

BS EN 16603-35:2014



BSI Standards Publication

Space engineering — Propulsion general requirements

bsi.

...making excellence a habit.
AVA Documents™
Document Sharing Hub

National foreword

This British Standard is the UK implementation of EN 16603-35:2014.

The UK participation in its preparation was entrusted to Technical Committee ACE/68, Space systems and operations.

A list of organizations represented on this committee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

© The British Standards Institution 2014.
Published by BSI Standards Limited 2014

ISBN 978 0 580 83984 9

ICS 49.140

Compliance with a British Standard cannot confer immunity from legal obligations.

This British Standard was published under the authority of the Standards Policy and Strategy Committee on 30 September 2014.

Amendments issued since publication

Date	Text affected
------	---------------

English version

Space engineering - Propulsion general requirements

Ingénierie spatiale - Exigences générales pour la
propulsion

Raumfahrttechnik - Antrieb, allgemeine Anforderungen und
Grundsätze

This European Standard was approved by CEN on 23 February 2014.

CEN and CENELEC members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration. Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the CEN-CENELEC Management Centre or to any CEN and CENELEC member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN and CENELEC member into its own language and notified to the CEN-CENELEC Management Centre has the same status as the official versions.

CEN and CENELEC members are the national standards bodies and national electrotechnical committees of Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, Former Yugoslav Republic of Macedonia, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and United Kingdom.



CEN-CENELEC Management Centre:
Avenue Marnix 17, B-1000 Brussels

Table of contents

Foreword	5
Introduction.....	6
1 Scope.....	7
2 Normative references	8
3 Terms, definitions and abbreviated terms.....	9
3.1 Terms defined in other standards	9
3.2 Terms specific to the present standard	9
3.2.1 General terms	9
3.2.2 Definition of masses	20
3.3 Abbreviated terms.....	21
3.4 Symbols.....	23
4 Propulsion engineering activities	25
4.1 Overview	25
4.1.1 Relationship with other standards	25
4.1.2 Characteristics of propulsion systems	25
4.2 Mission	26
4.3 Development	26
4.4 Propulsion system interfaces	27
4.5 Design	28
4.5.1 General	28
4.5.2 Global performance.....	28
4.5.3 Reference envelope	29
4.5.4 Transients	31
4.5.5 Sizing	31
4.5.6 Dimensioning	32
4.5.7 Imbalance	32
4.5.8 Thrust vector control	33
4.5.9 Contamination and cleanliness.....	33
4.5.10 Plume effect.....	34

4.5.11	Leak tightness	35
4.5.12	Environment	35
4.5.13	Impact of ageing on sizing and dimensioning	36
4.5.14	Components	36
4.5.15	Monitoring and control system	38
4.6	Ground support equipment (GSE)	38
4.6.1	General	38
4.6.2	Mechanical and fluid	39
4.6.3	Electrical	39
4.7	Materials	39
4.8	Verification	39
4.8.1	Verification by analyses	39
4.8.2	Verification by tests	40
4.9	Production and manufacturing	41
4.9.1	Overview	41
4.9.2	Tooling and test equipment	41
4.9.3	Marking	41
4.9.4	Component manufacturing and assembly	42
4.10	In-service	42
4.10.1	Operations	42
4.10.2	Propulsion system operability	42
4.11	Deliverables	43
Annex A (normative) Propulsion performance analysis report (AR-P) - DRD		44
Annex B (normative) Gauging analysis report (AR-G) - DRD		48
Annex C (normative) Addendum: Specific propulsion aspects for thermal analysis - DRD		52
Annex D (normative) Plume analysis report (AR-PI) - DRD		61
Annex E (normative) Nozzle and discharge flow analysis report (AR-N) - DRD		65
Annex F (normative) Sloshing analysis report (AR-S) - DRD		69
Annex G (normative) Propulsion transients analysis report (AR-Tr) - DRD		73
Annex H (normative) Propulsion subsystem or system user manual (UM) - DRD		77

Annex I (normative) Mathematical modelling for propulsion analysis (MM-PA) - DRD	85
Annex J (normative) Addendum: Additional propulsion aspects for mathematical model requirements (MMR) - DRD	89
Annex K (normative) Addendum: Additional propulsion aspects for mathematical model description and delivery (MMDD) - DRD	91
Annex L (normative) Propulsion system instrumentation plan - DRD.....	93
Annex M (informative) Standards for propellants, pressurants, simulants and cleaning agents	95
Bibliography.....	98

Figures

Figure 3-1 Burning time	10
Figure 3-2: NPSP	15
Figure 3-3 Relief flap or floater	16

Tables

Table 4-1 Deliverable DRD.....	43
--------------------------------	----

Foreword

This document (EN 16603-35:2014) has been prepared by Technical Committee CEN/CLC/TC 5 "Space", the secretariat of which is held by DIN.

This standard (EN 16603-35:2014) originates from ECSS-E-ST-35C Rev. 1.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by March 2015, and conflicting national standards shall be withdrawn at the latest by March 2015.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN [and/or CENELEC] shall not be held responsible for identifying any or all such patent rights.

