



Space engineering

Solid propulsion for spacecrafts and launchers

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Noordwijk, The Netherlands**

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 without rewriting the standards.

This Standard has been prepared by the ECSS-E-ST-35-02 Working Group, reviewed by the ECSS Executive Secretariat and approved by the ECSS Technical Authority.

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Change log

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Table of contents

| | |
|--|-----------|
| Change log | 3 |
| Introduction | 6 |
| 1 Scope | 7 |
| 2 Normative references | 8 |
| 3 Terms, definition and abbreviated terms | 9 |
| 3.1 Terms from other standards | 9 |
| 3.2 Terms and definition specific to this document..... | 9 |
| 3.3 Acronyms | 10 |
| 4 Solid propulsion engineering activities | 11 |
| 4.1 Overview | 11 |
| 4.2 Development | 11 |
| 4.3 Spacecraft and launch vehicle Interfaces..... | 12 |
| 4.3.1 General interfaces | 12 |
| 4.3.2 Induced and environmental temperature..... | 13 |
| 4.3.3 The operating range of the motor can require a thermal control system | 13 |
| 4.3.4 General environment..... | 13 |
| 4.3.5 Special constraints | 13 |
| 4.4 Design at propulsion system level..... | 14 |
| 4.4.1 Propulsion system selection and design process..... | 14 |
| 4.4.2 Global performance | 15 |
| 4.4.3 Transient phases: ignition transient..... | 16 |
| 4.5 Solid rocket motor Components | 16 |
| 4.5.1 Constraints | 16 |
| 4.5.2 MEOP | 16 |
| 4.5.3 Material selection..... | 17 |
| 4.5.4 Motor case..... | 17 |
| 4.5.5 Thermal insulation | 17 |
| 4.5.6 Propellant grain | 18 |

| | | |
|---|--|-------------------------------------|
| 4.5.7 | Nozzle assembly | 19 |
| 4.5.8 | Igniter..... | 20 |
| 4.6 | Thrust vector control (TVC) | 21 |
| 4.7 | Ground support equipment (GSE)..... | 21 |
| 4.8 | Verification..... | 21 |
| 4.8.1 | Verification by analysis | 21 |
| 4.8.2 | Verification by test | 21 |
| 4.9 | Production and Manufacturing | 27 |
| 4.10 | In-service | 27 |
| 4.10.1 | General..... | 27 |
| 4.10.2 | In flight operations | 27 |
| 4.11 | Deliverables..... | Error! Bookmark not defined. |
| 4.12 | Dimensioning methodology for visco elastic or non linear behaviour materials | 28 |
| 4.12.1 | General..... | 28 |
| 4.12.2 | Procedure | 28 |
| Annex A (informative) Definition for transient phases : ignition and tail off..... | | 30 |
| A.1 | Overview | 30 |
| A.2 | Motor Ignition transient..... | 30 |
| Bibliography..... | | 32 |
| | | |
| Figures | | |
| Figure 4-1: Design methodology for materials with non linear behaviour | | 29 |
| | | |
| Tables | | |
| Table 4-1: Coefficient values..... | | 18 |
| Table 4-2: Test on solid propulsion systems, subsystems and components | | 23 |
| Table 4-3: List of deliverables | | Error! Bookmark not defined. |

Introduction

The requirements in this Standard ECSS-E-ST-35-02C Draft 3 (and in the 3 other space propulsion standards ECSS-E-ST-35, ECSS-E-ST-35-01 and ECSS-E-ST-35-03) are organized with a typical structure as follows:

- functional;
- constraints;
- interfaces;
- design;
- GSE;
- materials;
- verification;
- production and manufacturing;
- in-service (operation and disposal);
- deliverables.

This standard is part of ECSS-E-ST-35 as per the following Propulsion standards structure;

ECSS-E-ST-35: Propulsion general requirements

- ECSS-E-ST-35-01 Liquid and electric propulsion for spacecrafts
- ECSS-E-ST-35-02 Solid propulsion for spacecrafts and launchers
- ECSS-E-ST-35-03 Liquid propulsion for launchers.

All the normative references, terms, definitions, abbreviated terms, symbols and DRD of the 4 standards ECSS-E-ST-35, ECSS-E-ST-35-01, ECSS-E-ST-35-02 and ECSS-E-ST-35-03 are collected in this ECSS-E-35 standard

1 Scope

General requirements applying to all type of Propulsion Systems Engineering are defined in ECSS-E-ST-35, which is part of the mechanical discipline.

This Standard defines the regulatory aspects that apply to the elements and processes of solid propulsion for launch vehicles and spacecraft. It specifies the specific activities to be performed in the engineering of this propulsion systems and their applicability. It defines the requirement for the engineering aspects such as functional, physical, environmental, quality factors, operational and verification.

