AEROSPACE REPORT NO.
TOR-2006(8506)-4732 REV. A

Space System Verification Program and Management Process

30 June 2008

Prepared by

S. Nagano
Directorate H West
Electronic Programs Division

Prepared for

SPACE AND MISSILE SYSTEMS CENTER
AIR FORCE SPACE COMMAND
483 N. Aviation Blvd.
El Segundo, CA 90245

Authorized by: National Systems Group

Contract No. FA8802-04-C-0001

THE AEROSPACE CORPORATION
EL SEGUNDO, CALIFORNIA

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The update was suggested by the NSS-MAIW, as the function of late change verification management incorporates the report as a key element of the re-verification process.

Foreword

The original technical operating report that has been updated based on suggestions by the government-industry National Security Space-Mission Assurance Improvement Workshop (NSS-MAIW) to include requirements for verifying directly and collaterally impacted “late changes.”

These “late changes” may involve those relating to requirements, designs, manufacturing, piece-parts, etc. In addition, a “critical clearances” related requirement was added to the document based on a suggestion by the NSS-MAIW.

The detailed requirements for these two added areas were developed by the following working groups: NSS-MAIW, Verification Management/Late Changes, and Critical Clearances.

Contents

Tables

1. Scope

1.1 Introduction

It is important for each space system (SS) contractor to establish a distributed-verification program that requires implementation of a standard set of verification management processes at every level of the contracted system. This is to ensure that "system is built right" verification, in requirement, design/analysis, manufacturing, test, and sell-off phases is properly planned and executed at every level of the developing system in order to minimize/avoid costly late changes or post-launch failures.

This approach is intended to force each space system contractor to move away from a traditional "centralized verification" approach that tends to lack solid verification at lower levels of system development, such as subsystem and unit development.

1.2 Purpose

This document establishes the requirements for the SS verification program and associated management processes specific to the acquisition of a space system that includes all or combinations of the SS, space vehicle/launch vehicle (SV/LV) segment, ground system (GS) segment, and the overall integrated system element as well as their lower-level subsystems, units, and interfaces (IFs).

1.3 Application

This document is intended for use in the acquisition of space systems. The document supplements the Systems Engineering and Verification standards/requirements cited in the contract proposal or statement of work.

1.4 Scope of Deliverable Documents

No duplicate data item descriptions (DIDs) shall be delivered based on the requirements specified here and in other contractually agreed-upon common documents, such as systems engineering standards, quality assurance, and integration and test. It is important that any such common documents be clearly referenced when they are used to satisfy requirements of this verification plan.

2. Applicable Documents

2.1 Applicable Documents for Developing the SS Verification Management Process

"Applicable documents" are defined herein as any contractually agreed-upon compliance documents that relate to the planning and execution of the verification program, which enforces that the "system is built right" in terms of verification of requirements, design/analysis, manufacturing, test, and sell-off at each level of system development.

3. Space System (SS) Verification Program and Management Processes

3.1 SS Verification Program

The contractor shall establish a SS verification program and conduct its verification activities including those relating to late changes, test like you fly (TLYF), heritage, and critical clearances, utilizing a set of verification management (VM) approaches and processes specified in paragraphs 3.2 and 3.3.

3.1.1 SS Verification Program Management Approach

The verification program shall utilize work breakdown structure/working group (WBS/WG)-based management so that experts from both the contractor and the customer participate in the planning and execution of the verification for their responsible parts of the space systems on a continuous basis throughout the existence of the program. (See Appendix A-1 for an example of a WBS/WG-based VM structure.)

3.1.1.1 SS Verification Management Board

Establishment of a Verification Management Board is highly encouraged, in order to provide insight into and oversight of each area of the SS verification activity. Doing so will help ensure that all activities are properly planned, approved/coordinated at all levels of the program, and executed on behalf of program management.

3.1.2 SS Verification Program Management Process

The SS verification program shall utilize, at minimum, the following set of VM processes further delineated in paragraphs 3.3.1 through 3.3.6:

- VM Process 1: Requirement Flow-Down and Verification Cross Reference Matrix (VCRM)
- VM Process 2: Requirement Verification by Analysis, Test, Inspection, and Demonstration
- VM Process 3: Integration and Test (I&T)
- VM Process 4: Individual Specification Dedicated-Verification Ledger (ISDVL)
- VM Process 5: Sell-Off/Consent-to-Ship
- VM Process 6: Verification-Related Issue/Watch List Management

3.1.3 SS Verification Program Flow-Down to Subcontractors and Vendors

The SS verification program and verification management approach/process shall be flowed-down from the prime contractor to the subcontractors and vendors.

3.2 SS Verification Program Plans

A verification program plan that implements the verification management approach and processes as described in paragraphs 3.1.1 and 3.1.2 shall be developed for each of the SS and lower-level systems.

3.2.1 Review of SS Verification Program Plans for the SS Element, Segment, Module, and Subcontractor/Vendor

A verification program for each of the SS elements, higher-level interfaces (IFs), segment (e.g., space vehicle (SV), launch vehicle (LV), ground system (GS), system internal IF, and module (e.g., bus, payload, and upper stage) levels as well as for each of the subcontractors and vendors shall be reviewed at each of the major program technical reviews — i.e., System Requirements Review (SRR), System Design Review (SDR), Preliminary Design Review (PDR), and Critical Design Review (CDR).

A single verification program plan for each segment (SV, LV, GS, or system internal IF segment) may be produced without producing separate module-level plans, if a single contractor develops the segment and its modules.

A sample contract data requirements list (CDRL) is provided in Appendix B-1.

3.2.2 Verification Program Plans for Systems Lower than Module Level

Each of the verification program plans for lower than module level systems (e.g., subsystem, assembly, section, unit, and lower-level IFs) also shall be reviewed at each associated SRR, SDR, PDR, and CDR. (See Appendix A-2 for the summary of the SS verification program plans delivery and review cycles.)

3.3 SS Verification Management Process Details

Each of the SS and lower-level systems shall follow the management processes detailed in paragraphs 3.3.1 through 3.3.6.

3.3.1 VM Process 1: Requirement Flow-Down and Verification Cross-Reference Matrix (VCRM)

Requirement flow-down from the SS, segment, and module specifications to lower-level system specifications (including interface specifications) and the assignment of verification method(s) at each specification level shall be properly performed such that 1) each of the top-level flowed-down requirement has documented traceability to the lowest level, 2) each of the flowed-down requirement is well defined and objectively verifiable, and 3) the rationale for the selected choice for the flow-down and verification method assignment are well explained and documented.

3.3.1.1 Review of Requirement Flow-Down and VCRM Plans for the SS Element, Segment, Module, and Subcontractor/Vendor

A requirement flow-down and VCRM plan and the results for each SS, segment, module, and subcontractor/vendor shall be delivered for review at SRR, SDR, PDR, and CDR.

A sample CDRL is provided in Appendix B-2.

3.3.1.2 Requirement Flow-Down and VCRM Plans for Systems Lower than Module Level

A requirement flow-down and VCRM plan for each system lower than the module level shall be reviewed at each related SRR, SDR, PDR, and CDR.

3.3.2 VM Process 2: Verification by Analysis, Test, Inspection, and Demonstration

Approaches, methods, and the associated worst-case design life, environmental, and operational conditions, i.e., Design Reference Cases (DRCs), used to "verify by analysis, test, inspection, and demonstration" for the SS and lower-level specifications shall be properly defined and documented for each requirement of a specification. Execution of the processes shall include active participation by the customer to ensure insight into methodology used.

3.3.2.1 Verification by Analysis

A list of analyses along with the approaches/methods, and a set of DRCs used for "verification by analysis" shall be identified and documented for each applicable requirement of the SS and lower-level specifications.

3.3.2.2 Verification by Test

A list of tests along with the approaches/methods (such as with the use of flight units, engineering units, breadboard, coupons, software/hardware-in-the-loop test, etc.), and test conditions for "verification by test" shall be identified and documented for a test requirement document (TRD) for each applicable requirement of the SS and lower-level specifications.

3.3.2.3 Verification by Inspection and Demonstration

A list of approaches/methods used for "verification by inspection and demonstration" shall be identified and documented for each applicable requirement of SS and lower-level system specifications.

3.3.2.4 Verification by Similarity

Verification by similarity shall be avoided unless documented analyses/assessments demonstrate that application of the system is completely the same as the earlier use in terms of applications, operating environments, electrical/mechanical/physical interfaces, design life, piece parts, manufacturing and I&T processes, and other relevant technical constraints.

3.3.2.5 Verification of Internal and External IF Requirements/Compatibility

Verification of internal and external IF specifications that are associated with the SS and lower-level systems shall be conducted with the same set of verification processes (VM Process 1 through 6, specified in paragraph 3.1.2).

3.3.2.6 Verification of Critical Clearances

A verification plan for critical clearance shall be developed and executed to ensure that critical clearances related requirements/criteria for any deployable systems are properly established, designed, manufactured, and tested using the same set of verification processes (VM Process 1 through 6, specified in paragraph 3.1.2).

3.3.2.7 Verification by Analysis, Test, Inspection, and Demonstration Plans for the SS Element, Segment, Module, and Subcontractor/Vendor

Verification by analysis, test, inspection, and demonstration plans and the results for each of the SS, segment, module, and subcontractor/vendor shall be delivered for review at SRR, SDR, PDR, and CDR.

A sample CDRL is provided in Appendix B-3.

3.3.2.8 Review of Verification by Analysis, Test, Inspection, and Demonstration Plans for Systems Lower than Module Level

Verification by analysis, test, inspection, and demonstration plans and the results for each of the systems lower than module level shall be reviewed at SRR, SDR, PDR, and CDR.

3.3.3 VM Process 3: I&T Plan

An I&T plan shall be developed for the SS and each of the lower-level systems 1) to test all the items listed in the TRD (see paragraph 3.3.2.2) for each associated specification, and 2) to verify the integrity of the designed/manufactured system under the appropriate environments specified in such documents as the appropriate version of MIL-STD-1540.

3.3.3.1 SS and Lower-Level I&T Sequence and Test Environments

A test sequence, environment types/levels, duration, and test monitoring approaches/methods, with documented rationale for selecting the acceptance, proto-qualification, or qualification test program, shall be established and documented for each of the SS and lower-level systems.

3.3.3.2 TLYF for the SS, Segment, and Module

A TLYF test plan shall be incorporated at the appropriate test level for a component to verify that the planned flight sequences and timelines, command operations, and data/telemetry up- and downlinks, deployments, etc., function under nominal and possible off-nominal conditions.

3.3.3.3 Test Readiness Review (TRR)

TRR shall be conducted prior to each of the SS and lower-level systems I&T, based on the entry and exit criteria that are reviewed and approved at SRR, SDR, PDR, and CDR.

3.3.3.4 Test Discrepancy Resolution and Retest

Test discrepancies, resolution, and scope of retest at level of integration shall be reported to the Failure Review Board (FRB), Parts, Materials, and Processes Control Board (PMPCB), Quality Assurance (QA), the appropriate WBS lead, and to SS verification program management for their approval.

3.3.3.5 Test Summary and "As Tested" Data Review

Each test level shall include a list of discrepancies, their disposition, and retest. This list shall be documented and reviewed and approved by QA, the FRB, PMPCB, the appropriate WBS lead, and SS verification program management at the conclusion of the test and before the item is integrated into the next level of integration.

3.3.3.6 I&T Plans for the SS Element, Segment, Module, and Subcontractor/Vendor

An I&T plan for each SS, segment, module, and subcontractor/vendor shall be delivered for review and approval at SRR, SDR, PDR, and CDR.

A sample CDRL is provided in Appendix B-4.

3.3.3.7 Review of SS Verification I&T Plans for SS Lower than Module Level Systems

Each verification program plan for unit through system level shall be reviewed and approved at major review milestones: SRR, SDR, PDA, CDA, and TRR.

3.3.3.8 Verification Management Process for Late Changes

A. Late Changes Definition

Late changes are defined as those changes to the SV, LV, GS, or their interfaces, procedures or processes, which compromise or potentially invalidate previously executed verification analysis, test, inspection, or demonstration.

Late changes would typically be introduced to, but not limited to, the SV, LV, or GS during their I&T in the factory or at the launch site, and may occur for various reasons:

(1) LCC-1: Late Changes Caused by Requirement/Concept of Operations (CONOPS) Issue

- Improper, incomplete or late allocation of requirements
- System element-to-element (e.g. space-to-ground, SV-to-LV) interface requirements issues
- Changes to CONOPS (all levels)

(2) LCC-2: Late Changes Caused by Design Synthesis Issue(s)

- Both flight and non-flight design issues or changes, including hardware-software interface compatibility

(3) LCC-3: Late Changes Caused by Pre-System Integration Manufacturing Issue(s)

- Flight and non-flight hardware non-compliance or non-conformance occurring during fabrication, manufacturing, and assembly, including repair, removal, and replacement issues

(4) LCC-4: Late Changes Caused by System Integration and Test Issue(s)

- A discrepancy or anomaly associated with a test or a process
- Hardware assembly and integration issues (including flight or non-flight hardware build or process issues)
- A "cause unknown" scenario

(5) LCC-5: Late Changes Caused by Alerts

- Internal: Contractor- or supplier-initiated alert, notice, or communication
- External: Customer- or industry-initiated directive, notice, or communication (i.e., GIDEP, MDA, or NASA).