This document has been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association.

This document has been developed to cover specifically space systems and has therefore precedence over any EN covering the same scope but with a wider domain of applicability (e.g. : aerospace).

According to the CEN-CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, Former Yugoslav Republic of Macedonia, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom.

Introduction

The requirements in this Standard (ECSS-E-ST-35) and in the three space propulsion standards dedicated to particular type of propulsion (ECSS-E-ST-35-01, ECSS-E-ST-35-02 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.

All the normative references, terms, definitions, abbreviated terms, symbols and DRDs of the ECSS Propulsion standards are collected in this ECSS-E-ST-35 standard.

The ECSS Propulsion standards structure is as follows.

ECSS-E-ST-35 Propulsion general requirements

- Standards, covering particular type of propulsion
 - 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.
- Standard covering particular propulsion aspects
 - ECSS-E-ST-35-06 Cleanliness requirements for spacecraft propulsion hardware
 - ECSS-E-ST-35-10 Compatibility testing for liquid propulsion systems

Further information on the use of conventional propellants, pressurants, simulants and cleaning agents is given in Annex M.

1

Scope

This Standard defines the regulatory aspects that apply to the elements and processes of liquid propulsion for launch vehicles and spacecraft, solid propulsion for launch vehicles and spacecraft and electric propulsion for spacecraft. The common requirements for the three types of space propulsion are written in the ECSS-E-ST-35 document. The specific requirements for each type of propulsion are given in ECSS-E-ST-35-01, ECSS-E-ST-35-02 and ECSS-E-ST-35-03. It specifies the activities to be performed in the engineering of these propulsion systems and their applicability. It defines the requirement for the engineering aspects such as functional, physical, environmental, quality factors, operational and verification.

Other forms of propulsion (e.g. nuclear, nuclear–electric, solar–thermal and hybrid propulsion) are not presently covered in this issue of the Standard.

This standard applies to all types of space propulsion systems used in space applications, including:

- Liquid and electric propulsion for spacecraft.
- Solid propulsion for launch vehicles and spacecraft;
- Liquid propulsion for launch vehicles.

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

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.

EN reference	Reference in text	Title
EN 16601-00-01	ECSS-S-ST-00-01	ECSS system – Glossary of terms
EN 16603-10	ECSS-E-ST-10	Space engineering – System engineering general requirements
EN 16603-10-02	ECSS-E-ST-10-02	Space engineering – Verification
EN 16603-35-06	ECSS-E-ST-35-06	Space engineering – Cleanliness requirements for spacecraft propulsion hardware
EN 16603-31	ECSS-E-ST-31	Space engineering – Thermal control general requirements
EN 16603-32	ECSS-E-ST-32	Space engineering – Structural general requirements

3

Terms, definitions and abbreviated terms

3.1 Terms defined in other standards

For the purpose of this Standard, the terms and definitions from ECSS-S-ST-00-01 apply.

For the purpose of this Standard, the following definitions from ECSS-E-ST-10 apply:

technology readiness level (TRL)

For the purpose of this Standard, the following definitions from ECSS-E-ST-32 apply:

MDP

MEOP

mission life

3.2 Terms specific to the present standard

3.2.1 General terms

3.2.1.1 ablated thickness

removed thickness of thermal protection material, due to thermal and mechanical loads, during combustion duration

NOTE Mathematically called “ea”

3.2.1.2 barbecue mode

mode where a stage or **spacecraft** slowly rotates in space in order to obtain an even temperature distribution under solar radiation

3.2.1.3 beam divergence

semi-angle of a cone, passing through the thruster exit, containing a certain percentage of the current of an ion beam at a certain distance of that thruster exit

3.2.1.4 buffeting

fluctuating external aerodynamic loads due to vortex shedding

3.2.1.5 burning time, t_b

time for which the propulsion system delivers a **thrust**

NOTE Figure 3-1 illustrates an arbitrary **thrust** or pressure history of a rocket propulsion system. An igniter peak can, but need not, be observed. Depending on the application, a time, t_0 , is defined at which the propulsion system is assumed to deliver a **thrust**, and a time, t_e , at which the propulsion system is assumed not to deliver an **thrust** any more.

The **burning time** is the time interval defined as the difference between the two times: $t_b = t_e - t_0$.

