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Space engineering

Mechanical — Part 6: Pyrotechnics

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Foreword

This Standard is one of the series of ECSS Standards intended to be applied together for the management, engineering and product assurance in space projects and applications. ECSS is a cooperative effort of the European Space Agency, national space agencies and European industry associations for the purpose of developing and maintaining common standards.

Requirements in this Standard are defined in terms of what shall be accomplished, rather than in terms of how to organize and perform the necessary work. This allows existing organizational structures and methods to be applied where they are effective, and for the structures and methods to evolve as necessary.

This Standard has been prepared by by the ECSS Mechanical Engineering Standard Working Group, reviewed by the ECSS Technical Panel and approved by the ECSS Steering Board.

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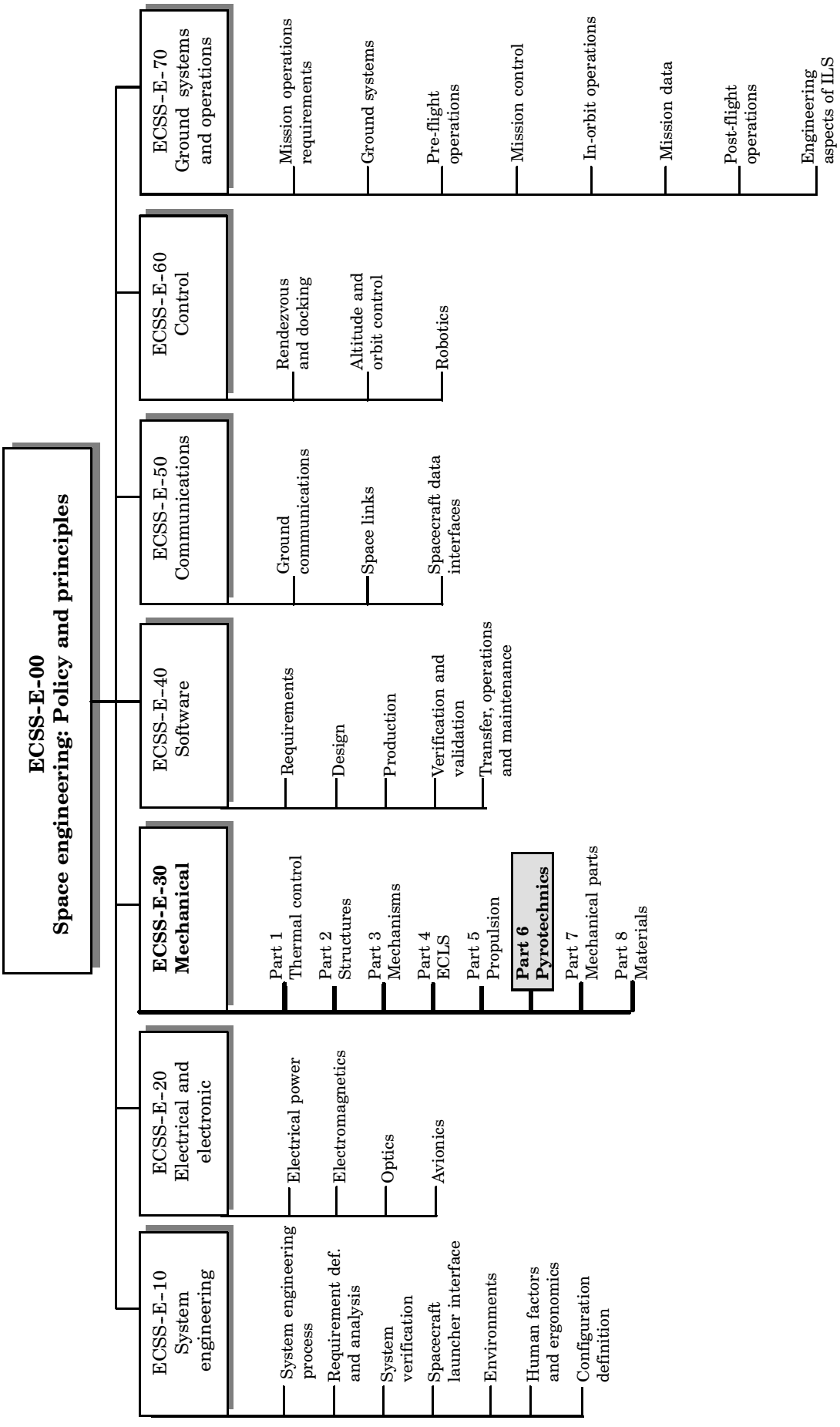
Structure of the ECSS-Engineering standards system



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Scope

Part 6 of ECSS-E-30 in the engineering branch of ECSS series of standards defines the requirements for the discipline of pyrotechnics engineering.

This part defines the standards to be applied for the use of pyrotechnics on all spacecraft and other space products including launch vehicles. It addresses the aspects of design, analysis, verification, manufacturing, operations and safety.

As any pyrotechnic item used for flight can function only once, it can never be fully tested before its crucial mission operation. The required confidence can only be established indirectly by the testing of identical items. Test results and theoretical justification are essential for demonstration of fulfilment of the requirements. The requirement for repeatability shows that product assurance plays a crucial role in support of technical aspects.

The failure or unintentional operation of a pyrotechnic item can be catastrophic for the whole mission and life threatening. Specific requirements can exist for the items associated with it. As all pyrotechnic functions are to be treated similarly, collective control needs to be applied in the manner of a subsystem.

When viewed from the perspective of a specific project context, the requirements defined in this Standard should be tailored to match the genuine requirements of a particular profile and circumstances of a project.

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

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Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this ECSS Standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this ECSS Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references,the latest edition of the normative document referred to applies.

ECSS-P-001	Glosary of terms
ECSS-E-10	Space engineering — System engineering
ECSS-E-10-03	Space engineering — Testing [1)]
ECSS-E-20	Space engineering — Electrical and electronic
ECSS-E-40	Space engineering — Software
ECSS-E-30 Part 2	Space engineering — Mechanical - Part 2: Structural
ECSS-M-00	Space project management — Policy and principles
ECSS-M-00-02	Space project management — Tailoring [1]
ECSS-M-30-01	Space project management — Organization and conduct of reviews
ECSS-Q-00	Space product assurance — Policy and principles
ECSS-Q-20	Space product assurance — Quality assurance
ECSS-Q-30	Space product assurance — Dependability
ECSS-Q-40	Space product assurance — Safety
ECSS-Q-70	Space product assurance — Materials, mechanical parts and processes
ESA SCC 3401/052	Connectors, electrical, circular, bayonet coupling, scoop-proof, removable crimp contacts
ESA SCC 3401/056	Connectors, electrical, circular, triple-start sel-locking coupling, scoop-proof, removable crimp contacts

MIL-STD-1576 Issue 31/7/84 Electro-explosive Sub-system Safety Requirements

ST/SG/AC 10/1 Rev. 7 UNO Transport of Dangerous Goods

References to sources of approved lists, procedures and processes can be found in the bibliography.

1) To be published.

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Terms, definitions and abbreviated terms

3.1 Terms and definitions

The following terms and definitions are specific to this Standard in the sense that they are complementary or additional with respect to those contained in ECSS-P-001.