B. Late Changes Verification Requirements

Late changes shall be assessed for both direct and collateral impacts to verify and validate the compliance of the SV to the program requirements and mission goals. The verification process shall:

(1) Encompass re-performance of, or additional analysis, inspection, test and demonstration, as necessary
(2) Assure applicability and validity of the verification criteria and methodology, as warranted by the change
(3) Follow the minimum set of checklists for planning and executing late changes, as explained in Appendix C.

3.3.4 VM Process 4: ISDVL

The ISDVL process shall be implemented for the SS through unit, including associated IFs, using a form that clearly summarizes a set of key information that demonstrates proof of verification and establishes traceability.

3.3.4.1 ISDVL Content

The content of an ISDVL for each of the SS and lower-level systems shall include, but is not limited to, a brief requirement description/ID number in the specification, a synopsis of the verification method/approach, the department responsible for verification, and the verification product ID, such as the analysis or test report. (An example of an ISDVL is illustrated in Appendix 3. The entire set of ISDVLs for all the SS and lower-level items can be stored easily in a computer data file for quick access and future traceability using this form.)

3.3.4.2 ISDVL Plans for the SS Element, Segment, Module, Subsystem, Unit, and Subcontractor/Vendor

An ISDVL plan and results for each unit through SS and subcontractor/vendor shall be delivered for review and approval at SRR, SDR, PDR, CDR, and Sell-Off/Consent-to-Ship.

A sample CDRL is provided in Appendix B-5.

3.3.4.3 Review of ISDVL Plans

ISDVL plans shall be reviewed and approved at each major review milestone: SRR, SDR, PDR, and CDR.

3.3.4.4 ISDVL Results at Sell-Off/Consent-to-Ship

Each of the ISDVL results shall be delivered, reviewed, and approved at each Sell-Off/Consent-to-Ship.

3.3.5 VM Process 5: Sell-Off and Consent-to-Ship

A set of entry and exit criteria and a standardized set of review data packages shall be developed for each of the SS and lower-level systems' Sell-Off/Consent-to-Ship. (Note: Entry/exit criteria for the Sell-Off and Consent-to-Ship reviews are not necessarily the same, since the completion of a SS Sell-Off/Consent-to-Ship sometimes requires the results of higher-level I&T results.)

3.3.5.1 SS and Lower-Level Component's Sell-Off and Consent-to-Ship Data Package

A data package for each of the SS and lower-level systems' Sell-Off and Consent-to-Ship shall include, at minimum, the following items with the approval signature of the appropriate WBS lead, verification program management, and the representatives from QA, PMPCB, and FRB:

- ISDVL
- As-tested test report approved by the WBS lead/QA/FRB/PMPCB
- Test summary, including environment test history, test anomaly, and disposition summary
- FRB/PMPCB summary, including approved/waived part lists
- Deviations/waivers summary
- Disposition status of action items generated at associated system's CDR, TRR, and test data review
- Disposition status of all the issue/concern items associated with each SS

3.3.5.2 Sell-Off and Consent-to-Ship Plans for the SS Subsystem, Unit and Subcontractor/Vendor

Sell-Off and Consent-to-Ship plans and the results for unit through SS, subsystem, and subcontractor/vendor shall be delivered for review and approval at SRR, SDR, PDR, CDR, and Sell-Off/Consent-to-Ship.

A sample CDRL is provided in Appendix B-6.

3.3.5.3 Review of Sell-Off and Consent-to-Ship Plans for Unit Through System

Each Sell-Off and Consent-to-Ship plan and the results for each system component shall be reviewed at SRR, SDR, PDR, and CDR.

3.3.5.4 Sell-Off/Consent-to-Ship Data Package

The Sell-Off/Consent-to-Ship data package for unit through system shall be delivered and reviewed and approved at each level of requirement Sell-Off/Consent-to-Ship.

3.3.6 VM Process 6: Verification-Related Issue/Watch List Management

Verification-related issue and concern items shall be proactively and continuously identified, resolved, and documented for each verification activities throughout the requirement flow-down, design, manufacturing, test, and Sell-Off/Consent-to-Ship phases of the program.

3.3.6.1 Status Tracking of Verification-Related Issue and Concern Items

Each of the verification-related issue and concern items shall be documented in a list, including the problem description, responsible department/engineers, problem identification and required resolution date, and its resolution status. This list shall be tracked continuously by the responsible WBS/WG team.

3.3.6.2 Reporting of Verification-Related Issues to the Program Risk Management Board

All verification-related issues that may seriously impact the performance, schedule, or cost of the program shall be reported to the program-level risk management board in a timely manner.

3.3.6.3 Verification-related Issue/Watch List Management Plans for the SS Element, Segment, Module, and Subcontractor/Vendor

A verification-related Issue/Watch List Management plan and the status for each of the SS, segment, module, unit, and subcontractor/vendor shall be delivered for review at SRR, SDR, PDR, CDR, and Sell-Off/Consent-to-Ship.

A sample CDRL is provided in Appendix B-7.

3.3.6.4 Review of Verification-Related Issue/Watch List Management Plans for Systems Lower Than Module Level

A verification-related Issue/Watch List Management plan and the status for each level shall be reviewed and approved at SRR, SDR, PDR, CDR, and Sell-Off/Consent-to-Ship.

3.4 CDRL Content Requirements

The content of each of the CDRLs specified in paragraphs 3.2 and 3.3 shall, at minimum, include the outlines shown in Appendix B-1 through B-7. This represents: 1) A verification program plan, 2) a requirement flow-down and VCRM plan, 3) verification by an analysis, test, inspection, and demonstration plan, 4) an I&T plan, 5) an ISDVL plan, 6) a Sell-Off/Consent-to-Ship plan, and 7) a verification-related Issue/Watch List Management plan.

4. Definitions and Acronyms

4.1 Definitions

4.1.1 Space System (SS)

Generally, an overall integrated space system consisting of four segments: Space Segment, Launch Segment, Ground Segment (GS), and User Segment. (Note: the User Segment is not discussed in this document.)

4.1.2 SS, Segment, Element, Module and Lower-Level Systems

As illustrated in Appendix A-1, SS typically consists of:

- Space segments with multiple SV elements
  - An SV element consists of bus and payload modules and their subsystems and units, as well as external and internal interfaces
- Ground segments with multiple ground elements
  - Ground element typically consists of command & control stations, telemetry and mission data receiving, processing and dissemination stations
- LV segments with multiple elements
  - LV element typically consists of subsystems and units and, in some cases, includes upper-stage module

4.1.3 SS External Interfaces (IFs)

SS external interfaces are those relating to the physical/operational connectivity between the acquiring program and the users, or assets that belong to other government agencies/industries.

4.1.4 SS Internal IFs

SS internal interfaces are those relating to the physical/operational connectivity between SS internal assets such as between GS and SV, GS and LV, SV and LV, SV bus and payload, LV and upper stage, and interfaces within GS internal assets, etc.

4.1.5 SS Verification

SS verification activities assess/ensure that the “system is built right” by establishing and executing a verification plan at every level and every phase of system development, i.e., verification activities ensure whether or not requirement, design/analysis, manufacturing, test and sell-off have properly completed at every level of system development.

4.1.6 Issue Items

Issue list includes those relating to verification of requirements, design/analysis, manufacturing, test and sell-off. In particular, verification-related issue lists includes those impact cost and schedule, require consultation with upper-level integrated product teams/working groups (IPTs/WGs), and ultimately become program-level risk items if not solved within the IPT/WG in a timely manner.

4.1.7 Watch List (or Concern) Items

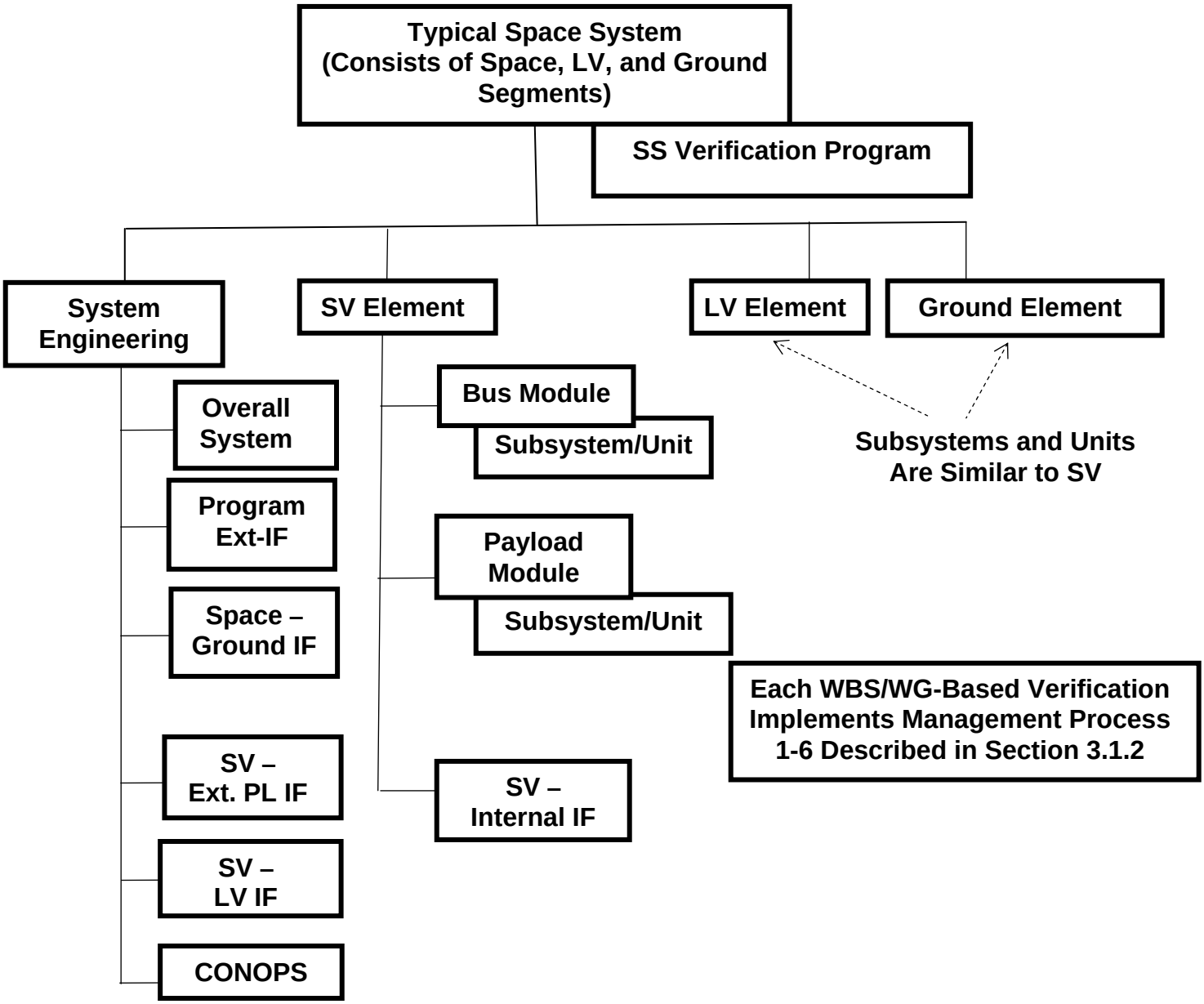
Watch list (or concern items) are those that are known and understood to be planned/executed but can be easily overlooked/forgotten by IPT/WG members to follow up.