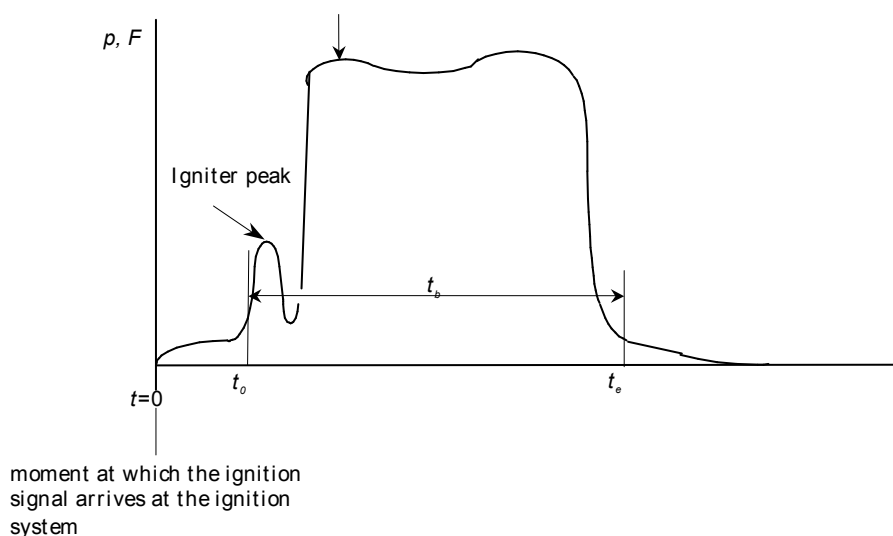


Figure 3-1 Burning time

3.2.1.6 characteristic velocity, C^*

<instantaneous characteristic velocity> ratio of the product of the throat area of a rocket engine and the total pressure (at the throat) and the propellants **mass** flow rate

NOTE 1 In accordance with this definition, the instantaneous **characteristic velocity** is:

$$C^* = \frac{p_c A_t}{m}$$

NOTE 2 Instantaneous and overall characteristic velocities are usually referred to as **characteristic velocity**.

NOTE 3 The usual units are m/s.

3.2.1.7 characteristic velocity, C^*

<overall characteristic velocity> ratio of the time integral of the product of throat area and total pressure (at the throat) and the propellants **ejected mass** during the same time interval

NOTE 1 In accordance with this definition, the overall **characteristic velocity** is:

$$C^* = \frac{\int_{t_1}^{t_2} p_c A_t d\tau}{\int_{t_1}^{t_2} m d\tau}$$

In many cases t_1 is taken to be the ignition time, t_0 , and t_2 is taken to be the time at burnout (t_b). In that case, $t_2 - t_1 = t_b$ and the integral in the denominator equals the **ejected mass**.

NOTE 2 Instantaneous and overall characteristic velocities are usually referred to as **characteristic velocity**.

NOTE 3 The usual units are m/s.

3.2.1.8 charred thickness

remaining thermal material thickness after motor operating, affected by thermal loads

NOTE 1 For example, composition evolution.

NOTE 2 Mathematically, it is called "ec"

3.2.1.9 chill-down

process of cooling the engine system **components** before ignition in order to reach specific functional and mechanical criteria (e.g. the propellants proper thermodynamic state)

3.2.1.10 component

smallest individual functional unit considered in a **subsystem**

NOTE For example tanks, valves and regulators.

3.2.1.11 contaminant

undesired material present in the propulsion system at any time of its life

3.2.1.12 corridor

variation envelope of a time dependent parameter

3.2.1.13 critical speed

speed at which the eigenfrequency of the rotor coincides with an integer multiple of the rotational speed

3.2.1.14 cryo-pumping

condensation of gas on cryogenic fluid (e.g. LH₂, LHe) lines or **components**, thereby sucking in more gas and thereby preventing normal operation of cryogenic system

NOTE For example, preventing proper **chill-down**.

3.2.1.15 de-orbiting

controlled return to Earth or other celestial body or burn-up in the atmosphere of a **spacecraft** or stage

3.2.1.16 dimensioning

process by which the dimensions of an **entity** (**system**, **subsystem** or component) is determined and verified, such that the **entity** conforms to the **entity** requirements and can withstand all loads during its mission

NOTE Dimensioning is only possible after the sizing process for the particular system or subsystem has been completed.

3.2.1.17 dimensioning case

set of loads combinations which have been identified by failure modes analysis

3.2.1.18 discharge coefficient, C_d

<for nozzle> inverse of the **characteristic velocity**

NOTE 1 In accordance with this definition, the **discharge coefficient** is

$$C_d = \frac{1}{C^*}$$

NOTE 2 In this Standard, the units are s/m.

NOTE 3 Also called mass flow rate coefficient

3.2.1.19 draining

emptying the fluid contents from a volume

3.2.1.20 electric thruster

propulsion device that uses electrical power to generate or increase **thrust**

3.2.1.21 engine inlet pressure

propellant stagnation pressure at the engine inlet

3.2.1.22 envelope

set of physical data in which the propulsion system, subsystem, or component is intended to operate

NOTE 1 It is also called domain.

NOTE 2 For propulsion systems, the concept of operational envelope is applied in the design. The concept of extreme envelope is commonly used for liquid propulsion for launchers (see ECSS-E-ST-35-03).

3.2.1.23 erosive burning

increase of the solid burning rate of the **propellant** due to high gas velocities parallel to the burning surface

3.2.1.24 fluid hammer

see **water hammer** (see 3.2.1.88).

