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Space engineering

Solid propulsion for spacecrafts and launchers

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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 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.

Disclaimer

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Introduction

The requirements in this Standard ECSS-E-ST-35-02C (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;
- development;
- interfaces;
- design;
- GSE;
- materials;
- verification;
- production and manufacturing;
- in-service (operation and disposal);
- deliverables.

This standard forms parts of ECSS-E-ST-35 series which has the following structure;

- ECSS-E-ST-35 Propulsion general requirements
- ECSS-E-ST-35-01 Liquid and electric propulsion for spacecraft
- ECSS-E-ST-35-02 Solid propulsion for spacecraft and launchers
- ECSS-E-ST-35-03 Liquid propulsion for launchers
- ECSS-E-ST-35-06 Cleanliness requirements for spacecrafts propulsion hardware
- ECSS-E-ST-35-10 Compatibility testing for liquid propulsion components, subsystems, and systems

ECSS-E-ST-35 contains all the normative references, terms, definitions, abbreviated terms, symbols and DRD that are applicable for ECSS-E-ST-35, ECSS-E-ST-35-01, ECSS-E-ST-35-02 and ECSS-E-ST-35-03.

1
Scope

General requirements applying to all type of Propulsion Systems Engineering are defined in ECSS-E-ST-35. For solid propulsion activities within a space project the standards ECSS-E-ST-35 and ECSS-E-ST-35-02 are applied together.

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

NOTE 1 Some solid propulsion systems use hot gas valves, for thrust or pressure modulation. The requirements applicable to these systems are not covered by the present document.

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

This standard may be tailored for the specific characteristic and constrains 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-S-ST-00-01	ECSS System- Glossary of terms
ECSS-E-ST-20	Space engineering - Electrical and electronic
ECSS-E-ST-20-07	Space engineering - Electromagnetic compatibility
ECSS-E-ST-32	Space engineering - Structural general requirements
ECSS-E-ST-32-08	Space engineering - Materials
ECSS-E-ST-32-10	Space engineering - Structural factors of safety for spaceflight hardware
ECSS-E-ST-33-11	Space engineering - Explosive systems and devices
ECSS-E-ST-35	Space engineering - Propulsion general requirements
ECSS-Q-ST-20	Space product assurance – Quality assurance
ECSS-Q-ST-40	Space product assurance - Safety
ECSS-Q-ST-70	Space product assurance - Materials, mechanical parts and processes

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, and ECSS-E-ST-32-10 apply, in particular for the following terms:

ECSS-E-ST-32

maximum design pressure (MDP)

maximum expected operating pressure (MEOP)

test factors (KA and KQ)

ECSS-E-ST-35

ablated thickness (ea)

burning time

charred thickness (ec)

corridor

hump effect

ignition time (t_{ign})

insulation thickness (ei)

non affected thickness(es)

pre-heating time

solid rocket motor

thrust centroid time

3.2 Abbreviated terms

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

Abbreviation	Meaning
AIV	assembly, integration and verification
COG	centre of gravity
COM	centre of mass
DLAT	destructive lot acceptance test
EMC	electromagnetic compatibility
EMI	electromagnetic interference
ESD	electrostatic discharge
GSE	ground support equipment
HCl	chloride acid
MCI	mass, centre of mass, inertia
MDP	maximum design pressure
MEOP	maximum expected operating pressure
NDI	non-destructive inspection
OBDH	on-board data handling
SRM	solid rocket motor
TBPM	to be provided by manufacturer
TBPU	to be provided by user
TM/TC	telemetry/telecommand
TVC	thrust vector control

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.

Solid propulsion systems can either deliver a velocity increment in a fixed direction (with respect to the launcher or spacecraft) or in a variable direction, depending on whether TVC is present or not. Most solid propulsion systems use a single nozzle and roll control is usually provided by a separate system. Solid propulsion systems are "one-shot" systems and do not need a lot of preparation before use. Because a solid propellant motor is a 'one shot' item, an acceptance firing test cannot be performed with the actual flight motor.

