AEROSPACE REPORT NO.
TOR-2009(8591)-15

Space Vehicle Checklist for Assuring Adherence to "Test-Like-You-Fly" Principles

30 June 2009

Frank L. Knight
Systems Engineering and Software Directorate
Engineering and Integration Division

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

Authorized by: Space Systems Group

Developed in conjunction with Government and Industry contributions as part of the U.S. Space Programs Mission Assurance Improvement workshop.

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Contents

1. Scope

1.1 Introduction

The phrase "test like you fly" means different things to different people. It is relatively simple to understand the concept of testing a system in the same manner in which it will be used in an operational environment. However creating a test and verification program to implement this philosophy is very complex and challenging, if not expensive. In many cases, individual engineers or managers have experience creating and executing a test program where specific aspects of test like you fly (TLYF) are successfully utilized. However very few programs or organizations have created a full-scale test program that incorporates "like you fly" test activities and tools comprehensively up through the system-level of configuration. Finally, the lack of a common lexicon and description of TLYF activities has challenged the aerospace industry by creating road blocks to communication and agreement on this topic. The checklist provided here is the culmination of decades of painful and costly lessons learned. The items in the checklist trace their heritage to failures or close calls that could have been prevented through testing that more realistically simulated launch or operational conditions.

1.2 Purpose

This document is intended for use by both procurement organizations as well as the producers of aerospace hardware, software, and systems. The content that follows takes the form of a checklist to ensure that TLYF principles are followed, and noted exceptions are identified as they occur. It is intended that the "Evidence" column be used in the evaluation of TLYF principles to describe the degree to which these principles were followed and where the documentation for that particular item can be found.

1.3 Application

The TLYF checklist is intended to be used as a tool or guideline for systems and test engineers as they develop a TLYF verification program. The specific items on the checklist were created to address a flight system test program which has reached an integrated "space vehicle" level of configuration. Furthermore, it is assumed that the flight system is still undergoing testing operations, prior to launch (this TOR will not address on-orbit or commissioning activities). To maximize the utility of this checklist, it is paramount that procurement organizations use these TLYF principles to influence their development of flight system acquisition strategies. Finally, the producers of flight system hardware/software should rely on this checklist to create their unique test and verification plans as well as refresh their adherence to the checklist at major program reviews (e.g., System Requirements Review, Preliminary Design Review, Critical Design Review, Test Readiness Reviews, etc.).

The checklist consists of two types of items: (1) Those of a general nature applying simultaneously to multiple subsystems comprising the integrated space vehicle; (2) Those specific to particular subsystems within the integrated space vehicle.

Recognizing the diversity of space-vehicle programs and the engineering approaches to these missions, this TOR does not endeavor to provide an exhaustive list of TLYF considerations. Certain considerations will apply to most programs (e.g., Sec. 4.1, item 1.17) whereas others will have more limited application (Sec. 4.3, item 3.3). The authors believe that both types of checklist items will stimulate further discussion within system and test engineering communities and ultimately improve the quality and thoroughness of program TLYF methodologies.

In general, the checklist items represent qualities of idealized testing situations. It is recognized that many items will have exceptions to these idealized situations. The checklist also assumes that all prerequisites to its use have been met, namely that a mission concept of operations has been established and there is knowledge of how the mission will indeed be flown. The scope of the checklist questions is for integrated vehicle systems testing in the factory.

2. Test Like You Fly Checklist

2.1 General Considerations

This section discusses general considerations that apply across multiple spacecraft subsystems. Note that the set of fault conditions and responses tested on the flight space vehicle need to be carefully screened so as not to damage the flight article or create a non-flight configuration for testing.

Item	General Consideration	Comments	Evidence
1.1	Are tests performed using the flight commands, including sequence and timing, and telemetry?	Consider all operational modes/states (sensitivity thresholds, power settings, rates, etc.—this is unique for each type/class and design of payload)	
1.2	Are the flight command and telemetry responses being tested using the flight and the intended ground system (both hardware and software)?	Limited to devices that are not expended such as pyrotechnically actuated devices. Antennas are normally tested at a unit level or using hats on the integrated vehicle. Comment: radio frequency (RF) (air-link) testing through antennas is not generally possible at the vehicle level. Unit-level tests verify antenna characteristics and performance requirements including polarization, overall gain, and RF patterns. Interferometric considerations (overlapping antenna patterns and their impact on RF reception) are verified by analysis for applicable antenna deployments.	
1.3	Are all space vehicle commands (and command sequences) that intentionally change the state of any space vehicle item in every flight phase tested?	Consider all operational modes/states.	
1.4	Are on-board fault condition detection, modes and responses being exercised during all mission phases (ascent, transfer orbit, automated initialization,	Per designed fault responses.	

