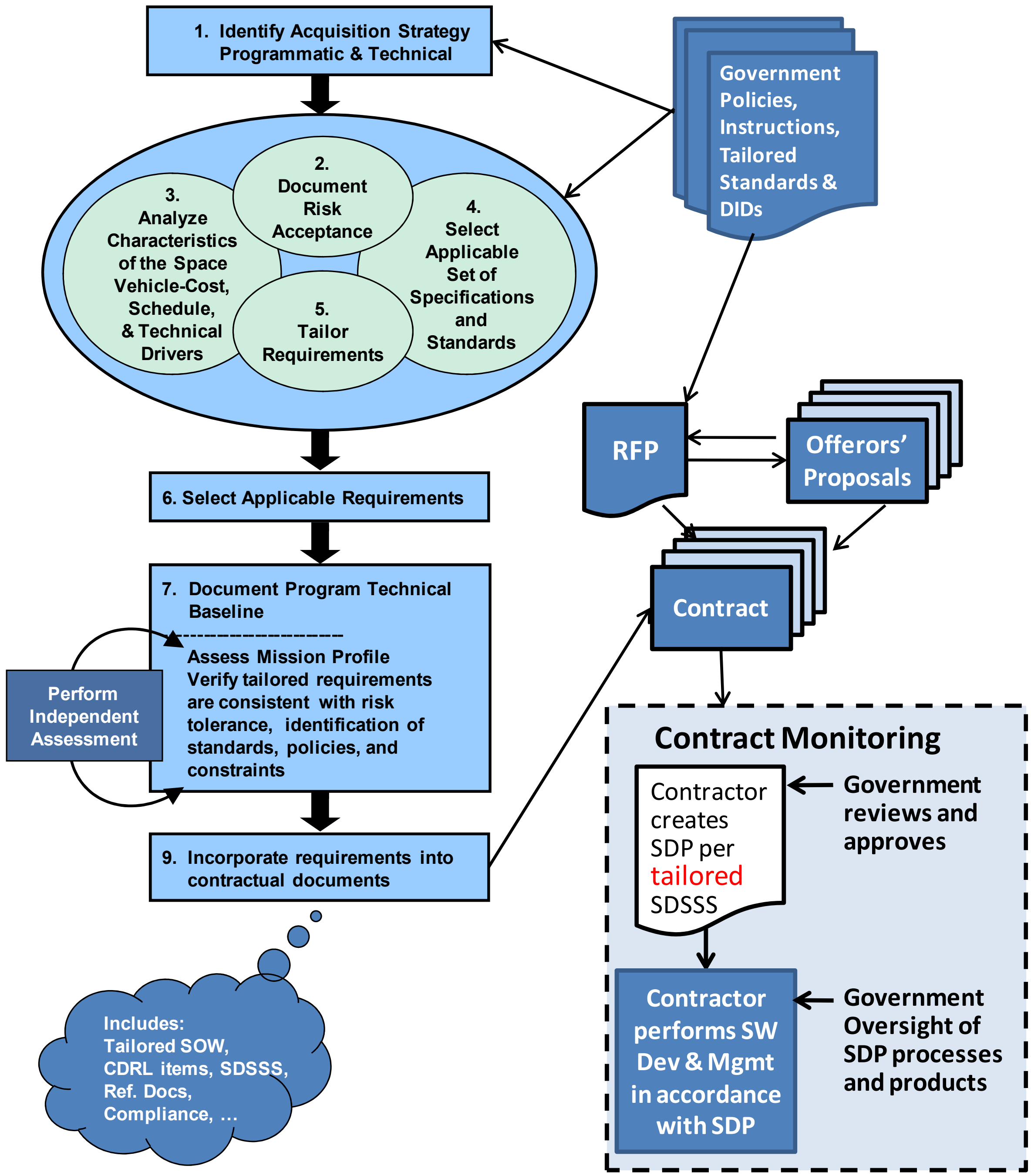


Figure K-1. Government involvement in tailoring the SDSSS.

K.1.2 Software Development Standard for Space Systems (SDSSS) — Overview

The SDSSS is a compliance document invoked on contract for development of systems containing software and can be applied in any phase of the system life cycle. It contains the requirements for developing, modifying, and documenting software. It defines standard terminology and captures the activities, tasks, and products for a software development or maintenance project. It applies to the following categories of software:

- Onboard software (e.g., space vehicle, communications, payload)
- Ground operations software (e.g., mission planning; mission processing; mission support; telemetry, tracking and commanding; infrastructure and services)
- User equipment (e.g., software in terminals, handheld receivers, receivers aboard wheeled vehicles, aircraft, ships, and weapons
- Other software (e.g., applications, security, safety, training, modeling, simulation, analysis, database support, automatic test equipment, test facility and environment, and maintenance) used in any of the following:
  - Satisfying, verifying, or validating requirement
  - Performing or supporting operations
  - Performing or supporting sustainment

The SDSSS can be applied to any type of software, including application software, the software portion of firmware, reusable software, etc.

K.2 Key Practices and Activities

The software acquisition life cycle typically includes a planning phase where software standards such as the SDSSS are identified and produced. The SDSSS standard is tailored to meet the acquisition requirements of the program. Each software acquisition program office is required to document and implement a Software Acquisition Management Plan (SWAMP). For additional information on the software acquisition activities and the approach to generating the SWAMP, refer to chapter 3 of the *Software Acquisition Management Plan Preparation Guide* (Table K-1 [2]). Class D and some Class C missions are not subject to this requirement.

A tailored SDSSS is an important provision to software mission assurance because it will direct the activities a contractor will perform to develop flight software and resultant government oversight of these stipulated requirements.

K.2.1 Definitions

Flight Software: Flight software consists of all the software on the satellite space vehicle while on orbit. This software can be divided into two basic groups: Payload, and Space Vehicle Bus.

Space Vehicle Bus software consists of all software used in the processing and controlling of space vehicle bus functions. They include:

- Onboard operating system
- Thermal control
- Electrical power
- Attitude control

- Propulsion
- Telemetry tracking and command

For more information on space vehicle bus software, refer to "Recommended Process for Qualification Testing of Space vehicle Bus Software Prior to Use on Orbit" (Table K-1 [3]).

Payload software refers to all software used by the payload hardware. Such software includes any firmware used to directly control hardware, as well as the programs used in any form on any processors included with the payload. Along with the software to conduct the mission data processing, examples of some of the more critical payload software consists of: bootstrap startup, space vehicle communications, system upload, hardware/software status reporting and hardware control. For additional information on payload software, refer to, "Recommended Process for Qualification Testing of Payload Software Prior to Use on Orbit" (Table K-1 [4]).

Requirements:

- A characteristic that a system or software item must possess in order to be acceptable to the acquirer.
- A mandatory statement in the SDSSS or any portion of the contract.

Software Acquisition: The process of obtaining a software product, from conception to retirement. Software acquisition is part of a larger space system acquisition.

Software Mission Assurance: The disciplined application of software engineering, acquisition, and management principles, processes, and standards to achieve mission success.

Software product: Software or associated information created, modified, or incorporated to satisfy a contract. Examples include plans, requirements, design, code, databases, test information, and manuals.