4.2 Functional

4.2.1 Mission

a. ECSS-E-ST-35 clause 4.2 'mission' shall apply.

4.2.2 Functions

4.2.2.1 Steady state

a. The propulsion system shall:

1. conform to the interfaces (see "interfaces" clause 4.4),
2. provide the specified total impulse, a thrust profile (nominal and dispersion) versus time.

b. The overall thrust profile shall be defined, taking into account the following launcher or spacecraft system constraints:

1. the general loads on the launcher or spacecraft (due to aerodynamics, thermal fluxes and guidance or attitude control),
2. the induced accelerations.

c. To conform to 4.2.2.1a and 4.2.2.1b, the following aspects shall be covered:

1. thrust level and orientation versus time;
2. burning time;
3. total impulse;
4. reliability level.

4.2.2.2 Transients

a. The initial and final transient thrusts shall conform to the lift-off and separation constraints and requirements.

4.2.2.3 End-of-flight mass

a. The mass of the motor shall conform to the system requirements.

NOTE The "end-of-flight" mass of solid motors strongly depends on the internal ballistics, functional parameters and the applied technologies.

4.2.2.4 First stage

a. The first stage configuration and thrust profile shall be thoroughly analysed and a trade-off made against system constraints and requirements.

4.2.2.5 Electrical

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

4.2.2.6 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.

4.3 Constraints

4.3.1 Dynamic phenomena

a. Pressure or thrust oscillation levels vs frequency range shall be specified at system and subsystem level.

b. Pressure or thrust oscillation vs frequency range shall be characterised.

c. The maximum allowable dynamic mechanical loads induced by the solid rocket motor during transient phases shall be specified vs frequency.

NOTE For example shock during ignition and pressure wave.

d. The dynamic mechanical loads induced by the solid rocket motor during transient phases shall be characterised.

e. The Report for dynamic phenomena shall be delivered in conformance with the DRD of Annex A.

4.3.2 External loads during the life cycle of the propulsion system

a. All external loads, static and dynamic (including mechanical, thermal, electrical, magnetic, humidity and radiation) shall be specified as input for the design.

4.3.3 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.

4.3.4 Acoustic noise

a. The acoustic noise generated by the motor operating in the atmosphere shall be characterised.

b. The Report for acoustic noise phenomena shall be delivered in conformance with the DRD of Annex A.

4.3.5 Pollution

a. Pollution constraints shall be specified.

NOTE For example propellant without HCl emissions, space debris mitigation.

b. The propulsion system shall conform to the pollution constraints specified in 4.3.5a.

4.3.6 Ejected parts

a. Constraints on parts foreseen to be ejected during the missions by the solid rocket motor shall be specified.

NOTE For example nozzle plugs and igniters.

b. The propulsion system shall conform to the constraints specified in 4.3.6a.

c. The ejected parts shall be characterized.

4.3.7 Safety

a. For safety aspects, ECSS-Q-ST-40 shall apply.

b. Constraints on safety due the regulation shall be specified.

c. The propulsion system shall conform to the constraints specified in 4.3.7b.

d. The propulsion system safety parameters shall be characterized and delivered in conformance with the DRD of Annex B.

4.4 Interfaces

4.4.1 General

a. All the following interfaces shall conform to the propulsion system requirements during the whole life of the system or subsystems and include the following:

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) explosive devices;
   (f) stage or spacecraft thermal protection;
   (g) contamination (e.g. plume effects);
   (h) termination and destruction devices;
   (i) 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, preventing ESD, EMI, and EMC;
   (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.

4.4.2 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 1 E.g. motors which have a long in-orbit life before being operated.

   NOTE 2 The operating range of the motor can require a thermal control system.

4.4.3 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.

4.5 Design

4.5.1 Overview

The following clauses define requirements applicable to the overall propulsion system derived from specific characteristics of each component of the system itself. Therefore they do not intend to cover the mayor requirements applicable to each component.

4.5.2 Propulsion system selection and design process

4.5.2.1 General

a. ECSS-E-ST-35 clause 4.3 (Development) shall apply.

b. 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.

c. The design and dimensioning of the SRM and the components shall be compliant with the manufacturing capabilities (available facilities, and processes, and reproducibility).