3.1.1
cartridge
explosive device designed to produce pressure for performing a mechanical function, i.e. operating a cartridge actuated device such as a pin-puller or cable cutter

NOTE 1 A cartridge is called an initiator if it is the first or only explosive element in an explosive chain.

NOTE 2 Electrically actuated cartridges are EEDs.

3.1.2
charge
quantity of explosive loaded in a cartridge, detonator, or separate container for use in a pyrotechnic device

3.1.3
detonator
initiator for high order detonating explosives

NOTE Detonators used in space vehicles are generally EEDs, i.e. electrically actuated.

3.1.4
electro-explosive device (EED)
explosive initiator that is electrically actuated

NOTE 1 The EED is the explosive element used to operate a cartridge actuated device, to initiate an explosive charge, or to ignite a deflagrating material.

NOTE 2 Detonators, initiators and cartridges when electrically actuated are EEDs.

3.1.5
initiator
first element in an explosive chain that, upon receipt of the proper mechanical or electrical impulse, produces a deflagrating or detonating action

NOTE 1 The deflagrating or detonating action is transmitted to the following elements in the chain.

NOTE 2 Initiators can be mechanically actuated, percussion primers, or electrically actuated (EEDs).

3.1.6
lifetime
period over which any of the subsystem properties are required to be within defined limits

3.1.7
pyrotechnic actuator
mechanism that converts the products of explosion into useful mechanical work

3.1.8
pyrotechnic chain
all the elements necessary to supply, operate, support, protect and monitor a pyrotechnic function

NOTE The schematic of a typical pyrotechnic chain is shown in Figure 1.

3.1.9
pyrotechnic component
any discrete item containing explosive substance, that is permanently changed as a result of operation

3.1.10
pyrotechnic function
any function that uses energy released from explosive substances for its mechanical operation

3.1.11
pyrotechnic subsystem
collection of all the pyrotechnic chains on the spacecraft or launcher system, and any on-board computers, launch operation equipment, ground support and test equipment and all software associated with pyrotechnic functions

NOTE Pyrotechnic subsystem is referred to as “the subsystem” throughout this Standard.

3.1.12
secondary characteristic
any characteristic, other than its primary function, affecting the capability of an item to meet requirements

3.1.13
sequential firing
application of the firing pulses to redundant initiators separated in time

3.1.14
simultaneous firing
application of the firing pulse to both redundant initiators at the same instant

3.1.15
sympathetic firing
firing of the second of two redundant pyrotechnic devices due to the output of the first

3.2 Abbreviated terms

The following abbreviated terms are defined and used within this Standard.

Abbreviation	Meaning
AIV	assembly integration verification
DPA	destructive physical analysis
EED	electro-explosive device
EGSE	electrical ground support equipment
EMC	electromagnetic compatibility
ESD	electrostatic discharge
MGSE	mechanical ground support equipment
UNO	United Nations Organisation
TBI	through-bulkhead initiator
RF	radio frequency
SRD	system requirements document

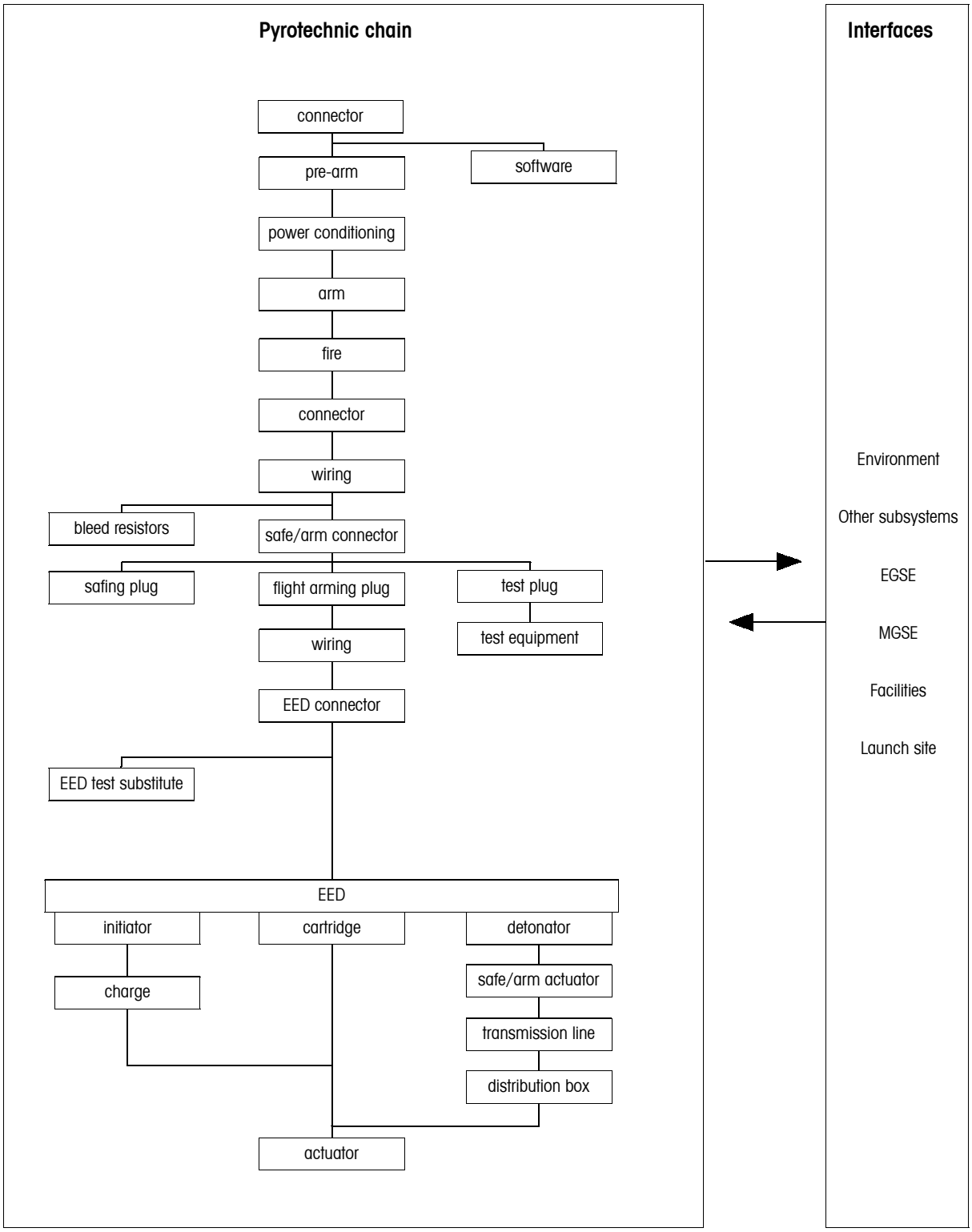

Figure 1: Typical pyrotechnic chain and associated items

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Requirements

4.1 General

4.1.1 Overview

This Standard defines the requirements that are not already covered by existing standards applicable to spacecraft or launchers and shall apply in addition to their requirements.

To ensure all important requirements are included, requirements addressed by external references are noted under each subject headings.