K.3 Requirements

The SDSSS defines the general and detailed requirements associated with a software development process. The government tailors these requirements in the RFP and contracts. The contractor's detailed approach to implementing the tailored requirements is defined in the developer's Software Development Plan (SDP).

SDSSS Section 4 includes a set of general requirements that are to be reviewed as a part of tailoring the detailed requirements in SDSSS Section 5. This appendix does address tailoring of these general requirements that apply across all the detailed requirements and are considered as a part of tailoring them. These general requirements cover the following subjects:

- Software development process
- Software development methods
- Standards to be applied for software products
- Bi-directional traceability of requirements
- Reusable software products

- Assurance of critical requirements
- Computer hardware resource utilization
- Rationale for recording key decisions
- Granting the acquirer access to review software products, activities and subcontractor facilities

They are implemented as a part of addressing the SDSSS Section 5 requirements and generating the SDP. The one possible exception is the "Assurance of critical requirements." The user should review and determine if there are critical mission requirements whose failure could lead to violations of those critical requirements that are satisfied through a computer subsystem (software and computer hardware included). Some types of critical requirements are:

- Safety
- Security
- Privacy protection
- Specialty requirements (e.g., dependability, reliability)
- Other mission-critical requirements

This appendix provides guidance for tailoring the 25 detailed requirements contained in SDSSS Section 5 addressing the major software activities:

1. Project Planning and Oversight
2. Establishing a software development environment
3. System requirements analysis
4. System design
5. Software requirements analysis
6. Software Design
7. Software Implementation and Unit Testing
8. Unit Integration and Testing
9. Software Item Qualification Testing
10. Software/Hardware Item Integration and Testing
11. System Qualification Testing
12. Preparing for Software Transition to Operations
13. Preparing for Software Transition to Maintenance
14. Software Configuration Management
15. Software Peer Reviews and Product Evaluations
16. Software Quality Assurance
17. Corrective Action
18. Joint Technical and Management Reviews
19. Risk Management
20. Software Management Indicators
21. Security and Privacy
22. Subcontractor Management
23. Interface with Software Independent Verification and Validation Agents

24. Coordination with Associate Developers
25. Improvement of Project Processes

The order of the requirements is not intended to specify the order in which they must be carried or to designate a priority. Some activities may not be applicable to the project or contracted effort. Many of the activities may be ongoing simultaneously; different software products may proceed at different paces; and activities specified in early subsections may depend on input from activities in later subsections. If the software is developed in multiple builds, some activities may be performed in every build, others may be performed only in selected builds, and activities and software products may not be complete until several or all builds are accomplished. A project involving a single build will accomplish all required activities in that build.

Each of the 25 major software activities includes further detail in the form of “subsection activities” and software products comprising the major software activity. Table K-1 provides a tailoring matrix for the 25 major software activities as defined in section 5 of the SDSSS.

K.3.1 Software Reference Documents

Table K-1 contains a list of software policies, instructions, specification, standards, guides, and best practices that apply to software acquisition, development, and management. These documents contain requirements that should be reviewed and incorporated appropriately in the software development plan, and should be used for managing the software elements of the program.

Table K-1. Software Specifications and Standards That Apply to Software Acquisition

Subject	Reference Number	Document Number	Document Title	Document Abstract
Acquisition	[7]	DoD Instruction 5000.2	*Operation of the Defense Acquisition System*	This directive instruction includes a mandatory acquisition process: competitive pricing, focus on program reviews to assess process, configuration steering boards, technology readiness assessment, engineering and manufacturing development and more effective test and evaluation.
Software Acquisition	—	Policy dated 20 August 2004	Software Acquisition at SMC	This policy defines the requirements for: • Using software evaluation techniques to evaluate the software portion of contractors proposal (e.g., SCAMP[SM] • Ensuring all new contracts require contractors to implement SMC approved software-related specifications and standards. • Using the SMC Software Acquisition Handbook to provide SMC personnel with a clear understanding of what is required for successful software intensive program acquisition and management of weapons systems software. • Use the Software Acquisition Process Improvement Instruction [5] at SMC
Software Acquisition	—	Policy dated 13 May 2009	Chief Software Engineers	This policy defines the requirements that all Wing and Direct Report Group Commanders designate a Chief Software Engineer (CSE) for their organization. The Program's CSE will be an active participant in the SMC CSE working group.
Software Management	—	AFI 33-114, 1 July 2000	Air Force Instruction "Software Management"	This Air Force instruction (AFI) implements Executive Order (E.O.) 13103, *Computer Software Piracy*, September 30, 1998; Department of Defense Directive (DoDD) 3405.1, *Computer Programming Language Policy*, April 2, 1987; and Air Force Policy Directive (AFPD) 33-1, *Command, Control, Communications, and Computer (C4) Systems*. It identifies responsibilities for management of commercial off-the-shelf (COTS) and Air Force-unique software acquired by the Air Force (other than software internal to a weapon system; see AFPD 63-1, *Acquisition System*).
Software Development	[1]	TOR-2004(3909)-3537B, 13 June 2008	Software Development Standard for Space Systems (Also known as SMC-S-012)	This is a standard for the software development process that can be applied on NRO and SMC contracts. This report provides a full life cycle software development process standard based on *MIL-STD-498, Software Development and Documentation* dated December 5, 1994 (hereafter referred to as "MIL-STD-498").

Subject	Reference Number	Document Number	Document Title	Document Abstract
Software Acquisition	—	SMCI 63-103, 28 May 2009	Software Acquisition Instruction	This Space and Missile Systems Center Instruction (SMCI) outlines the process, roles, and responsibilities regarding software acquisition that provide a new, improved, or continuing system or service capability in response to an approved need at Air Force Space Command's Space and Missile Systems Center (SMC). It serves as a method to standardize all software acquisitions at SMC.
Specification and Standards/ Tailoring	[6]	SMCI 63-106, 1 October 2009	Specifications and Standards (S&S)	This SMCI directs the development, use, and maintenance of S&S as an integral element of SMC acquisition processes. Compliance with this instruction is mandatory for programs executed by SMC Wings, SMC staff organizations and SMC/AFPEO-Space. S&S shall be included in all solicitations, placed on contract as compliance documents, and implemented through the supplier chain. Section K.5 of this instruction requires that the S&S be customized to match the acquisition program's objectives, taking into account cost, schedule, and other constraints.
Software Acquisition	[5]	SMCI 63-104, 26 May 2009	Software Acquisition Process Improvement Instruction	This SMCI outlines the process to comply with the requirements of the Air Force Software Acquisition Process Improvement Strategy.
Software Acquisition	[2]	Aerospace Report No. TOR-2006(1455)-5743, 3 November 2006	Software Acquisition Management Plan Preparation Guide	The purpose of this preparation guide is to provide guidance to Space and Missile Systems Center (SMC) program office personnel on how to write a Software Acquisition Management Plan (SWAMP) in accordance with SMC policies.
Software Acquisition	—	TR-2004(8550)-1, 30 September 2004	Software Acquisition Best Practices: Experiences from the Space Systems Domain	This report describes a comprehensive set of software acquisition best practices developed by the authors based on experiences in the space systems domain.
Software Acquisition	—	TR-2006(8550)-1, 31 January 2006	Reducing Software Acquisition Risk: Best Practices for Early Acquisition Phases	This report addresses what can be done early in the acquisition life cycle to reduce the risk of software problems occurring later in the program. The authors have identified an additional set of software acquisition best practices for the early acquisition life cycle phases that extend those published in 2004.These best practices are targeted at reducing downstream software development risk, and thereby improving mission success for software-intensive space systems.