This standard may be tailored for the specific characteristics and constraints of a space project in conformance with ECSS-S-ST-00.

2

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 revision 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 more recent editions of the normative documents indicated below. For undated references, the latest edition of the publication referred to applies.

| | |
|------------------|---|
| ECSS-E-ST-35 | Space engineering – Propulsion – general Requirements |
| ECSS-S-ST-00-01 | ECSS System – Glossary of terms |
| ECSS-E-ST-20 | Space engineering – Electrical and electronic general requirements |
| ECSS-E- ST-32 | Space engineering – Structural general requirements |
| ECSS-E- ST-32-01 | Space engineering – Fracture control |
| ECSS-E- ST-32-02 | Space engineering – Structural design and verification of pressurised H/W |
| ECSS-E- ST-32-10 | Space engineering – Factors of safety |
| ECSS-E- ST-33-01 | Space engineering – Mechanisms |
| ECSS-E- ST-33-11 | Space engineering – Explosive Systems and Devices |
| ECSS-E- ST-35-01 | Space engineering – Liquid and Electric Propulsion for Spacecraft |
| ECSS-E- ST-35-02 | Space engineering – Solid Propulsion for Spacecraft and launchers |
| ECSS-E- ST-35-03 | Space engineering – Liquid Propulsion for launchers |
| ECSS-Q- ST-30-02 | Space product assurance – Failure modes, effects and criticality analysis (FMECA) |

3

Terms, definition and abbreviated terms

3.1 Terms from other standards

For the purpose of this Standard, the terms and definitions from ECSS-S-ST-00-01, ECSS-E-ST-35, ECSS-E-ST-32, ECSS-E-ST-32-10 apply, in particular for the following terms:

ablated thickness (ea)

burning time

charred thickness (ec)

ignition time (tign)

Insulation thickness (ei)

non affected thickness (es)

pre-heating time

pyrogen igniter

pyrotechnic igniter

required factor (Kr)

solid rocket motor

termination point

triple point

thrust centroid time

corridor

Hump effect

design allowable (DA)(see ECSS-E-ST-E32)

KQ test factor for qualification(see ECSS-E-ST-32-10)

KA test factor for acceptance (see ECSS-E-ST-E32 10)

3.2 Terms and definition specific to this document

3.2.1 design criteria

criteria used to reduce a complex structural solicitation state to an equivalent one dimensional stress (or strain) for materials with non linear behaviour

NOTE mathematically called “DC”

NOTE This criteria, determined by tests is a combination of stress (or strain) components.

3.2.2 safety factor for non linear material

ratio between design allowable and design criteria for materials with non linear behaviour

NOTE Mathematically called “Knl”

3.3 Acronyms

For the purpose of this Standard, the abbreviated terms from ECSS-S-ST-00-01 and the following apply:

| Abbreviation | Meaning |
|---------------------|-------------------------------------|
| TVC : | Thrust Vector Control |
| NDI : | Non Destructive Inspection |
| SRM : | Solid Rocket Motor |
| OBDH : | On Board Data Handling |
| TMTC : | Telemetry – Telecommand |
| AIV : | Assembly, Integration, Verification |
| ESD : | Electrostatic Discharge |
| EMI : | Electromagnetic Interferences |
| GSE : | Ground Support Equipment |
| COM : | Center of Mass |
| MCI : | Mass, Center of mass, Inertia |
| COG : | Center of Gravity |
| MEOP : | Maximum Expected Operating Pressure |
| DLAT : | Destructive Lot Acceptance Test |
| TBPM : | to be provided by manufacturer |
| TBPU : | to be provided by user |

4

Solid propulsion engineering activities

4.1 Overview

A solid propulsion system comprises the following main subsystems.

- The gas generating system consisting of a solid propellant contained in a thermally protected case
- A nozzle with or without TVC.
- An ignition system to ignite the solid propellant.

This document applies to large and small systems; the latter usually have some different requirements to the large systems.

The requirements for the design, verification and constraints for ignition chains are defined in ECSS-E-ST-33-11C

Compared to other propulsion systems, the large solid propulsion is characterised by an acceptance done only by NDI and samples tests (no acceptance firing, one shot-item)

As firing tests cannot be performed on the actual flight motor, the development of solid propulsion systems is performed in such a way that it results in a very well designed and well reproducible product.

NOTE 1 Some solid propulsion systems use hot gas valves, for thrust or pressure modulation. The requirements applicable to these systems will be defined later (not taken into account in the present document)

NOTE 2 For SRM with TVC, only moveable nozzle with flexseal are addressed.