The pyrotechnic requirements are defined in three levels. This top-level standard covers subsystem aspects and calls up requirement documents for the subsystem elements. The properties of the electro-explosive device (EED) govern the major part of the behaviour of the whole subsystem. EEDs and their derivatives, such as cartridges and detonators, are treated in more detail at a lower level. The requirements for these standard elements are defined in specific requirements documents related to the specific types. Actuator properties, which cannot be covered by requirements for the EED alone, are defined in specific requirement documents relating to the types of actuator. Other elements of the pyrotechnic subsystem which can be fully tested and do not need specific requirements are subject to the general technical and product assurance requirements. Detailed aspects of these elements are included for these elements where they have a significant influence on success of the pyrotechnic functions.

4.1.2 Appliciation

The requirements in this Standard cover the interaction of pyrotechnic engineering with project management, processes, parts and components, product assurance, and the related requirements affecting the conceptual definition, design, sizing, analysis, development, and hardware production of pyrotechnic devices.

4.1.3 Stability of properties

a. The properties of the subsystem shall remain stable before and after firing, even when subject to external loads or environmental conditions, except if these external conditions exceed the defined values.

b. The functional requirements shall be met within the limits of environmental and loading conditions required by the user programme.

4.1.4 Subsystem performance

The specific functions and performance to be delivered by the subsystem shall be compatible with those defined by the user.

4.1.5 Response time

Each pyrotechnic function shall respond to its electrical firing command within the time interval defined by the user.

4.2 Mission

a. The use of pyrotechnic functions during all phases of the mission shall be identified.

b. The nature of the orbit, mission purpose and duration, functions being activated shall be described (e.g. launcher ignition, staging and safety functions, payload separation, apogee motor ignition, solar array, antenna, boom or cover release, propulsion system branch opening or closing).

c. Specific mission-related requirements placed on the subsystem shall be identified.

4.3 Functionality

a. Each function of the subsystem is required at a particular time. It shall react to a defined stimulus and shall be insensitive to all others.

b. Using available supplies, the subsystem shall ensure that the correct stimulus arrives at the proper place at the required time and prevent it reaching the reactive element at any other time.

c. Unintentional function shall be prevented by the design and operation of the subsystem.

d. The subsystem, including software and procedures, shall be specifically designed to prevent and resist human error in this and other subsystems.

4.4 Constraints

4.4.1 Survival and operational conditions

The subsystem shall survive the complete sequence of conditions in the order shown in the ECSS requirements or the customer requirements without functioning or degrading, and to operate at the extremes of the ranges of conditions defined. The limits defined shall include the margins for qualification.

4.4.2 Actuators and components

4.4.2.1 General

Actuators and their components are subject to the conditions laid down in subclause 4.4.2. Other elements of the subsystem, which can be fully tested before flight, shall conform to the equipment environmental test conditions of the user.

4.4.2.2 Tolerances

Except where otherwise specified the activities shall take place under the conditions and within the tolerances defined in ECSS or user defined requirements.

4.4.2.3 Lifetime

The lifetime of the subsystem extends to the time at which the mission is no longer sensitive to subsystem properties. This can be long after the firing of the last pyrotechnic actuator.

4.4.2.4 Disturbance

The subsystem shall limit the mechanical, electrical and thermal effects of its operation within limits defined by the application to avoid disturbance (e.g. shock) or damage to other sensitive elements on the space vehicle.

4.4.2.5 Contamination, debris, particles

Contamination of other parts of the space vehicle shall be prevented by the use of approved materials and by design to contain products of the operation of pyrotechnic actuators and of their consequences (e.g. debris).

4.4.2.6 Fire resistance

Provision shall be made within the subsystem to eliminate fire hazard and to limit susceptibility to the effects of fire.

4.4.2.7 Materials compatibility

a. All materials, including explosive substances, shall be compatible with those materials with which they can come into contact.

b. Continued exposure to the predicted environmental conditions shall not cause degradation or increased sensitivity which can result in a hazard.

c. Any sealing system used to prevent degradation shall be demonstrated to be effective for the conditions.

4.4.2.8 After functioning

After functioning, no pyrotechnic actuator shall cause any disturbance or contamination of any other subsystem.

4.4.3 Mechanical constraints

4.4.3.1 Mass

The mass of the subsystem shall be as low as possible and consistent with the mission strength requirements.

4.4.3.2 Dimensions

The dimensions of the subsystem components shall be as small as possible and consistent with the strength requirements and the mission interface requirements.

4.4.3.3 Strength

The subsystem shall sustain the internal loads due to operation and the external loads defined by the user application. These loads represent the sum of preload, static, dynamic, thermal and any other load to be seen in service.

4.4.3.4 Reaction

The subsystem shall rely upon the structure and appendages for mechanical support, mechanical reaction to the generated loads and protection.

4.4.3.5 Dynamic environment

The subsystem shall survive and operate according to performance requirements when subject to the dynamic environmental conditions described in ECSS-E-10-03 or the mission definition.

4.4.4 Electrical constraints

4.4.4.1 Circuit independence

a. EEDs shall not be connected in series or in parallel with each other.

b. Each firing circuit shall be electrically independent from any other.

c. All other configurations shall be justified by test and analysis to meet the requirements on the prevention of unintentional function (see subclause 4.6.1).

4.4.4.2 Energy source for firing

a. The subsystem shall obtain electrical power from the space vehicle power subsystem.

b. No dedicated batteries or capacitors shall be used.

c. The supply capability shall be in accordance with the requirements of ECSS-E-20.

4.4.4.3 Power system overload

The subsystem shall ensure that the power subsystem is not overloaded before, during or after the actuation of any pyrotechnic device. This applies also in case of combined single-point failure and EED short circuit after firing (both pin-to-pin and pin-to-ground).

4.4.4.4 Electromagnetic compatibility (EMC)

Electrostatic and electromagnetic conditions are defined in MIL-STD-1576 (31 Jul 1984) and ECSS-E-20.

4.5 Interface

4.5.1 Functional

a. Each interface shall be simple and self-contained to ensure no assembly errors can be made and to prevent damage during assembly or dismantling.

b. Whilst separated, each interface shall provide for simple protection to prevent activation or damage by external loads and environmental conditions.

c. When closed, each interface shall establish stable continuity of properties between the joined elements without disturbing or being disturbed by external loads and environmental conditions.

d. Each interface shall sustain without degradation the assembly and dismantling duty-cycle as well as the operational and environmental conditions of the application in both coupled and separated states.

4.5.2 Internal

a. Each element in the subsystem shall be compatible with its neighbour.

b. Each element shall provide outputs (electrical, mechanical, thermal and with respect to time) at each interface with positive margins over the input requirements of the next element.

4.5.3 External

Although the subsystem places certain requirements upon the other subsystems, it shall be compatible with the requirements of all other subsystems on board, external loading and environmental conditions.

4.6 Design

4.6.1 Prevention of unintentional function

a. The firing pulse shall be prevented from reaching any pyrotechnic initiator at any time except the correct instant by means of switchable electrical or mechanical barriers.

b. The subsystem shall contain sufficient features to tolerate a minimum number of credible failures or operator errors according to the following criteria. The severity categories to be considered shall be in accordance with ECSS-M-00 and ECSS-Q-40.