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

NOTE Reproducibility requirements are provided by the customer.

e. 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 reconsidered,
- the system or subsystem design modified, or
- the manufacturing and control processes modified (see ECSS-E-ST-10).

f. 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, environmental considerations and restrictions (e.g. pollution).

g. It shall be ensure that the solid propulsion components, subsystems and systems can sustain without degradation the loads during manufacturing, handling, test and transport.

4.5.2.2 MEOP and MDP

a. The MEOP shall be calculated as specified in ECSS-E-ST-32 clause 4.2.7 'Limit loads'.

NOTE 1 The MDP is calculated as defined in ECSS-E-ST-32 clause 3.2.27 'MDP'.

NOTE 2 If model uncertainties are included in the MEOP determination, *Km* is 1 for the calculation of MDP.

b. Dedicated MEOP and MDP may be calculated for each component to take into account the axial gradient of pressure in the bore.

c. During the development phase, it shall be verified for each component that the MDP remains higher than the one determined by calculation of the internal ballistics of the motor updated on the basis of the development tests results.

4.5.2.3 Electrical

a. Electrical bonding between all SRM components shall be ensured in compliance with ECSS-E-ST-20-07 clause 4.2.11 'Electrical bonding requirements'.

b. Electrical grounding shall be ensured in conformance with ECSS-E-ST-20-07 clause 4.2.10 'Grounding'.

c. The propulsion system shall have electrical continuity, including grounding.

4.5.2.4 Contamination

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

4.5.2.5 Detonation risk

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

4.5.2.6 Testing

a. The motor shall be designed to undergo firing static tests according to the development plan.

4.5.2.7 Leak tightness

a. ECSS-E-ST-35 clauses 4.5.11.1 'Risks of accidental fire or explosion' and 4.5.11.2 'External leakage' shall apply.

b. The motor shall conform to the system requirements on leak tightness during the mission life.

c. Under pressure loads mechanical assembly tightness shall be guaranteed.

NOTE This is performed with an appropriate design of seals and mechanical parts.

4.5.2.8 Adhesive bonding

a. For adhesive bonding mechanical dimensioning ECSS-E-ST-32 clause 4.5 'Design' shall apply.

b. It shall be ensured that, if a bonded assembly fails under loads, the rupture is within one of the constitutive materials and not at the interface (cohesive rupture).

4.5.2.9 Ageing

a. For ageing, ECSS-E-ST-35 clause 4.5.13 'Impact of ageing on sizing and dimensioning' shall apply.

4.5.3 Global performance

a. ECSS-E-ST-35 clause 4.5.2 'Global performance' shall apply.

b. The SRM parameters shall be identified by the supplier and reported in conformance with the AR-P DRD in Annex A of ECSS-E-ST-35 to the customer, covering at least the following;

1. ejected mass flow rate (propellant and inert mass), vacuum thrust vs time, including during tail-off;
2. non ejected mass vs time;
3. MCI (mass, COM, inertia,) vs time;
4. thrust centroid time;
5. motor dynamic behaviour;
6. pressure and thrust oscillations;
7. plume effects to be reported in conformance with Annex D 'Plume analysis report' DRD in ECSS-E-ST-35;
8. interfaces with TVC;
9. thrust imbalance for multiple motors functioning simultaneously (including ignition and tail off).

NOTE Nominal values, uncertainties and dispersions in the specified operational conditions shall be provided.

4.5.4 Ignition and tail-off

a. For ignition phase, the percentage of the theoretical pressure defining t_{ign} shall be defined in the motor or system specification.

NOTE t_{ign} is defined in ECSS-E-ST-35 clause 3.2.1.32.

b. The pressure and mass flow rate corridor shall be defined in the motor specifications for ignition and tail-off phases.

c. The operating time of the igniter shall exceed the ignition time t_{ign}.