4.2 Development

- a. ECSS-E-ST-35 Clause 4.3 (Development) shall apply
- b. During the development phase the following objectives shall be completed to arrive at establish, justify, and freeze the design of the solid propulsion system by doing the following
 1. the sizing process to be executed;
 2. verification models to be established,
 3. mathematical modelling to be implemented and provided.

4. validation and verification tests to be performed.
- c. A FMECA shall be performed according to ECSS-Q-ST-30-02.
 - NOTE 1 The development program strongly depends on the size, the level of applied technology, specific requirements and intended use of the propulsion system.
 - NOTE 2 The testing, analyses and experience identify the possible failure modes.
- d. All unacceptable failure modes shall be avoided by design.
- e. The propulsion system shall be verified by analysis or testing.
- f. If knowledge of given margins is required by the customer, this knowledge shall be determined either by analyses or tests.
 - NOTE The customer provides the list of margins to be accurately determined

4.3 Spacecraft and launch vehicle Interfaces

4.3.1 General interfaces

- a. All the following interfaces shall conform to the propulsion system requirements during the whole life of the system or subsystems:
 1. Other stages of the launcher.
 2. The launcher or spacecraft spaceonics.
 3. Stage or spacecraft components:
 - (a) skirts;
 - (b) spaceonics (including hardware, OBDH, TM/TC, wiring and tunnels);
 - (c) separation devices;
 - (d) TVC;
 - (e) stage or spacecraft thermal protection;
 - (f) contamination (e.g. plume effects);
 - (g) termination and destruction devices;
 - (h) environmental protection devices (e.g. rain, dust, and Sun).
 4. The nature of the interfaces, i.e.:
 - (a) geometry, including the analysis of the dimensions for all phases of life (e.g. assembly or AIV, transport, integration on the spacecraft and flight);
 - (b) mechanical, including induced loads, static and dynamic;
 - (c) thermal, including thermal fluxes;

- (d) electrical, including ensuring continuity, ESD and EMI;
- (e) materials, including ensuring compatibility

NOTE Refer to ECSS-E-ST-32-08.

- 5. Interfaces with GSE and transport, including:
 - (a) definition of interfaces for launcher or spacecraft GSE and transport, with the launch authorities for safety;
 - (b) capability for the electrical grounding of the systems and subsystems.

4.3.2 Induced and environmental temperature

- a. The temperature range during the mission shall be specified.
- b. The number and amplitude of the temperature variations (thermal cycling) during the motor life shall be specified

NOTE E.g. motors which have a long in-orbit life before being operated.

4.3.3 The operating range of the motor can require a thermal control system

4.3.4 General environment

- a. The motor shall comply with the specified and its self-induced loads (thermal, dynamic) environment.
- b. Measurement and control devices shall be protected against specified and self-induced adverse effects.

4.3.5 Special constraints

4.3.5.1 Oscillatory combustion

- a. Vibration levels resulting from oscillatory combustion shall be specified at system and subsystem level.
- b. Vibration levels resulting from oscillatory combustion shall be characterised

4.3.5.2 Thrust centroid time

- a. For solid thrusters that provide thrust impulsion, the thrust centroid time shall be characterized.

NOTE Examples of solid thrusters: separation or braking rockets, control systems

4.3.5.3 Ballistics: acoustics

- a. The noise generated by the motor shall be characterised

4.4 Design at propulsion system level

4.4.1 Propulsion system selection and design process

4.4.1.1 General

- a. All components of a solid rocket motor shall:
 1. demonstrate compatibility with materials, propellants and fluids;
 2. be selected assessing safety, economics, reliability and environmental considerations and restrictions

NOTE E.g. debris, pollution.

- b. The causes for potential dispersions shall be analysed in the project phases A and B.

NOTE reproducibility requirements are provided by the customer

- c. For PDR the following characteristics shall be provided :
 1. the mass and COM of the propulsion system;
 2. performance;
 3. type of ignition system;
 4. nozzle structure and configuration (e.g. thrust orientation);
 5. propellant type.

NOTE If the requirements given by customer cannot be met, (including. target cost and industrial feasibility) either:

- the requirements are re-considered,
- the system or subsystem design modified, or
- the manufacturing and control processes modified (see ECSS-E-ST-10).

- d. For PDR the technological choices of the design shall be performed, justified, and documented, assessing the mission requirements, interface with other systems or subsystems, lifetime, safety, availability, manufacturing process, performance, cost and environmental considerations and restrictions (e.g. pollution).