Subject	Reference Number	Document Number	Document Title	Document Abstract
Software Acquisition	[10]	TR-2006(8550)-3, 20 December 2006	The Position of Software in the Work Breakdown Structure (WBS) for Space Systems	This report was prepared to address the issue of where software should reside in the Work Breakdown Structure (WBS) for a space system. The report first provides some background on Integrated Product and Process Development (IPPD) and the standard product-oriented WBS structure established for space systems by MIL-HDBK-881A. The report then describes the various software activities that must be performed for space system development and provides recommendations as to where these activities belong in this standard product-oriented space system WBS structure.
Software CDRLs	[8]	TOR-2006(8506)-5738, 14 February 2008	Recommended Software-Related Contract Deliverables for National Security Space System Programs	This report was prepared in order to provide current best practices for software and software related Contract Deliverable Requirements List (CDRL) items for a Request for Proposal (RFP). It provides the rationale for requiring these CDRL items as deliverables on contracts, the list of recommended software and software-related system level CDRL items, the purpose and justification of each of these software CDRL items, the timing of these CDRL items with respect to major program milestones, and the identification and tailoring of the Data Item Descriptions (DIDs) used for each software CDRL item. It provides DD 1423-1 forms that can be customized to reflect specific program requirements for use on contracts. These CDRL items are recommended as contract deliverables for all space, ground, and user equipment systems for National Security Space programs. With additional tailoring, they could apply to other systems as well. Putting these CDRL items on contract is one step in systems engineering revitalization efforts to ensure mission success.
Software Reviews	—	TOR-2007(8583)-6414, V1, 30 January 2009	Technical Reviews and Audits for Systems, Equipment and Computer Software	This Aerospace Technical Operating Report, TOR-2007(8583)-6414 Volume 1, represents an update to MIL-STD-1521B (USAF) Technical Reviews and Audits for Systems, Equipments, and Computer Software, and will be reissued as an interim USAF Space and Missile Systems Center (SMC) standard (STD) for planning and execution of key system engineering reviews and audits for active and new space system acquisition programs. This TOR is composed of two volumes: Volume I defines a generic set of technical reviews and audits for systems, equipment, and computer software end items. Volume 2 provides specific and unique supplemental criteria content for the core technical reviews in Volume 1 for Space Systems specific equipment and computer software items.

Subject	Reference Number	Document Number	Document Title	Document Abstract
Qualification Test	[4]	Aerospace Report No. TR-2006(1472)-1, 20 March 2006	Recommended Process for Qualification Testing of Payload Software Prior to Use on Orbit	This report defines the minimum conditions required for qualifying payload software prior to launch or use on orbit.
Qualification Testing	[3]	Aerospace Report No. TOR-2008(3207)-8191, 15 May 20	Recommended Process for Qualification Testing of Spacecraft Bus Software Prior to Use on Orbit	This report defines the minimum conditions required for qualifying space vehicle bus software prior to launch or use on orbit.
FFRDC	[9]	20 January 2004	SMC FFRDC Users Guide	The document describes policies and procedures and assigns responsibilities for the utilization of Aerospace as an FFRDC.

K.3.2 Tailoring

The SDSSS, specifications, standards and the DIDs are applied at the discretion of the acquirer within the limitations defined in the SMCI 63-106 (Table K-1 [6]). In each application, the SDSSS, specifications, standards, and DIDs are tailored to the specific requirements of a particular program, program phase, or contractual structure beginning early in the RFP development and continue through issuance of the contract. Tailoring for the SDSSS consists of the alteration of activities to more explicitly reflect or clarify the

- Application to a particular effort;
- Addition of activities to satisfy program requirements and other requirements to strengthen mission assurance; or
- Deletion of activities that may not be applicable to the program's objectives, taking into account risk, cost, schedule, or other constraints.

This tailoring is specified in the SOW or Compliance Documents section of the RFP or contract. Tailoring for the DIDs consists of clarifying, modifying, or deleting requirements and making other changes such as combining two documents into one. DID tailoring for deliverables is specified in the CDRL.

K.3.2.1 SDSSS Tailoring Matrix

The tailoring matrix provides a description of the high level description of the degree of formality to be implemented for each of the 25 top-level software activities across the risk classes. It is still necessary for the user to read the comprehensive requirements contained in the SDSSS and create their detailed tailoring.

The descriptions in the tailoring matrix contained in Table K-2 were developed by interviewing subject matter experts responsible for managing and developing different classes of space vehicle software. The interview data is reflected in the matrix and as such reflects what is done or expected to be done in each of the four risk classes. Section 5.1 contains a list of the participants that were involved in these interviews.

Before using the Table K-1, the space vehicle's risk classification level needs to be determined for the flight/onboard software to be developed. It is most likely that the software will be at the same risk classification level as the space vehicle. Once the space vehicle's risk classification level is determined, use the matrix as guidance to tailor SDSSS sections 5.1, "Project Planning and Oversight" through 5.25, "Improvement of Project Processes." Also review SDSSS Section 4, "General Requirement" and tailor each requirement in this section accordingly. Since these requirements are general to the development of most software systems and usually accepted as is, they are not covered in this table.

In general, the formality of performing the 25 tasks decreases as you move from Class A to Class D. The exception to this is when a system may share a launch vehicle of a higher classification, in which case the system may be required to adopt the higher classification requirements. Many times for the Class C and D systems, the software activities become a part of the overall system requirements rather than being performed as a separate activity. An example to illustrate this is below.

Table K-2. Software Development Requirements[6]

	Discipline	Class A	Class B	Class C	Class D
1	**Project planning And oversight**	Contractor develops and maintains Software Development Plan (SDP) and other related plans. Performs comprehensive strategic and tactical planning. Government oversight to evaluate compliance to plans. Subsequent revisions require government review and approval.	SDP and other project plans (e.g., IMP, IMS, SCMP, SQAP) and subsequent updates require government approval. Other plans, such as test and transition, are often provided for review and comments. Government may evaluate compliance to plans.	Deliver high level SDP and Software Test Plan (STP) documents for review and comments. Emphasis on early testing of requirements.	Generate non-deliverable SDP and STPs per iteration, through iterative tactical negotiations between the key stakeholders; document agreement (e.g., Excel, MS Project).
2	**Establishing a software development environment**	Software environments including: engineering, test, code libraries, tools, and deliverable and non-deliverable software items, are set up and maintained subject to government oversight and approval.	Software environments are established and maintained subject to government oversight and approval. However areas of lower risk software environments may not have government oversight or approval.	Contractor responsible for establishing and managing software environments that satisfy government requirements.	Contractor is responsible for establishing and maintaining the software development environment.
3	**System requirements analysis**	Contractor software engineering participates in Operational Concept definition, elicitation of user needs, and recording of the system requirements (e.g., OCD, SSS).	Recommended participation by contractor's software engineering in Operational Concept definition, elicitation of user needs, and recording of the system requirements (e.g., OCD, SSS).	Systems engineering performs requirements analysis. Software engineering participation is optional.	Contractor engineering (not separate systems and software) negotiates and documents agreements on capabilities and risks mitigation strategies (incl. prioritization, and opportunities).
4	**System design**	Define, document, review the system design for each software build. Government oversight and approval (e.g., SSS, review process) is required.	Same as Class A with the government focus on higher risk elements.	Typically system level designs w/o software engineering input. Recommend: Software subject matter expert should be included.	Contractor establishes and manages design (build) activities without government involvement. Usually under development leads control.
5	**Software requirements analysis**	Contractor provides all software requirements artifacts (e.g., Software Requirements Specification [SRS], Interface Requirements Specification [IRS]), including verification and traceability from software item to system requirements and designs to government for review and approval.	Same as Class A	Contractor to provide government software requirements artifacts including, verification, and traceability from software item to system requirements and designs. Software Requirement Specifications and Interface Requirements Specifications often not provided to government.	Contractor may include software requirements as a part of the system requirements.