	commanded initialization, normal operations, A to B side switching, etc.)?		
1.5	Are prepared contingency sequences being tested?	May become ground contingency sequences. Include any defined contingency procedures for any payload that would apply to the initialization phase.	
1.6	Does testing include off-nominal conditions for space vehicle/launch vehicle separation, such as: worst case tip off rates, failed sensors, failed actuators, no Initial Condition Vector (ICV), bad ICV, etc.?	Assess impact on all subsystems.	
1.7	Does testing include initial conditions representative of the mission phase or activity?	Consider conditions such as power-on transients and capacitance that might only occur when a system is activated in the same sequence and timeline as launch day or other mission event.	
1.8	Have TLYF tests been invalidated by any disassembly, adjustments, or repairs made on hardware during and/or after functional and environmental acceptance testing (except in the case of necessary refurbishment, such as crushable honeycomb, split spool devices, pyrotechnic devices, etc.)?	How are changes post-environmental testing addressed?	
1.9	Does the TLYF plan include tests using a complete set of command sequences executed per a TOCT approach?	This is different from 1.3 because this is vehicle-level, run-of-system level test. (test pyramid)	
1.10	Are interfaces tested using flight-like stimuli?	Intended to include multiple types of stimuli. (see glossary)	
1.11	Are ground-system settings being used during vehicle integration and test (I&T)?		
1.12	Are dead-bus recovery features demonstrated during testing?		
1.13	Is the vehicle subjected to a full range of operational scenarios that address the variations in all applicable mission characteristics?	Where resources are limited, prioritize by criticality.	

1.14	Does testing include Mission Timeline Testing (excess of several days)—placing the spacecraft into nominal modes of operation for extended periods of testing and evaluation?	This test can help identify memory leaks, stability, or timing issues. Possible combination testing with mission scenario testing, or TVAC.	
1.15	Does testing exercise all primary and redundant hardware?	Cross-strapped paths should be tested.	
1.16	Does testing include operations during thermal transitions as well as under thermally stable conditions?	Could apply to multiple subsystems. Consider testing between TVAC plateaus. For applications involving significant on-orbit temperature transitions, make sure hardware is validated between thermal vacuum (TVAC) plateaus.	
1.17	Are payload and bus units being exercised and performance measured at low, nominal and high bus voltages while exposed to low, nominal, and high temperature extremes?	Some of this may be verified at the unit level.	
1.18	Are the hardware and software configurations defined for orbit transfer tested?		
1.19	Is flight telemetry data reviewed during integrated system tests (e.g., during TVAC and thermal balance) to demonstrate accurate reasonable telemetry and alarms as intended?	Validate calibration factors in the database.	
1.20	During testing, are harnesses configured as for flight?	Consider both electrical and mechanical harness.	
1.21	Are the simulators that are used during testing an accurate representation of the flight vehicle systems and environments?	What is the fidelity of the simulator and how much does it deviate from the actual environment?	
1.22	Is the hardware subjected to a flight like depressurization profile?		

2.2 Structures and Mechanisms

This section identifies TLYF items to be considered when defining space-vehicle level testing for the structures and mechanisms subsystem including moving mechanical assemblies (MMA) and electro-explosive devices (EED). The majority of the items in this section are primarily focused on MMA's, as there were not many structure-specific TLYF aspects.

Item	Structures and Mechanisms Consideration	Comments	Evidence
2.1	Does testing include verifying proper phasing (all directions of travel)?		
2.2	Are travel limits, including any potential off nominal conditions, being exercised?		
2.3	Are Electro-Explosive Devices (EEDs) actuated devices being tested at the integrated-vehicle level?		
2.4	Are motors for deployables exercised using LYF mechanical loads and conditions?		
2.5	Are MMAs tested in their launch or on-orbit configuration (i.e., passive or operating) corresponding to the environment being simulated?		
2.6	Is the release of MMAs performed under both high- and low-preload conditions?		
2.7	Have large (solar array radiator, etc.) panels been replaced by dummy loads or frames to minimize the effects of air damping, and more realistically simulate deployment dynamics and loads?		
2.8	Are launch-vehicle separation tests performed in a flight like manner, including umbilical separation and physical space-vehicle to launch-vehicle adapter separation?	Include umbilical pull test.	
2.9	Are mechanisms being exercised during exposure to thermal vacuum or other environmental conditions to the maximum extent practical?		
2.10	Are mechanisms being exercised and performance measured at low, nominal, and high-bus voltages while exposed to low, nominal, and high temperature extremes?		
2.11	Are wiring harnesses fully installed in their proper configuration, particularly in the areas of rotating parts or joints?		
2.12	Is multilayer insulation installed according to released flight drawings, to possess adequate clearance with respect to adjacent MMAs, switches, etc., and to ensure movement of the assemblies will not be impeded during operation?		