   1. for EEDs the minimum no-fire rating shall be 1A (current) or 1W (power) for five minutes;

2. if loss of function is safety critical or catastrophic, the design of the subsystem shall preclude single-point failures and include at least two EEDs;
3. if inadvertent firing is safety critical, the design of the subsystem shall ensure that no single failure or single operator error can cause a critical hazard and no combination of two failures or operator errors can cause a catastrophic hazard;
4. at least one of the barriers, in any electrical firing circuit, shall be mechanical, providing complete disconnection of that circuit;
5. the prime and redundant EEDs shall not be activated through the same electrical firing circuit;
6. stray circuits and coupling which can result in unintentional firing shall be avoided.

4.6.2 Protection

Provision shall be made within the subsystem to protect all its sensitive elements against unwanted operation or degradation.

4.6.3 Monitoring

a. The subsystem shall provide for measurements of electrical properties during the integration of any circuit before and after firing, without inducing firing or degradation, and, during the mission, the status of the barriers and the functions.

b. It shall be possible to verify the status of the barriers protecting the EED before inserting the arm plug for any reason.

c. Monitoring facilities shall be galvanically isolated from firing circuitry or have such high impedance that current flow is negligible. This applies also after any single-point failure.

d. Provision shall be made for an immediate warning signal to be given for any unplanned change of status of any subsystem control or monitoring device.

4.6.4 Avoidance of single-point failures

Space vehicle system architecture shall provide at least two independent pyrotechnic chains, each capable of ensuring any particular function with the required reliability.

4.6.5 Mechanical design

4.6.5.1 Integrity

Making use of the structure subsystem capabilities, the subsystem shall maintain its integrity and position.

4.6.5.2 Main fixings

Each element of the subsystem shall be provided with its own attachment interface compatible with the standard methods of attachment to the structure or appendage. ECSS-E-30 Part 2 applies.

4.6.5.3 Modularity of elements and components

The subsystem shall be assembled from modular elements which can be made and tested separately, to ensure that attachment, installation, repair and replacement can be done with minimum disruption to surrounding equipment.

4.6.5.4 Interchangeability

a. All components having the same function shall be interchangeable.

b. Measures shall be taken to ensure that components specifically intended for different applications cannot be confused.

4.6.5.5 Accessibility

The subsystem shall provide easy access to the EEDs, safe, test and arm plugs for connection and for measurements of electrical properties and to all elements for inspection throughout the space vehicle integration.

4.6.5.6 Inert models

Inert models used for test purposes shall be visibly different from live items to prevent confusion and to ensure incorrect items are not used for flight.

4.6.6 Electrical design

4.6.6.1 Firing sequence: simultaneous or sequential

The chosen firing sequence shall cause no anomaly at unit or subsystem level. This applies to secondary characteristics as well as for primary function.

4.6.6.2 Firing pulse

a. The subsystem shall provide direct current pulses to each EED at the times required by the application.

b. Under worst case conditions, the current pulse amplitude and duration shall be as defined in the EED input requirements.

c. Theoretical analysis and demonstration by test shall be required.

4.6.6.3 Electrostatic discharge

a. The subsystem shall neither function nor degrade as a result of discharge described in MIL-STD-1576 (31 Jul 1984), subclause 5.11.1.1.

b. Electrostatic discharge to ground through the explosive elements shall be prevented by design.

c. The subsystem shall be designed to prevent the build-up of electrostatic charge. Static bleed resistors shall not prevent fulfilment of the single-point grounding requirement.

4.6.6.4 Voltage drop

The voltage drop in the electrical circuit firing lines shall be taken into account in the provision of the required firing pulse.

4.6.6.5 Grounding

a. The firing circuits shall be grounded at one point only.

b. The resistance to ground shall not exceed the value given in ECSS-E-20.

c. Provision shall be made to isolate power and return lines of the subsystem to prevent continued drain on the power system after firing when short circuit to ground can occur.

d. Shielding may be multi-point-grounded to the structure. Its resistance shall not be more than the value given in ECSS-E-20.

4.6.6.6 Isolation

a. Each electrical firing circuit shall be electrically independent from power source to EED. No connection to any other circuit shall be permitted.

b. Each circuit shall be isolated to avoid inadvertent coupling with any other.

c. All switching related to pyrotechnic functions shall be confined to separate, dedicated electronic units.

d. The subsystem shall isolate the function to prevent power drain or stray circuits before and after firing.

e. Provisions for redundancy shall not prevent fulfilment of this requirement.

f. Safe and arm device control and monitoring circuits shall be completely independent of the firing circuits, with separate non-interchangeable connectors.

4.6.6.7 Insulation resistance

a. The insulation resistance of the electrical firing circuits and shielding shall be measured in accordance with ECSS-E-20.

b. The insulation resistance shall not be less than the value given in ECSS-E-20 before firing and shall be as high as possible after firing.

c. The subsystem shall neither function nor degrade as a result of the potential defined.

4.6.6.8 Dielectric strength

a. The current leak from electrical firing circuits to ground shall be measured in accordance with ECSS-E-20.

b. The current leak shall not exceed the value given in ECSS-E-20.

c. The subsystem shall neither function nor degrade as a result from this leakage current.

4.6.6.9 Sensitivity to RF energy

When exposed to RF conditions as described in ECSS-E-20, the induced power shall not exceed a level which is 20 dB below the EED no-fire power, or 20 dB below the EED RF sensitivity threshold.

4.6.6.10 Electromagnetic compatibility (EMC)

The subsystem shall meet the EMC requirements described in ECSS-E-20.

4.6.6.11 Magnetic cleanliness

a. Residual magnetism shall be avoided by the choice of suitable materials.

b. The magnetic field strength, due to exposure to the subsystem, shall not exceed the electromagnetic interference safety margins defined in ECSS-E-20.

4.6.6.12 Continuity current

The susceptibility of the subsystem to continuity measurement shall remain below the safety margin (see ECSS-E-20).

4.6.6.13 Lightning

The susceptibility of the subsystem due to lightning shall remain below the safety margin (see ECSS-E-20).

4.6.7 Thermal design

All parts of the subsystem shall be thermally continuous. The temperature control shall be by passive means via the main fixing interfaces and radiative surfaces.

4.6.8 Specific elements

4.6.8.1 Connectors

a. Mis-mating of connectors shall be prevented by design or selection.

b. The insert polarization and contact arrangement of the connectors used in the subsystem shall not be used elsewhere on the space vehicle.

c. Source circuits shall be terminated by female contacts.

d. Spare or unterminated contacts shall not be used.

e. Prime and redundant circuits for the same function shall not pass through the same connector.

4.6.8.2 Permanent connection

All methods of permanent electrical connection shall conform to ECSS-E-20.

4.6.8.3 Wiring

a. Electrical supply for each EED shall be by a separate shielded, twisted-pair line with shielding effectiveness as defined in this Standard.

b. Each conductor shall be continuous (with no splicing).

c. Wiring used for pyrotechnics shall be clearly and uniquely identifiable by marking and colour-coding.

d. Wires and wiring shall conform to ECSS-E-20.

4.6.8.4 Shielding

Shielding shall uniformly cover at least 85% of the surface for 360 degrees of the circumference.

4.6.8.5 Power conditioning

a. The subsystem shall make use of the available voltage and current supplies from the power subsystem to produce power pulses of suitable size, duration and timing for each of the functions.

b. The pulse requirements are defined by the requirements for the input to the EEDs, augmented to account for losses in the subsystem (see ECSS-E-20).