4.5.5 Solid rocket motor components

4.5.5.1 Motor case

a. Elements that are connected to the case shall be dimensioned by cumulating the forces due to internal pressure and other forces such as external loads, inertial forces and local loads.

NOTE e.g. skirts, mounting parts and interface connectors.

b. If dimensional variation constraints are given for the propulsion systems, the dimensioning of the case shall be performed to comply with these constraints.

4.5.5.2 Internal thermal protection

4.5.5.2.1 Thermal dimensioning

a. 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 safety and reliability requirements.

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

$$e \geq Kp \times Ka \times ea + Kc \times ec + Ki \times ei$$

where:

ea = ablated thickness

ec = charred thickness

ei = insulation thickness

Ka = ablation coefficient

Kc = char coefficient

Ki = isolation coefficient

Kp = factor project

NOTE 1 See ECCS-E-ST-32-10 definition 3.2.4.

NOTE 2 *Kp* is applied only on *ea* 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

c. Dimensioning shall be done with the combustion duration at the lower temperature of the operational envelope, including the expected combustion duration deviation (n x s), n being a real number determined by the supplier in accordance with the reliability allocation.

d. Radiative and conductive thermal loads during pre-heating time shall be determined and used for the dimensioning of the floater and inhibitor areas.

NOTE For floater and inhibitor see 'pre-heating time' definition in ECSS-E-ST-35.

e. If requirements 4.5.5.2.1b, 4.5.5.2.1c, and 4.5.5.2.1d are not applied an alternative methodology may be used under customer approval.

4.5.5.2.2 Mechanical dimensioning

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

b. For mechanical dimensioning, ECSS-E-ST-32 clause 4.5 'Design' shall apply.

4.5.5.3 Propellant grain

4.5.5.3.1 Ballistics

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,
2. uncertainties,
3. scattering.

c. The dependence of the burning rate on pressure and temperature, including dispersions shall be determined by tests.

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

4.5.5.3.2 Mechanical dimensioning

a. For mechanical dimensioning, ECSS-E-ST-32 clause 4.5 'Design' shall apply.

b. The methodology for determining margin of safety shall be approved by the customer.

NOTE Margin of safety can be determined in reference to a probabilistic approach (reliability requirements) or by deterministic ones (FOSU).

4.5.5.4 Nozzle assembly

4.5.5.4.1 Flexible bearing

a. The flexible bearing shall operate under compression during the solid rocket motor functioning.

b. The gimbaling stiffness vs pressure shall be determined by modelling and testing to guarantee a positive torque, for the whole mission life.

c. The effects of ageing on the gimbaling stiffness shall be characterized.

4.5.5.4.2 Nozzle thermal protection

a. To design the thickness, e, of thermal material, clauses 4.5.5.2.1b and 4.5.5.2.1c shall apply.

b. If requirements 4.5.5.2.1b and 4.5.5.2.1c are not applied an alternative methodology may be used under customer approval.

4.5.5.4.3 The nozzle housing

a. Nozzle housing stiffness and strength shall conform to the system and subsystem requirements.

b. The brackets (TVC attachment points) shall have capability for dismounting the actuators for transport, inspection and maintenance.

c. Nozzle housing stiffness including brackets shall be characterized using conditions representative of the beginning and the end of the solid rocket motor functioning.

4.5.5.5 Igniter

a. For the design, verification and constraints for ignition chains, ECSS-E-ST-33-11 shall apply.

b. The igniter shall have the functionality to be dismounted, completely or partly.

c. The igniter shall be in a state to undergo static firing test independently from the motor.

4.5.5.6 Thrust vector control (TVC)

a. For thrust vector control, ECSS-ST-E-35 clause 4.5.8 shall apply.

4.6 Ground support equipment (GSE)

a. For GSE ECSS-E-ST-35 clause 4.6 shall apply.

b. Due to explosive environment, groundings shall be ensured.

4.7 Materials

a. For materials ECSS-E-ST-35 clause 4.7 shall apply.

b. For solid motors for spacecraft, the outgassing materials shall be characterized after burn-out.

c. As thermal protection materials, propellants and liner–primer materials often contain additives to adjust their properties, the effect of the migration of these additives shall be characterized.