Item	Structures and Mechanisms Consideration	Comments	Evidence
2.13	Have lubricant reservoirs that have shipping lubricants in them had that lubricant replaced with flight lubricant before all testing?		
2.14	Are peripheral hardware such as retention latches, mechanical stops, installation attachments, or other space-vehicle interfaces that are critical for the proper performance of the device in flight configuration?		
2.15	Are torque or force margins demonstrated throughout the MMA's full range of travel, not just beginning and end?		
2.16	Are release tests conducted using worst-case environmental conditions, including vacuum (or not), dynamic environments, and largest temperature excursion from ambient?		
2.17	Are MMAs tested while attached to their movable and/or deployable system or a simulated dummy load (which provides a reasonable representation of the dynamic characteristics—inertia, stiffness, free play, natural frequencies—of the actual driven member)?		
2.18	Are torque-angle (or force-distance) measurements made in both the stowing and deploying direction in order to generate a proper hysteresis curve to determine margins?	Consider multiple deployment items.	
2.19	Are MMAs that contain redundancy in their design shown to demonstrate performance to their requirements in each redundant mode of operation?		
2.20	Is a first motion test of all deployables included as part of the space vehicle thermal testing to verify release of the deployables at the acceptance level cold or hot temperature, whichever has a larger excursion relative to room temperature?		
2.21	Are any ground test 1G induced alignment affects taken into account?		

2.3 Telemetry, Tracking, and Command (TT&C) and Communications Payloads

This section includes bus-ground (TT&C), crosslink, and communication-payload items. The simplest bus TT&C (telemetry, tracking, and command) systems usually include primary and redundant transponders and supporting cabling, switches, and antennas. Transponders support telemetry downlinks, command uplinks, and turn-around ranging functionality. Complex communication systems may consist of large numbers of transmitters, multiplexers, frequency converters, receivers, antennas, filters, and high-power amplifiers and employ sophisticated encoding and modulation methods. Different modes of operation should be tested in flight-like combinations to ensure non-interference of signal channels and to demonstrate the interfaces between the communication equipment and the C&DH within the space vehicle, as well as the communication system and the ground external to the space vehicle.

Item	TT&C and Communications Considerations	Comments	Evidence
3.1	Are the polarities of phase-modulated signals verified across all communication interfaces?		
3.2	Are communication links tested using a complete, flight-like, end-to-end configuration?		
3.3	Does crosslink tracking and autotrack functional testing envelope LYF signals?		
3.4	Are high-sensitivity receivers tested in a LYF electromagnetic interference/electromagnetic compatability EMI/EMC environment (e.g., with potential spacecraft—including payload hardware—spurious- and noise-producing hardware in a LYF state)?	Includes switching transients generated by bus hardware, spurious emission generated by cryocoolers etc.	
3.5	Is integrated system testing sufficiently flight-like to ensure that spurs generated by the communication system will not interfere with payload sensors?	Out-of-band spurs generated by communications system, if high-enough power (e.g., at TWTA outputs) may interfere with payload sensor operation.	
3.6	Are Bit Error Rate (BER) tests performed through TV temperature transitions?		
3.7	Are antenna final mates to wave guides and cables validated with hats prior to launch?		
3.8	Are all communication units exercised as integrated subsystems per the planned CONOPS?		
3.9	Are ranging links tested in a LYF manner (e.g., with command signals present on the uplink)?		
3.10	Is TVAC testing sufficiently flight-like to ensure that high-power paths through wave guides and cables will not arc, mulitpact, or produce corona discharges on orbit?		
3.11	Is integrated system testing performed with the flight EPS and batteries to ensure that bus-generated noise will not degrade high-frequency, phase-modulated signals?	Use flight-like batteries and overall system test including TVAC.	

Item	TT&C and Communications Considerations	Comments	Evidence
3.12	Are flight contingency-mode validations performed to show that communication units behave as required during these operations?		
3.13	Are launch-to-space-vehicle umbilical paths tested at the launch site to show that communications hardware using these paths will be available for command and telemetry per planned and contingency launch operations?		
3.14	Are all encrypted links validated using flight and ground KGRs and KGTs?		
3.15	Is testing performed with both flight receivers integrated to the bus and “ON” to ensure that command routing through the receivers and C&DH processors occurs as expected on orbit?		
3.16	Are digital communications units exercised during spacecraft-level tests using flight-like command sequences and flight-like (TT&C and mission data) RF signals.		
3.17	Are communication payload receivers and/or transmitters exercised in a LYF manner to demonstrate adequate inter-band filtering and spur rejection?	Consider filtering and spur rejection over all thermal environments.	
3.18	Are high-power communication units tested simultaneously in LYF combinations and per LYF duty cycling to demonstrate the anticipated power draw on the EPS?	Over thermal environments and low, nominal, high bus voltages.	
3.19	Does LYF testing demonstrate frequency-source stabilization within the power-up period of the anticipated concepts of operation (CONOPS)?		
3.20	Do payload and bus TWTAs demonstrate reliable start-up performance during LYF testing?	Over thermal environments and low, nominal, high bus voltages. Show that TWTAs can turn on per the anticipated CONOPS.	