4.2.1 Acronyms

CDR	Critical Design Review
CDRL	Contract Data Requirements List
DID	Data item description
FRB	Failure Review Board
GS	Ground system
I&T	Integration and test
IF	Interface
ISDVL	Individual Specification Dedicated-Verification Ledger
LV	Launch vehicle
PDR	Preliminary Design Review
PMPCB	Parts, Materials, and Processes Control Board
SDR	System Design Review
SRR	System Requirement Review
SS	Space system
SV	Space vehicle
TRR	Test Readiness Review
VCRM	Verification Cross-Reference Matrix
VM	Verification management

Appendices

Appendix A-1: Example of WBS/WG-Based Verification Management Structure



Appendix A-2: Deliverable/Review Documents Associated with Each Verification Management Process

- VM Process 1: Requirement Flow-Down and Verification Cross-Reference Matrix (VCRM)
- VM Process 2: Requirement Verification by Analysis, Test, Inspection, and Demonstration Plan
- VM Process 3: Integration and Test (I&T) Plan
- VM Process 4: Individual Specification Dedicated-Verification Ledger (ISDVL)
- VM Process 5: Sell-Off/Consent-to-Ship Plan
- VM Process 6: Verification-Related Issue/Watch List Management Plan

		RFP	SRR	SDR	PDR	CDR	Manufacturing/Test	Sell-Off/Consent-to-Ship
SS, Higher-Level IFs, Segment, and Module	Data Item Description (DID)	Proposed Verification Approach	Requirement Verification	VCRM/Detailed Verification Approaches	Preliminary Design analysis	Final Design Analysis	Inspection/Demo/Test	Sell-Off Package
SS Verification Program	SS Verification Program Plan	X	X	X	X	X	X	
VM Process 1	Requirement Flow-Down and VCRM Plan		X	X	X	X		
VM Process 2	Requirement Verification by Analysis, Test, Inspection, and Demonstration Plan		X	X	X	X	X	
VM Process 3	I&T Plan	X	X	X	X	X	X	
VM Process 4	ISDVL Plan		X	X	X	X	Y	X
VM Process 5	Sell-Off/Consent-to-Ship Plan		X	X	X	X		X
VM Process 6	Verification-Related Risk Management Plan		X	X	X	X	Y	X
Subsystem, Unit, Lower-Level IFs	Review Data Package	**RFP**	**SRR**	**SDR**	**PDR**	**CDR**	**Manufacturing/Test**	**Sell-Off/Consent-to-Ship**
Lower-Level SS Verification Program	SS Verification Program Plan		Y	Y	Y	Y	Y	
VM Process 1	Requirement Flow-Down and VCRM Plan		Y	Y	Y	Y		
VM Process 2	Requirement Verification by Analysis, Test, Inspection, and Demonstration Plan		Y	Y	Y	Y	Y	
VM Process 3	I&T Plan		Y	Y	Y	Y	Y	
VM Process 4	ISDVL Plan		Y	Y	Y	Y	Y	Y
VM Process 5	Sell-Off/Consent-to-Ship Plan		Y	Y	Y	Y		Y
VM Process 6	Verification-Related Risk Management Plan		Y	Y	Y	Y	Y	Y

x: Deliverable Items for Review, y: Presented at Review

Appendix A-3: Example of Individual Specification Dedicated-Verification Ledger (ISDVL)

ISDVL is a process to ensure that each requirement of a specification has proof of verification, as well as traceability to the responsible party and the appropriate documents/data set. The ISDVL generally consists of a traditional Verification Cross-Reference Matrix (VCRM), which specifies the verification method for each requirement of a specification, and also identifies who performed the verification and where, as well as which document captures the verification results.

Table A-1 is an example of an ISDVL using a hypothetical SV component.

- The first column, "Paragraph or Requirement Number," identifies the requirement or paragraph numbers designated in a specification.

- The second column, "Requirement Description," provides a synopsis of each requirement.

- The third column, "Verification Method," indicates the assigned verification method for each requirement.

- The fourth column, "Verification Level," identifies at what level of SV the requirement was actually verified. It should be noted that some of the requirements (specifically some system-level SS specification requirements) might not necessarily be verified at this level. Some of these requirements can be directly flowed-down to lower-level specifications where the actual verification takes place. This column is particularly useful for the verification planning and sell-off of a higher-level SV/LV and GS component, since it will identify a particular unit(s) or subsystem where the requirement has been or shall be verified.

- The column, "Responsible Person or Department," identifies the designated parties responsible for performing the verification and will help those individuals with regard to discussions/inquiries about planning or the results.

- The "Documentation" column, which consists of two sub-columns ("Verification Approach Summary" and "Verification Product"), is a summary of the verification and the data package/reports. This column is important because it forces official publication of the data.

- All of the ISDVL columns will help to expedite the sell-off, latent troubleshooting, or Independent Readiness Review process, since the data can be easily tracked down and obtained when required.

Table A-1: Example of ISDVL

	Power Conditioning Unit ISDVL (Example)**								
Paragraph or Requirement No. Designated in PCU Specification	**Requirement Description**	**Verification Method***				**Verification Level**	**Responsible Person or Department**	**Documentation**	
		A	**I**	**D**	**T**			**Verification Approach Summary**	**Verification Products**
3.2.1	The output voltage regulation must be ≤100mV.	X			X	PCU Unit level	Unit design engineer or dept. name	SABER/SPICE based W.C end of life analysis and EM Test	Power quality W.C analysis doc.; EM Test Doc.
3.2.2	The Phase margin of the unit must be greater than 30 deg.	X			X	PCU Unit level	Unit design engineer or dept. name	SABER/SPICE based W.C stability analysis and EM Test	W.C stability analysis doc.; EM Test Doc.
3.2.3	Unit weight			X		PCU Unit level	Unit Test Dept.	By actually weighing unit	S/V mass property doc

* A: Analysis, I: Inspection: D: Demonstration, T: Test
** It may be desirable to indicate the verification completion date by adding another column

Appendix B-1: Verification Program Plan

DD Form 1423-1, JUN 90 **(Computer Generated)** **Page 1 of 1 Pages** **CONTRACT DATA REQUIREMENTS LIST**	Form Approved OMB 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**	C. CATEGORY **TDP[ ] TM[ ] Other[x]**
D. SYSTEM/ITEM	**E. CONTRACT/PR NO.**	**F. CONTRACTOR**
1. Data Item No.	**2. Title:** Verification Program Plan for SS, Segment, Higher-level External IF, or Module **3. Subtitle:**	
4. Authority (Data Acquisition Document No.)	**5. Contract Reference**	**6. Requiring Office**

7. DD 250 Req	**9. Dist Statement Required**	**10. Frequency**	**12. Date Of First Submission**	**14 & 15. Distribution and Total**
8. App Code		**11. As Of Date**	**13. Date Of Subsequent Submission**	

16. Remarks

G. Outline for Verification Program Plan:

The outline is generally common to each of the plans for SS, segment, higher-level program external IF, module, and key subcontractor and vendor providing systems. A single plan is permitted for all the SS, Segment external IF, and module, if one contractor develops all. If not, a separate plan must be produced for each contractor, subcontractor, and vendor

1) Describe verification program management approaches, and organization based on WBS/WG that involves government and contractor experts' participation in each of their applicable WBS(s):
   - Explain who is responsible for managing each WBS verification program and the relationship with the program manager
   - Explain the frequency of the WG/WG meetings
   - Explain the verification program flow-down to each subcontractor/vendor and how/what/when the progress status are monitored
   - Inclusion of Verification Management Board is highly encouraged.

2) Describe, in detail, the implementation plan for each required verification management process:
   - VM-Process 1,Requirement Flow-Down, and Verification Cross-Reference Matrix (VCRM)
   - VM-Process 2, Requirement Verification by Analysis, Test, Inspection and Demonstration
   - VM-Process 3, Integration and Test (I&T)
   - VM-Process 4, Individual Specification Dedicated-Verification Ledger (ISDVL)
   - VM-Process 5, Sell-Off/Consent-to-Ship
   - VM-Process 6, Verification-related Issue/Watch List Management

H. Document Delivery Requirement

Each plan shall be delivered at the time of proposal, SRR, SDR, PDR, and CDR

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

Appendix B-2: Requirement Flow-Down and VCRM Plan

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A. CONTRACT LINE ITEM NO.	B. EXHIBIT A	C. CATEGORY TDP[ ] TM[ ] Other[x]
D. SYSTEM/ITEM	E. CONTRACT/PR NO.	F. CONTRACTOR
1. Data Item No.	2. Title: Requirement Flow-Down and VCRM for SS, Segment, Higher-level External IF, or Module 3. Subtitle:	
4. Authority (Data Acquisition Document No.)	5. Contract Reference	6. Requiring Office

7. DD 250 Req	9. Dist Statement Required	10. Frequency	12. Date Of First Submission	14 & 15. Distribution and Total
8. App Code		11. As Of Date	13. Date Of Subsequent Submission	

16. Remarks

G. Outline for Requirement Flow-Down and VCRM Plan

The outline is generally common to each of the plans for SS, segment, higher-level program external IF, module, and key subcontractor and vendor providing systems.

1) Requirement Flow-Down Planning:
- Categorize, by function, the top-level SS requirements into such functions as mission performance, operational environments, reliability, safety, housekeeping, fault management, etc.
- Describe rationale for each requirement flow-down from SS to each lower-level system
- Describe approaches for ensuring each requirement is well defined and “objectively” verifiable
- Explain approaches/methods to document the traceability of each requirement flow-down

2) VCRM:
- Explain the rationale for selecting the particular assigned verification method(s) for each requirement

H. Delivery Requirement

Each plan shall be delivered at the time of SRR, SDR, PDR, and CDR

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

Appendix B-3: Verification by Analysis, Test, Inspection, and Demonstration Plan

DD Form 1423-1, JUN 90 **Page 1 of 1 Pages** **CONTRACT DATA REQUIREMENTS LIST**	Form Approved

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A. CONTRACT LINE ITEM NO.	B. EXHIBIT	C. CATEGORY TDP[ ] TM[ ] Other[x]
D. SYSTEM/ITEM	E. CONTRACT/PR NO.	F. CONTRACTOR
1. Data Item No.	2. Title: Analysis, Test, Inspection, and Demonstration Plan for SS, Segment, Higher-level External IF, and Module 3. Subtitle:	
4. Authority (Data Acquisition Document No.)	5. Contract Reference	6. Requiring Office

7. DD 250 Req	9. Dist Statement Required	10. Frequency	12. Date Of First Submission	14 & 15. Distribution and Total
8. App Code		11. As Of Date	13. Date Of Subsequent Submission	

16. Remarks

G. Outline for Verification by Analysis, Test, Inspection, and Demonstration Plan

The outline is generally common to each of the plans for SS, segment, higher-level program external IF, module, and key subcontractor and vendor providing systems.

1) List all the requirements (with requirement ID and brief description of the requirement) by each verification category, verify by analysis, test, inspection, and demonstration, for each specification
2) Explain scope and approaches to verify each category of the verification methods such that they will ensure each requirement listed for each category will be properly verified
3) Explain the Design Reference Case associated with each “Verify by Analysis” requirement
4) Explain Test approaches/methods for each “Verify by Test” requirement
5) Explain the rationale for “Verify by Similarity” for each applicable requirement such that none of the constraints relating to its application to the system/program, software/hardware design, environments, safety, and life, etc. has changed from the earlier system

H. Delivery Requirement

Each plan shall be delivered at the time of SRR, SDR, PDR, and CDR

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

Appendix B-4: I&T Plan

DD Form 1423-1, JUN 90 **(Computer Generated)** **Page 1 of 1 Pages** **CONTRACT DATA REQUIREMENTS LIST**	Form Approved OMB No. 0704-0188

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A. CONTRACT LINE ITEM NO.	**B. EXHIBIT**	C. CATEGORY **TDP[ ] TM[ ] Other[x]**
D. SYSTEM/ITEM	**E. CONTRACT/PR NO.**	**F. CONTRACTOR**
1. Data Item No.	**2. Title:** I&T Plan for SS, Segment, Higher-level External IF, and Module Verification **3. Subtitle:**	
4. Authority (Data Acquisition Document No.)	**5. Contract Reference**	**6. Requiring Office**

7. DD 250 Req	**9. Dist Statement Required**	**10. Frequency**	**12. Date Of First Submission**	**14 & 15. Distribution and Total**
8. App Code		**11. As Of Date**	**13. Date Of Subsequent Submission**	

16. Remarks

G. Outline for I&T Plan:

The outline is generally common to each of the plans for SS, segment, higher-level program external IF, module, and key subcontractor and vendor providing systems. A single plan is permitted for all the SS, segment external IF, and module if one contractor develops all. If not, a separate plan must be produced for each contractor, subcontractor, and vendor.