3.2.1.25 flushing

passing a fluid through a volume with the objective of removing any remains of other fluids in this volume

3.2.1.26 flutter

aero-elastic instability

3.2.1.27 functional transducer

transducer used as an input for controlling the system in real time

3.2.1.28 graveyard orbit

orbit about 300 km or more above a GEO or GSO into which spent upper stages or satellites are injected to reduce the creation of debris in GEO or GSO

3.2.1.29 ground support equipment GSE

equipment adapted to support verification testing and launch preparation activities on the propulsion system

3.2.1.30 hump effect

effect by which the solid **propellant** burning rate varies with the penetration depth into the **propellant** grain

3.2.1.31 hypergolic propellants

propellants which spontaneously ignite upon contact with each other

3.2.1.32 ignition time, t_{ign}

<for solid propulsion> time at which the solid motor pressure has reached a given percentage of the theoretical pressure corresponding to the combustion of the main **propellant** grain only (explicitly excluding the igniter peak)

3.2.1.33 impulse bit

time integral of the force delivered by a thruster during a defined time interval

NOTE **Impulse bit** is expressed in Ns.

3.2.1.34 initiator

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

NOTE The impulse can be provided by mechanical, electrical, optical action.

3.2.1.35 insulation thickness (ej)

thickness of non affected material to ensure a given interface temperature

3.2.1.36 interface

common boundary involving a direct interaction between two or more **systems**, **subsystems** or **components**

3.2.1.37 launch vehicle

vehicle intended to move a **spacecraft** from ground to orbit or between orbits

3.2.1.38 limit testing

determining experimentally the operating limit under which a **system**, **subsystem**, component or material can be used without loss of integrity or loss of functional capability

3.2.1.39 liquid rocket engine

chemical rocket motor using only liquid **propellants**

NOTE This includes catalytic bed monopropellant engine.

3.2.1.40 minimum impulse bit

smallest impulse delivered by a thruster at a given level of reproducibility, as a result of a given command

NOTE Minimum impulse bit is expressed in Ns.

3.2.1.41 mission

see mission life (see 3.1)

NOTE The mission encompasses the complete life of the propulsion system or subsystem: delivery, (incoming) inspection, tests, storage, transport, handling, integration, loading, pre-launch activities, launch, in-orbit life, passivation and, if applicable, disposal.

3.2.1.42 mixture ratio

ratio of oxidizer to fuel **mass** flow rates

3.2.1.43 non affected thickness(es)

remaining thermal protection material thickness after solid motor operating, non affected by thermal and mechanical loads

3.2.1.44 nozzle

Device to accelerate fluids from a rocket motor to exhaust velocity

3.2.1.45 net positive suction pressure NPSP

difference between the total pressure and the vapour pressure at a given temperature

NOTE 1 In accordance with this definition,
 $NPSP = p_{tot} - p_{vap}(T)$.

NOTE 2 There are 3 types of NPSPs (see Figure 3-2):

- $NPSP_{available}$ which is the **NPSP** at a given instant and at a certain location.
- $NPSP_{cr}$, or critical **NPSP** which is the **NPSP** below which the pump pressure rise decreases below a pre defined value due to cavitation.
- $NPSP_{req}$, or required **NPSP** which is $NPSP_{req} = NPSP_{cr} + \text{safety margin}$.

In accordance with these definitions,
 $NPSP_{cr} < NPSP_{available}$

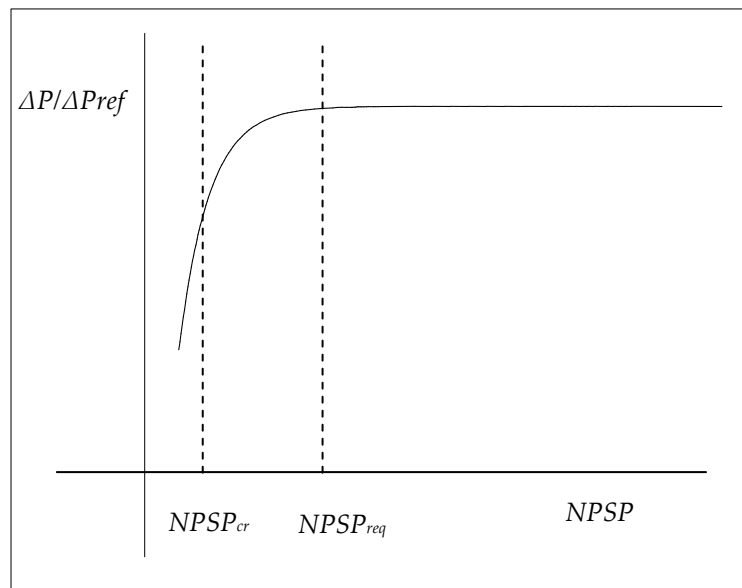


Figure 3-2: NPSP

3.2.1.46 plasma

ionized gas

NOTE **Plasma** contains neutral species, ions and electrons.

3.2.1.47 POGO

coupling between the dynamic behaviour of the launcher structure and a fluctuating thrust, resulting in a fluctuation of the mass flow rate at the engine inlet

3.2.1.48 pre-heating time

time that the thermal protection is exposed to the combustion gases in the “dead water” zone

NOTE The floater (see Figure 3-3) is assumed to be consumed by the combustion products roughly at the same rate as the **propellant** regresses. Between the remaining floater and the thermal protection, a “dead water” zone of combustion products exists. Because of the relatively low gas velocity in this “dead water” zone, the heat transfer to the thermal protection is reduced to conduction and radiation only.