2.4 Command and Data Handling (C&DH)

The C&DH functions as the interface between the communication system and the rest of the space vehicle. C&DH systems collect (e.g., via a standard data bus) analog and/or digital telemetry data from bus sensors and units and pass the resulting digital streams to the TT&C system for transmission to the ground. Digital command streams from demodulated RF signals received by the TT&C units are sent to the C&DH for controlling the space vehicle. Payload data is also routed through the C&DH subsystem and then processed by the communications system for ground transmission. Flight software (including any stored command sequences) is generally resident in the spacecraft processors of the C&DH, and these units interpret space-vehicle telemetry to autonomously perform various housekeeping and fault-management operations. Considering the large number of digital and analog interfaces interconnecting the C&DH with other space-vehicle subsystems, a thorough TLYF program for validating C&DH operations will substantially improve the chances for mission success.

Item	C&DH Considerations	Comments	Evidence
4.1	Are proposed on-orbit uploads demonstrated per LYF link availability?		
4.2	Are interfaces between C&DH units and between the C&DH units and other hardware demonstrated during TVAC?		
4.3	Are database alarm limits stored in the C&DH subsystem validated?		
4.4	Are all interfaces between the C&DH and flight payload hardware tested with flight calibration data and software in place?		
4.5	Does acoustic testing include flight-hardware telemetry collection via the C&DH (for units on at launch)?		
4.6	Is the data bus tested with a flight-like level of traffic to ensure that telemetry and commands are reliably routed to and from the C&DH?	Address compatibility testing including a command throughput test.	
4.7	Is data from all payloads demonstrated to be successfully routed to the SSR in a flight-like manner and in a flight-like environment (TVAC) during integrated system tests?		

2.5 Electrical Power Subsystems (EPS)

This section identifies TLYF items to be considered that relate mostly to configuration issues involving batteries (simulators compared to test batteries compared to actual flight batteries), the use of solar array simulators, and wire harness configurations. Operational power-load scenarios are also addressed.

Item	EPS Considerations	Comments	Evidence
5.1	Are all EPS conditions of operation (e.g., sunlight, eclipse, reconditioning, safemode) included in test?		
5.2	Are flight batteries or flight-like batteries used during testing?		
5.3	Is ground power required for battery charge as part of launch count-down?	Transfer of ground to flight power—transients, etc.	
5.4	Is the SV subjected to worst case operational scenarios involving system electrical loads during TVAC?	Need to identify all aspects of electrical loading which might impact the SV, not just the total load. For instance, rapid duty cycling might cause power-bus transients which stress power converters.	
5.5	Are all solar array mechanical configurations that provide power tested?		
5.6	Are the solar array simulators used to test the spacecraft electrically equivalent to the flight solar arrays?		
5.7	Is a demonstration performed to ensure that the solar arrays are capable of producing system power using a light source?		
5.8	Are SV safe-mode operations tested for the stowed solar array configuration?		
5.9	If the batteries employ a redundancy architecture, is the redundancy verified in an operational setting?		
5.10	Do operational tests demonstrate that power will be processed correctly in representative operational modes (including transitions)?		

2.6 Propulsion

This section is rather limited with respect to TLYF issues. This is primarily because spacecraft thermal concerns drive almost all of the operational thruster tests into the development test arena. Once the performance characteristics have been established for the thruster mechanisms, the thrusters may then be tested in limited operational scenarios that ensure thruster performance under expected conditions. The bulk of operational evaluations are performed within the realm of the attitude determination and control subsystem.

Item	Propulsion Considerations	Comments	Evidence
6.1	Are all propulsion modes of operation (e.g. orbit adjust, attitude maneuvers) identified and tested in a LYF manner?		
6.2	Are EMI/EMC tests planned to determine the effects of electric propulsion systems operations on system electronics?		

2.7 Thermal Control

This section covers thermal control considerations when designing a TLYF program for a space vehicle. Besides TLYF items that impact the temperatures or thermal control design during thermal vacuum testing, other items to be considered include power transients during all phases of operation, software code used for control (heaters) and use of flight or flight-like blankets during phases other than thermal vacuum.