4.8 Verification

4.8.1 Verification by analysis

a. For requirements on verification by analysis of solid propulsion systems for launchers and spacecraft, ECSS-E-ST-35 clause 4.8.1 shall apply.

4.8.2 Verification by test

a. For verification by test ECSS-E-ST-35 clause 4.8.2 shall apply.

b. Verification by test shall be performed for qualification of components, subsystems and systems of solid propulsion systems as specified in Table 4-2.

c. Depending on SRM technical requirements and in agreement between the customer and the supplier, additional verification by test should be performed for qualification of components, subsystems and systems of solid propulsion systems.

NOTE Table 4-3 presents examples where additional verification by test can be performed.

d. NDI shall be performed in conformance with ECSS-E-ST-32-08 clause 4.6.5 ‘Non-destructive inspection’.

Table 4-2: Test for qualification of solid propulsion systems, subsystems and components

ID	Category	Item	Test for qualification
1.	Materials	Raw materials for propellant NOTE: For other materials ECSS-Q-ST-70 and ECSS-E-ST-32-08 applies.	NDI, chemical analysis, and Safety tests
2.	Components	Nozzle flexible bearing	-Dynamic and static characterization test -Ageing behaviour tests -Characterization tests under pressure p= KQ * MDP and TBPM gimballing
3.	Components	Nozzle fixed housing	Characterization tests under pressure p= KQ * MDP and TBPM gimballing
4.	Components	Nozzle housing component (structural)	Characterization tests of stiffness without and with thermal protection
5.	Components	Other specially manufactured components and of the shelf parts	
6.	Components	Case	-NDI including X-ray -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* * MDP or up to burst pressure
7.	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
8.	Subsystems	Thermal protection (external)	-NDI and characterisation tests of thermal, mechanical, adhesive bonding, and ablative properties -Ageing tests - Motor post–firing inspection
9.	Subsystems	Grain (applicable also to pyrogen grain)	-Propellant characterization tests of ballistic, mechanical, safety, adhesive bonding properties -Ageing tests -NDI including X-ray -Firing tests at motor level to characterise the behaviour of the grain-at one or more TBPM points of the qualification envelope

ID	Category	Item	Test for qualification
10.	Subsystems	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
11.	Subsystems	Igniter	-NDI including measurement of mass, dimensions, leak rate, electrical bonding resistance and electrical checkout -Characterization test of the igniter case under pressure p = KQ * (igniter MDP) -Vibration Mechanical and thermal environment tests -Firing tests of the igniter - SRM Post firing inspection - SRM tests results analysis of the ignition phase
12.	Systems	Motor	-NDI including measurement of mass, dimensions, interfaces, leak rate, electrical bonding resistances -TVC functional 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

Table 4-3: Examples of mission dependent verification tests for qualification

Reference to Table 4-2	Category	Item	Test for qualification
5.	Components	Other specially manufactured components and of the shelf parts	Characterization tests as agreed with customer , NDI , DLAT
9.	Subsystems	Grain (applicable also to pyrogen grain)	-Vibration and thermal cycling tests at loaded case level (To be proposed by supplier and agreed by customer) -NDI after qualification environmental load
12.	Systems	Motor	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

4.9 Production and manufacturing

a. Clause 4.9 (Production and manufacturing) of ECSS-E-ST-35 shall apply to the production and manufacturing of solid propulsion systems for launchers and spacecraft.

b. For the quality of the production and manufacturing methods, ECSS-Q-ST-20 clauses 5.5.1 to 5.5.8 shall apply.

c. For the structural components of a solid propulsion system or subsystem, ECSS-E-ST-32 clause 4.7 shall apply.

d. The loads during manufacturing, handling, test and transport on structural elements, components, subsystems and systems shall be analysed.

e. The manufacturing process, handling and transport shall not contaminate or damage the product.

f. Tests shall be performed for acceptance of components, subsystems and systems of solid propulsion systems as specified in Table 4-4.

g. Depending on SRM technical requirements and in agreement between the customer and the supplier, additional tests should be performed for acceptance of components, subsystems and systems of solid propulsion systems.