[6]Acronyms used in this table are described in Table K-3.

	Discipline	Class A	Class B	Class C	Class D
6	**Software design**	For all software items, the contractor provides all architectural and detailed design documentation (e.g., Software Architecture Description [SAD]) for government review and approval.	For most software items, the contractor provides design documents to government for review and approval. Records are available for government review.	Contractor provides design artifacts for the software items to government for review and comments. Detailed design artifacts are not reviewed by the government.	Contractor establishes and manages all design activities without government approval.
7	**Software implementation and unit testing**	Contractor performs software implementation per the approved software item design. Verification is planned and performed for each software unit. Unit test cases and procedures are used to perform unit tests. Records are maintained in SDFs. Regression tests performed. Records are available for government review.	Same as Class A except government selects their participation in reviews and inspections based on risk.	Contractor performs software implementation per the software item design. Verification may be performed for each software unit. Records may be maintained in SDFs. Little to no government oversight.	Contractor implements the software design. Verification records may be kept in engineering logs. No government involvement.
8	**Unit integration and testing**	Contractor performs software unit integration and tests and maintains records (e.g., test cases, test results, analysis) in SDF's. Regression testing performed on modified software. Evaluated on target/target-like environment. Records are available for government review.	Same as Class A	Contractor performs software unit integration and tests, including regression tests. Records may be maintained in SDFs.	Same as Class C except that records may be kept in engineering logs.
9	**Software item qualification testing**	Formal demonstration to the government that software requirements have been met by software item. Performed by person(s) independent from software developers on target/ target-like environment with Government witness and acceptance. Comprehensive records generated, analyzed and reported. Software Test Plan, Test Procedures, Test Reports reviewed and approved by government.	Same as Class A	Software is qualified as a part of the system qualification process.	Usually not applicable.

	Discipline	Class A	Class B	Class C	Class D
10	**Software/hardware item integration and testing**	Establishment of test cases for software/hardware integration testing. Focus on SW-to-SW and SW-to-HW interfaces (e.g., fault tolerance, fail over, CPU, memory, storage, bandwidth). Subject to government review and approval.	Same as Class A	Integration and testing conducted per contractor practices. Government may participate in contractor demonstrations and review and comment on artifacts (e.g., test cases, test results).	Integration and testing conducted per contractor practices. Government to participate in contractor demonstrations.
11	**System qualification testing**	Contractor software engineering participates to support analysis of software anomalies. Formal demonstration to the government that system requirements have been met. Government witness and acceptance. Comprehensive records generated, analyzed and reported. Test Plan, Test Procedures, Test Reports reviewed and approved by government.	Same as Class A	Software is qualified as a part of systems qualification, not as a separate item and is witnessed by the government.	Same as C.
12	**Preparing for software transition to operations**	Contractor prepares and delivers all software artifacts (e.g., software, user, and operation manuals) for transition to operations. All artifacts are subject to government review and approval.	Same as Class A	As applicable, contractor prepares and delivers executable software, version descriptions, and user manuals for government review.	Usually not applicable.
13	**Preparing for software transition to maintenance**	Contractor prepares and delivers all software artifacts (e.g., software, version description document, user manuals) for transition to operations. All artifacts are subject to government review and approval.	Same as Class A	Usually not applicable due to short duration of contract.	Usually not applicable.
14	**Software configuration management**	Contractor performs software configuration management (CM) including: identification, change control, audits, and status accounting. CM applies to all deliverable and non-deliverable software artifacts. Change control boards (CCBs) implemented at multiple levels. Government participates at software item level CCB and above.	Same as Class A except government participation varies per program.	Contractor implements configuration management, tools, and methods per organization practices.	Same as C.

	Discipline	Class A	Class B	Class C	Class D
15	**Software peer reviews and product evaluations**	Peer review preparation, materials, reviews, follow-up and data analysis are performed by contractor. Meeting records kept with evaluations and resolutions documented. Contractor provides peer review status, metrics, and corrective actions to the government for review.	Same as Class A	Contractor determines the applicability of peer reviews and product evaluations.	Same as Class C.
16	**Software quality assurance**	Contractor performs ongoing independent evaluations of software development process, products, work products, and software services. Documents evaluation records and resolutions for all software quality assurance activities and non-compliance issues and makes them available to the government for review.	Same as Class A	Contractor determines the applicability of software quality assurance product and process evaluations.	Not performed.
17	**Corrective action**	Contractor implements corrective action system to manage problem/defect reports. Reports describe problems detected in software entities and processes under any level of configuration control above the author. All corrective action artifacts are subject to government review and approval.	Same as Class A.	Contractor implements corrective action system per organizational practices. Government may review and provide comments.	No formal corrective action system. Problems solved when needed.
18	**Joint technical and management reviews**	Joint (government, contractor team) technical reviews (e.g., PDR, CDR, TRR) conducted for evolving software products, project status, and ongoing communications. Joint management reviews conducted for project status, approvals, commitments, and to resolve management issues. Risk mitigation strategies are presented at both types of reviews.	Government and contractor participation is dependent on specific program needs, and government leadership.	Less formal Technical Interchange Meetings (TIMs) with the government may be conducted for the review of such things as design and test.	Not required.