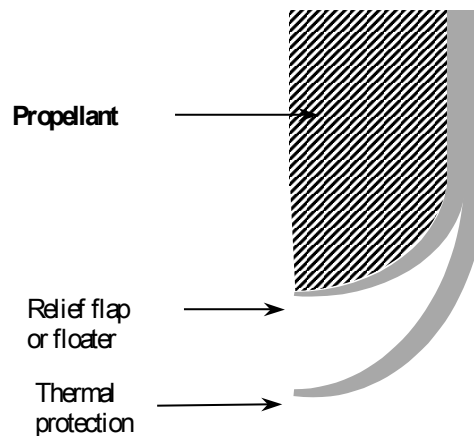


Figure 3-3 Relief flap or floater

3.2.1.49 **pressurant**

fluid used to pressurize a **system** or **subsystem**

3.2.1.50 **pressure drop coefficient**

coefficient which expresses the pressure drop over a component

NOTE The pressure drop coefficient is usually represented by k , and in accordance with this definition $k = \rho \Delta p / S$ for instance.

3.2.1.51 **priming**

filling operation of a fluid volume as a first step of operation

3.2.1.52 **propellant**

material or materials that constitute a **mass** which, often modified from its original state, is ejected from a propulsion device to produce **thrust**

3.2.1.53 **propellant gauging**

determination of the remaining propellant on board at a given time in the mission.

3.2.1.54 **propulsion system**

system to provide **thrust**

NOTE 1 In this standard it is also referred to as the system.

NOTE 2 Propulsion system comprises all components used in the fulfilment of a mission, e.g. thrusters, propellants, valves, filters, pyrotechnic devices, pressurization subsystems, feeding system, tanks and electrical components.

NOTE 3 Electrical power sources are only included in Electrical propulsion system.

3.2.1.55 **purging**

removing fluid from a volume containing liquid and gas

3.2.1.56 pyrogen igniter

igniter for a (solid) rocket motor producing a heat flux and a flux of hot gases, and that builds up pressure under its own action

3.2.1.57 pyrotechnic igniter

igniter for a (solid) rocket motor that primarily produces a heat flux of hot particles but hardly builds up pressure under its own action

3.2.1.58 repeatability

ability to repeat an event with the same input commands

3.2.1.59 required factor, K_r

<solid propulsion> factor of safety used for mechanical dimensioning of visco elastic or non linear behaviour materials

3.2.1.60 re-orbiting

injection of a **spacecraft** or stage into a **graveyard orbit**

3.2.1.61 simulant

fluid replacing an operational fluid for specific test purposes

NOTE 1 The **simulant** is selected such that its characteristics closely resemble the characteristics of the operational fluid whose effects are being evaluated in the **system**, **subsystem** or **component** test.

NOTE 2 The **simulant** is selected such that it conforms to the compatibility requirements of the **system**, **subsystem** or **component**.

3.2.1.62 side load

lateral force on a **nozzle** during transient operation due to asymmetric plume

3.2.1.63 sizing

process by which the overall characteristics of a **system** or **subsystem** are determined during the conceptual phase of the design

NOTE At the end of the **sizing** process, functional and material characteristics are also established. The **sizing** process conforms to the functional requirements.

3.2.1.64 solid rocket motor

chemical rocket motor using only solid **propellants**

3.2.1.65 spacecraft

vehicle purposely delivered by the upper stage of a **launch vehicle** or transfer vehicle

NOTE For example, satellite, ballistic probe, re-entry vehicle, space probes and space stations.

3.2.1.66 specific impulse, I_{sp}

<instantaneous specific impulse> ratio of **thrust** to **mass** flow rate

NOTE 1 The **specific impulse** is expressed in Ns/kg or m/s.

NOTE 2 In engineering, another definition is often still used where the **specific impulse** is defined as the ratio of **thrust** to weight flow rate. This leads to an I_{sp} in seconds (s). The numerical value of I_{sp} (s) is obtained by dividing the I_{sp} expressed in m/s by the standard surface gravity, $g_0 = 9,80665 \text{ m/s}^2$.

3.2.1.67 **specific impulse, I_{sp}**

<average specific impulse> ratio of **total impulse** and **total propellant ejected mass** in the same time interval used for the establishment of the **total impulse**

NOTE See notes for 3.2.1.66 “specific impulse”.

3.2.1.68 **subsystem**

set of independent elements combined to achieve a given objective by performing a specific function

NOTE 1 See ECSS-S-ST-00-01 ‘subsystem’.

NOTE 2 For example: tanks, filters, valves and regulators constitute a propellant feed subsystem in a propulsion system.

3.2.1.69 **system**

See **propulsion system** (see 3.2.1.54).

3.2.1.70 **termination point**

location, in a bonding application, where the local stress is multi-directional due to a geometric discontinuity

NOTE It can also be referred to as triple **point** (see 3.2.1.82).