NOTE Table 4-5 presents examples where additional verification by test can be performed.

Table 4-4: Test for acceptance of solid propulsion systems, subsystems and components

ID	Category	Item	Test for Acceptance
1.	Materials	Raw materials for propellant NOTE: For other materials ECSS-Q-ST-70 and ECSS-E-ST-32-08 applies.	NDI and chemical analysis
2.	Components	Nozzle flexible bearing	Proof pressure test under pressure $p = KA$ * MDP and TBPM gimballing
3.	Components	Nozzle fixed housing	Proof pressure test under pressure p= KA * MDP
4.	Components	Nozzle housing component (structural)	NDI
5.	Components	Other specially manufactured components and of the shelf parts	NDI, DLAT as agreed with the customer
6.	Components	Case	-NDI including X-ray -Proof pressure test under pressure $p >$ KA* MDP
7.	Subsystems	Thermal protection (internal, together with the case)	Characterisation tests on representative bond samples
8.	Subsystems	Thermal protection (external)	Characterisation tests on representative bond samples
9.	Subsystems	Grain (applicable also to pyrogen grain)	-Mechanical characterisation tests for every propellant batch - Ballistic characterisation for every propellant batch -Bond characterisation for every propellant batch - NDI including X-ray
10.	Subsystems	Nozzle and actuation system	NDI Measurement of deflection torque -Leak test
11.	Subsystems	Igniter	Proof test NDI
12.	Systems	Motor	NDI including measurement of mass, dimensions, interfaces, leak rate, electrical bonding resistances TVC tests (for motor with moveable nozzles)

Table 4-5: Examples of mission dependent verification tests for acceptance

Reference to Table 4-4	Category	Item	Test for acceptance
6.	Components	Case	Proof test of the case with a KA factor on external loads with or without MDP
7.	Subsystems	Thermal protection (internal, together with the case)	Verification of leak–tightness when integrated with the case (if a leakage rate is specified for the thermal protection)
9.	Subsystems	Grain (applicable also to pyrogen grain)	NDI after acceptance environmental load
12.	Systems	Motor	For series produced motors, DLAT if specified by customer or proposed by the supplier and agreed by the customer

4.10 In-service

4.10.1 General

a. ECSS-E-ST-35 clause 4.10 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 be

1. maintained in the condition for ignition, or
2. 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 launcher motor

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 the needs identified in 4.10.2.2a.

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 positions identified during FMECA or specified by the customer;

(d) deformations.

2. In addition, for TVC with a movable nozzle:

(a) the nozzle position;

(b) the force in the nozzle actuation brackets.

4.10.2.3 In–flight measurements for spacecraft motor

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 the needs identified in 4.10.2.3a.

c. The motor shall be such that the following measurement can be carried out:

1. chamber pressure;

2. the outside temperature in areas identified during FMECA or specified by the customer.

d. The following additional parameters should be measured:

1. the motor blanket pressure to verify that the motor has not developed leaks;

2. the motor temperature to allow active temperature control.

NOTE In particular, this applies for motors that have a long life in orbit.

4.11 Deliverables

a. For solid rocket motors, the documentation listed in Table 4-1 of ECSS-E-ST-35 shall be delivered with the exception of 'Gauging analysis' and 'Sloshing analysis'.

NOTE 1 The Dynamic analysis report (Annex A) is called by requirements 4.3.1e and 4.3.4b.

NOTE 2 The Material safety data sheet (Annex B) document is called by requirement 4.3.7d.

Annex A (normative)
Dynamic analysis report (AR-DY) - DRD

A.1 DRD identification

A.1.1 Requirement identification and source document

This DRD is called from ECSS-E-ST-35-02, requirements 4.3.1e and 4.3.4b.

A.1.2 Purpose and objective

The objective of the Dynamic analysis report is to analyse and establish the characteristic of the environment, dynamic and acoustic, induced by the propulsion system. With environment, this DRD intends specifically dynamic and acoustic behaviour induced by the propulsion system.

