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Space engineering - Mechanical - Part 5-1: Liquid and electric propulsion for spacecraft

Raumfahrttechnik - Mechanik - Teil 5-1: Antrieb

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Space engineering - Mechanical - Part 5-1: Liquid and electric propulsion for spacecraft

Assurance produits des projets spatiaux - Mécanique - Partie 5-1: Propulsion liquide et électrique pour engins spatiaux

Raumfahrttechnik - Mechanik - Teil 5-1: Antrieb

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Contents

page

Figures

Tables

Foreword

This document (EN 14607-5-1:2004) has been prepared by CMC.

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of an identical text or by endorsement, at the latest by February 2005, and conflicting national standards shall be withdrawn at the latest by February 2005.

It is based on a previous version[1)] prepared by the ECSS Engineering Standards Working Group, reviewed by the ECSS Technical Panel and approved by the ECSS Steering Board. The European Cooperation for Space Standardization (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 document 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.

The formulation of this document takes into account the existing ISO 9000 family of documents.

EN 14607 Space engineering - Mechanical is published in 8 Parts:

- Part 1: Thermal control
- Part 2: Structural
- Part 3: Mechanisms
- Part 4: ECLS
- Part 5: Propulsion
  - Part 5.1: Liquid and electric propulsion for spacecraft
  - Part 5.2: Solid propulsion for spacecraft, solid and liquid propulsion for launchers
- Part 6: Pyrotechnics
- Part 7: Mechanical parts
- Part 8: Materials

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

1) ECSS-E-30 Part 5.1A.

1 Scope

EN 14607 Part 5.1 of Space engineering - Mechanical defined the requirements for the discipline liquid and electric propulsion for spacecraft

This document belongs to the propulsion field of the mechanical discipline, as defined in EN 13292, and defines the regulatory aspects applicable to elements and processes for liquid, including cold gas, and electrical propulsion for spacecraft. It specifies the activities to perform in the engineering of such propulsion systems, their applicability, and defines the requirements for the engineering aspects: functional, configurational, interfaces, physical, environmental, quality factors, operational and verification.

General requirements relating to Mechanical Engineering are defined in EN 14607 Part 1.

This document applies only to liquid, including cold gas, and electrical propulsion systems used in spacecraft and to related mechanical parts. Solid propulsion for spacecraft, and solid and liquid propulsion for launchers are not covered by this document.

Other forms of propulsion currently under development (e.g. nuclear, nuclear-electric, solar-thermal and hybrid propulsion) are not presently covered by this document.

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

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

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 13291-3, *Space product assurance — General requirements — Part 3: Materials, mechanical parts and processes.*

EN 13292:1999, *Space* engineering standards — *Policy and principles.*

EN 13701:2001, *Space systems — Glossary of terms.*

EN 14101:2001, *Space product assurance — Material selection for controlling stress-corrosion cracking.*

EN 14607-1, *Space engineering — Mechanical — Part 1: Thermal control.*

EN 14607-2, *Space engineering — Mechanical — Part 2: Structural.*

EN 14607-6, *Space engineering — Mechanical — Part 6: Pyrotechnics.*

EN 14607-7, *Space engineering — Mechanical — Part 7: Mechanical parts.*

EN 14607-8, *Space engineering — Mechanical — Part 8: Materials.*

EN 14725:2003, *Space engineering — Verification.*

EN 14737-1, *Space engineering — Ground systems and operations — Part 1: Principles and requirements.*

EN 14824, *Space engineering — Testing.*

EN ISO 14620-1, *Space systems — Safety requirements — Part 1: System safety (ISO 14620-1:2002).*

ECSS-E-10, *Space engineering — Systems engineering.*

ECSS-E-20, *Space engineering — Electrical and electronic.*

ECSS-E-50, *Space engineering — Communications.*

ECSS-Q-30, *Space product assurance — Dependability.*

3 Terms and definitions, abbreviated terms and symbols

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in EN 13701:2001 and the following apply.

3.1.1
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 from that thruster exit

3.1.2
chill-down
process of cooling the engine system components before ignition to ensure that the cryogenic propellants enter the boost pumps in their proper state

NOTE On ground, chill-down may be done with dedicated cooling fluids, or with on-board propellants that are vented.

3.1.3
component
smallest individual functional unit considered in a subsystem

EXAMPLE Tanks, valves, regulators.