4.4.1.2 Material selection

- a. As thermal protection materials, propellants and liner-primer materials often contain liquids to adjust their properties; they shall be selected to

ensure that, during the mission, the migration of these liquids does not change the properties of any material (mechanical, thermal, ballistic) or their bonding in an unacceptable way.

4.4.1.3 Electrical

- a. The propulsion system shall have electrical continuity, including grounding.

4.4.1.4 Thrust orientation

- a. The propulsion system shall provide TVC or a thrust in a fixed orientation (with respect to the launcher or spacecraft) according to the system requirements.

4.4.1.5 Contamination

- a. The motor shall be protected against external contaminants (including moisture) which can enter the motor.

4.4.1.6 Detonation risk

- a. It shall be demonstrated that failures in the motor during the mission profile shall not lead to detonation.

4.4.1.7 Testing

- a. The motor shall be in a state to undergo static test firing.

4.4.1.8 Electrical bonding

- a. Electrical bonding between all SRM components shall be ensured in compliance with ECSS-E-ST-20 clause .3.8).

4.4.1.9 Interfaces and connections

- a. The design of mechanical assemblies under gas pressure loads (e.g. case-igniter, case-nozzle connections) shall insure a closure of the gaps under these loads.

4.4.1.10 Adhesive Bonding

- a. It shall be ensured that if a bonded connection fails under loads the rupture shall not be adhesive.
- b. For adhesive bonding mechanical dimensioning clause 4.11 shall be applied.

4.4.2 Global performance

- a. ECSS-E-ST-35 clause 4.5.2 (Global Performance) shall apply

- b. The SRM characteristics reported in accordance with report AR-P (ECSS-E-ST-35 Annex B) or report MM-PA (ECSS-E-ST-35 Annex J) which are necessary for system analysis shall be defined by customer
- c. If the necessary characteristics are not defined by customer, the functional characteristics of the propulsion system, listed here after, shall be determined and reported in report AR-P (ECSS-E-ST-35 Annex B) (nominal value, uncertainties and dispersions in the specified operational conditions)
 - 1. Ejected mass flow rate (propellant and inert mass), vacuum thrust vs time, including during tail-off
 - 2. non ejected alumina mass vs time
 - 3. MCI (mass, COG, inertia,) vs time
 - 4. Thrust centroid time
 - 5. Motor dynamic behavior
 - 6. Pressure and thrust oscillations
 - 7. Plume effects
 - 8. Interfaces with TVC
 - 9. Thrust imbalance for two motors functioning both (including ignition and tail off)

4.4.3 Transient phases: ignition transient

- a. The percentage of the theoretical pressure defining t_{ign} shall be defined in the motor or system specification.

NOTE Transient phase definitions are presented in Annex A
- b. The pressure and mass flow rate corridor shall be defined in the motor specifications
- c. The operating time of the igniter shall exceed the ignition time t_{ign} .

4.5 Solid rocket motor Components

4.5.1 Constraints

- a. The design and dimensioning of the SRM and the components shall be compliant with the manufacturing capabilities (available facilities and process, reproducibility)
- b. The design and dimensioning of the SRM and the components shall be compliant with the reliability requirements

4.5.2 MEOP

- a. The maximum expected operating pressure (MEOP) shall:

1. be determined at the maximum expected burning rate according to the conditions of operational envelope;
2. be determined by including the expected nominal pressure deviation ($n \times s$), n being a real number determined by the supplier in accordance with the reliability allocation, and s the pressure standard deviation

NOTE the SRM reliability specification is reallocated by the supplier to each component

4.5.3 Material selection

- a. ECSS-E-ST-35 clause 4.7 shall be applied

4.5.4 Motor case

- a. For the dimensioning of all parts, except elastomeric junctions, ECSS-E-ST-32-10 shall be applied on MEOP and external loads

NOTE External loads include the thermal and mechanical loads during propellant casting and curing

- b. For elastomeric junctions, the methodology presented in 4.11 shall be applied.
- c. During the development phase, it shall be verified that the MEOP used for mechanical design is lower than the one determined by calculation of the internal ballistics of the motor
- d. The axial evolution of pressure in the bore shall be determined to establish a local MEOP.
- e. Elements that are connected to the case (e.g. skirts, mounting parts and interface connectors) shall be dimensioned by cumulating the forces due to internal pressure and other forces such as external loads, inertial forces and local loads.
- f. The dimensioning of the motor case shall be performed including the effect of thermal mechanical loads and the thermal effects on the material characteristics.