The AR-DY is prepared on the basis of the applicable specifications and requirements documentation.

A.2 Expected response

A.2.1 Scope and content

<1> Introduction

a. The AR-DY shall contain a description of the purpose objective, content and the reason prompting its preparation.

<2> Applicable and reference documents

a. The AR-DY shall list the applicable and reference documents in support to the generation of the document.

<3> Terms, definition, abbreviated terms and symbols

a. The AR-DY shall use the terms, definitions, abbreviated terms and symbols used in ECSS-E-ST-35.

b. The AR-DY shall include any additional term, definition, abbreviation or symbol used.

<4> General description of the propulsion system, subsystem or component

<4.1> Overview

a. The AR-DY shall describe the propulsion system, subsystem or component and introduce its terminology.

b. Reference shall be made to the applicable design definition file, inclusive its revision status.

<4.2> Coordinate systems

a. The AR-DY shall describe the coordinate systems used in the propulsion system, propulsion subsystem or propulsion component.

<5> Summary and understanding of the requirements related to the environment induced by the propulsion system

a. The AR-DY shall list and summarize the parameters that are used to assess the environment induced by the propulsion system.

b. The AR-DY shall include the discussion on the understanding and clarification of the requirements.

c. The AR-DY shall include the description of the reference conditions used for the analysis.

<6> Analysis description

<6.1> Assumptions, simplifications and models

a. Since analysis covers both model computations and elaboration of measurements, the AR-DY shall cover:

1. the description of the used assumptions,
2. the description of simplifications, and
3. a brief summary of rationale and software used for the analysis of the environment induced by the propulsion system and the related uncertainties.

NOTE Uncertainties can result from numerical inaccuracies, measurement inaccuracies, models that are based on simplifications and the conditions under which data was obtained.

<6.2> Approach

a. The AR-DY shall include a description and a discussion of the analysis methodology, describing what is done and why.

b. If experimental input data is used:

1. the data sheet or test results shall be referenced or reproduced in the AR-DY;
2. the test plan, test procedures, individual test item descriptions, and existing deviations from the generic design on which the experimental data is based shall be referenced;
3. a description of the test conditions shall be given in the AR-DY.

c. If data from modelling, coming from an external project, is used, the following shall be done:
1. the data referenced or reproduced;
2. refer the models from which this data results.

d. If modelling is used, the models shall be referenced and summarized.

e. An estimate of the accuracy of the methodology shall be included in the AR-DY.

f. The AR-DY shall include a justification and validation of the methodology, either in the AR-DY itself, or by referenced documents.

<6.3> Calculations

a. The AR-DY shall describe the calculations that are being made to obtain the characteristics of the environment induced by the propulsion system.

<7> Discussion of results and comparison with requirements

a. The AR-DY shall include a discussion of the results in view of:
1. the accuracy of input data,
2. the validation status of the computational methods and models used,
3. deviations in test conditions and test items used to obtain experimental data, and
4. the simplifications and assumptions used in the models and calculations.

b. The AR-DY shall include an assessment of the effects of the subjects given in section <7>a on the characteristics of the environment induced by the propulsion system.

c. The AR-DY shall include a comparison of the characteristics of the environment induced by the propulsion system with the requirements, taking into account the inaccuracies of the characteristics of the environment induced by the propulsion system, and deviations shall be commented in the AR-DY.

d. In case previous environment analyses are available, the AR-DY shall include:
1. comparison of the result of the characteristics of the environment induced by the propulsion system with the previous ones, and
2. report including a discussion on the differences.

NOTE Requirements are not limited to system or subsystem requirements; they can also be "internal" or "derived" requirements.

<8> Recommendations

a. The AR-DY, based on the information given in section <7>, shall include a list with the following recommendations:

1. suggestions for future work and additional investigations or improvements;
2. feedback to improve the environment induced by the propulsion system.

<9> Summary and conclusions

a. In the AR-DY, a summary of the results shall be given containing the following information:

1. a statement whether or not the objective has been achieved;
2. limitations of the performed work.