1) Explain the objectives and the scope of the test in terms of certification, on-orbit test, launch readiness, factory test, acceptance, proto-flight, qualification level test, etc as well as the test assets/configurations involved and the schedule
2) Explain using a test matrix to indicate that all the “Verify by Test” is the associated specification will be tested at different test phases (such as at different environment sequence)
3) Explain test conditions (such as the level of test environments, durations, etc), test monitoring and telemetry data, and frequency/timing of the monitoring
4) Explain approaches, methods, FRB, and PMPCB, QA, WBC lead involvement with regard to test discrepancy/anomaly resolution retest and approval to proceed with the next level test
5) Explain approaches/methods for documentation and approval by program management, WBS leads, FRB, PMPCB, and QA for the “as tested” sequence and results
6) Explain documentation and review approval approaches/methods for test completion/summary report for system certification, or Sell-Off/ Consent-to-Ship activity

H. Delivery Requirement

Each plan shall be delivered at the time of proposal, SRR, SDR, PDR, and CDR

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

Appendix B-5: ISDVL Plan

DD Form 1423-1, JUN 90 **(Computer Generated)** **Page 1 of 1 Pages** **CONTRACT DATA REQUIREMENTS LIST**	Form Approved

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A. CONTRACT LINE ITEM NO.	B. EXHIBIT	C. CATEGORY TDP[ ] TM[ ] Other[x]
D. SYSTEM/ITEM)	E. CONTRACT/PR NO.	F. CONTRACTOR
1. Data Item No.	2. Title: ISDVL Plan for SS, Segment, Higher-level External IF, and Module 3. Subtitle:	
4. Authority (Data Acquisition Document No.)	5. Contract Reference	6. Requiring Office

7. DD 250 Req	9. Dist Statement Required	10. Frequency	12. Date Of First Submission	14 & 15. Distribution and Total
8. App Code	D	11. As Of Date N/A	13. Date Of Subsequent Submission	

16. Remarks

G. Outline for the ISDVL Plan:

The outline is generally common to each of the plans for SS, segment, higher-level program external IF, module, and key subcontractor and vendor providing systems.

1) Explain approaches/methods for implementing/managing the ISDVL process such that the content of each ISDVL will be properly reviewed (by each WBS/WG experts and other appropriate functions) and ensure that each requirement of a specification has proof of verification, and traceability to the responsible party and the appropriate documents/data set.
2) Explain approaches/methods for accessing the pre-approved/approved ISDVL data for each unit, subsystem, module, segment and system by the government, Independent Readiness Review, and other applicable experts and members.

H. Delivery Requirement

Each plan shall be delivered at the time of SRR, SDR, PDR, CDR, and Sell-Off/Consent-to-Ship

PREPARED BY		I. APPROVED BY	J. DATE

Appendix B-6: Sell-Off/Consent-to-Ship Plan

DD Form 1423-1, JUN 90 **(Computer Generated)** **Page 1 of 1 Pages** **CONTRACT DATA REQUIREMENTS LIST**	Form Approved OMB No. 0704-0188

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A. CONTRACT LINE ITEM NO.	B. EXHIBIT A	C. CATEGORY TDP[ ] TM[ ] Other[x]
D. SYSTEM/ITEM	E. CONTRACT/PR NO.	F. CONTRACTOR
1. Data Item No.	2. Title: Sell-Off/Consent-to-Ship for SS, Segment, Higher-level External IF, and Module Verification 3. Subtitle:	
4. Authority (Data Acquisition Document No.)	5. Contract Reference	6. Requiring Office

7. DD 250 Req	9. Dist Statement Required	10. Frequency	12. Date Of First Submission	14 & 15. Distribution and Total
8. App Code		11. As Of Date	13. Date Of Subsequent Submission	

16. Remarks

G. Outline for Sell-Off/Consent-to-Ship Plan

The outline is generally common to each of the plans for SS, segment, higher-level program external IF, module, and key subcontractor and vendor providing systems.

1) Describe approaches/methods for implementing/managing/approving the Sell-Off/Consent-to-Ship process
2) Explain entry/exit criteria for conducting successful Sell-Off/Consent-to-Ship for each system
3) Describe a standard sell-off/consent-to-ship data package that include ISDVL results, an “as-tested” test report, test summary including environment test history, test anomaly and disposition summary, FRB/PMPCB summary (including approved/waived part lists), deviations/waivers summary, disposition status of action items generated at associated system’s CDR, TRR, and test data review, and disposition status of all the issue/concern items associated with each SS

Outline for Sell-Off/Consent-to-Ship Plan

H. Delivery Requirement

Each plan shall be delivered at the time of SRR, SDR, PDR, CDR, and Sell-Off/Consent-to-Ship

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

Appendix B-7: Verification Issue/Watch List Management Plan

DD Form 1423-1, JUN 90 **(Computer Generated)** **Page 1 of 1 Pages** **CONTRACT DATA REQUIREMENTS LIST**	Form Approved OMB No. 0704-0188

A. CONTRACT LINE ITEM NO.	B. EXHIBIT	C. CATEGORY TDP[ ] TM[ ] Other[x]
D. SYSTEM/ITEM	E. CONTRACT/PR NO.	F. CONTRACTOR
1. Data Item No.	2. Title: Verification Issue/Watch List Management Plan for SS, Segment, Higher-level External IF, and Module 3. Subtitle:	
4. Authority (Data Acquisition Document No.)	5. Contract Reference	6. Requiring Office

7. DD 250 Req	9. Dist Statement Required	10. Frequency	12. Date Of First Submission	14 & 15. Distribution and Total
8. App Code		11. As Of Date	13. Date Of Subsequent Submission	

16. Remarks

G. Outline for Verification-Related Issue/Watch List Management Plan

The outline is generally common to each of the plans for SS, segment, higher-level program external IF, module, and key subcontractor and vendor providing systems. It explains the WBS IPT/WG-based Issue/Watch List identification and resolution management approach, in which the WG experts identify and disposition verification related-risk items in a proactive and continuous manner to ensure that problems are identified and resolved in a timely manner to prevent/minimize late changes or post launch failures. Issue/Watch List items should include those relating to verification of requirements, design/analysis, manufacturing, test and Sell-Off/Consent-to-Ship.

- Verification-related issue list should include those will impact cost and schedule, and require consultation with an upper-level IPT/WG, and ultimately become program-level risk items if not solved within the IPT/WG in a timely manner.
- Watch List (or concern) items are those items that are known and understood to be planned/executed but can be easily overlooked/forgotten by IPT/WG members to follow up

1) Explain the approaches/methods/format Issue/Watch List documentation format for capturing/tracking each item in terms of origination date, area/synopsis, responsibility/assignment, status, resolution approach, and approval authority/status.
2) Explain approaches/methods for raising critical risk items to upper-level WBS IPT/WG and eventually to the program-level Risk Management Board.

H. Delivery Requirement: Each plan shall be delivered/reviewed at the time of SRR, SDR, PDR, CDR, and Sell-Off/Consent-to-Ship

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

Appendix C: Check List for Planning and Executing Late Changes

It is important that one plans and executes any given late change for not only the affected system but also other collateral systems including the lower and upper level systems. A checklist for planning and execution process for each late change category is explained as follows:

A. Checklist for Planning and Executing Late Changes Caused by LCC-1: Requirement/CONOPS

1. Are the rationales for the requirement change clearly defined?
2. Is the requirement change properly approved by a requirement change board avoiding ad-hoc change?
3. Is the requirement change properly communicated to and understood by all the internal and external parties, affected by the change?
4. Is the requirement change clearly written, specified, and verifiable?
5. Are the design reference cases (i.e., reasonable worst-case conditions) specified?
6. Is (measurement) unit tolerance specified? In particular, impacts of any requirement changes must be closely examined for such areas as (a) critical clearances, (b) subsystem to subsystem interfaces (IFs), and (c) HW/SW IFs.
7. Is the requirement written with one requirement ID or requirement?
8. Is the requirement change properly specified for both primary and redundant configuration?
9. Is the requirement verification method and/or approach properly delineated?
10. Does the requirement change impact other requirements and associated verification methods in the same specification?
11. Does the requirement change impact the flowed-up and flow-downed requirements and associated verification methods?
12. Does the requirement change impact other systems (assembly, unit, subsystem, etc) requirements and associated verification methods?
13. Does the requirement change impact both HW and SW requirements? If so, compatibility of both HW and SW analyzed and tested?

B. Checklist for Planning and Executing for Planning and Executing LCC-2: Design and Analysis Issue

1. Are the rationales for the design change clearly defined?
2. Is the design change properly approved by design change board avoiding ad-hoc change?
3. Is the redesign to correct problems developed based on a clear understanding of the problem, such as test anomaly and root cause?

4. Is the design change properly communicated to and understood by all the internal and external parties impacted by the change? This is to avoid overlooking necessary changes relating to critical clearances, subsystem-subsystem IFs, and HW/SW IFs, etc.
5. Is the design change (HW/SW) under configuration control?
6. Is the design change properly specified for both primary and redundant configuration?
7. Is the design change clearly verified by the new set of worst-case analyses including the thermal, mechanical, EMC/EMI and radiation environments, turn on, turn-off, and steady state mode?
8. Is the new design analyzed for FMEA, propagated failure analysis, and sneak circuit analysis instead of depending on previous analyses?
9. Does the design change need to be verified by other verification methods such as test and inspection? If so, are these verification approaches properly planned?
10. Does the design change impact any requirements? If so, is a requirement change checklist listed in A (1) through (13) above used?
11. Does the design change impact the other designs within the same HW/SW system?
12. Does the design change impact other systems (module, unit, subsystem, etc.) and related interface designs? If so, is a verification plan for these affected areas properly planned?
13. Does the design change impact both HW and SW requirements? If so, compatibility of both HW and SW analyzed and tested under test like you fly (TLYF)?
14. Is the design (HW/SW) change that uses a heritage (reuse) design analyzed/tested for the appropriate applications and operating conditions?
15. Is the new design with new piece parts analyzed for the new piece parts characteristics?
16. Does the design change (HW/SW) impact the fault management architecture? If so, make sure that the change does not cause computer lock-up, endless-loop operation, or create a problem of a space vehicle unable to settle in safe mode in case of failure.
17. Is the flight SW change tested with high-fidelity hardware-in-the-loop using the flight test configuration?
18. Are the memory and throughput margins adequate after the SW change?

C. Checklist for Planning and Executing LCC-3: Manufacturing Issue

1. Are the rationales for the manufacturing change clearly defined?
2. Is the manufacturing change properly approved by configuration management, material review board?
3. Is the manufacturing change properly communicated to and understood by all the internal and/or external parties impacted by the change? This is to avoid latent problems such as those relating to critical clearances, electrical ground changes, sneak path, EMC/EMI, or single-point failures.
4. Is the manufacturing change properly specified for both primary and redundant configuration?
5. Is the manufacturing change clearly written and specified, and each step of the change procedure verifiable by an independent inspector, such as QA personnel? In particular, unambiguous inspection points and criteria should be developed.
6. Does the manufacturing change involve soft materials such as cable and multi-layer insulation? If so, ensure that they cannot move unexpectedly in the launch or space environment and cause interference.
7. Does the manufacturing change involve structures that can snag soft items? If so, ensure to route wires to avoid pinching or snagging by a deployed structure.

8. Does the manufacturing change involve deployable mechanisms? If so, make sure that the deployable arms and shoulder are not obstructed by other structures such as thermal blankets or wires, etc.
9. Does the manufacturing change disturb the EMC/EMI shield? If so, make sure that EMC/EMI leaks are tested after the change and repairs.
10. Does an electrical related manufacturing change include rerouting and/or addition of wires or piece parts? If so, make sure that it did not create a sneak path or ground path change.
11. Does the manufacturing change procedure specify tolerance such as for torque for bolts or nuts, spacing, wire separation, etc.?

D. Checklist for Planning and Executing LCC-4: System Integration and Test Issue

1. Are the test change rationales clearly defined?
2. Is the test change properly approved by test conductor, failure review board, and design organizations avoiding ad-hoc change?
3. Is the extent and type of retest (penalty test), including test procedures/test configurations after test anomaly troubleshooting and resolution, properly approved by internal and external experts? In particular, is the retest plan written based on clear understanding of the test anomaly and its root cause?
4. Are the retest procedures properly written so the system will be retested under the test condition and/or configuration that caused the anomaly, as well as those successful test items in earlier tests? These tests should include those relating to critical clearances, subsystem-subsystem IFs, HW/SW IFs, etc.
5. Does the test change properly test all applicable space-vehicle operating modes such as cold start, turn-on turn-off sequence, eclipse, deployment separation, etc.?
6. Does the test change properly test electrical and electronic unit in turn-on/off and steady state modes?
7. Is the test change properly communicated to and understood by all the internal and external parties impacted by the change?
8. Is the reuse of heritage test equipment or test configuration properly validated before testing, so that it will not damage or erroneously test flight articles?
9. Is the polarity (phasing) of test equipment compatible with flight articles?
10. Does the test equipment and configuration prevent any test equipment failure propagate to the flight article?
11. Does the test equipment and configuration provide some electrical sneak paths such as for flight article's grounding, signal, or power path?
12. Is the test procedure change clearly written and specified, and is it verifiable?
13. Is the test configuration change clearly written and specified, and is it verifiable?
14. Is the test environments change clearly written and specified, and is it verifiable?
15. Have the test results been analytically predicted before testing? For most test cases, tests should be used to verify analysis, not for discovery.
16. Is the test change planned such that it will help review for trends, oddities, "out-of-family" values, and other indicators of anomalies?
17. Does the test plan include the inspection of flight articles after testing particularly after vibration, acoustic tests, thermal cycling, or live pyrotechnic firing?
18. Is the test equipment qualified for flight article if it resides with flight article in T/V or T/C chamber?