4.6.8.6 Pre-arm function

a. The pre-arm function shall be the first in a sequence of three electrical barriers.

b. The pre-arm function shall be independent and respond only to a unique action, but may be used to control a number of arm functions.

c. The pre-arm function shall remain in its switched state after operation.

4.6.8.7 Arm function

a. The arm function shall be the second-last activated barrier in the sequence.

b. The arm function shall be independent and respond only to a dedicated command.

c. The arm function shall be used to control only one pyrotechnic function.

d. It shall be possible to restore its initial (disarm) state immediately after the arm command has ended.

4.6.8.8 Fire function

a. The fire function shall be the last activation in the sequence.

b. The fire function shall be independent and respond only to a unique command.

c. The fire function shall revert to its initial state immediately after the firing command has ended.

4.6.8.9 Safe and arm connector

a. A connector shall be provided on the exterior surface of the space vehicle to enable isolation, coupling or testing of any pyrotechnic chain by means of manually inserted plugs.

b. The safe and arm connector shall be qualified for the number of connection cycles necessary to cover integration, test and use.

c. The safe and arm connector shall be easily accessible.

d. The receptacle shall be a scoop-proof, self-locking bayonet or triple start thread type conforming to ESA SCC 3401/052.

4.6.8.10 Safe plug

a. The safe plug shall short-circuit and ground each firing circuit through a resistor to provide protection from EMC and ESD as defined in ECSS-E-20.

b. The safe plug shall be compatible with the safe and arm connector receptacle.

c. The safe plug used with the flight space vehicle shall be of a standard suitable for use with flight hardware.

d. The safe plug shall be qualified for the number of connection cycles necessary to cover integration, test and use.

e. A connector-saver shall be used to prevent the receptacle and contacts from wear and damage.

f. The safe plug shall be a scoop-proof, self-locking bayonet or triple-start thread type conforming to ESA SCC 3401/056.

g. The safe plug shall be clearly identified and carry a “Remove before Flight” banner.

4.6.8.11 Arming plug

a. The arming plug shall provide electrical continuity between the supply and firing circuits with the resistance in any line not exceeding the value given in ECSS-E-20.

b. The arming plug shall be compatible with the safe and arm connector and shall meet all the requirements for flight hardware.

c. The plug shall be a scoop-proof, self-locking bayonet or triple-start thread type conforming to ESA SCC 3401/056.

4.6.8.12 Test plug

a. The test plug shall provide electrical access to the firing circuits with the resistance in any line not exceeding the value given in ECSS-E-20.

b. The test plug shall not carry any potential or current at the time of insertion or removal. It shall be compatible with the safe and arm connector.

c. The test plug used with the flight space vehicle shall be of a standard suitable for use with flight hardware.

d. The test plug shall be qualified for the number of connection cycles necessary to cover integration, test and use.

e. The test plug shall be a scoop-proof, self-locking bayonet or triple-start thread type conforming to ESA SCC 3401/056.

4.6.8.13 EED harness connector

a. The connector on the harness shall be of MS 3126F8-2S type, compatible with the integral connector of the EED.

b. The harness connectors used for the pyrotechnic EEDs shall not be used for other purposes on the space vehicle.

c. Precautions shall be taken by design, build and marking procedures to prevent connection of the wrong firing line to any EED.

4.6.8.14 EED test substitute

Any item used as an EED test substitute shall have been approved as being representative in all respects that affect the results of the test.

4.6.8.15 Pyrotechnic components

a. The pyrotechnic elements of the subsystem shall be treated as components.

b. Existing devices with proven performance, manufacturing and qualification records shall be used.

c. Justification of alternatives shall be provided for approval by the space vehicle customer.

d. This provision shall include, but is not limited to, the following:

1. EED test substitute;
2. EED;
3. charge;
4. cartridge;
5. detonator;
6. safe and arm actuator;

7. transmission line or detonating cord;
8. distribution box;
9. through-bulkhead initiator (TBI);
10. actuators (e.g. cutters, release-nuts, valves, pin-pullers, pin-pushers, expansion tube devices).

4.6.8.16 Interface elements

Threaded fasteners and all other elements which interface with pyrotechnic actuators shall conform to approved standards and procedures.

4.6.8.17 Software

a. Commands used for a subsystem shall be such that neither correct nor erroneous commands of other subsystems can be interpreted as pyrotechnic commands.

b. All software used in the operation and check-out of the subsystem shall conform to ECSS-E-40.

4.6.8.18 Tools

Tools made or procured for use with the subsystem or elements shall be neither magnetic nor spark-generating.

4.6.8.19 Mechanical ground support equipment

a. Mechanical ground support equipment shall provide support and protection to maintain the subsystem within its proven envelope. This shall include grounding to prevent electrostatic build-up.

b. Mechanical ground support equipment shall conform to the ground operations requirements defined in ECSS-Q-40.

4.6.8.20 Electrical ground support equipment

a. No test equipment shall be used in connection with pyrotechnic devices other than test equipment which has been specifically built or checked as completely suitable for use with pyrotechnic devices.

b. Resistance measurements on EEDs, or any circuit containing EEDs, shall be made only with safety ohmmeters. All other test equipment shall be current limited to prevent firing the EED.

c. All electrical ground support equipment shall be fully maintained, with a service record document, and be checked for correct performance and output limitations before each use. Test procedures shall include these preparation steps.

d. The test harness shall not increase system susceptibility to unwanted stimuli.

e. A comprehensive display of status information for the complete subsystem shall be provided on the monitor screens. Clear indications shall be provided of the state changes. Hardcopy records of the data screens shall be provided. Coherence and consistency shall be provided in this display to enable direct comparison at any time during the integration and launch preparation, launch, mission operational and disposal phases.

4.6.8.21 Launch site

a. Control and monitoring of conditions in all locations shall be provided to protect all pyrotechnic devices and materials. These shall include temperature, humidity, RF and EMC environments, electricity supply regulation and precautions against lightning and electrostatic charge build-up.

b. The status of all pyrotechnic functions shall be visible at all times when the space vehicle is on the launcher. Clear, unambiguous indicators shall be used to show the status of the functions and the control barriers.

4.7 Verification

4.7.1 General

Verification of each of the subsystem properties and performance characteristics shall be performed by means of test and supporting analyses.

4.7.2 Methods

a. If test or measurement methods affect the accuracy of conditions or results, specific methods shall be defined, including instrumentation and procedures, to ensure consistency.

b. The test and analysis methods shall be subject to the requirements of the ECSS engineering, product assurance and management standards.

4.7.3 Essential confirmation

For every test, measurement and connection it shall be checked and recorded that the correct firing line or test line is connected to the correct EED, including noting the EED and connector identity numbers at each such activity.

4.7.4 Routing tests

a. Tests shall be performed to demonstrate that for all commands the correct pulse appears at the connector for the correct EED, and does not appear at any other EED connector.

b. Records shall be kept of the routing test results.

4.7.5 End-to-end tests

Tests demonstrating correct performance of complete chains shall be performed, including power supplies, telecommands, telemetry and end functions.

a. Only preplanned and approved activities may be performed, according to approved procedures.

b. Rehearsals shall be performed to check procedures for adequacy and to enable updating.

c. Firing tests shall not be performed until a successful rehearsal has been completed.