4.5.5 Thermal insulation

4.5.5.1 Thermal Dimensioning

- a. The temperature of the interface between the thermal protection and the case shall be defined and justified
- b. Worst case conditions for thermal dimensioning between flight and ground tests shall be determined and applied
- c. The temperature of the interface between the thermal protection and the propellant shall be defined and justified such that the propellant

combustion rate increase remains consistent with SRM reliability requirements (e.g. thrust, combustion time, safety)

- d. To design the thermal insulation thickness, e , the coefficients of Table 4-1 shall be used and the following formula met

$$e \geq K_p \times K_a \times e_a + K_c \times e_c + K_i \times e_i$$

Where:

K_p : factor project

NOTE See ECCS E-ST-32-10C clause 3.1.4

K_a : ablation coefficient

K_c : char coefficient

K_i : isolation coefficient

NOTE K_p is applied only on e_a due to uncertainty on ablation phenomena:

Table 4-1: Coefficient values

| | Ka | Kc | Ki |
|----------------------|-----------|-----------|-----------|
| Spacecraft | 1,3 | 1,25 | 1 |
| Launcher | 1,3 | 1,25 | 1 |
| Man rated S/C | 1,7 | 1,25 | 1 |

- e. Dimensioning shall be done with the combustion duration at the lower temperature of the operational envelope, including the expected combustion duration deviation ($n \times .s$), n being a real number determined by the supplier in accordance with the reliability allocation
- f. Radiative and conductive thermal loads during pre-heating time shall be determined and used for the dimensioning of the floater and inhibitor areas.

4.5.5.2 Mechanical Dimensioning

- a. After having dimensioned the thermal protection on thermal loads and ablation, it shall be verified that the dimensioning satisfies the mechanical requirements (i.e. expansion-contraction and transfer of loads, ageing effect.) during the whole mission.
- b. For mechanical dimensioning, the methodology presented in 4.11. shall be applied.

4.5.6 Propellant grain

4.5.6.1 Ballistics: dimensioning

- a. For the ballistic dimensioning of the propellant grain, the pressure and mass flow rate histories shall be determined, in conformance with the

- system and subsystem requirements, according to the throat design (i.e. dimensions and erosion).
- b. The pressure and mass flow rate time histories shall be calculated including
 1. the range of the driving parameters
 - (a) propellant burning rate
 - (b) combustion efficiency
 - (c) throat erosion
 - (d) scale factor
 - (e) propellant temperature
 - (f) hump effect
 2. uncertainties
 3. scattering.
 - c. The dependence of the burning rate on pressure and temperature, including dispersions shall be determined by tests.

4.5.6.2 Ballistics: reproducibility

- a. To assess the effect of all dispersions the variations due to ingredients and manufacturing processes shall be determined during the development

4.5.6.3 Mechanical dimensioning

- a. Based on external and internal applied loads, the dimensioning load has to be determined and considered for the grain mechanical dimensioning.
- b. Stress concentrations and ageing of material shall be determined and used for mechanical dimensioning
- c. For mechanical dimensioning, the methodology presented in 4.11 shall be applied.

4.5.7 Nozzle assembly

4.5.7.1 Overview

The following types of material can be used for the nozzle components:

- High temperature materials in contact with combustion products (e.g. pyrolytic graphite, carbon-carbon and refractory metals).
- Ablative materials in contact with combustion products (e.g. carbon-phenolic and silica-phenolic).
- Insulating materials used as a sub-layer for insulation purposes (e.g. carbon-phenolic and silica-phenolic).

4.5.7.2 Fixed housing

- a. For the fixed housing structure, dimensioning shall be done using :

1. combined loads including pressure, thrust, TVC reaction forces, in accordance with ECSS-E-ST-32 clause 4.2.6
 2. boundary conditions
- b. Factors of safety specified in ECSS-E ST-32-10 clauses 4.3 and 4.4 shall apply for dimensioning the fixed housing.

4.5.7.3 Flexible bearing

- a. The flexible bearing should operate under compression.
- b. For dimensioning of elastomer pads, the methodology presented in 4.11 shall be applied.
- c. For dimensioning of other structural parts ECSS-E-ST-32-10 clauses 4.3 and 4.4 shall apply
- d. The gimbaling stiffness vs pressure shall be determined by modelling or testing to guarantee a positive torque, for the whole mission profile

4.5.7.4 Nozzle thermal protection: thermal design, sizing and dimensioning

- a. The temperature of the interface between the thermal protection components themselves and at structural part interface shall be defined and justified
- b. To design the thickness [e] of thermal material, clauses 4.5.5.1d and 4.5.5.1e shall be applied.

4.5.7.5 Nozzle thermal protection: thermomechanical sizing and dimensioning

- a. For thermomechanical dimensioning of thermal protection components the methodology presented in 4.11 shall be applied.