19. Is the test equipment properly calibrated and maintained?
20. Is the test procedure written such that flight article responses will be characterized in trial runs with limited force, current, or temperature before going into full tests?
21. Does the test plan include a test to verify that a flight article can initiate its task by itself, and not by the help of the test equipment or manual operation?

E. Checklist for Planning and Executing LCC-5: Late Changes Due to Internal and External Alerts

1. Are the rationales for the change due to alerts clearly defined?
2. Is the change due to alerts approved by an appropriate change board and internal and external experts?
3. Are the changes due to an alert properly analyzed and/or tested for the actual flight applications?
4. Does the change due to an alert cause changes in requirements, design, manufacturing, and test? If so, make sure to follow the check list specified in A through D above.

Appendix D: User's Guide for a Distributed Verification Program with a Modular Management Process

(Enabling the Cost-Effective Acquisition of Complex Yet Reliable Space Systems by Preventing/Minimizing "Late Changes" and Post-Launch Mishaps)

Outline

- Background
  - Problems associated with the traditional centralized verification approach
  - Examination of prior space vehicle (SV) and launch vehicle (LV) mishaps
  - Summary of the deficiencies of traditional centralized verification approach
- A solution for past problems
  - A distributed verification program with a modularized management process
- Summary (centralized vs. distributed verification program)
- TOR-2006(8506)-4732, Rev. A: *User's Guide for Space System Verification Program and Management Process*
- Acronyms
- References

Background

Problems Associated with a Traditional Centralized Verification Approach

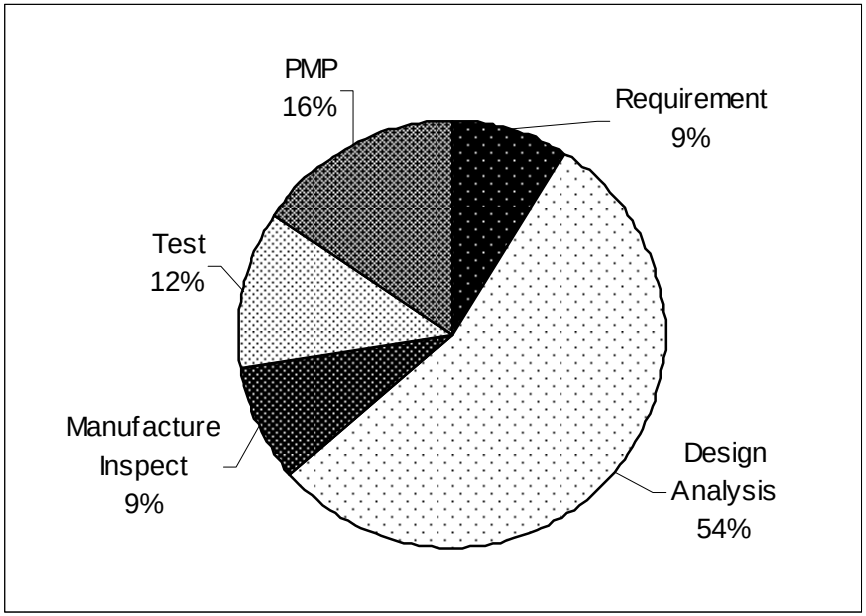
- Traditional space system verification, “system is built right” methods mostly utilized a centralized verification program approach even after the “Faster, Better, Cheaper or Total System Program Responsibility (TSPR)” era
  - The systems verification approach is “broadly” described as a part of systems engineering standards or handbooks (see Refs. 2-6)
    - Verification addressed mostly for the top-level requirements
      - Verification plan generally is required for only top system level, not for SV, LV, or ground system (GS)
  - Rather ineffective addressing a complex space system involving the development of numerous units, several subsystems, payloads, bus, and internal/external interfaces
  - Problems continuing in NASA, DOD (SMC and NRO), and commercial programs
    - SV and LV post-launch mishaps (see examples on next pages)
    - Cost overruns and schedule delays
      - Example: Unit design/test problems found late in system integration and test

Examination of Prior SV and LV Mishaps

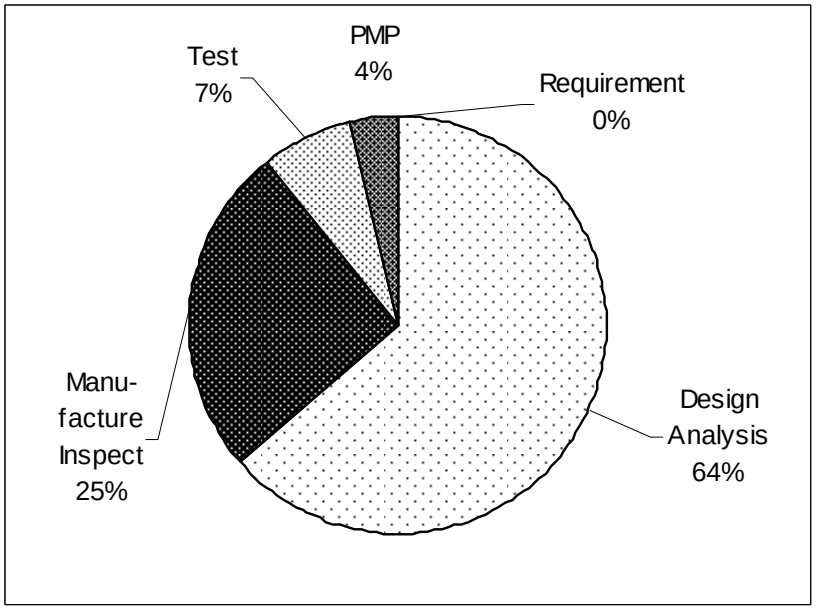
- Examined 102 SV and 29 LV failures from 1964-2003 (Ref. 1)
- Failure causes were examined with regard to:
  - In which “development phase" was the mistake made?
    - Requirement, design/analysis, part and material process, manufacturing, or test phase
    - In theory, mistakes could have occurred in multiple phases; however, only the primary source was singled out in the analysis
  - In which level of system development was the mistake made?
    - Unit, subsystem, system or interface (IF) development, or launch integration
  - In which technical discipline was the mistake made ?
    - SV: Attitude control and determination subsystem (ACDS), electrical power subsystem (EPS), propulsion, structure/thermal/mechanism, communications, bus, or payload (PL)
    - LV: propulsion, avionics, electrical, or structure/thermal/mechanical
    - GS: Command, TLM, or communication*

* included in either SV or LV as the primary source of the problems

Past SV and LV Mishaps Caused by Deficiencies
In Which "Development Phase" Was the Mistake Made?



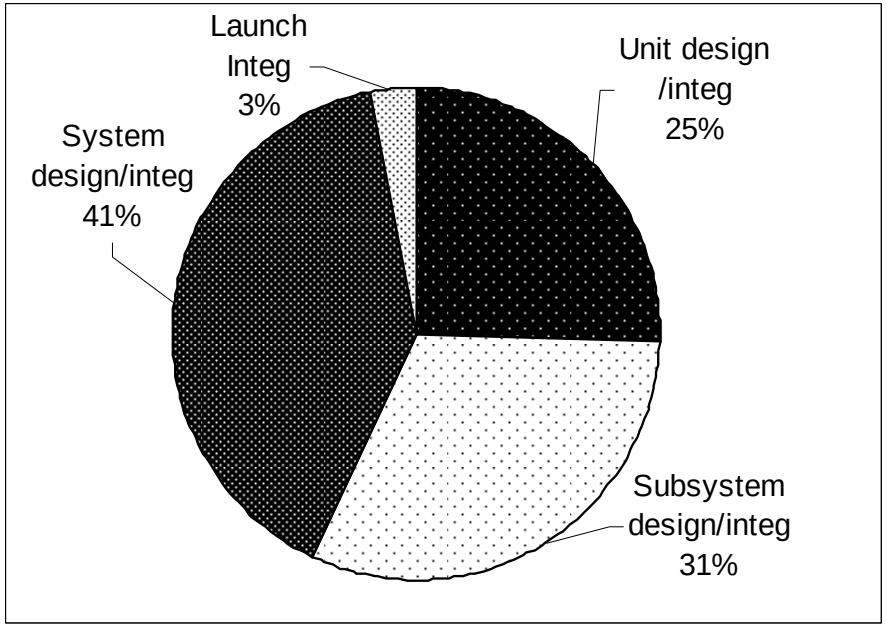
102 SV Failures
(1964-2003)



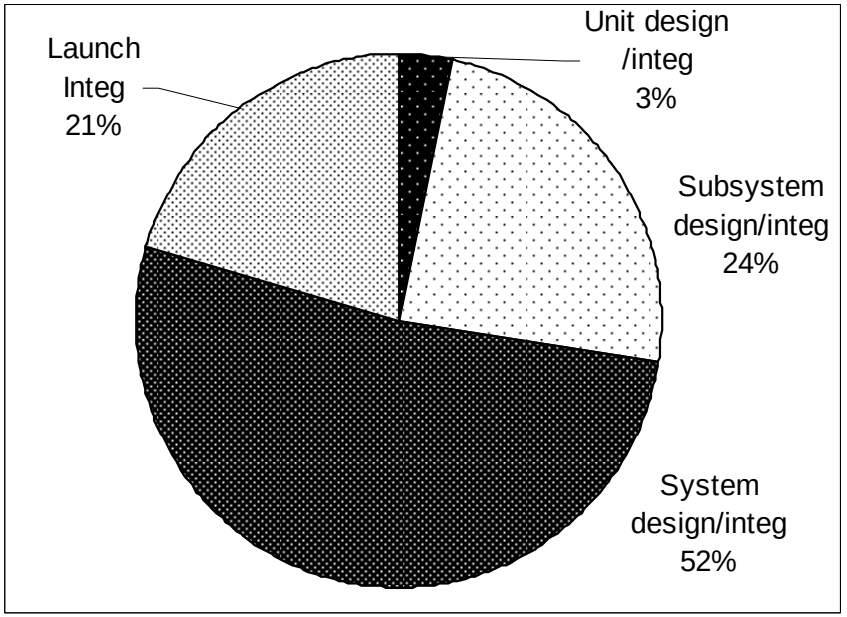
29 LV Failures
(1964-2003)

The majority of "culprit" deficiencies occurred during the early phase of system development: Requirement and design/analysis

Past SV and LV Mishaps Caused by Deficiencies
In Which Level of System Development Was the Mistake Made?



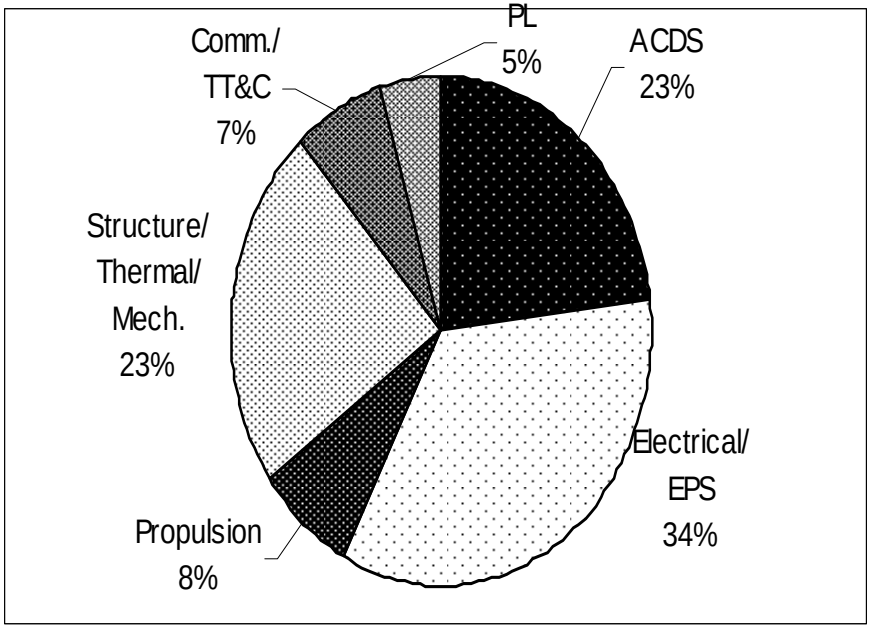
102 SV Failures (1964-2003)



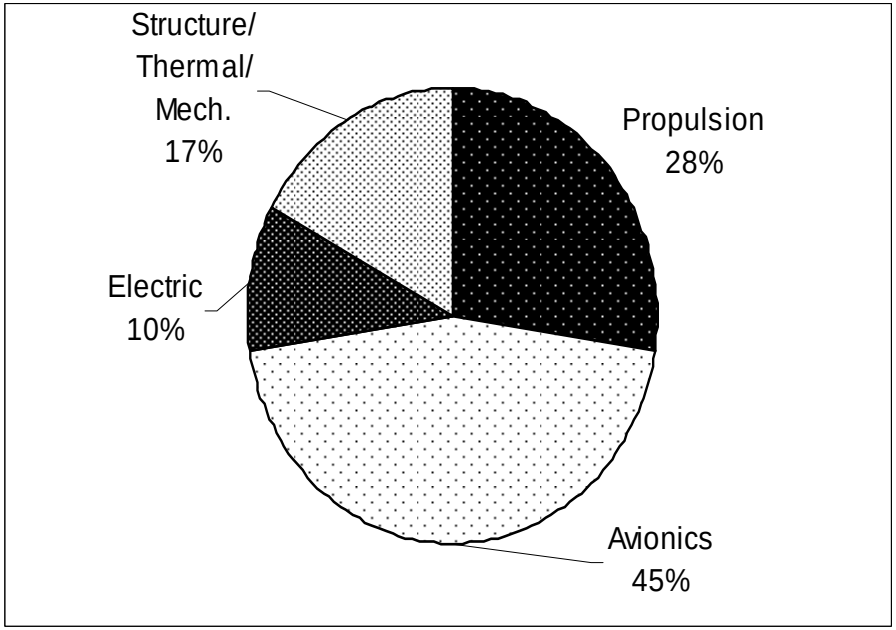
29 LV Failures (1964-2003)

- **Most of the "culprit" deficiencies occurred prior to shipment of vehicles to their launch sites**
- **Majority of culprit-problems existed at lower-level system: Unit/subsystem**

Past SV and LV Mishaps Caused by Deficiencies
In Which Technical Discipline Was the Mistake Made?