3.2.1.71 **throttling**

adjustment of the thrust level using control devices

3.2.1.72 **thrust**

generated force due to acceleration and ejection of matter

3.2.1.73 **thrust centroid time**

time at which an impulse, of the same magnitude as the **impulse bit**, is applied, to have the same effect as the original **impulse bit**

3.2.1.74 **thrust chamber assembly (TCA)**

assembly of one or more injectors, igniters, combustion chambers, coolant **systems** and **nozzles**

NOTE There are concepts where one engine has more than one combustion chamber, e.g. a modular plug **nozzle** engine.

3.2.1.75 **thrust coefficient, C_F**

<instantaneous thrust coefficient> ratio of (instantaneous) **thrust** and the product of throat area and throat total pressure

NOTE 1 In accordance with this definition, the instantaneous **thrust coefficient** can be calculated as:

$$C_F = \frac{F}{P_c A_t}$$

NOTE 2 Instantaneous and average **thrust coefficients** are usually referred to as **thrust coefficient**.

3.2.1.76 thrust coefficient, C_F

<average thrust coefficient> ratio of the **thrust** integrated over an appropriate time interval divided by the integral over the same time interval of the product of throat area and throat total pressure

NOTE 1 In accordance with this definition, the average **thrust coefficient** can be calculated as:

$$C_F = \frac{\int_{t_1}^{t_2} F d\tau}{\int_{t_1}^{t_2} P_c A_t d\tau}$$

In many cases, t_1 is taken to be the ignition time, t_0 , and t_2 is taken the time at burnout (t_b). In this case, $t_2 - t_1 = t_b$ and the integral of the **thrust** becomes the **total impulse**.

NOTE 2 Instantaneous and average **thrust coefficients** are usually referred to as **thrust coefficient**.

3.2.1.77 thrust misalignment

difference between the real and intended direction of the **thrust** vector

3.2.1.78 thrust out-centring

thrust vector not passing through the instantaneous COM

3.2.1.79 thrust vector control

sub system used to adjust the direction of the thrust vector on command

3.2.1.80 total impulse

time integral of the force delivered by a thruster or a **propulsion system** during the operational time interval

NOTE Total impulse is expressed in Ns.

3.2.1.81 trimming

adjustment of the operating point (mixture ratio and thrust level) using control devices

3.2.1.82 triple point

<for solid motor> See **termination point** (see 3.2.1.70).

NOTE In this Standard, **triple point** only refers to thermal protection.

3.2.1.83 turbo pump

device in a rocket motor consisting of a turbine driven by a high energy fluid, driving one or more rotating pumps in order to deliver specific ranges of fluid **mass** flow rates at specified ranges of pressure

3.2.1.84 ullage volume

volume in a tank not occupied by liquid **propellant** and equipment and lines present in the tank

3.2.1.85 valve manoeuvring time

moving time of the valve between an initial predetermined position and a final predetermined position

3.2.1.86 valve response time

time between the command given to the valve to move and the initial movement of the valve

3.2.1.87 venting

opening a closed volume to the ambient with the objective of decreasing the pressure in the volume

3.2.1.88 water hammer

pressure surge or wave caused by the kinetic energy of a fluid in motion when it is forced to stop or change direction suddenly

NOTE This is also generically indicated as **fluid hammer** (see 3.2.1.24)

3.2.2 Definition of masses

3.2.2.1 dry mass

initial mass without loaded mass

3.2.2.2 end of flight or final mass

mass of the propulsion system directly after the end of the propulsion system operation

3.2.2.3 ejected mass

difference between the initial mass and the end of flight mass

3.2.2.4 initial mass

total propulsion system mass just before activation

3.2.2.5 loaded mass

sum of propellants mass, pressurant mass and mass of (other) fluids just before activation of the propulsion system

3.2.2.6 propellant mass

sum of the mass of the main propellant, the gas generator and starter propellants, the propellants for attitude control, and the igniter propellants

3.2.2.7 residual mass

propellants mass that remains in the propulsion system at the end of operation

3.3 Abbreviated terms

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

Abbreviation	Meaning
AIV	assembly, integration and verification
ACS	attitude control system
AOCS	attitude and orbit control system
BOL	beginning-of-life
CEX	charge exchange
CFC	chloro fluoro carbons
CFD	computational fluid dynamics
COM	centre of mass
CPIA	chemical propulsion information agency
DDF	design and definition file
DF	definition file
DJ	justification file NOTE: Dossier justificatif in French
DJF	design and justification file
DLAT	destructive lot acceptance test
DRD	document requirements definition
EIDP	end item data package
EJMA	expansion joints manufacturer association
EMC	electromagnetic compatibility
EMI	electromagnetic interference
EOL	end-of-life
EP	electric propulsion
FEPP	field emission electric propulsion
FMECA	failure modes, effects and criticality analysis
FOS	factor of safety
GEO	geostationary orbit
GSE	ground support equipment
GSO	geosynchronous orbit
IATA	international air transport association