4.5.7.6 The nozzle housing (structural)

- a. Nozzle housing stiffness and strength shall conform to the system and subsystem requirements.
- b. For dimensioning ECSS-E-ST-32-10 clauses 4.3 and 4.4 shall apply.

4.5.8 Igniter

4.5.8.1 Overview

For explosive devices and non-explosive components fitted to the igniter (initiators, Safe and Arm device), and for pyrotechnic igniter, ECSS-E-ST-33-11 applies.

The igniter consists of:

- An initiation system (one or more initiators)
- A pyrotechnic igniter,

- A pyrogen igniter

The initiator ignites a pyrotechnic igniter (pyrotechnic mixture), which in turn, ignites the pyrogen igniter which resembles a small solid rocket motor and then ignites the main propellant grain.

NOTE For some motors, depending on propellant mass, there is no pyrogen igniter

4.5.8.2 General

- The igniter shall have the functionality to be dismantled, completely or partly for safety constraints.
- The igniter shall be in a state to undergo static test firing independent of the motor.
- The igniter shall not degrade the functioning of the motor.

NOTE The risk is increased with the consumable igniters

4.5.8.3 Dimensioning

- For the design and dimensioning of the igniter clauses 4.5.1 to 4.5.7 shall be applied

4.6 Thrust vector control (TVC)

- For thrust vector control, ECSS-ST-E-35 clause 4.4.8. shall be applied.

4.7 Ground support equipment (GSE)

- ECSS-E-ST-35 clause 4.5 shall apply
- Due to explosive environment, groundings shall be ensured

4.8 Verification

4.8.1 Verification by analysis

- For requirements on verification by analysis of solid propulsion systems for launchers and spacecraft, ECSS-E-ST-35 clause 4.7.1 shall apply

4.8.2 Verification by test

- ECSS-E-ST-35 clause 4.7.3 shall apply
- Verification by test shall be performed on components, subsystems and systems of solid propulsion systems as specified in column 4 (required for qualification) of Table 4-2.

- c. Verification by test should be performed on components, subsystems and systems of solid propulsion systems as specified in column 5 (optional for qualification) of Table 4-2.

Table 4-2: Test on solid propulsion systems, subsystems and components

| ID | Category | Item | Required for qualification | Optional for qualification | Required for Acceptance | Optional for acceptance | |
|-----|--------------------|---|--|---|---|---|--|
| c | Materials | Raw materials for propellant | NDI and chemical analysis Safety tests | | NDI and chemical analysis | | |
| d.1 | Parts & Components | Nozzle flexible bearing | -Dynamic and static characterization test -Ageing behaviour tests -Characterization tests under pressure $p = KQ * MEOP$ and TBPM gimbaling | | Proof pressure test under pressure $p = KA * MEOP$ and TBPM gimbaling | | |
| d2 | | Nozzle fixed housing | Characterization tests under pressure $p = KQ * MEOP$ and TBPM gimbaling | | Proof pressure test under pressure $p = KA * MEOP$ | | |
| d3 | | Nozzle housing part (structural) | Characterization tests of stiffness without and with thermal protection | | NDI | | |
| d4 | | Other specially manufactured components | | Characterization tests as agreed with customer , NDI , DLAT | | NDI, DLAT as agreed with the customer | |
| d5 | | Case | NDI Characterization tests of the case with a KQ factor on external loads with and without MEOP Characterization test of the case under pressure $p > KQ * MEOP$ or up to burst pressure | | | NDI Proof pressure test under pressure $p > KA * MEOP$ | Proof test of the case with a KA factor on external loads with or without MEOP |

| ID | Category | Item | Required for qualification | Optional for qualification | Required for Acceptance | Optional for acceptance |
|----|------------|---|---|--|--|---|
| e1 | Subsystems | Thermal protection (internal, together with the case) | -NDI and characterisation tests of thermal, mechanical, adhesive bonding, and ablative properties - Ageing tests - Motor post-firing inspection | | - Characterisation tests on representative bond samples | Verification of leak-tightness when integrated with the case (if a leakage rate is specific for the thermal protection) |
| e2 | | Thermal protection (external) | -NDI and characterisation tests of thermal, mechanical, adhesive bonding, and ablative properties -Ageing tests - Motor post-firing inspection | | Characterisation tests on representative bond samples | |
| e3 | | Grain (applicable also to pyrogen grain) | -Propellant characterization tests of ballistic, mechanical, safety, adhesive bonding properties -Ageing tests -NDI -Firing tests at motor level to characterise the behaviour of the grain-at one or more TBPM points of the qualification envelope | Vibration and thermal cycling tests at loaded case level (To be proposed by supplier and agreed by customer) | -Mechanical characterisation tests for every propellant batch - Ballistic characterisation for every propellant batch -Bond characterisation for every propellant batch - NDI | |