A.2.2 Special remarks

None.

Annex B (normative) Material Safety Data Sheet (AR-MSDS) - DRD

B.1 DRD identification

B.1.1 Requirement identification and source document

This DRD is called from ECSS-E-ST-35-02, requirement 4.3.7d.

B.1.2 Purpose and objective

The objective of the Material Safety Data Sheet is to give the safety parameters for the propulsion system.

The AR-MSDS is prepared on the basis of the applicable specifications and requirements documentation.

B.2 Expected response

B.2.1 Scope and content

<1> Technical or commercial identification

a. The AR-MSDS shall contain the technical or commercial identification of the propulsion system.

<2> Product characteristics

a. The AR-MSDS shall provide a description of the propulsion system and its components.

b. For each component, the AR-MSDS shall precise if it is a live or a passive component.

c. The AR-MSDS shall provide the total mass of live materials.

d. The AR-MSDS shall describe the operating principle.

e. The AR-MSDS shall describe the packaging.

f. The AR-MSDS shall provide the Risk/compatibility category.

<3> Risks identification

a. The AR-MSDS shall describe the fire hazards.

b. The AR-MSDS shall describe the pyrotechnic propagation accident.

c. The AR-MSDS shall describe the effects of provoked initiation.

<4> Emergency first aid

a. The AR-MSDS shall provide the measures to be implemented in case of contact with the propellant or the decomposition products.

b. The AR-MSDS shall provide the measures to be implemented in the event of an accident.

<5> Fire prevention

a. The AR-MSDS shall provide the appropriate fire-extinguishing means.

b. The AR-MSDS shall provide the forbidden fire-extinguishing means.

<6> Accidental spillage

a. The AR-MSDS shall provide the measures to be implemented in case of accidental spillage of propellant.

<7> Storage and handling

a. The AR-MSDS shall provide the needed handling precautions for the propulsion system.

b. The AR-MSDS shall provide the needed storage conditions for the propulsion system.

<8> Protective clothes and equipment

a. The AR-MSDS shall provide the needed protective clothes and equipment to operate the propulsion system.

b. The AR-MSDS shall provide the recommended protective clothes and equipment to operate the propulsion system.

<9> Physical and chemical properties

a. The AR-MSDS shall provide the following propulsion system characteristics:

1. physical general properties: shape, colour, odour, density;
2. temperature of decomposition.

<10> Stability and reactivity

a. The AR-MSDS shall provide the following propulsion system characteristics:
   1. self ignition temperature
   2. sensitivity to electrostatic discharge
   3. sensitivity to electromagnetic radiation
   4. sensitivity to friction
   5. detonation sensitivity
   6. sensitivity to vibrations
   7. sensitivity to shock
   8. sensitivity to drops

<11> Toxicity contamination data

a. The AR-MSDS shall provide the toxic combustion products generated by the propulsion system in case of fire.

<12> Environmental contamination data

a. The AR-MSDS shall provide the products which could be dangerous for environment, generated by the propulsion system in case of fire.

<13> Waste treatment and disposal

a. The AR-MSDS shall define the procedures which will have to be used to eliminate materials, components or the propulsion system itself.

<14> Shipping

a. The AR-MSDS shall provide the precautions to be taken for the propulsion system shipping.

b. The AR-MSDS shall provide the classification w.r.t. shipping means.

<15> Applicable code & regulations

a. The AR-MSDS shall provide the code and regulations applicable to the propulsion system.

<16> Miscellaneous

a. The AR-MSDS should provide all other information relative to safety which the provider estimates necessary for the use of the propulsion system, from the delivery until the flight.

B.2.2 Special remarks

None.

Bibliography

ECSS-S-ST-00	ECSS System - Description, implementation and general requirements
ECSS-E-ST-10	Space engineering - System engineering general requirements
ECSS-E-ST-35-01	Space engineering - Liquid and electric propulsion for spacecraft
ECSS-E-ST-35-03	Space engineering - Liquid propulsion for launchers