3.1.4
constraint
characteristic, result or design feature that is made compulsory or is prohibited for any reason

NOTE 1 Constraints are generally restrictions on the choice of solutions in a system

NOTE 2 Two kinds of constraints are considered, those that concern solutions, and those that concern the use of the system.

NOTE 3 For example, constraints can come from environmental and operational conditions, law, standards, market demand, investments and means availability, and organization policy.

3.1.5
contaminant
undesired material present in the propulsion system at any time of its life

3.1.6
de-orbiting
controlled return to Earth or burn-up in the atmosphere of a spacecraft or stage

3.1.7
electric thruster
propulsion device that uses electrical power to generate or increase thrust

3.1.8
external
entity or entities not related to “internal” or “interface”

NOTE See 3.1.14 for internal and 3.1.13 for interface.

3.1.9
graveyard orbit
orbit about 300 km or more above a GEO or GSO into which spent upper stages or satellites are being injected to minimize creation of debris in GEO or GSO

3.1.10
ground support equipment (GSE)
equipment adapted to support verification testing and launch preparation activities on the propulsion system

3.1.11
hypergolic propellants
propellants that spontaneously ignite upon contact with each other

3.1.12
impulse bit
time integral of the force delivered by a thruster during a defined time interval

NOTE It is expressed in Ns.

3.1.13
interface
direct interaction between two or more systems or subsystems

NOTE It is essential that there is a direct interaction.

3.1.14
internal
entity or entities of the system or subsystem itself only

3.1.15
launcher
vehicle intended to move a separate spacecraft from ground to orbit or between orbits

3.1.16
liquid rocket engine
chemical rocket motor using only liquid propellants

NOTE 1 It includes catalytic beds.

NOTE 2 The liquid rocket engine is the main part of a liquid propulsion system.

NOTE 3 A liquid rocket engine comprises

- combustion chamber or chambers;
- nozzle or nozzles;
- a propellant feed system (including injectors; pressure-fed or turbo-pump fed);
- an active or passive coolant system;
- an ignition system (in case of non-hypergolic propellants);
- valves;
- power systems (such as pre-combustion chamber and gas generator), if applicable.

3.1.17
maximum expected operating pressure (MEOP)
maximum expected pressure experienced by the system or components during their nominal life time

NOTE 1 It includes the effects of temperature, vehicle acceleration and relief valve tolerance.

NOTE 2 See 4.2.7 for requirements on MEOP.

3.1.18
minimum impulse bit
smallest impulse delivered by a thruster at a given level of reproducibility as a result of a given command

NOTE It is expressed in Ns.

3.1.19
mission life
life cycle from the delivery to the disposal

NOTE 1 For abbrevity, in this document it is referred to as the mission.

NOTE 2 The mission encompasses the complete life of the propulsion system: delivery, (incoming) inspection, tests, storage, transport, handling, integration, loading, pre-launch activities, launch, in-orbit life and disposal.

3.1.20
nozzle
device to accelerate fluids from a rocket motor to exhaust velocity

3.1.21
plasma
ionized gas

NOTE It contains neutral species, ions and electrons.

3.1.22
pressurant
fluid used to pressurize a system or subsystem

3.1.23
priming
ensuring that the system or subsystem conditions conform to operational conditions

3.1.24
propellant
material or materials that constitute a mass which, often modified from its original state, is ejected at high speed from a rocket engine to produce thrust

NOTE 1 In cold gas engines, the gas is accelerated due to the difference between storage and ambient pressure.

NOTE 2 In chemical rocket engines, either a combustion reaction between two kinds of propellants, fuel and oxidizer, or a decomposition reaction of a monopropellant provides the energy to accelerate the mass.

NOTE 3 In electric engines, either an electromagnetic or an electrostatic field accelerates the mass, which in some cases has been heated to high temperatures or electric heating provides additional energy to accelerate the mass (the latter in the case of power augmented thrusters and resistojets).

NOTE 4 Combinations of the above are possible.

3.1.25
propulsion system
system to provide thrust autonomously

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

NOTE 2 It comprises every component necessary for the fulfilment of the mission, e.g. thrusters, propellants, valves, filters, pyrotechnic devices, pressurisation subsystem, tanks and electrical components such as power sources in case of electrical propulsion.

3.1.26
repeatability
ability to repeat an event with the same input commands

3.1.27
re-orbiting
injection of a spacecraft or stage into a graveyard orbit

3.1.28
simulant
fluid replacing an operational fluid for specific test purposes

NOTE 1 Normally the operational fluid is replaced because it is not or is less suitable for the specific test purposes.