| ID | Category | Item | Required for qualification | Optional for qualification | Required for Acceptance | Optional for acceptance |
|----|----------|-----------------------------|--|----------------------------|---|-------------------------|
| e4 | | Nozzle and actuation system | -NDI , measurements of mass, dimensions, stiffness, deflection of movable nozzle -Burst pressure test of nozzle closure disk -Leak test - At motor level: Firing test Analysis of the results including thermo-mechanical behaviour and deflection torque Post-firing inspection including erosion | | NDI Measurement of deflection torque -Leak test | |
| e5 | | Pyrogen igniter | -NDI including measurement of mass, dimensions, leak rate, electrical bonding resistance -Characterization test of the igniter case under pressure $p = KQ^*$ (igniter MEOP) -Vibration Mechanical and thermal environment tests -Firing tests of the igniter - SRM Post firing inspection - SRM tests results analysis of the ignition phase | | Proof test NDI | |

| ID | Category | Item | Required for qualification | Optional for qualification | Required for Acceptance | Optional for acceptance |
|----|----------|-------|--|--|---|--|
| d | Systems | Motor | -NDI including measurement of mass, dimensions, interfaces, leak rate, electrical bonding resistances -TVC tests (for motor with moveable nozzles) -Ground Firing tests (with TVC for motor with moveable nozzles) to characterise the behaviour of the motor for one or more TBPM points of the qualification envelope - SRM Post firing inspection - SRM tests results analysis | Safety tests, if specified by customer or proposed by the supplier and agreed by the customer Environmental tests if specified by customer or proposed by the supplier and agreed by the customer | NDI including measurement of mass, dimensions, interfaces, leak rate, electrical bonding resistances TVC tests (for motor with moveable nozzles) | For series produced motors, DLAT if specified by customer or proposed by the supplier and agreed by the customer |

4.9 Production and Manufacturing

- a. General ECSS-E-ST-35 clause 4.9 (Production and manufacturing) shall apply
- b. Column 6 (required for acceptance) in Table 4-2 shall apply
- c. Column 7 (optional for acceptance) in Table 4-2 should apply

4.10 In-service

4.10.1 General

- a. ECSS-E-ST-35 clause 4.9 shall apply

4.10.2 In flight operations

4.10.2.1 Control of an upper stage propulsion system during the operation of a lower stage propulsion system

- a. During the operation of a lower stage propulsion system, the propulsion system of the next stage to be activated shall
 1. be maintained in the condition for ignition, or
 2. be brought into the condition for ignition..

NOTE E.g. arming sequence, thermal control, nozzle actuation, TVC on

4.10.2.2 In-flight measurements for SRM

- a. The measurements needs shall be identified and agreed between customer and supplier at the beginning of development
- b. The design of the measurement system and the SRM shall be compliant with these needs
- c. The chamber pressure should be measured during flight.
- d. The propulsion system should be such that the following measurements can be carried out during the flight:
 1. In general:
 - (a) pressure in the igniter;
 - (b) accelerations and vibrations;
 - (c) temperatures at critical positions;
 - (d) deformations.
 2. In addition, for TVC with a movable nozzle:

- (a) the nozzle position;
- (b) the force in the nozzle actuation brackets.

4.11 Dimensioning methodology for visco elastic or non linear behaviour materials

4.11.1 General

- a. For components using visco elastic or non linear behavior materials, a Stress-Strength analysis shall be used for mechanical dimensioning.

NOTE 1 E.g case thermal protection, adhesive bonding, propellant grain, nozzle thermal protection and throat component and flexseal elastomer, case elastomeric junction

4.11.2 Procedure

- a. The following procedure (depicted in Figure 4-1) shall apply :
 1. determine combined loads, according to ECSS-E-ST-32 clause 4.2.6
 2. Determine and justify material behaviour model and failure criteria by samples tests
 3. Justify that the calculation method is compliant with the material behaviour (used assumptions deduced from samples tests results)
 4. Validate the calculation method by tests results
 5. Determine the design allowable (DA) by tests
 6. Design allowable definition is given in ECSS-E-ST-32 clause 3.1.7
 7. Determine ageing effect on material behaviour and design allowable
 8. Calculate DC
 9. Calculate $K_{nl} = DA/DC$
 10. Check that the coefficient K_{nl} is greater than $K_r \times K_p$

NOTE the project factor K_p , which definition is given in ECSS-ST-32-10, is specified by the project manager

NOTE the design or the requirements are modified until $K_{nl} > K_r \times K_p$

- b. The methodology for determining K_r shall be approved by the customer

NOTE K_r can be determined in reference to a probabilistic approach (reliability requirements) or by deterministic one (FOSU).