Item	Thermal Control Considerations	Comments	Evidence
7.1	Are all thermal control elements (e.g., blankets, heaters, temperature sensors, software, database coefficients, heat leaks, etc.) in a flight configuration for TVAC tests?		
7.2	Is IR backloading onto all the radiators quantified and then incorporated into the test program?		
7.3	Are flight blankets around mechanisms deployed or actuated over the temperature extremes?	A similar item exists in the Structures and Mechanism section. Each subsystem should be considered separately.	
7.4	Are the primary and redundant thermal control subsystem (heaters and temperature sensors) validated for all operational conditions and transitions such as during transfer orbit or on-orbit conditions, as well as for during the transition between transfer orbit to a fully deployed configuration?		
7.5	Are the effects of solar reflections on solar or IR sensors or sensitive surfaces simulated during testing simulated?	Not limited to reflections on attitude determination and control subsystem ADCS units. Potential IR interference on payloads IR sensors.	

Item	Thermal Control Considerations	Comments	Evidence
7.6	Are transient thermal loads (such as the battery) adequately accounted for in the integrated test?		
7.7	Does testing show that the thermal control system responds to a maximum RF power condition for all payload and bus elements involved (passive and active hardware)?		
7.8	Is the operation of heat pipes verified under all expected environmental conditions (S/C loads, sun angles, back-loading, etc)?	Are 1-G effects mitigated during heat pipe testing?	
7.9	Are failure modes of the thermal subsystem exercised for such items as heaters and temperature sensors and shown that minimum required temperatures are maintained?	Is this tested under TVAC conditions that simulate flight operations and potential failure scenarios?	
7.10	Does thermal balance testing include charging and discharging the batteries?		
7.11	If heaters are being controlled by an on-board computer, is the final flight code version tested using the flight temperature sensors?		

2.8 Attitude Determination and Control Subsystems (ADCS)

This section identifies TLYF items to be considered when defining space-vehicle level testing for the Attitude Determination and Control subsystem including all sensors, actuators, and software required to affect and control a space vehicle's attitude, control authority, and pointing accuracy. In general the items are not specific to certain design solutions or discrete technology applications, rather they relate to general ADCS design principles and industry-wide subsystem capabilities.

Item	ADCS Considerations	Comments	Evidence
8.1	Does testing include “closed loop” ADCS operation?	Consider: maneuver times, agility, stability, pointing accuracy, keep-out regions (e.g., sun avoidance), all modes of operation, and transitions to each mode.	
8.2	Does testing include verifying proper phasing (all directions of travel)?		
8.3	Does testing include maneuver performance?	Envelope worst case changes in attitude (e.g., can the spacecraft complete a large maneuver in the required time while maintaining control over any keep-out regions).	
8.4	Does testing include a Stress Test designed to push the limits of the ADCS subsystems in off-nominal conditions resulting from multiple failures or faults?	These tests are used to characterize the system performance and response at the “edges” of specification requirements.	
8.5	Is the ADCS tested using flight-like stimulus, and are correct responses physically verified?		
8.6	Are GPS systems tested in a LYF manner (e.g., with real GPS signals and with the rest of the communication subsystem ON)?		
8.7	Is the version of flight software resident in the flight C&DH subsystem used to test control electronics under flight-like conditions (e.g., TVAC)?		

2.9 Mission Payloads

Each satellite system that flies has a mission. To achieve the mission a payload is designed to support that mission. The payload is distinct from the spacecraft bus in that it contains unique features for carrying out the systems’ mission. Payload operations requirements, constraints, and unique considerations should be understood well enough by the operations team to alter planned payload activities in response to unexpected conditions.

Item	Payload Consideration	Comments	Evidence
9.1	Are all payloads tested as they will be operated in flight, including concurrent operations?	Are there defined coupled payload operations (two or more payloads that must perform specified activities in tandem or sequence)?	
9.2	Are payload-related spacecraft commands to be executed during automated initialization activities that change the state of any payload item tested?		
9.3	Are all payload-initiated automated initialization activities tested?		
9.4	Are manually commanded payload initialization activities tested?		
9.5	Are payload operations during any transitory phases tested?		
9.6	Are payload flight calibration procedures tested?		
9.7	Are payload failure modes that could occur in each flight phase tested?	Includes failure modes falsely triggered in software or via test access circuits.	
9.8	Are interactions between the payload interfaces (internal and external) tested? (e.g., all types of transmit/receive (Tx/Rx) devices/terminals for payload services)		
9.10	Are demonstrations of RF connectivity to the antennas (e.g., with hats) conducted with flight blankets in place?”		