4.7.6 Operators

a. Testing and measurements shall only be done by trained operators.

b. Operators shall use special purpose equipment that has been certified and calibrated according to the manufacturer's instructions and according to plans and procedures agreed and approved in advance. Uncontrolled modifications to this equipment or to these procedures shall not be performed.

4.7.7 Subsystem testing

The pyrotechnic functions can be required for testing during the verification of other space vehicle or launcher subsystems. Appropriate precautions and information transfer shall be applied to ensure avoidance of hazards and problems with meeting objectives.

4.8 Production and manufacturing

4.8.1 Elements

a. The subsystem shall be constructed from elements which have been built and tested in advance.

b. The use of pyrotechnic elements from previous programmes shall be conditional upon the element being in a suitable condition, and with adequate documentation. The risk assessment for these elements shall take account of the completeness of the storage record and the nature of the storage conditions.

4.8.2 Transport and handling

a. Preparation for delivery and transportation shall be in accordance with ECSS-Q-20. ST/SG/AC.10/1 Rev. 7 for pyrotechnic devices; the minimum classification required is 1.2D, with minimum recommended 1.4S.

b. National and local requirements at all the facilities during the transport and handing of pyrotechnic devices shall apply.

4.8.3 Facilities

a. Provision shall be made for the safe storage and handling of pyrotechnic hardware and all associated equipment.

b. The facilities shall provide for indications of all environmental conditions which may fire or affect the performance of the pyrotechnic items.

c. The provisions of ECSS-Q-20, for handling, storage and preservation of pyrotechnic hardware, and ECSS-Q-40 shall apply.

4.8.4 Electrostatic charge

a. Precautions shall be taken to avoid electrostatic build-up on support equipment and personnel that can be discharged and cause disruption or damage to the subsystem.

b. Space vehicle equipment shall be grounded.

4.8.5 Pyrotechnics installation, test and replacement

a. Installation of pyrotechnic devices and associated elements shall be performed by trained, experienced, operators in accordance with ECSS-Q-20.

b. The installation operators shall follow approved procedures from the pyrotechnic device manufacturer.

c. Only approved tools, aids and test equipment shall be used for the installation of pyrotechnic devices. The acceptance status of the actuators or chains concerned shall be dependent upon this operation.

d. Consistent, coherent and complete records shall be maintained of all assemblies or any subsystems which have a direct effect upon the subsystem, including test activities and measurements during any break-in activities.

e. Restoration of the original accepted condition shall be required.

f. The correctness of all connections shall be confirmed and a record of all connections shall be maintained.

4.8.6 Special-purpose aids

a. The use of special tools or jigs to install or remove elements of the subsystem shall be avoided by design wherever possible.

b. The restrictions resulting from the higher levels of assembly shall be taken into account.

c. Where necessary purpose-built rigs shall be provided with specific procedures and training of operators as required.

4.8.7 Pyrotechnics hardware tracking

a. The location of every single live pyrotechnic hardware item shall be known and identifiable at any time.

b. A continuous, comprehensive record of movements shall be performed. All fired items shall be returned to their original locations and bagged for later inspection and analysis.

c. All pyrotechnics items, hardware and accessories, such as shielding caps, safing plugs, test connectors and wiring, tools and instruments shall be clearly listed and provided with a dedicated location to ensure tracking throughout the integration and launch campaign.

4.9 In-service

4.9.1 Launch facilities

a. Facilities shall be provided for the safe, protected storage and handling of pyrotechnic hardware and their related equipment.

b. Controls shall ensure no environmental stress condition is applied, especially to the flight and flight spare items.

4.9.2 Information feedback

a. For each different stage and activity of the launch campaign, a complete description shall be provided of all hardware and software provisions for the monitoring and command of all pyrotechnic functions. This shall clearly show any changes from one stage to the next.

b. The identities of all RF links, wiring, connectors and pin functions shall be defined to the level at which checks can be made of the correct source and destination.

c. Diagrams or photographs of consoles and installations shall be provided showing the positions and meaning of switches, meters, controls or connectors.

d. The diagrams or photographs shall clearly show the colour of indicators, wiring, markers, labels, plugs, sockets and all visual, ergonomic, electronic labels and logic indicators to assure correct connection. Confirmation of the correctness of this description shall be required before certification of results.

e. Control and monitoring of conditions in all locations shall be checked for adequacy in relation to pyrotechnics. A full check of all indicators shall be carried out for function and meaning. Results shall be recorded explicitly on a check report. Certification shall be provided.

f. Regular cross-checks of records shall be carried out to confirm that no responses have occurred as a result of activity in other subsystems and that no drifts or significant changes have occurred in properties.

4.9.3 Launch site procedures

a. Only planned and approved activities which follow approved procedures shall be undertaken.

b. A complete set of procedures shall be compiled to include contingency actions to be taken in the event of a launch delay or the termination of the launch.

c. Only trained personnel shall carry out work involving the pyrotechnic subsystem elements even when no live elements are present.

d. Only approved tools, aids and test equipment shall be used.

e. Rehearsals shall be performed to ensure the correctness of procedures.

f. Comprehensive, coherent records of all activities shall be made, including any intrusions for measurements on the subsystem or any subsystem which has a direct effect upon the subsystem. Restoration of the original “Accepted” condition shall be required.

4.9.4 Commands

Only approved telecommands and telecommand sequences shall be used.

4.9.5 Monitoring

Confirmation of operation shall be registered at the earliest possibility.

4.9.6 Recovery

Where possible, equipment shall be recovered for inspection and analysis.

4.9.7 Disposal of flight equipment

Where disposal in orbit requires the use of pyrotechnics this shall be taken into account during design and operations. The state of pyrotechnics hardware and software shall not prevent fulfilment of mission disposal requirements.

4.9.8 Final activities

All pyrotechnic hardware, including spares and items, procedures and record documents shall be packed in appropriate containers for controlled return to an accessible location for inspection.

4.10 Data exchange

4.10.1 General

4.10.1.1 Application and use

Details of the application and expected use of pyrotechnic items shall be communicated to the manufacturer.

4.10.1.2 Precautions

The manufacturer of a pyrotechnic item shall inform the user of all recommendations covering the application and use, together with all precautions to be taken during the use of that item.

4.10.1.3 Facilities

a. The nature of and precautions required for all pyrotechnic hardware and systems shall be communicated to facility providers and authorities.

b. The nature of and precautions required information shall be taken into account in the formulation of instructions and procedures.

4.10.1.4 Media

a. The requirements for the methods and media to be used for data exchange shall be defined by the customer.

b. The choice of media made shall not prevent comparison of results between any stages of the AIV and launch, mission and disposal process.

4.10.1.5 Facility monitoring

Records of all environmental conditions in locations where pyrotechnics items are stored or handled shall be maintained and be available for review.

4.10.1.6 Status monitoring

Status information shall be made available to the appropriate personnel as soon as technically possible.

4.10.2 Assembly, integration and verification records

4.10.2.1 Safety data package

Safety related information shall be compiled in accordance with the requirements of the launch site or other facility authority requiring such information.

4.10.2.2 Review documentation

AIV data shall be provided for review purposes (see ECSS-M-30-01).

4.10.2.3 Flight readiness

A review of all check-out and flight operations procedures for pyrotechnic functions shall be performed to ensure completeness and correctness.