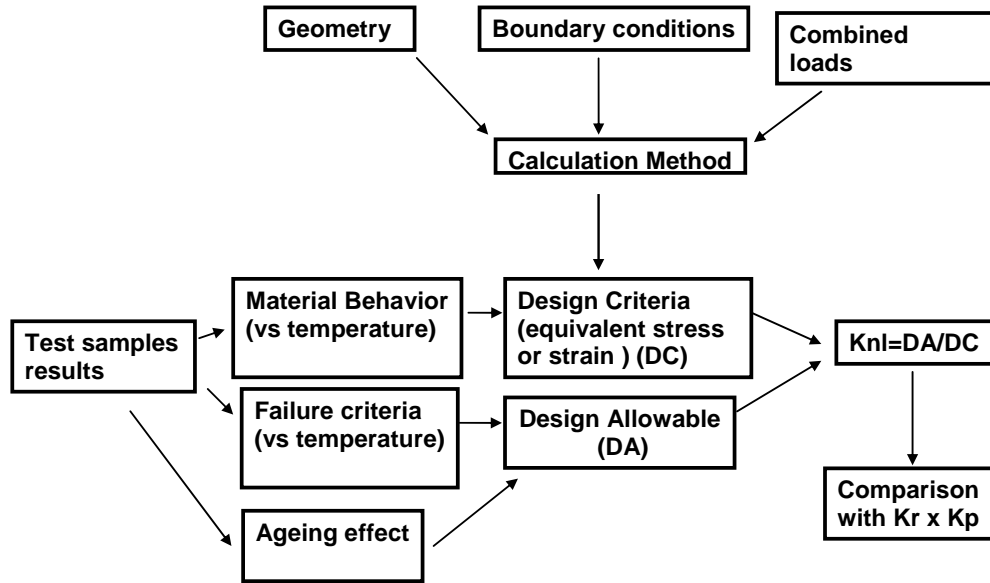


Figure 4-1: Design methodology for materials with non linear behaviour

Annex A (informative)

Definition for transient phases : ignition and tail off

A.1 Overview

Three main phases shall be considered during SRM operation (see figure A-1)

- Ignition : the main grain is ignited by hot gases provided by the igniter, and the pressure is increasing until steady pressure
- Quasi-steady phase : pressure and thrust variation are low
- Tail-off phase : end of grain combustion (and extinction)

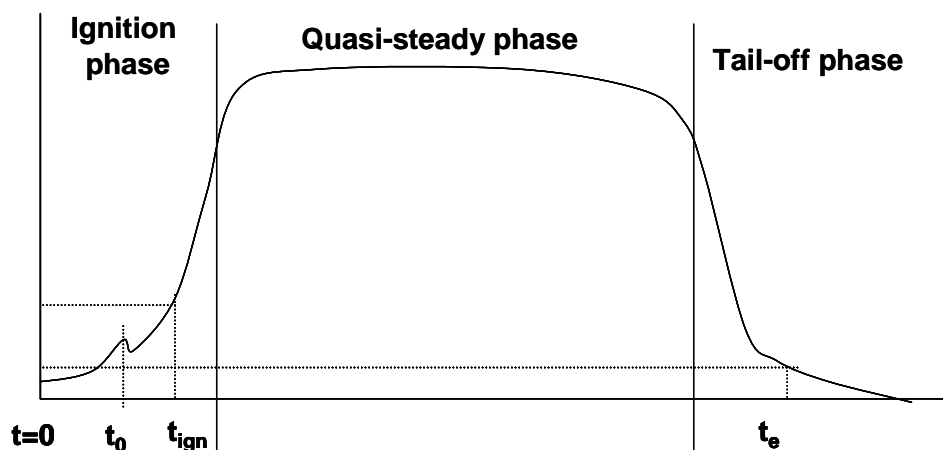


Figure A-1: Phases during SRM operation

A.2 Motor Ignition transient

This phase occurs from the moment at which the ignition signal arrives at the ignition system ($t=0$) until the moment when the chamber pressure reaches a given level (generally 80 to 90 % of the theoretical steady pressure corresponding to the combustion of the main grain only).

Two characteristic times are defined:

- t_0 : time at which the SRM delivers an effective thrust (closure burst time if a nozzle closure is used)

t_{ign} : ignition time, i.e. the time at which the motor pressure has reached a certain percentage of the theoretical pressure corresponding to the combustion of the main grain only (explicitly excluding the igniter peak).

Bibliography