2.10 Space Vehicle to Ground Interface

This section is only applicable to ground issues directly related to space vehicle interfaces and not intended to encompass all aspects of the ground segment, which is out of scope of this document.

Item	Ground Segment Considerations	Comments	Evidence
10.1	Are mission-trending tools being used to evaluate space vehicle data?		
10.2	Have commands been transmitted to the flight space vehicle from the Ground Segment?	Each command should be sent to the space vehicle in applicable mission sequences using end-item ground system hardware, software, processes and procedures and mission operations personnel. Command LYF throughput capability should be verified. Validate ground software used in testing the spacecraft prior to tests. Ensure unit under test (UUT) is compatible with the operational ground SW; e.g. command key, modulation, waveform, etc.	
10.3	Is flight telemetry transmitted to the Ground Segment from the flight space vehicle?	All telemetry responses to command sequences from the flight space vehicle to the ground segment should be evaluated using end-item ground-system hardware, software, processes and procedures, and mission operations personnel with the objective to receive, interpret, and analyze the flight data.	
10.4	Does testing demonstrate that mission/payload data, transmitted from the flight space vehicle to the ground system in a flight-like manner, can be successfully received, interpreted, and analyzed?	Mission data Transmission should be accomplished while other nominal flight operations are conducted, under	

Item	Ground Segment Considerations	Comments	Evidence
		nominal flight timelines and constraints, and using flight operational procedures generated and executed from the mission operations team.	
10.5	Are flight operational procedures, generated and executed from the Mission Operations team and using end-item ground systems, used to configure the flight space vehicle for downlink transmission of state-of-health and mission data?		
10.6	Does testing include ground operator response to scenarios in which the fault-management senses and corrects anomalies by swapping units?		

2.11 Software

Although software affects nearly all other spacecraft sub-systems, this section treats software as its own spacecraft subsystem and identifies software-specific TLYF considerations.

Item	Software Considerations	Comments	Evidence
11.1	Is the final version of the flight software, all associated on-board data, and all stored command procedures loaded into the spacecraft and payload processors before the start of integrated space vehicle testing?	Flight software includes all associated data (e.g., variable parameters used by the flight software, formats of commands and telemetry). Stored command procedures are also considered part of the flight software. (See definition of "software" in Section 3.)	
11.2	Are all commands that can be exercised processed by the flight software during the integrated space vehicle tests?	This excludes commands that cannot be executed due to destruction of space vehicle hardware, safety considerations for people and space vehicle hardware, etc.	
11.3	Have commands that are unable to be executed in the integrated space vehicle environment (see 11.2, above) been previously tested using simulated interfaces in a flight software test bed containing the target processing hardware?	This includes all commands that cannot be executed in the integrated space vehicle environment due to destruction of space vehicle hardware, safety considerations for people and space vehicle hardware, etc.	
11.4	Does the integrated space-vehicle test exercise all interfaces of the flight software with on-board hardware?	For most on-board hardware, integrated space vehicle testing is the first opportunity to verify that the flight software correctly interfaces with the hardware (e.g., accepts and interprets input from the hardware	

Item	Software Considerations	Comments	Evidence
		correctly, sends correct commands and data to the hardware, meets all timing and sequencing requirements of the interface). Testing of the software prior to this point is generally performed with simulated interfaces. The software must be tested with the real hardware interfaces before launch.	
11.5	Does the integrated space vehicle testing include end-to-end testing of the space-ground interface?	This includes execution of the ground software to produce and upload the commands and execution of the flight software to process the commands. It also includes execution of the flight software to produce and download the telemetry data and execution of the ground software to process that telemetry data.	
11.6	Does the integrated space vehicle testing thoroughly verify all flight software timing and sequencing requirements?	Prior to integrated, space-vehicle testing, software timing and sequencing requirements have been tested in the flight software test bed, and the software timing and sequencing characteristics can differ between the test bed environment and the actual space vehicle hardware.	
11.7	Are flight software functional and performance requirements, including timing and sequencing requirements, tested during TVAC testing?	Flight processing hardware characteristics differ under orbital temperatures. Prior to	

Item	Software Considerations	Comments	Evidence
		launch, it must be verified that the flight software will correctly execute on the actual flight hardware in the orbital environment.	
11.8	Does the integrated space vehicle testing include scenarios that appropriately exercise the closed loop control of the ADACS? Apply a similar question for closed loop control by the flight software for other spacecraft and payload subsystems (dependent upon SV design).	Actual hardware response needs to be verified against expected hardware response to verify correctness of the algorithms implemented in flight software.	
11.9	Is qualification testing of the flight software completed before the start of integrated space vehicle testing?	Qualification testing of the flight software generally occurs in a flight software test bed that contains the flight-processing hardware in the operational configuration with high-fidelity, simulated interfaces. Software qualification testing verifies all software requirements, including software interface requirements.	
11.10	Are all stored command procedures tested during integrated space vehicle testing (except for those containing commands that cannot be executed due to safety, destruction of flight hardware, or other considerations)?	The correctness of all stored command procedures must be verified before launch. Ideally, this needs to occur during integrated, space-vehicle testing to fully verify their correctness. However, some command sequences may not be able to be executed due to destruction of space vehicle hardware, safety considerations for people and space	