102 SV Failures
(1964-2003)



29 LV Failures
(1964-2003)

"Culprit" deficiencies were found in each technical discipline

Examination of the Past SV and LV Mishaps: Findings

- Each of the 102 SV and 29 LV failures could have been avoided with use of a systematic verification program from unit to system level

- Examples
  - **Mistake in requirement at unit/subsystem**
    - Wrong polarity in S/A power IF spec. between off-shore S/A and domestic PLs
    - Contamination control not specified, causing arc in PLs, obscuring telescope, etc.
  - **Wrong design/analysis/unit and subsystem**
    - Wrong worst-case conditions
    - Wrong applications of heritage designs
  - **Manufacturing/inspection error at unit/system level**
    - Improperly installed thermal blanket preventing the deployments of antenna
    - Insufficient electrical insulation
  - **Insufficient or incorrect test/system level**
    - Deployment sequence not properly tested
    - S/C-PL computer IF not properly tested
  - **PMP**
    - Tin whisker causing electrical shorts
    - Lubricant dried up during storage in moving mechanisms

"System is built right" verification must address requirements, design/analysis, manufacturing and test at every phase, level, and technical discipline in space system development

Deficiencies of Traditional Centralized Verification Approach Summary

- **Deficiency 1: Lack of Well Orchestrated End-to-End Systems Verification Program and Plan**
  - Budget constraints for managing very complex, large-scale space systems
  - Reliance on contractors to verify mature and heritage low-level systems
  - Focus mostly on the verification of mission requirements and top-level systems
  - Systems engineering-centric verification cannot conduct thorough verification at **every level and phase** of system development, as space systems are large and very complex systems
- **Deficiency 2: Lack of Documented and Traceable Proof of End-to-End Systems Verification**
  - Documentation focused on mostly on the verification of mission requirements and top-level systems
  - Documented and traceable proof of verification of each requirement not available because of a large numer of requirements (8,000-42,000 per SV) that need to be verified
- **Deficiency 3: Lack of Government Oversight of End-to-End Systems Verification**
  - Unintended “Faster, Better, Cheaper” or TSPR exists, as contractors are practically given full responsibility to develop these low-level systems
  - Contractors perform systems engineering-centric verification of low-level systems
  - Contractor production managers/engineers are always working under cost and schedule pressure
- **Deficiency 4: Lack of End-to-End Systems Verification Risk Management**
  - Risk management is focused on only top-level system or programmatic problems
  - Lack of proactive and continuous watch/issue items identification and timely resolution at each system level
  - Cause for very costly discovery of problems later in systems development or in worst-case loss of SVs or LVs

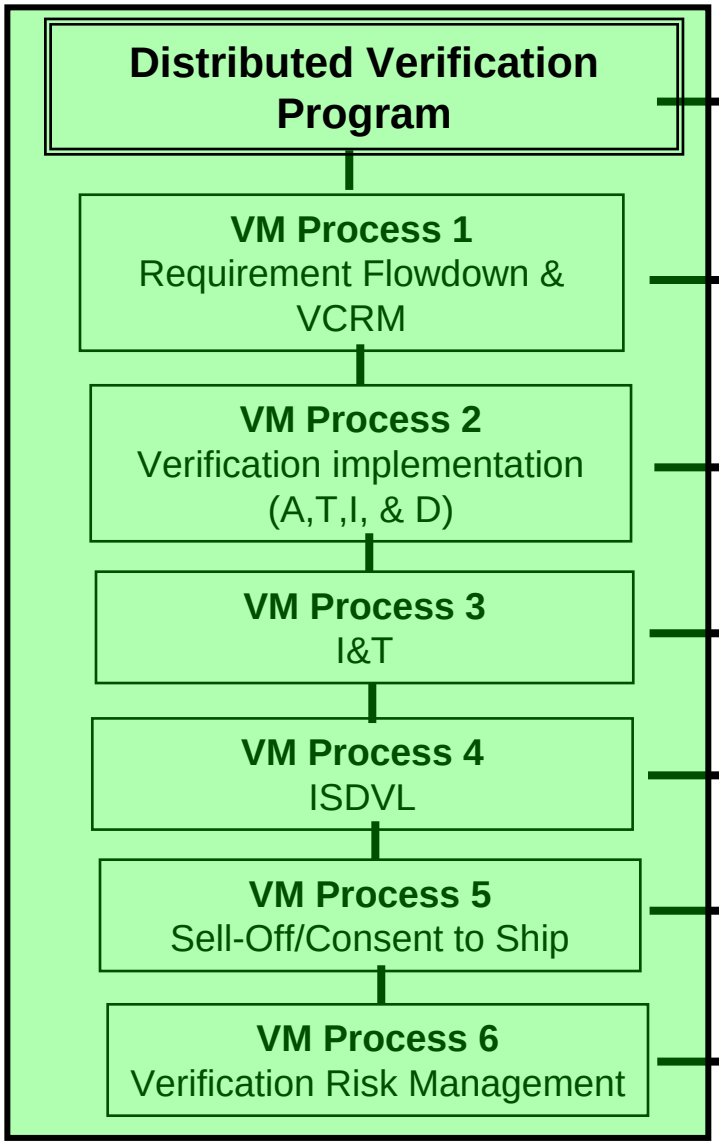
A Solution for the Past Problems

A Distributed Verification Program with Modular Management Processes

- **Distributed Verification Management Approach**
  - Each system-level developer takes ownership/responsibility for verifying his/her system is built right
    - SS generally involves the development of hundreds of units, several subsystems, PLs, bus, SVs/LVs, and IFs
  - Recognize verification as an important standalone program
  - Establish verification program management board
- **Modularized Verification Management Process**
  - Six verification generic management processes that will be:
    - Tailored for every level, phase, and technical discipline in SS development
    - Implemented by prime contractor, subcontractors, and critical vendors

A distributed verification program is recommended with the use of modularized management processes in the contract

Distributed Verification Program with "Modular" Standardized Management Processes



Ensure the establishment of program dedicated to verification

Ensure the development of solid spec and VCRM

Ensure solid verification plan will be developed and executed for each requirement of a specification (A,T,I, and D), unit, subsystem, system, and IFs

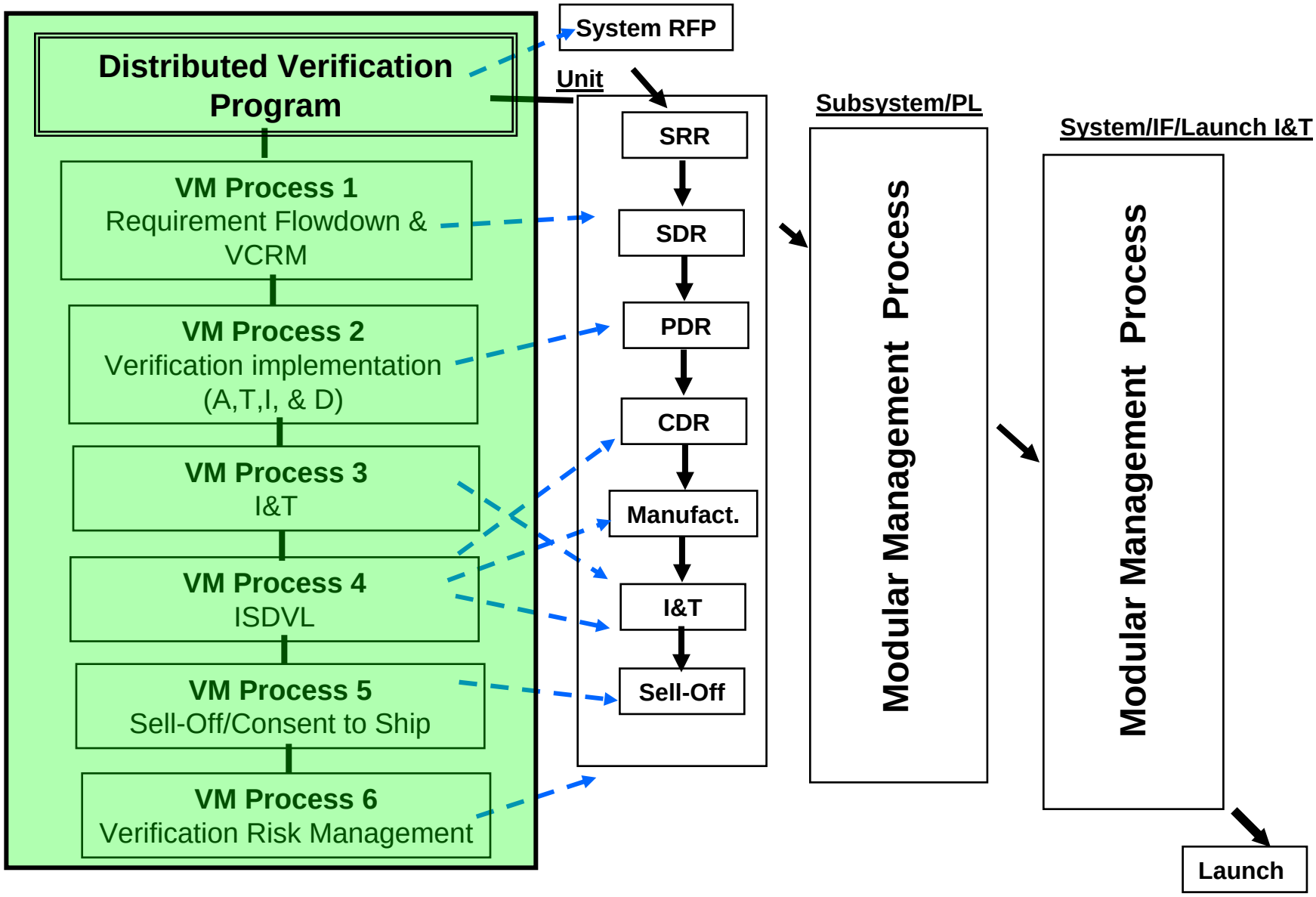
Ensure solid planning and execution of integration and test