4.11 Product assurance

4.11.1 General

a. The pyrotechnic functions on a space vehicle or launcher shall be treated collectively as a single subsystem. All pyrotechnic devices are defined as critical items according to the definitions in ECSS-P-001 and shall be treated as configuration items.

b. The subsystem design, software and procedures shall be specifically checked for prevention of, and resistance to, human error in this and other subsystems.

c. The risk and consequences of function at the wrong time or of failure to function shall be assessed according to the requirements of ECSS-M-00 and ECSS-Q-00. Measures shall be taken to minimize the cause and effect.

d. In general all activities shall be governed by the ECSS product assurance standards. In particular, for pyrotechnic devices, where additional provisions apply, specific requirements are given in the following subclauses.

4.11.2 Design and verification

The subsystem shall be designed and verified in accordance with the requirements in ECSS-Q-20 and ECSS-E-10.

4.11.3 Dependability

a. Subsystem dependability shall be according to the requirements of ECSS-Q-30.

b. The reliability figures for the function and for the avoidance of unintentional function shall be established according to the system requirements document (SRD).

c. Each pyrotechnic function shall remain operational after first failure and safe after second failure unless specified differently in the SRD.

d. The contractor shall identify age-sensitive parts and materials and submit a surveillance plan to the procuring activity for review and approval.

4.11.4 Safety

a. The properties of the subsystem and all activities shall meet the safety requirements defined in ECSS-Q-40.

b. Immediately before every connection and disconnection activity, it shall be confirmed and recorded that no potential difference exists between the interfaces to be connected and that no current flow exists across the interface to be broken.

c. No activities with pyrotechnic devices shall be allowed when conditions exceed those defined by local health and safety regulations.

d. Site safety regulations, provisions and procedures shall be checked for adequacy in relation to pyrotechnic activities to be carried out in the premises.

e. Safety submissions shall be prepared according to the requirements of the launcher authority.

4.11.5 Procurement

4.11.5.1 General

The subsystem (or parts of) shall be procured according to the requirements of ECSS-Q-20.

4.11.5.2 Equipment and components

a. All pyrotechnic devices are defined as critical items according to the definitions in ECSS-P-001 and shall be treated as configuration items.

b. The design, construction, quality and qualification testing shall conform to ECSS Standards.

c. The performance of each device shall be described in a specification document.

d. The elements of the subsystem as defined by the build standard at qualification shall not be changed without the agreement of the customer.

4.11.5.3 Lot definition

a. Pyrotechnic devices shall be procured in lots, according to ECSS-Q-70.

b. Each lot shall comprise a minimum number of items from the same production run conforming to the quality assurance requirements.

c. Each lot shall comprise enough items to cover the requirements for the complete test programme and the flight and flight spare hardware.

d. The number of items procured shall include the hardware for confirmation firing tests immediately prior to launch and contingencies for replacement.

4.11.5.4 Identification and marking

a. Colour coding for visual identification of the nature of the item according to GTPS/SPE/1 (document No. 1) should be used.

b. All elements used in the subsystem shall fulfil the requirements on traceability conforming with all requirements of ECSS-Q-20.

c. The identity of the manufacturer shall be shown.

d. The marking on the elements shall not be removable by the action of solvents or of the environmental conditions.

4.11.5.5 Workmanship

The workmanship requirements shall conform to ECSS-Q-20.

4.11.5.6 Responsibility for inspection and test

Unless otherwise specified the manufacturer is responsible for all inspections and tests required by the verification process. The customer shall reserve the right to witness any of these inspections and tests.

4.11.5.7 Logbook

The procurement requirements of ECSS-Q-70 shall apply to the logbook information accompanying each lot of parts.

4.11.6 Assembly, integration and testing

4.11.6.1 Overall

a. Assembly, integration and testing shall be according to the requirements of ECSS-Q-20.

b. Evidence of appropriate operator training and experience should be supplied to the customer.

c. All activities shall be inspected and registered in a documentary record.

d. Interfaces separated for test, replacement or any other reason shall be visually inspected for damage before reassembly. Damaged interfaces shall not be used.

e. Measurements shall be recorded as values. Statements such as “within specification” shall not be used.

4.11.6.2 Fired pyrotechnics hardware

All fired items are deliverable to the final customer, who shall determine where they shall be stored for later inspection and destructive physical analysis (DPA). All actuators and EEDs from lot acceptance tests, equipment and subsystem tests shall be included.

4.11.7 Qualification

4.11.7.1 General

Only qualified pyrotechnic devices shall be used.

4.11.7.2 Element qualification

a. Each element shall conform to the following requirements:
   1. the design has been frozen and placed under configuration control;
   2. the production process has been documented and is reproducible;
   3. the elements used for qualification have been assembled according to agreed procedures;
   4. the measurable properties have been recorded and are within the allowed tolerances;
   5. the required margins for the sensitive properties have been demonstrated by test under the working and environmental conditions of the application, over the duration of the defined lifetime;
   6. destructive physical analysis has shown correct function without any degradation to invalidate quantified properties;
   7. the manufacturing, inspection and test records are complete and up-to-date, with all nonconformances, deviations and waivers cleared.

b. The qualification testing shall be performed under the same configuration as to be flown. Any changes to design or manufacturing process invalidates any previous qualification.

c. In addition to prime function, qualification testing shall cover all failure mechanisms related to secondary properties, including sealing, contamination, integrity and redundancy.

d. Redundancy provisions shall be tested for resistance to failure caused by time separation of initiation, both active and passive, of the redundant items.

e. The previous qualification of any items submitted for qualification by similarity shall be demonstrated to meet the requirements defined in ECSS-Q-20. A compilation of individual test results or analyses on different aspects of different items shall not be adequate for qualification.

4.11.7.3 Interface qualification

a. All subsystem interfaces shall be qualified by testing.

b. The qualification of an interface is the demonstration that failures shall not be induced in the sensitive properties for the working and environmental conditions of the application, for the duration of the defined lifetime, extended to limits which include margins.

c. The qualification of pyrotechnic interfaces shall be subject to the approval of the space vehicle customer.

4.11.7.4 Subsystem qualification

a. Subsystem qualification shall be based upon
   1. subsystem design specification, and
   2. agreed qualification test plan.

b. Subsystem qualification shall be considered achieved when
   1. all elements in each chain have been qualified in their own right,
   2. all interfaces have been qualified,
   3. the subsystem has been assembled according to the agreed procedures,
   4. the agreed qualification test plan has been successfully completed,
   5. the measurable properties have been recorded and are within the allowed tolerances, and
   6. the manufacturing test and inspection records are complete and up-to-date, with all nonconformances, deviations and waivers cleared.

c. Testing shall conform to the requirements defined in ECSS-Q-20.

d. Only fully representative equipment shall be used for subsystem qualification testing.

4.11.7.5 Life

The capability of the subsystem to maintain its properties over the required lifetime shall be demonstrated by testing, supported by analyses and fully recorded in accessible form.

4.11.7.6 Post qualification activities

Only preplanned and approved activities shall be performed according to approved procedures.