Item	Software Considerations	Comments	Evidence
		vehicle hardware, etc.	
11.11	Are all stored command procedures tested using simulated interfaces in a flight-software test bed containing the target processing hardware before the start of integrated, space-vehicle testing?	Proper execution of all stored command procedures must be verified before launch.	
11.12	Is the flight software tested in all applicable SV states and modes during integrated space vehicle testing?	Integrated, space-vehicle testing must cover all SV states and modes. For any state or mode which requires execution of flight software in order to properly operate, the testing must include such execution.	
11.13	Is regression testing of appropriate integrated, space-vehicle test cases performed for all changes to flight software, its associated on-board data, and all stored command procedures made after the start of integrated space vehicle testing?	Most likely there will be changes to flight software, onboard data, and stored command procedures after the start of integrated space vehicle testing. Each of these changes requires analysis of affected integrated, space-vehicle test cases and execution of appropriate regression test cases to ensure no defects have been introduced.	
11.14	Are any changes to flight software made after the start of integrated, space-vehicle testing fully regression tested through execution of appropriate software unit, software integration, and software-qualification test cases before the change is uploaded to the SV?	It is critically important that all changes to flight software undergo full software-level testing before being used in integrated, space-vehicle testing.	
11.15	Are any changes to stored command sequences made after the start of integrated, space-vehicle testing, then tested using simulated interfaces in a flight software test bed containing the target-processing hardware before they	Stored command procedures need to be verified in a test bed environment before uploading to the vehicle.	

Item	Software Considerations	Comments	Evidence
	are uploaded to the SV?		
11.16	Is the end-to-end path for uploading changes to flight software, on board data, and stored command procedures verified using mission operations procedures, processes and equipment? Apply a similar question for the end-to-end path for downloading memory dumps to verify correct uploading of these changes.	Flight procedures, processes and equipment often follow a different electrical and software path than in-factory STE test configurations. Note that this end-to-end path includes both flight and ground software.	
11.17	Is the upload/patching capability for changes to flight software, onboard data, and stored command procedures verified with real-life mission limitations and the flight on-board firmware?	Remember to consider [limited ground/SV contacts per day low-earch orbit/geosynchronous orbit (LEO/GEO), noise, cut-offs, timing, upload rate, off-limited BER, network signal quality, angle above the horizon related to time, specific SV configurations]	
11.18	Do integrated SV tests verify that the automated FMS executes appropriately for the anticipated fault conditions, resulting in the proper end state?	Testing should include a sufficient sample of real life scenarios with simulated or actual fault conditions. These scenarios must cover all phases of the mission timeline and all SV states and modes	
11.19	Are integrated SV tests designed and executed to specifically demonstrate that the fault management system (FMS) can detect and isolate faults from the anticipated fault conditions?	Verification of proper functioning of the automated FMS on the actual flight hardware is essential before launch.	
11.20	Do the integrated SV tests include a sufficient number of test cases with nominal and off-nominal conditions for each subsystem controlled by the flight software?	The correct behavior of the flight software under off-nominal conditions must be verified on the actual flight hardware before launch. Sufficient off-	

Item	Software Considerations	Comments	Evidence
		nominal test cases must be executed to provide confidence that the flight software correctly controls each SV subsystem under off-nominal conditions as well as nominal conditions.	
11.21	Are the flight software, on-board data, and stored command sequences under configuration control?	Maintenance of strict configuration control of these items is essential to know the configuration of the space vehicle.	

3. Acronyms

ADCS	Attitude Determination and Control Subsystem
BER	Bit Error Rate
C&DH	Command and Data Handling
EPS	Electrical Power Subsystem
ESD	Electrostatic Discharge
FMS	Fault Management Subsystem
GPS	Global Positioning System
GSE	Ground Support Equipment
IR	Infrared
LYF	Like You Fly
L/V	Launch Vehicle
MMA	Moving Mechanical Assembly
SAS	Solar Array Simulator
S/C	Spacecraft
STE	Special Test Equipment
S/V	Space Vehicle
TLYF	Test Like You Fly
TOCT	Total Operations Chain Test
TT&C	Telemetry, Tracking, and Command
TVAC	Thermal Vacuum Test
TWTA	Travelling Wave Tube Amplifier

4. Glossary

Test Like You Fly (TLYF)—TLYF is a pre-launch verification and validation approach that examines ***all applicable mission and flight characteristics*** within the intended operational environment and determines the fullest practical extent to which those characteristics can be applied in testing. The application of this philosophy is intended to avoid experiencing those conditions for the first time on orbit, discover anomalous behavior under those conditions, and validate end-to-end operability and performance of the item under test.