LOx	liquid oxygen
MDP	maximum design pressure
MEOP	maximum expected operating pressure
MLI	multi layer insulation
MMH	monomethyl hydrazine
MON	mixed oxides of nitrogen
MPD	magneto–plasma–dynamic thruster
NDI	non-destructive inspection
NPSP	net positive suction pressure
NTO	nitrogen tetroxide
OBC	on–board computer
OBDH	on–board data handling
ODE	one-dimensional equilibrium
PACT	power augmented catalytic thruster
PCU	power conditioning unit
PED	positive expulsion device
PMD	propellant management device
PPT	pulsed plasma thruster
RAMS	reliability, availability, maintenance and safety
RCS	reaction control system
RFNA	red fuming nitric acid
SRM	solid rocket motor
STD	surface tension device
TBI	through bulkhead initiator
TBPM	to be provided by manufacturer
TBPU	to be provided by user
TCA	thrust chamber assembly
TEG	turbine exhaust gases
TM/TC	telemetry/telecommand
TRL	Technology readiness level
TS	Technical Specification
TVC	thrust vector control
UDMH	unsymmetrical-dimethylhydrazine
VCD	verification control document

3.4 Symbols

The following symbols are defined and used within this Standard:

Symbol	Meaning
a_e	half nozzle cone angle (at exit)
θ	thrust deflection angle (for TVC)
C^*	characteristic velocity
C	discharge coefficient
C_F	thrust coefficient
D	diameter
Δ	increment
F	thrust
f	frequency
F	mixture ratio, ratio of oxidizer and fuel mass flow rate
g_0	standard Earth surface gravity, 9,806 65 m/s ²
h	enthalpy
I_{sp}	specific impulse
k	pressure drop coefficient
L	length
L^*	characteristic length of a combustion chamber
l	correction factor for divergence loss
$\dot{m}$	mass flow rate
M_p	total expelled mass
M_0	initial mass of a propulsion system
M_f	mass of the propulsion system at end of motor operation
n -D	(n is 1,2 or 3) n-dimensional
p_{max}	maximum pressure due to ignition
p_{vap}	vapour pressure
S	surface area or cross section area
σ_N	normal stress at the interface of a bond
T	temperature
T	torque (pumps and turbines)
t_b	burning time
t_i	time at which combustion starts
t_{ign}	ignition time
τ	shear stress at the interface of a bond
ΔV	ideal velocity increment of a rocket delivered in a

	gravitation free environment and without other disturbing forces (drag, solar wind, radiation pressure)
w	rotational speed
()_{eff}	effective

4

Propulsion engineering activities

4.1 Overview

4.1.1 Relationship with other standards

For the propulsion quality assurance system, see ECSS-ST-Q-20.

For safety requirements see ECSS-Q-ST-40.

For mechanical aspects, structural design and verification of pressurized hardware, see ECSS-E-ST-32-02.

For space environment, see ECSS-E-ST-10-04.

For radiation, see ECSS-E-ST-10-12.

For shock, see ECSS-E-ST-32 and ECSS-HB-32-25.

For mechanism, see ECSS-E-ST-33-01, ECSS-E-ST-35-01, ECSS-E-ST-35-02 and ECSS-E-ST-35-03.

For pyrotechnics devices, see ECSS-E-ST-33-11.

4.1.2 Characteristics of propulsion systems

The specification, design and development of a propulsion system should be always done in close collaboration between those responsible for the system and those responsible for the propulsion engineering.

Propulsion systems have the following characteristics:

- They provide the specified thrust.
- They use materials (propellants, simulants and cleaning agents) that can be toxic, corrosive, highly reactive, flammable, and dangerous with direct contact (e.g. causing burns, poisoning, health hazards or explosions). The criteria for the choice and use of material are covered by ECSS-E-ST-32-08.
- Handling, transportation and disposal of dangerous or toxic materials and fluids is subject to strictly applied local regulations.
- Risks (e.g. contamination and leakages) are properly analysed and covered, and RAMS studies are widely performed.
- Rocket engines can be subject to instabilities which can result in damage or loss of the motor or the vehicle. Design and development includes the definition of solutions at the system and vehicle level.

4.2 Mission

- a. The propulsion system shall conform to the mission requirements described in the propulsion system technical specification, including:
 - 1. Ground operations (i.e. functional control, testing, propellant, simulant loading and transportation).
 - 2. Pre-launch and launch activities (i.e. integration, storage, ageing and transport).
 - 3. In-orbit operations (i.e. orbit transfer, orbit maintenance and attitude control) and the complete in-orbit life.
 - 4. Disposal operations.

4.3 Development

- a. The safety requirements shall be specified for the Preliminary Design Review.

NOTE 1 For example, requirements related to risks of human casualties, launch pad destruction, test facility destruction.

NOTE 2 For development phases see ECSS-M-ST-10, Project planning and implementation.

- b. During the development the following shall be established and documented:
 - 1. All characteristics of the system, subsystems and components.
 - 2. The manufacturing and control processes.

NOTE The objective is to reach a product satisfying the maximum product-to-product variation limit, while conforming to the functional, performance and system requirements (see 4.3g).