	Discipline	Class A	Class B	Class C	Class D
19	**Risk management**	Contractor performs formal risk management throughout the software development process. Strategies for managing the risk are developed, measured, and tracked, and are subject to government oversight and approval.	Same as Class A except government oversight often limited to participation in milestone reviews.	Contractor performs program risk management per their practices.	None performed.
20	**Software management indicators**	Contractor documents and delivers software measurements throughout the software lifecycle as defined per contract. Subject to government review and approval.	Same as Class A.	Management indicators usually only focus on schedule and cost at the system level.	Not done.
21	**Security and privacy**	Contractor ensures all security and privacy requirements specified in the contract are documented and traced to the implementation. Government reviews and approves all artifacts.	Same as Class A.	Same as A except, for those without contract requirements, they may be required to satisfy the security and privacy requirements specified in the payload vehicle or launch vehicle contract.	Same as Class C.
22	**Subcontractor management**	Contractor manages all subcontractors providing software products or services in accordance with the contract requirements flowed down to the subcontractors. Subject to government oversight and approval.	Same as Class A.	Same as Class A except no government oversight and approval.	Not required.
23	**Interface with software independent verification and validation agents**	Contractor interfaces with software IV&V agents as specified in the contract and overseen by government.	Contractor may use non-project personnel under the contractors control as IV&V agents as specified in the contract. Usually overseen by government.	When required by contract, IV&V is performed on a small set of selected program items. Government may review and comment.	Not required.
24	**Coordination with associate developers**	Contractor coordinates with associate developers, working groups, and interface groups, as specified in the contract.	Typically not required by contract. Contractor may conduct informally.	Same as Class B.	Same as Class B.
25	**Improvement of project processes**	Contractor periodically assesses the suitability, efficiency, and effectiveness of the processes used on the program, updates the SDP to incorporate improvements. Government monitors improvement activities, ties to award fees and reviews and approves SDP revisions.	Same as Class A.	Contractor may conduct lessons learned and post mortems typically after each iteration and apply in next iteration and/or SDP revision.	Not performed.

K.3.2.2 Enabling Products

This section provides an overview of the software products recommended as deliverable products under the contract as items on the Contracts Data Requirements List (CDRL). This should not be used without referring to Section 5 in the SDSSS for the specific details and implementation guidance for each. Table K-3 lists these software products, the applicable Data Item Description (DID), and the purpose of each document. In addition it also specifies whether the document should be delivered uniquely for each software item (per software item), or whether it can be delivered to address all software (software level) on the program.

Tailoring of these products may consist of reducing the formality of the documents, e.g., allowing the developer to delivery it as a Data Accession List (DAL) item, or having it developed internally available to the acquirer. Table K-2 also identifies which items are commonly provided as DAL items. Tailoring may also consider combining similar documents in less complex systems.

When performing tailoring, it is important to contact the software acquisition experts for assistance with identifying, justifying, and tailoring software requirements and software-related CDRL items for the particular program. These experts understand the contractual ramifications and have experience in tailoring.

Data Item Descriptions (DID) are tailored to meet the needs of the program using DD Form 1423-1, "Contract Data Requirements List." An example of a tailored Software Product Specification on a DD Form 1423-1 is provided in Figure K-2. The DIDs must be listed, as applicable, on the CDRL in order to have the product delivered under the contract.

Table K-3. Recommended Software Products

Software Product	DID Number	Software Level	Per Software Item (SI)	Common DAL[7] Item	Brief Description
Plans					
Software Development Plan (SDP)	Use Appendix H of SDSSS, based on requirements in SDSSS	X			The Software Development Plan (SDP) describes a developer's plans for conducting a software development effort. The term "software development" is meant to include new development, modification, reuse, reengineering, incorporation of commercial item (also known as COTS) packages, maintenance, and all other activities resulting in software products. The SDP provides the acquirer insight into, and a tool for monitoring, the processes to be followed for software development, the methods to be used, the approach to be followed for each activity, and project schedules, organization, and resources. Note: The DID is tailored to require compliance with the content outlined in Appendix H of TOR-2004(3909)-3537, Software Development Standard for Space Systems, as tailored for the contract. The DID and the TOR are used when the developer is tasked to develop and record plans for conducting software development activities.
Software Measurement Report (SSMR)	DI-MISC-80508B [2]	X			Each Software and System Measurement Report (SSMR) is an integrated report covering the software and system development activities for all significant software and system team members, as defined in section 1.2.2 of TOR- 2004(3909)-3537, (i.e., any internal or external organization supporting or performing software and systems development or test including support provided through informal and formal agreements and contracts) throughout the project development. The SSMR provides explanations and interpretations of reported measurement data, including deviations from expected or projected values and breaches of thresholds, as well as any corrective actions being undertaken. The software and system measurements collected and reported each month are expected to vary because the lifecycle activities vary over time.

[7]Data Accession List - A CDRL item called the Data Accession List (DAL) consists of an index of the internally generated data items and computer software used by the contractor to develop, test, and manage a program or to document compliance with the work effort described in a Statement of Work (SOW). The contractor is not required to deliver the items shown on the DAL to the government. However, the government has the option to purchase one or more hard or electronic copies of the items listed in the DAL. The government requires access to the DAL items as specified per the contract.

Software Product	DID Number	Software Level	Per Software Item (SI)	Common DAL[7] Item	Brief Description
Software Master Build Plan (SMBP)	DI-MISC-80508B [2]	X			The Software Master Build Plan (SMBP) contains plans for the integration and verification of software. It ensures that the contractor follows a disciplined approach to software build planning. The SMBP defines the hierarchy/ies of software integration stages and the software requirements verification events in the integration hierarchy/ies (i.e., the specific integration stages at which requirements verification will occur). The SMBP includes the allocation of software components and software requirements to integration stages and the allocation of software requirements to verification events. The SMBP also includes integration and verification schedules and the responsibilities for and location of each integration stage and verification event in the integration hierarchy. (The SMBP is sometimes known as the Master Software Integration and Verification Plan.)
Software Installation Plan (SIP)	DI-IPSC-81428A [2]				The SIP is a plan for installing software at user sites, including preparations, user training, and conversion from existing systems. It is used when the installation process will be sufficiently complex to require a documented plan.
Software Transition Plan (STrP)	DI-IPSC-81429A [2]	X			The STrP identifies the hardware, software, and other resources needed for life cycle support of deliverable software and describes the developer's plans for transitioning deliverable items to the support organizations. The STrP is developed if the software support concept calls for transition for responsibility from the developer to the operations and support organizations. The STrP is used when the developer is tasked to develop and record plans for transitioning deliverable items to the operations and support organizations.
Requirements					
Software Requirements Specification (SRS)	DI-IPSC-81433A [2]		X		The SRS specifies the requirements for a Software Item and the methods to be used to ensure that each requirement has been met. Requirements pertaining to a software item's external interfaces may be presented in the SRS or in one or more Interface Requirements Specifications (IRSs) (DI-IPSC-81434A) referenced from the SRS.

Software Product	DID Number	Software Level	Per Software Item (SI)	Common DAL[7] Item	Brief Description
Interface Requirements Specification (IRS)	DI-IPSC-81434A [2]	X (IRS-E)	X (IRS-I)		The IRS-I specifies the interface requirements within the contract on one or more systems, segments, hardware items (HIs), software items (SIs), manual operations, or other system components to achieve one or more interfaces among these entities. An IRS can cover any number of interfaces. An IRS can be used to supplement the System/Segment Specification (SSS) and Software Requirements Specification (SRS) as the basis for design and qualification of testing of systems and software items. The IRS can reflect interfaces external to the contract (IRS-E) or interfaces internal to the contract (IRS-I). The IRS-I specifies the requirements for the interfaces internal to the contract. e.g., if the contract is for a segment the IRS-I would specify the interfaces within the segment. The IRS-External specifies the requirements for the interfaces external to the contract. e.g., if the contract is for a segment, the IRS-External would specify the interfaces between the segment and other segments and systems.
Design					
Software Architecture Description (SAD)	DI-MISC-80508B [2]	X			The Software Architecture Description (SAD) contains multiple architectural perspectives, including both models and detailed textual descriptions of the logical organization, dynamic behavior, process decomposition, software organization, and physical realization of the software. The SAD consists of a collection of components with well-defined interface and service semantics that operate over an underlying infrastructure.
Software Design Description (SDD)	DI-IPSC-81435A [2]			X	The SDD describes the design of a Software Item: the design decisions, the architectural design, and the detailed design needed to implement the software. It provides the acquirer visibility into the design and provides information needed for software support.