Ensure the development of proof of verification and traceability

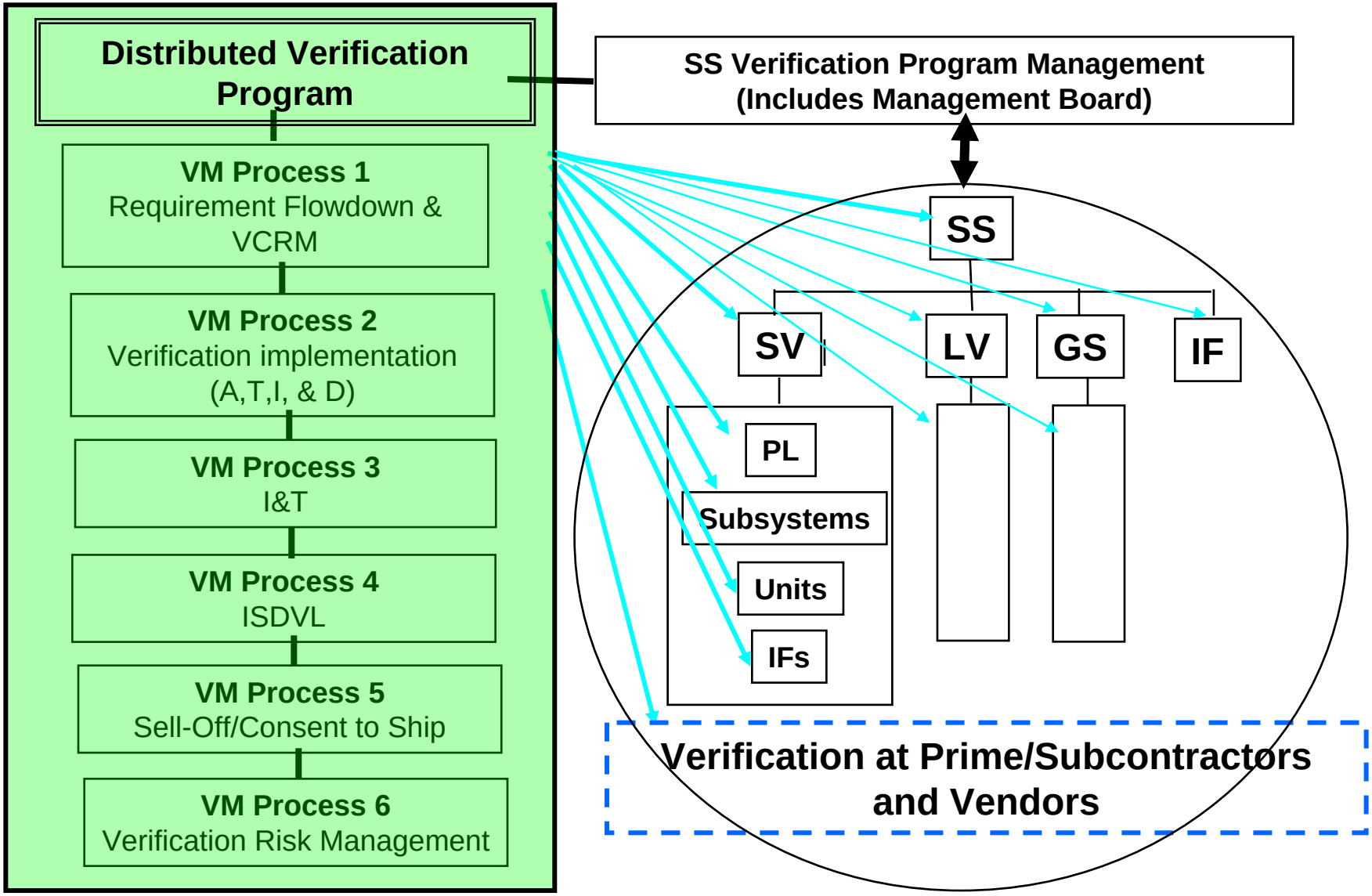
Ensure solid products are being delivered

Ensure continuous/proactive risk items identification and resolution

Modularized Verification Program and Management Processes Applied at Each System Development Phase and Level



Modularized Verification Program and Management Processes Applied at Each Contractor/Vendor and Technical Discipline

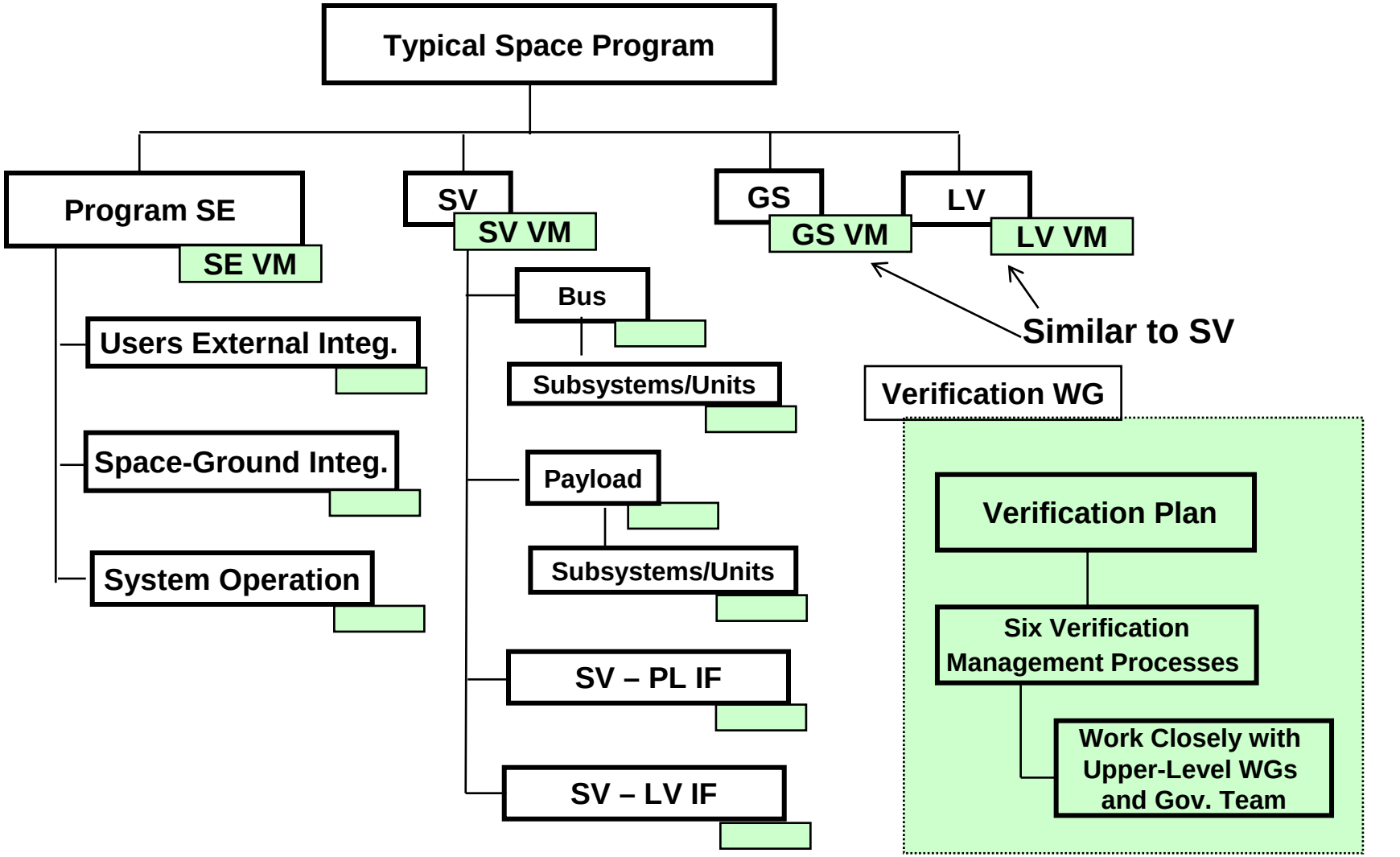


Distributed Verification Program Based on Cooperative Working Group (WG)

- **Customer and contractor teams/managers/engineers/technicians must recognize the importance of conducting verification based on "cooperative" WG approaches**
  - Verification WG provides very effective and thorough verification in each phase, level, and discipline of system development
  - Simultaneous verification ("system is built right") and validation ("right system is built") efforts
    - Eliminate any misunderstandings of requirements between customer and developers
    - Customer experts perform independent assessment on key design/analysis, test, etc.)
    - Continuous issue and problem identification and resolution

A properly operated, cooperative WG will help to prevent errors and/or misunderstandings and bring in optimum/sound solutions that, in turn, help to minimize cost and schedule impacts

Distributed Verification Program with Modular Management Process Implementation Based on WG



A cooperative customer/contractor WG process is essential to accomplish solid verification

Summary: Centralized vs. Distributed Program

	Centralized Program	Distributed Program
Top-level system verification plan	Yes	Yes
Product-level verification plan	No	Yes
Managed by program level	Yes	Yes
Managed by each development level	No (causes for unintended TSPR at lower system levels)	Yes
Proof of verification and traceability for every requirement	No (only for mission requirements)	Yes (each requirement of every specification)
Continuous verification	No (periodic review)	Yes
Continuous verification risk identification	No	Yes
Standard sell-off package for every level	No (only top system level)	Yes

Summary: Centralized vs. Distributed Verification Program

- **Traditional Centralized Verification Program**
  - Lacks insight into lower-level system verification
  - Causes of numerous cost overruns, schedule delays, and mishaps
- **Distributed Verification Program with a Modularized Management Process**
  - Require verification management at each phase, level, and discipline in SS
  - Based on cooperative customer-developer WG approach
  - Verification plan for each system level
  - Thorough documentation and proof of verification and traceability
  - Proactive/continuous problem/risk identification and resolution at earliest stage of the program phase, at the lowest level, and in every discipline in system development
  - Described in The Aerospace Corporation's core specification and standard/explained in a best practice U.S. government document
  - Adopted as a compliance document in several major U.S. space programs, such as GPS Block III, and national security space programs

A distributed verification program with modularized management processes helps acquire space systems that meet requirements in a cost-effective, timely manner

User's Guide

Space System Verification Program and Management Process

TOR-2006(8506)-4732, Rev. A, 30 June 2008

(A Distributed Verification Program with Modular Management Processes)

Space System Verification Program and Management Process

- **Ensure that the verification program is properly implemented and executed in a timely, integrated, and systematic manner**
  - Establishment of a verification program is required
    - Verification Management Board is strongly recommended
  - Verification plan
    - Need to specify exactly what needs to be done for verification
      - Implementation of program standards and compliance documents
      - Heritage/non-heritage
      - Qual, proto-qual, acceptance test program requirements
      - Proof of verification/traceability, etc.
  - **Verification program/plan should be included in Request for Proposal**
  - **Status should be reviewed at each of the major review milestones**
    - System Requirements Review (SRR), System Design Review (SDR), Preliminary Design Review (PDR), Critical Design Review (CDR), and SV/LV Sell-Off/Consent-to-Ship
  - **Verification planning and execution are accomplished by each system and subsystem WG**
  - **Six verification management processes are implemented at each WG**

Verification planning and execution based on modularized management processes must be owned by each WBS/WG team

Six Verification Management (VM) Processes Applicable to All SS Elements
VM Process 1: Requirement Flow-Down and VCRM

VM Process 1:
Ensure and verify that mission and derived requirements are properly developed and flowed down to the lowest-level component specification

- The mission/derived requirements flow-down process, results, and rationales must be documented in a computer database for easy traceability
- Each WG should verify that its specification is appropriate
- System level requirements must be easily identified at each component level specification
- Each requirement should be written in such a way that it is objectively verifiable
- Ensure that verification methods are properly assigned for each requirement in a specification
- The process and results of requirements flow-down should be reviewed at each SV/LV component's SRR, SDR, PDR, CDR, and Sell-Off/Consent-to-Ship

Documented proof of requirements flow-down/traceability and solid specifications/requirements will help prevent/reduce cost overrun and schedule delay

Six VM Processes Applicable to All SS Elements
VM Process 2: Verification by Analysis, Test, Inspection, and Demonstration

VM Process 2:
Ensure that requirements are properly flowed down to the lowest level of the developing space system's components and that each requirement of a specification is verified by the appropriate verification method

- "Verify by analysis" plan
  - Develop a list of analyses (including a description of modeling/simulation approaches) needed for verification of "verify by analysis" requirements for each SV/LV and lower-level specification
  - Develop a set of design reference cases (DRCs) defining reasonable and agreed-upon worst-case assumptions
- "Verify by test" plan
  - Develop list of test approaches/rationales for "verify by test" requirements in each specification
  - Develop SV/LV integration and test (I&T) plans
    - Define overall SV/LV testing approaches/methods, test articles, environmental test sequences/test levels, and test monitoring based on MIL-STD 1540E or equivalent
    - Define each SV/LV and subsystem/unit's acceptance/qual/proto-qual tests
    - Define "Test Like You Fly" (TLYF)
    - Develop Test Readiness Review (TRR) plan
    - Include Failure Review Board (FRB), Parts, Materials, and Processes Control Board (PMPCB) for test anomalies resolution/retest

Six VM Processes Applicable to All SS Elements
VM Process 2, Cont'd.