Test Like You Fly Exception—An instance in which testing cannot be performed in a like-you-fly manner due to physical or programmatic constraints (schedule cost, safety, etc.) that prevent creation of the flight environment/configuration during testing. Exceptions need to be systematically addressed to mitigate risks which arise from not performing testing in a like-you-fly manner.

Flight and Mission Characteristics—Concurrent attributes including, but not limited to, hardware and software configuration per mission phase or activity, external environments, internal induced environments, automated flight sequences, commanded operations, activity order and timing, up/downlinked telemetry, data product generation, signal services, mission planning, and end-user evaluation.

Integrated Space Vehicle/Space Vehicle—An integrated set of subsystems and units, including their software, capable of supporting an operational role in space. A space vehicle may be an orbiting vehicle, a major portion of an orbiting vehicle, or a payload that performs its mission. It may or may not be attached to a launch or upper-stage vehicle. The airborne support equipment that is peculiar to programs utilizing a recoverable launch or upper-stage vehicle is considered to be part of the space vehicle.

Mission Operability—The ability to execute mission activities per a mission-compatible timeline, with attendant initial and transitional conditions. Mission operability is also the ease with which system operators and end users can perform assigned mission tasks with one or more systems when those systems are functioning together as designed.

Element—A complete, integrated set of subsystems capable of accomplishing an operational role or function, such as navigation. It is the Configuration Item delivered by a single contractor.

System—A system is a composite of equipment, skills, and techniques capable of performing or supporting an operational role. A system includes all operational equipment, related facilities, material, software, services, and personnel required for its operation. An integrated set of segments and/or subsystems to accomplish a defined objective or mission.

Segment—A major product, service, or facility of the system (e.g., the space segment or ground segment). A segment is a logical and integrated group of similar functions provided by a combination of people, hardware, software, and data. Each segment is composed of both internal and external interfaces. The former where segment elements are joined together and the latter where segments are joined as part of a more complex integration.

System of Systems—A set or arrangement of interdependent systems that are related or connected to provide a given capability. The loss of any part of the system will significantly degrade the performance or capabilities of the whole.

Test Article—A test article can be anything from a complex component, through all levels of integration, up to and including all space and operational software and systems involved in conducting the mission, but the item ultimately should be the final flight article.

Total Operations Chain—The complete set of hardware, software, and processes to be used in the actual mission. The chain includes everything from the external stimuli experienced by the spacecraft on-orbit, the spacecraft and payload systems, uplinks/downlinks, the ground control system (including mission planning, backup, alternate, and payload ground systems as appropriate), tasking originators, the data dissemination system, and representative data or service users.

Subsystem—A subsystem is an assembly of functionally related units. It consists of two or more units and may include interconnection items such as cables or tubing, and the supporting structure to which they are mounted. An integrated set of assemblies that perform a clearly separated function (e.g., Attitude Control Subsystem) involving similar technical skills.

Assembly—An integrated set of subassemblies and/or units that comprise a well-defined part of a subsystem.

Subassembly—A single physical entity containing two or more parts, which is capable of disassembly or part replacement.

Unit—A functional item composed of one or more subassemblies capable of performing complex functions (hardware and, if applicable, software) that is viewed as a complete and separate entity for the purposes of manufacturing, maintenance, and record keeping.

Configuration Item (CI)—An aggregation of hardware, firmware, computer software, or any of their discrete portions, which satisfies an end-use function and is designated by the government for separate configuration management. CIs may vary widely in complexity, size, and type, from an aircraft, electronic, or ship system to a test meter or round of ammunition. Any item required for Logistics Support (LS) and designated for separate procurement is a CI.

End Item—1. The final production product when assembled, or completed, and ready for issue/ deployment. 2. Two or more parts joined together to form a unit, capable of disassembly, which is only a part of a complete machine, structure, or other article.

Component —A product that is not subject to decomposition from the perspective of a specific application.

Part/Piece Part—A single piece not normally subject to disassembly without destruction or impairment of use, such as resistors, transistors, relays, and gears. 2. A single physical entity packaged as an indivisible item composed of two or more joined pieces that are not normally subject to disassembly without destruction or impairment of the design use.

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