Software Product	DID Number	Software Level	Per Software Item (SI)	Common DAL[7] Item	Brief Description
Database Design Description (DBDD)	DI-IPSC-81437A [2]	X		X	The Database Design Description (DBDD) describes the design of a database, that is, a collection of related data stored in one or more computerized files in a manner that can be accessed by users or computer programs via a database management system (DBMS). It can also describe the software units used to access or manipulate the data. The DBDD is usually used to describe the database of space vehicle constants needed for various types and levels of testing, launch, on-orbit check out, and operations. This database also often contains code to be uploaded to the space vehicle and anomaly detection and recovery (ADR) values. The DBDD provides visibility into the design and provides information needed for software support.
Test and Verification					
Software Test Plan (STP)	DI-IPSC-81438A [2]		X		The STP describes plans for qualification testing of software items and software systems. It describes the software test environment to be used for the testing, identifies the tests to be performed, and provides schedules for test activities. The STP should address a logical collection of Software Items (SIs), e.g., one STP for the space segment, and one STP for the ground segment. The STP enables the acquirer to assess the adequacy of planning for software item and software system qualification testing. The STP is used when the developer is tasked to develop and record plans for conducting qualification testing or system qualification testing of a software system.
Software Test Description (STD)	DI-IPSC-81439A [2]		X		The STD describes the test preparations, test cases, and test procedures to be used to perform qualification testing of a Software item or a software system or subsystem. The STD enables the acquirer to assess the adequacy of the qualification testing to be performed. The STD is used when the developer is tasked to analyze, define, and record the test preparations, test cases, and test procedures to be used for the software item qualification testing or for system qualification testing of a software system.
Software Test Report (STR)	DI-IPSC-81440A [2]		X		The STR is a record of the qualification testing performed on a Software item, a software system or subsystem, or other software-related item. The STR enables the acquirer to assess the testing and its results. The STR is used when the developer is tasked to analyze and record the results of the software item qualification testing, system qualification testing of a software system, or other testing identified in the contract.

Software Product	DID Number	Software Level	Per Software Item (SI)	Common DAL[7] Item	Brief Description
Delivery, Installation, and Maintenance					
Software Version Description (SVD)	DI-IPSC-81442A [2]		X		The SVD identifies, describes, and records a software version consisting of one or more Software Items to be delivered to a user, support, or other site. It is used to control software versions.
Software Product Specification (SPS)	DI-IPSC-81441A [2]		X		The SPS contains or references the executable software, source files, and software support information, including "as built" design information and compilation, build, and modification procedures for the Software Item.
Operations					
Software User Manual (SUM)	DI-IPSC-81443A [2]		X		The SUM tells a hands-on software user how to install and use a software item, a group of related software items, or a software system or segment. It may also cover a particular aspect of software operation, such as instructions for a particular position or task. The SUM is developed for software that is run by the user and has a user interface requiring online user input or interpretation of displayed output. If the software is embedded in a hardware-software system, user manuals or operation procedures for that system may make separate SUMs unnecessary. The SUM is used when the developer is tasked to identify and record information needed by hands-on users of software.

Software Product Specification (SPS)

CONTRACT DATA REQUIREMENTS LIST (1 Data Item)	Form Approved QMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 110 hours per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information, Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503. Please DO NOT RETURN your form to either of these addresses. Send completed form to the Government issuing Contracting Officer for the Contract/PR No. listed in Block E.

A. CONTRACT LINE ITEM NO.	B. EXHIBIT A	C. CATEGORY: TDP X TM OTHER
D. SYSTEM / ITEM <Fill In>	E. CONTRACT / PR NO. <Fill In>	F. CONTRACTOR RFP Contractor - Not Identified
1. DATA ITEM NO.	2. TITLE OF DATA ITEM Software Product Specification (SPS)	3. SUBTITLE <Fill In or Leave Blank>
4. AUTHORITY *(Data Acquisition Document No.)* DI-IPSC-81441A/T	5. CONTRACT REFERENCE <Fill In>	6. REQUIRING OFFICE <Fill In>

7. DD 250 REQ <Fill In>	9. DIST STATEMENT REQUIRED D	10. FREQUENCY BLK 16	12. DATE OF FIRST SUBMISSION BLK 16	14 & 15. **DISTRIBUTION AND TOTAL** See CDRL Distribution Report
8. APP CODE A		11. AS OF DATE	13. DATE OF SUBSEQUENT SUBMISSION BLK 16	

16. REMARKS:

BLK 4: In DI-IPSC-81441A/T, tailor as follows. Contractor format is acceptable.

1. The SPS contains or references the executable software, source files, and software support information, including "as built" design information and compilation, build, and modification procedures, for a software item. The SPS can be used to order the executable software and source files for a software item and is the primary software support document for the software item.
2. One or more Software Product Specifications (SPSs) shall cover all software items in the following categories of software (including the software portion of firmware):
   a. onboard software (e.g., spacecraft, communications, payload); and
   b. ground operations software (e.g., mission planning; mission processing; mission support; telemetry, tracking and commanding; database software; infrastructure and services); and
   c. other software (e.g., software for training; modeling, simulation, and other analysis tools; database support, including data to be uploaded to the space vehicle) to be:
      1) delivered to the customer; or
      2) used in performing or supporting operations or
      3) used in performing or supporting sustainment.

G. PREPARED BY	H. DATE	I. APPROVED BY	J. DATE

DD FORM 1423-1, JUN 90 PREVIOUS EDITIONS ARE OBSOLETE PAGE 1 OF 2 PAGES

Figure K-2. Example CDRL Item Form 1423.

K.3.3 Implementation over the Life Cycle of the Acquisition

DOD 5000.02, *Operation of the Defense Acquisition System* (Table K-1 [7]) defines the Acquisition framework phases.

Many of the fielded systems will be delivered in increments where each increment provides some capability that can be developed and produced. The development of the program's RFP, which includes a tailored SDSSS (if applicable), occurs as the phases of the acquisition framework progress. As the RFP is being developed and the resulting contract, tailoring of the SDSSS is conducted. Table K-4 illustrates where the process of tailoring the SDSSS fits into the proposal and contract award activities.

The recommended software deliverable items are listed in this section by acquisition program phase. Many deliverables are frequently delivered multiple times over a contract's period of performance, initially providing a draft (D), a preliminary release containing the complete required content (P), a final release (F) and updates (U) as needed. Depending on the acquisition phase of the program, deliverable documents are timed to be delivered at major milestone reviews to support program decisions. Generally, a CDRL item (complete document) is required 45 days before the review and a version incorporating government comments is required 30 days after the review (allowing the government 45 days for comments and the contractor 30 days to incorporate the comments). Timing of CDRL item deliveries is subject to changes from the recommended CDRL delivery timing based upon the program's needs.