- "Verify by inspection/demonstration" plan
  - Define inspection and demonstration approaches/rationales for "verify by inspection/demonstration" requirements in each specification
  - Develop inspection plan for Manufacturing Readiness Review (MRR)
- "Verify by similarity" should be strictly monitored
  - Difficult to prove that the design and manufacturing/workmanship are same as before for new applications
  - Potential sources for cost overruns and mishaps
  - If required, thorough assessment efforts must ensure that "verify by similarity" is acceptable for new applications

Solid planning (including clearly defined approaches) for verification by analysis, test, inspection, and demonstration for each specification as well as for actual design, manufacturing, and test helps to avoid/minimize problems

Six VM Processes Applicable to All SS Elements
VM Process 3: Integration and Test (I&T)

VM Process 3:

Ensure that each component of the SS has a solid I&T plan:

- Ensure that the test plan for each SS component includes plans for satisfying all the “verify by test” requirements in the associated specification
- The test plan for each SS component must ensure that the integrity of the designed and manufactured system is tested under the appropriate environments specified by the appropriate version of MIL-STD-1540
- A TLYF plan must be included for higher-level SS such as SV, LV, GS, bus, and PL
- TRR plan (including review timing) must be clearly specified in each test plan
- Test plan must be reviewed at each major review milestone
- Test discrepancy and resolution (including retest) must be coordinated with REAs of applicable systems, WG team members, FRB, and PMPCB
- Test summary such as test procedure errors/modifications, test environment/duration, test anomalies, retest, and “as tested” data review summary must be developed for each SS component

Test plan and anomaly resolution/retest activities require well-coordinated efforts among the WG, FRB, PMPCB, and QA

Six Verification Management (VM) Processes Applicable to All SS Elements
VM Process 4: Individual Specification Dedicated Verification Ledger (ISDVL)

VM Process 4:

- Ensure and verify that each requirement in a specification is satisfied by the appropriate verification method(s) and that proof of verification is documented and traceable
- Proof of verification for each requirement in a SV/LV component specification should be documented and traceable using an ISDVL
  - ISDVL generally consists of a traditional VCRM, which specifies the verification method for each requirement in a specification and the summary of the verification approaches, responsible parties, and documentation
  - A set of ISDVLs should be stored in the computer database
  - ISDVL helps to verify that all of the requirements are satisfied

Documented proof of verification for each requirement in a specification using ISDVL forces each REA/engineer to perform/provide solid verification. Example: analysis/test reports should not be captured in personal notebooks because they are not presentable or traceable.

ISDVL Example

Power Conditioning Unit									
VCRM						**Documentation and Traceability**			
Paragraph or Requirement No. Designated in PCU Specification	**Requirement Description**	**D**	**I**	**A**	**T**	**Verification Level**	**Responsible Person or Department**	**Verification Method Summary**	**Verification Products**
3.2.1	The output voltage regulation must be ≤100mV.			X	X	PCU unit level	Unit design engineer or dept. name	SABER/SPICE based W.C. end of life analysis and EM test	Power quality WC analysis doc.; EM test doc.
3.2.2	The Phase margin of the unit must be greater than 30 deg.			X	X	PCU unit level	Unit design engineer or dept. name	SABER/SPICE based W.C. stability analysis and EM test	W.C stability analysis doc.; EM test doc.
3.2.3	Unit weight	X				PCU unit level	Unit Test Dept.	By actually weighing unit	S/V mass property doc.

Six Verification Management (VM) Processes Applicable to All SS Elements
VM Process 5: Sell-Off/Consent-to-Ship

VM Process 5:
Ensure and verify that Sell-Off/Consent-to-Ship of each component is properly planned and executed with an appropriate set of documents/data to satisfy proof of requirements

- **The Sell-Off/Consent-to-Ship data package of each SV/LV component should include, at minimum, the following items:**
  - ISDVL
  - As-tested report approved by REAs/QA
  - Test summary, including environment test history, test anomalies, and resolution summary
  - FRB/PMPCB summary, including approved/waived part lists
  - Deviations/waivers summary
  - Disposition status of action items generated at major SV unit-level SRR, SDR, PDR, CDR, and TRR

A standard set of documentation for each Sell-Off/ Consent-to-Ship helps to verify that the system meets all requirements and that a reliable system is delivered

Six Verification Management (VM) Processes Applicable to All SS Elements
VM Process 6: Verification Related Risk Management

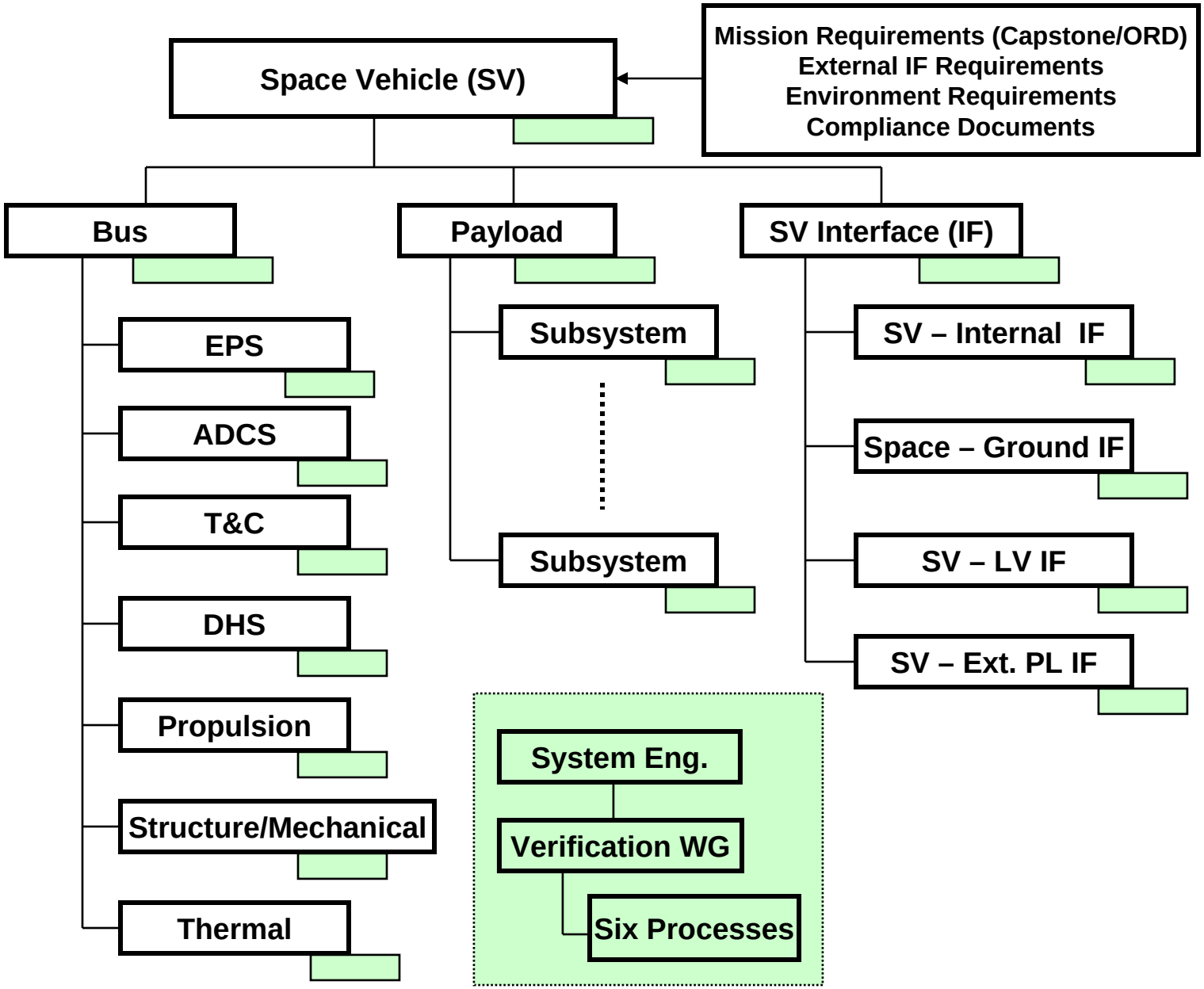
VM Process 6:

Ensure that all problems and concerns associated with each component verification are proactively identified and properly resolved in a timely manner throughout requirement, development, and delivery at each SS component level

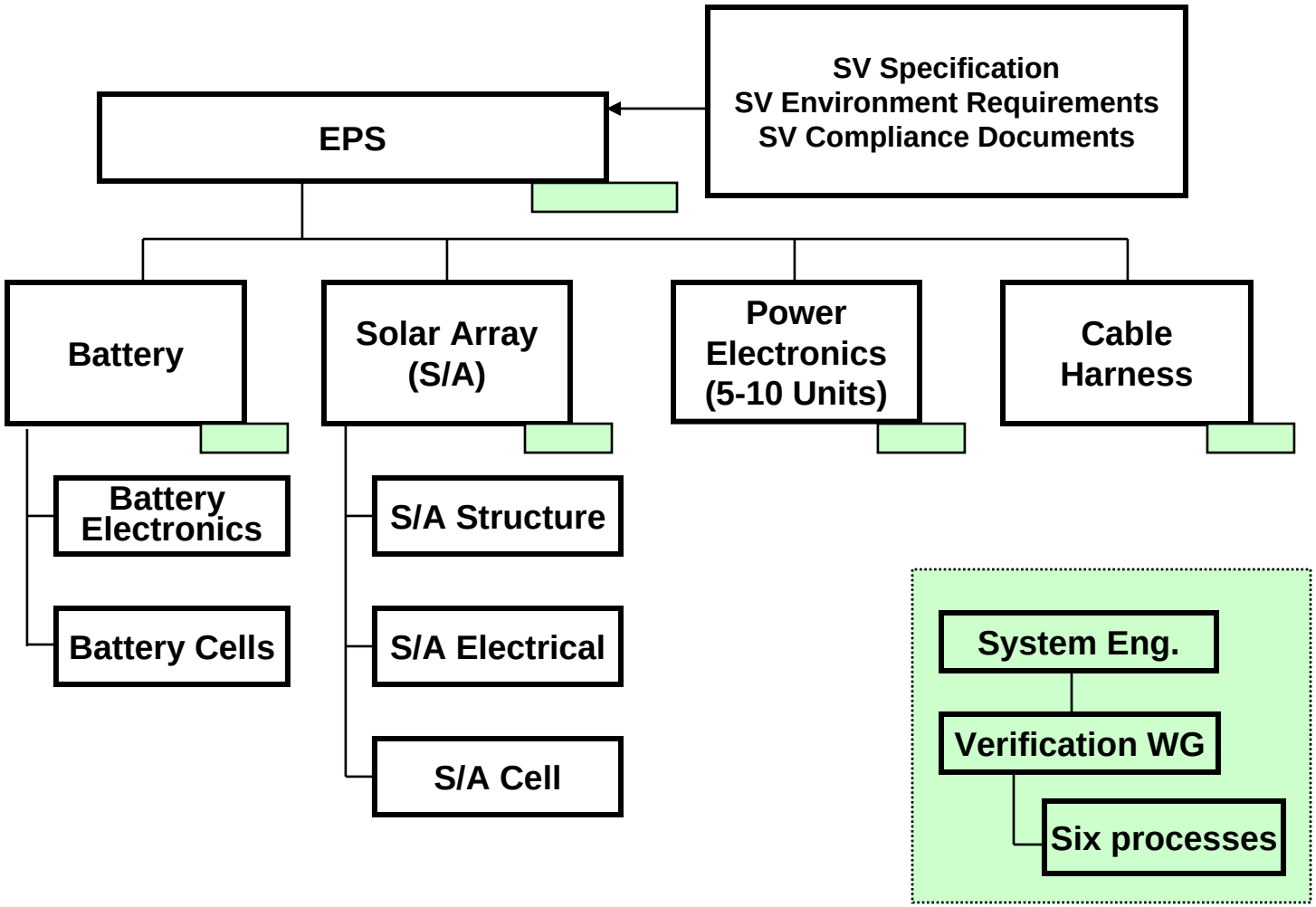
- Verification-related issues and concern items list at each WG
- Issue and concern items identified by WG experts
- Government experts usually bring experience and knowledge not necessarily available from contractors' engineers
- Initiated at program authority to proceed (ATP)
- Issues that cannot be resolved by lower-level WG should be flowed up to a higher-level WG and program-level Risk Management Board
- Issues and concern list status should be reviewed at each SV/LV component's SRR, SDR, PDR, CDR, and Sell-Off/Consent-to-Ship

A continuous/timely process for identifying and resolving issue and concern items reduces cost and schedule impacts

WG-Based Verification Program Management (Example)



WG-Based Verification Program Management Subsystem/Unit Level (Example)



Acronyms

ATP	Authority to Proceed
CDR	Critical Design Review
DID	Data Item Description
DRC	Design Reference Case
EM	Engineering Module
EXT-IF	External Interface
FRB	Failure Review Board
GPS	Global Positioning System
GS	Ground System
I&T	Integration and Test
IF	Interface
ISDVL	Individual Specification Dedicated Verification Ledger
LV	Launch Vehicle
MIL-STD	Military Standard
MRR	Manufacturing Readiness Review
PCU	Power Conditioning Unit
PDR	Preliminary Design Review
PMPCB	Parts, Materials, and Processes Control Board
QA	Quality Assurance
RFP	Request for Proposal
SE	System Engineering
SDR	System Design Review
SRR	System Requirement Review
SS	Space System
SV	Space Vehicle
TLYF	Test Like You Fly
TOR	Technical Operating Report
TRD	Test Requirement Document
TRR	Test Readiness Review
VCRM	Verification Cross-Reference Matrix
VM	Verification Management
WBS	Work Breakdown Structure
WG	Working Group

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