4.11.8 Acceptance

4.11.8.1 General

a. Acceptance of pyrotechnics shall be in accordance with ECSS-Q-20

b. Acceptance of pyrotechnics relies upon two major areas: documentation and testing. No item without the required proof of pedigree shall be considered for acceptance however well it performs under testing. Pyrotechnic items submitted for acceptance testing shall have been produced by the same production process used for qualification.

c. Acceptance testing shall show that the items for flight are of the required standard and provide measurements of properties which can be compared with the results from the qualification tests. All elements and interfaces in the subsystem shall be demonstrated to meet the requirements for acceptance for flight use.

4.11.8.2 Element acceptance

a. Actuators and their incorporated EEDs, cartridges, detonators and charges are subject to specific lot acceptance test requirements.

b. Each element shall be considered ready for acceptance only when the following can be demonstrated to the satisfaction of the customer:
   1. each element is in accordance with the defined build standard and is demonstrably identical to the qualification items with the exception of changes agreed with the customer;
   2. each element has been assembled according to the agreed procedures;
   3. the measurable properties have been recorded and are within the allowed tolerances;
   4. the manufacturing and inspection records are complete and up-to-date, with all nonconformances, deviations and waivers cleared.

4.11.8.3 Interface acceptance

Interfaces shall be accepted only upon demonstration of the following:

a. all interfaces in each chain are qualified individually;
b. each interface is in accordance with the defined build standard and is demonstrably identical to the qualification items with the exception of changes agreed with the customer;
c. each interface has been assembled according to the agreed procedures;
d. the measurable properties have been recorded and are within the allowed tolerances;
e. the number of couplings and separations is within the allowable limit;
f. the manufacturing and inspection records are complete and up-to-date, with all waivers and discrepancies cleared.

4.11.8.4 Subsystem acceptance

The subsystem shall be accepted only upon demonstration of the following:

a. each chain in the subsystem has been qualified;
b. all elements in each chain have been accepted individually;
c. all interfaces in each chain have been accepted individually;
d. the subsystem has been assembled according to the agreed procedures;
e. the subsystem has no workmanship errors, physical defects or signs of damage;
f. the performance of the completely assembled subsystem, as measured by the subsystem acceptance tests, conforms to the space vehicle performance requirements;
g. the manufacturing test and inspection records are complete and up-to-date, with all waivers and discrepancies cleared.

4.11.8.5 Subsystem acceptance testing

a. Subsystem acceptance testing shall consist of the following minimum activities in the order shown:
   1. end-to-end prime and redundant chain inspection and mechanical check;
   2. end-to-end prime and redundant chain electrical continuity check;
   3. electrostatic discharge test;
   4. insulation resistance measurement;
   5. electromagnetic compatibility test;
   6. dynamic tests;
   7. end-to-end prime and redundant chain inspection and mechanical check;
   8. end-to-end prime and redundant chain electrical continuity check;
   9. thermal vacuum conditioning and firing test;
   10. check of documentary records that acceptance status has been achieved.
b. Only fully integrated chains shall be eligible for acceptance. Non-representative substitute items shall not be used for subsystem-level testing. Only equipment which is fully representative of the properties being checked shall be used.
c. If the individual tests are performed as part of the tests of the user subsystems, the procedures and records shall conform to the pyrotechnics requirements to be compiled as a coherent, stand-alone record.

4.11.9 Post acceptance activities

a. Acceptance status shall not be valid following any disconnection.

b. Disconnections shall only be performed according to procedures agreed in advance.

c. Acceptance status shall be re-established by repeating the tests to confirm subsystem properties. Full records shall be kept of all repeat tests.

4.11.10 Control of pyrotechnics hardware

a. All pyrotechnic devices shall be kept in controlled storage except when required for controlled spacecraft activities.

b. Residual items shall be treated according to customer requirements agreed in advance.

4.12 Deliverables

4.12.1 General

All products (hardware, software, models, documents) delivered during the course of a project shall be clearly specified at the beginning of a project.

4.12.2 Documentation

a. The documents required for the control of the subsystem shall include but not be limited to the documents listed in Table 1. Where applicable reference is provided to the document requirements definition (DRD) title and the DRD controlling standard.

b. The coverage, content and layout of these documents shall be as defined by the applicable DRD.

c. Although the documents do not differ from those applied to all other subsystems, a specific set shall be used for the subsystem to provide a comprehensive picture of all the pyrotechnic functions used. The particular nature of pyrotechnics shall emphasize the establishment of reliability by test and analysis and upon product assurance which shall provide the evidence of the history of the hardware used and the correctness of the procedures for its use.

Table 1: Document requirements for pyrotechnic subsystem

Document title	Controlling DRD reference
Definition file	-
Justification file	-
Configuration item data list	ECSS-M-40
Top assembly drawing or general assembly drawing	-
Drawing family tree	-
Interface control drawing	ECSS-E-10
Circuit functional diagram	-
Equipment or detail specification	-
Manufacturing and inspection flow chart	-
Product assurance plan	ECSS-Q-00
Declared materials list	ECSS-Q-70
Declared parts list	ECSS-Q-70

Table 1: Document requirements for pyrotechnic subsystem (continued)

Document title	Controlling DRD reference
Test plan	ECSS-E-10-02
Qualification test procedure	–
Acceptance test procedure	–
Performance test procedure	–
Reliability analysis	–
Failure modes: Effects and criticality analysis	ECSS-Q-30
Worst case analysis	ECSS-Q-30
Thermal analysis	–
Stress analysis	–
Any other relevant analysis	–
User manuals	ECSS-E-10
Storage transport and handling procedure	–
Pyrotechnics subsystem logbook	–
Qualification test report	–
Acceptance test report	–
Performance test report	–

4.13 Use of the standard to define project requirements

a. In general, all the requirements in this Standard are applicable to all users of pyrotechnics for space applications.

b. Some tailoring can be appropriate according to the type of application, e.g. launcher, manned spacecraft, unmanned spacecraft, experiment or instrument.

c. Tailoring shall depend upon the criticality requirements and the failure tolerance philosophy applicable for the particular use. Tailoring guidelines are defined in ECSS-M-00-02.

d. When tailoring, the context of the requirement shall be taken into account since the failure of an item can, in some circumstances, have little effect upon the overall mission, but in other circumstances can lead to catastrophic failure of the complete mission.

e. Tailoring to reduce cost shall be supported by risk assessment which identifies the effects of the cuts.

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Bibliography

The publications listed below were used in the preparation of this Standard, and contain background information relating to the subject addressed.

CNES IT-21-50 Issue 1 Rev 1 11/5/93	Conception des Sous-Systèmes Pyrotechniques
DOD-E-83578A (USAF) 4 Sep 1992	General Specification for Explosive Ordonance for Space Vehicles
GTPS/SPE/1 July 1976	Codification des couleurs pour composants et systèmes pyrotechniques (Coding of colours for pyrotechnic components and systems)

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ECSS Document Improvement Proposal

1. Document I.D.	2. Document date	3. Document title
ECSS-E-30 Part 6A	25 April 2000	Mechanical — Part 6: Pyrotechnics

4. Recommended improvement (identify clauses, subclauses and include modified text or graphic, attach pages as necessary)

5. Reason for recommendation

6. Originator of recommendation

Name:	Organization:	
Address:	Phone: Fax: e-mail:	**7. Date of submission:**

8. Send to ECSS Secretariat

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Note: The originator of the submission should complete items 4, 5, 6 and 7.

This form is available as a Word and Wordperfect-Template on internet under
http://www.estec.esa.nl/ecss/improve/

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