For more detailed information on timing of software deliverables for space systems, refer to *Recommended Software-Related Contract Deliverables for National Security Space System Programs* (Table K-1 [8]). Table K-4 provides a high-level summary of these software deliverables.

The complete set of CDRL items might not apply to every contract. Some contracts are Phase A Concept Development contracts that only include activities and products through System Requirements Review (SRR) and System Design Review (SDR). Some contracts are only Phase B, Preliminary Design, Phase C, Complete Design, and Phase D, Build and Operations, or some combination.

Table K-4. Software Deliverable Products by Acquisition Phase[8]

	Acquisition Program Phase A					Acquisition Program Phases B, C, AND D							
	SCOPE	**PROPOSAL**	**CONTRACT AWARD^{+30} CD**	**SRR**	**SDR**	**PROPOSAL**	**CONTRACT AWARD^{+30} CD**	**PDR**	**CDR**	**EACH BUILD REVIEW**	**EACH SWI TRR**	**EACH BUILD COMPLETION**	**EACH TRANSITION**
ALL SOFTWARE				SDP^{D}	SDP^{F}	SDP^{D}	SDP^{F}	SDP^{U}	SDP^{U}				
								SRS^{P}	SRS^{F}	SRS^{F}	SRS^{U}	SRS^{U}	
				IRS-E^{D}	IRS-E^{P}			IRS-E^{P}	IRS-E^{F}	IRS-E^{F}	IRS-E^{U}	IRS-E^{U}	
								IRS-I^{P}	IRS-I^{F}	IRS-I^{F}	IRS-I^{U}	IRS-I^{U}	
					SAD^{D}	SAD^{D}	SAD^{D}	SAD^{P}	SAD^{F}	SAD^{F}	SAD^{U}	SAD^{U}	
								SMBP^{P}	SMPB^{F}				
			Software and System Measurement Report (Monthly)			Software and System Measurement Report (Monthly)							
							SRDR^{D}			SRDR^{D}	SRDR^{F}	SRDR^{F}	
SOFTWARE ITEM (SI)								STP^{P}	STP^{F}	STP^{U}	STP^{U}		
										STD^{P}	STD^{F}		
												STR^{F}	
												SVD^{F}	SVD^{F}
												SPS^{P}	
												SPS^{F}	
									SUM^{D}	SUM^{P}	SUM^{P}	SUM^{F}	SUM^{F}
									STrP^{P}	STrP^{U}	STrP^{U}		STrP^{F}

Legend: D = Draft F = Final
P = Preliminary (full content) U = Updates are required when changes occur
+30 CD = 30 calendar days after contract award
*Initial required at beginning and on each build.
**Final at each build and at each end.

[8]Product acronyms defined in Table K-3.

K.4 Contract Language

Each program requires careful review of the scope and acquisition phase to determine the appropriate words to be contained in the proposal and contract. At this time, standard "templates" do not exist to be used to generate the statement of work (SOW) or sections within the request for proposal (RFP). SME support in the development of your SOW and RFP software sections is recommended to ensure appropriate clauses are included.

The subsections below provide extracted *example* words that have been used during the acquisition of a Category A space system.[9]

K.4.1 Statement of Work (SOW)

K.4.2 SOW Section: Software Systems Engineering, Integration and Verification

- Software Planning, Tracking and Controlling

  "The contractor shall develop and maintain an integrated SDP in accordance with the Software Development Standard for Space Systems (TOR-2004(3909)-3537) over all team members for all software items…"

  "…plans the builds and the requirements to be met in each build"

- Software-Related Systems Engineering, Integration, and Verification

  "The contractor shall support, system, segment, element, and subsystem requirements flow down and allocate requirements to software items"

  "The contractor shall manage and conduct the integration, regression, and verification of each software item in bus, payload, satellite ground support, and software modeling and simulation"

Software would need to be addressed in many other sections such as "Software-related Technical Reviews and Audits," "Software configuration management," and "Software Quality Assurance." In addition, each major subsystem (e.g., payload) would require detailed SOW paragraphs and/or language to be written.

K.4.3 Award Fee Section

The SOW usually identifies the Award Fee and Incentive Plan that will be used during contract performance. Award fees reward the right behavior to arrive at desired outcomes using measurable criteria and are evaluated and given two to four times a year. On a Class A Space System, the contract award fee will identify requirements tied to the software development performance. An example of these technical performance award fee criteria for "Software Engineering" is shown below.

[9] Examples are extracted from The Aerospace Institute's *Space Systems Software Acquisition Management* course (S4460).

K.4.3.1 Technical Performance Criteria

- Technical Criteria will be evaluated based upon the quality of the products delivered.
- Product Performance will be assessed against the following criteria:
  - Peer (Subcontractors, Segment Partners, External Interfaces, User) reviewed and coordinated with government before critical dates needed.
  - Delivered in a timely manner in a format easily understood.
  - Justification for major allocations and trades (including Cost as an Independent Variable [CAIV] studies) carried out and results presented to stakeholders for review and decision-making. This information must be provided early enough in the process to allow the government sufficient time to make a decision.
  - Effective Technical Performance Measures for critical requirements are defined, understood, implemented, tracked, and reported.
- Evaluation Periods 1 and 2 – Software is a part of evaluations
  - Mature Technical Requirements Document
  - Requirements allocation to system specifications down through elements and test documentation
  - System Design
  - Earned Value Management System
  - System Engineering Plan
  - Configuration Management Plan
  - Software development environment
  - Software Development Plan
  - Verification Cross-Requirement Matrix
  - Requirement Verification Plans
  - Test plan
  - Integration plan
  - Architect test facility
  - Facility plans
  - Information Assurance requirements

K.4.4 Requests for Proposal (RFP)

During the proposal phase of the program, care must be taken to generate appropriate instructions and explanations to the bidders in order to obtain the appropriate data to complete source selection.

As in section 3.1 above, there are no standard template words to be used to generate the software related sections of the RFP as these are unique to the specific solicitation. Proposals address the following topics and are often generated using a uniform contract format:

1. Part I—The Schedule
   - A. Solicitation/Contract Form
   - B. Supplies or Services and Prices or Costs
   - C. Specification/SOW/SOO/Operational Requirements Document
   - D. Packaging and Marking
   - E. Inspection and Acceptance
   - F. Deliveries or Performance
   - G. Contract Administration Data
   - H. Special Contract Requirements
2. Part II—Clauses
   - I. Contract Clauses
3. Part III—List of Documents, Exhibits, and Other Attachments
   - J. List of Attachments
4. Part IV—Representations and Instructions
   - K. Representations, Certifications, and Other Statements
   - L. Instructions, Conditions, and Notices to Offerors or Quoters
   - M. Evaluation Factors for Award

The most common sections with requirements pertaining to software are sections "H," "L," and "M." A description of each section and an example of the application to software is provided.

L.4.4.1 Section H – Special Contract Requirements

Section H provides requirements such as the type and terms of contract, the maximum contract value, tax related information, requirements for electronic access, citizen requirements, etc. For software this section typically focuses on:

- Electronic and physical access to contractor and subcontractor information and facilities throughout the contract
- Appraisal of contractor and subcontractors' processes using the Capability Maturity Model® Integration℠ (CMMI®)[10] and the related appraisal method

[10] CMM Integration, IDEAL, and SCAMPI are service marks of Carnegie Mellon University.