- c. To establish and freeze the design, the following shall be done:
 - 1. To perform the sizing process.
 - 2. To establish the verification models.
- d. The tests, analysis and engineering activities should cover all possible failure modes.
- e. The characteristics of the propulsion system and its equipment shall be established from analyses, characterization of materials, test results and correlation with models.
- f. The critical technologies, manufacturing and control processes shall be identified, described, justified and subject to a qualification plan.
- g. It shall be analysed that the manufacturing and control processes lead to products that satisfy the required product-to-product deviation limit.

NOTE For complex systems, conformity to this requirement can be demonstrated only after a large number of units are produced.

- h. System verification shall be performed by both analysis and tests.
- i. The level of testing shall be justified and submitted for customer approval.

NOTE The level of testing include:

- The level of configuration: at equipment, subsystem or system level
- The representativeness of the mission and environment constraints
- The representativeness of the propellants

- j. When verification at system level is performed by test, a representative propulsion system, including electrical system, shall be tested in flight conditions or flight representative conditions.
- k. The differences between system test conditions and flight conditions shall be identified, assessed and documented in DJF.
- l. Margins shall be determined and documented.

NOTE Where knowledge of margins cannot be obtained by analyses and standard tests, materials, components and subsystems are submitted to limit testing.

4.4 Propulsion system interfaces

- a. Interface characteristics between the propulsion system and the space vehicle (spacecraft or launch vehicle) shall be accounted for in the requirements for the propulsion system.
- b. Interface characteristics amongst the components, sub-systems and the propulsion system shall be accounted for in the respective requirements.
- c. Interfaces identified in 4.4b shall include:

- 1. Geometry, including the analysis of the dimensions for all phases of life.

NOTE For example, assembly, transport, and flight.

- 2. Mechanical, including induced loads, static and dynamic.
- 3. Fluids, including propellants and venting.
- 4. Thermal boundary conditions.
- 5. Electrical functions, including electrical continuity when applicable.
- 6. Materials.

4.5 Design

4.5.1 General

- a. When developing a product intended for production use, only mature technologies with TRL higher or equal to 5 shall be used.
- b. If requirement 4.5.1a is not met, the technologies with TRL lower than 5 shall:
 - 1. Be subjected to a risk analysis.
 - 2. Lead to a dedicated maturation plan to be applied.
- c. The propulsion system lay-out shall allow the replacement of subsystems
- d. The propulsion system lay-out should allow the replacement of components.
- e. Parts identified as critical shall be made replaceable.

NOTE These are listed as such in the User's Manual.

4.5.2 Global performance

4.5.2.1 Reporting

- a. The supplier shall provide a report for the result of the propulsion performance analysis, in conformance with Annex A.
- b. The supplier shall provide a report for the result of the mathematical modelling for propulsion analysis in conformance with Annex I.

4.5.2.2 Thrust

- a. The thrust history shall be calculated for the whole mission.
- b. The standard deviation of the thrust shall be determined and justified in the report AR-P in conformance with Annex A.

4.5.2.3 The theoretical specific impulse

- a. The calculation of $I_{sp,th}$ of the propulsion system shall include the kinetics, the mixture ratio, the chamber pressure and area ratio.

NOTE Not applicable for EP.

4.5.2.4 The effective specific impulse

- a. All the losses involved in the process shall be analysed and justified in the AR-P in conformance with Annex A.
- b. The calculation of the specific impulse $I_{sp,eff}$ shall include all the losses specified in 4.5.2.4a.

NOTE The effective specific impulse, $I_{sp, eff}$, is the theoretical specific impulse, $I_{sp,th}$, corrected for

all the losses and gains ($I_{sp,eff} = I_{sp,th} - \Sigma \Delta I_{sp}$). According to the definitions of C^*_{eff} and CF_{eff} , the effective specific impulse, $I_{sp,eff}$, can be determined from:

- $I_{sp,eff} = C^*_{eff} \cdot CF_{eff} / g_0$
or

- $I_{sp,eff} = I_{sp,th} \cdot \eta_{Cf} \cdot \eta_{C^*}$

Where η_{Cf} η_{C^*} are respectively the efficiency of Cf and C^* .

- c. The effective specific impulse shall be verified by representative flight condition tests.

4.5.2.5 Masses

- a. The loaded mass, the residual mass, and their standard deviations, shall be determined and justified in the AR-P in conformance with Annex A, for the:
 1. Propellant mass
 2. Auxiliary fluids mass.

4.5.2.6 Mass flow history

- a. The mass flow history shall be calculated for the whole mission.
- b. The standard deviation of the mass flow shall be determined and justified in the report AR-P in conformance with Annex A.
- c. The mass flow shall be verified by representative flight condition tests.

4.5.2.7 Burning time of solid propellant rocket motor

- a. The burning time of a solid propellant rocket motor shall be calculated
- b. The standard deviation of the burning time shall be determined and justified in the report AR-P in conformance with Annex A.

4.5.3 Reference envelope

4.5.3.1 Operational envelope

- a. In the initial design process, an operational envelope shall be defined

NOTE 1 The operational envelope is also called limit envelope.

NOTE 2 This operational envelope is defined in conformance to the spacecraft, stage or launch vehicle requirements.

- b. The propulsion system or subsystem shall be capable to function within the operational envelope specified in 4.5.3.1a.