Examples of the topics addressed for software are:

- Electronic Data Interchange (EDI) Network
  - Requires implementation and maintenance by contractor during the contract
  - Provides government with electronic, secure access to all contractor and subcontractor information produced throughout the contract
  - Includes tools to query, report, and display information
- Enabling Clauses (Table K-1 [9])
  - Requires the contractor and all subcontractors to provide physical access and information to FFRDC and SETA personnel during the contract
  - States that FFRDCs, SETAs, etc., are not authorized to direct the contractor
  - Software Independent Verification and Validation (IV&V) (if applicable)
    - Requires the contractor and all subcontractors to provide access and information to the software IV&V organization(s) during the contract
- Capability Maturity Model® Integration℠ (CMMI®) Appraisals
  - Requires contractor to conduct periodic team-wide appraisals during the contract with government option to participate
  - Provides the right for the government to perform independent appraisals at any time with the first being 9 to 12 months after contract award

Sections L and M of the RFPs have a matching structure. An example of this structure is shown below in Table K-5.

® Capability Maturity Model, Capability Maturity Modeling, CMM, and CMMI are registered in the U.S. Patent and Trademark Office by Carnegie Mellon University.

Table K-5. Software Deliverable Products by Acquisition Phase

Section L	Section M
4.2.3 Software Development	**4.2.3 Software Development**
4.2.3.1 Software Development Processes, Plans, and Environment **a. The Offeror shall submit an integrated SDP that: …** **(1) proposes integrated processes, environment, standards, …**	**4.2.3.1 Software Development Processes, Plans, and Environment** **a. The Offeror's SDP describes:** **(1) comprehensive, consistent, compatible, and coordinated software development processes, environments, …**
4.2.3.2 Software Architecture **a. The Offeror shall show how the software architecture maps to the proposed specification**	**4.2.3.2 Software Architecture** **The Offeror proposes a technically sound software architecture that:** **a. Maps to the requirements in the proposed specification**
4.2.3.3 Software Top-Level Design	**4.2.3.3 Software Top-Level Design**
4.2.3.4 Development, Integration, Verification, and Deployment	**4.2.3.4 Development, Integration, Verification, and Deployment**
4.2.3.5 Software Risks	**4.2.3.5 Software Risks**

K.4.4.2 Section L – Instructions, Conditions, and Notices to Offerors or Quoters

Section L provides instructions to the Offerors including requirements for proposal delivery, content by volume, and instructions about attachments. It specifies the contract volumes and proposal volumes, e.g., executive overview volume, volumes, and attachments for each factor and subfactor. It provides specific instructions for the minimum information required with the proposal, including for each subfactor:

- Integrated Master Plan (IMP) content and format
- Integrated Master Schedule (IMS)
- Page count limits, size and format for some proposal items
- Attachments, e.g.,
  - Software Development Plan (SDP) *
  - Software Architecture Description (SAD)
  - CMMI® Process Questionnaire responses and data
  - Past Performance Questionnaire
  - Systems Engineering Management Plan (SEMP)
  - Reliability Plans
  - Basis of Estimates (BOEs), Size estimates (SLOC)
  - Contractor Statement of Work (CSOW)
  - Rights in Technical Data, Computer Software and Computer Software Documentation

K.4.4.3 Section M – Evaluation Factors for Award

Section M identifies all the significant factors and any significant subfactors that are to be considered in awarding the contract and their relative importance.

An example of the Section M wording for Software Engineering and Process subfactor is:

"The proposal requirement will be met when the Offeror:

- *Proposes mature, disciplined, systematic, and managed product development approach for [ground and space] software … and including a vetted development approach consistent with the level 2 and 3 project management, engineering, and support process areas of the Capability Maturity Model Integration® (CMMI®) operating at the defined capability level.*
- *Proposes a software development process that satisfies all SEI Standard CMMI® Appraisal Method for Process Improvement (SCAMPI℠) criteria effectively for all significant software team members; demonstrates consistency across and between significant software team members' SCAMPI℠ responses and the contractual documents; and demonstrates effective past usage."*

K.4.5 Integrated Master Plan (IMP) and Integrated Master Schedule (IMS)

The Integrated Master Plan is the central management plan that becomes a binding part of the contract. IMP narratives provide high level objectives, compliance documents, and processes for specific topics in Section L, including such areas as systems engineering, software development and maintenance, specialty engineering, configuration management and logistics.

The IMP is the primary tool for tracking the program's status and covers the entire program, including the prime and all subcontractors. The award and incentive fees are generally tied to completion of program events and functionality.

These IMP/IMS sections contain or reference the software development activities, software products, and associated work products from the tailored SDSSS. Careful consideration should be given when tailoring the SDSSS so that program applicable software development activities, software products, and associated work products can be included in the IMP and IMS at a level visible enough to track the software development status effectively.

The integrated master schedule outlines the program plan in sufficient detail to define resource requirements, material timing, and integration requirements with existing plans and schedules. The IMS, built around the work breakdown structure (WBS), is the top level of the scheduling system, and is supported by a hierarchy of intermediate and detailed schedules. All critical dependencies, resources needed, and critical path items are clearly identified on the IMS.

The structure of the WBS should be established to provide visibility into the status and software events. The recommended WBS for software-intensive space systems may be found in the Appendix to The Position of Software in the Work Breakdown Structure (WBS) for Space Systems (Table K-1 [10]).

K.5 Subject Matter References

K.5.1 Tailoring Guide Participants

The authors of this appendix would like to acknowledge the following SMEs for their contributions: Daniel Byrne, John Cantrell, David Hinkley, Bob Klungle, Lee Marvin, Dr. Daniel Rumsey, and Dr. Alan Unell.

K.5.2 Aerospace Software Capabilities, Computer Systems Division

This is a list of Aerospace capabilities available and involved in software related activities.

- Aviation Safety
- Software Safety
- Financial
- Human Systems Integration
- Information Assurance
- Reliability, Maintainability, and Availability
- Request for Proposal Training
- Software Acquisition (including Software CDRL items, RFPs and tailoring)
- Software and Systems Processes
- Software Architecture and Design
- Capability Maturity Model Integration®[11] and process appraisals
- Software Assurance
- Software Estimation
- Software Requirements Development
- Software Standards
- Software Testing
- Systems Engineering
- Software Configuration Management
- Software Quality Assurance
- Risk Management
- Subcontractor Management
- Software Management Indicators (measurement and analysis)

[11]CMMI, Capability Maturity Model, CMM, and Carnegie Mellon are registered in the U.S. Patent & Trademark Office by Carnegie Mellon University.

K.5.3 Space and Missile Systems Center (SMC) Resources

SMC can provide CDRL item expertise in the following areas. Other organizations have similar expertise to support their programs.

- SMC/PI Acquisition Center of Excellence (ACE)
- SMC/EA
  - Specifications and Standards Working Group
  - Engineering Acquisition Support Team (EAST)
  - SMC Chief Software Engineer