NOTE 2 The simulant is chosen such that the characteristics of the operational fluid whose effects are evaluated in the system, subsystem or component test, are closely approximated by the characteristics of the simulant

3.1.29
sizing
process by which the overall dimensions of a system or subsystem are determined such that the system or subsystem meets the requirements

NOTE At the end of the sizing process, functional and material characteristics are determined as well. The sizing process responds to the functional requirements.

3.1.30
solid rocket motor
chemical rocket motor using only solid propellants

NOTE 1 The solid rocket motor is the main part of a solid propulsion system.

NOTE 2 A solid rocket motor comprises

- a motor case;
- the internal thermal protection system;
- the propellant grain;
- the nozzle or nozzles;
- the igniter.

3.1.31
spacecraft
vehicle purposely delivered by the upper stage of a launcher or transfer vehicle

EXAMPLE Satellite, ballistic probe, re-entry vehicle, space probes, space stations.

3.1.32
specific impulse (I_{SP})
<instantaneous specific impulse>
ratio of thrust to mass flow rate

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

NOTE 1 It is expressed in Ns/kg or m/s.

NOTE 2 In engineering, often another definition is 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} expressed in seconds is obtained by dividing the I_{sp} expressed in m/s by the standard surface gravity, $g_0 = 9{,}80665\ m/s^2$.

3.1.33
subsystem
set of independent elements constituted to achieve a given objective by performing a specific function

NOTE See also EN 13071:2001. For this document, the present definition is used.

3.1.34
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

3.1.35
total impulse
time integral of the force delivered by a thruster or a propulsion system during a given time interval representative for the operation

NOTE It is expressed in Ns.

3.2 Definition of masses

3.2.1
mass
quantity of matter measured in terms of resistance to the acceleration by a force

NOTE Proper definition of masses is extremely important for a correct assessment of the propulsion system performance. This subclause states the terminology on propulsion related masses used in space systems. Such terminology is illustrated in figure 1.

In Tsjolkowski's equation,

$$\Delta V = I_{sp} \times \ln\left(\frac{M_0}{M_f}\right)$$

it is tacitly assumed that all masses leave the propulsion system with the same exhaust velocity.

In reality, launch systems eject masses at different velocities, and in some cases the ejected mass does not contribute at all to the velocity increment according to Tsjolkowski's equation. Examples are: lost oil from TVC systems and propellant used to achieve movements around the CoM (i.e. attitude control). Other mass is ejected at lower exhaust velocities, e.g. mass used for dump cooling, turbine exhaust gases.

Mass

- **Loaded** = Dry mass
  + propellant mass
  + pressurant mass
  + mass of (other) fluids
- **Dry** = Loaded mass without propellants and liquids, inclusive of igniter mass but without igniter propellant, inclusive of gas generator starter mass, but without propellants, inclusive of initiator masses, inclusive of explosive transfer lines
- **End of flight** = Loaded mass – ejected mass
- **Ejected** = Propellant mass (from main combustion chamber at nominal I_{sp})
  + mass used for dump cooling (at different I_{sp})
  + mass of turbine exhaust gases (at different I_{sp})
  + propellant mass used for attitude control
  + jettisoned mass consisting of:
    Instantaneously jettisoned mass:
    - Burst membrane, Igniter (consumable)
    Continuously jettisoned mass:
    - Thermal protection, nozzle erosion, grid erosion, igniter consumption (ablation/erosion), vented propellant, TVC lost oil
- **Propellant** = Mass of main propellant
  + mass of igniter and gas generator propellants (if ejected)
  + mass of propellant for attitude control

Figure 1 — Definition of propulsion-related masses

3.2.2
loaded mass
mass of a system just before the activation of the propulsion system

3.2.3
end of flight mass
mass of a system directly after the end of the propulsion system operation

NOTE End of flight mass = loaded mass - ejected masses.

3.2.4
dry mass
1. loaded mass without consumables, or

2. initial mass without propellants and fluids

NOTE 1 Dry mass can be weighed. Warning: explosive transfer lines and pyro valves usually are sealed, so that even when the explosive is consumed, they are not ejected from the system.

NOTE 2 Usually, initiators are considered part of the dry mass, as the mass of the explosive that leaves the propulsion system is negligible; initiators are mounted as conventional mechanical equipment.

NOTE 3 For solid propulsion systems, launchers and stages, it is defined as the initial mass without propellant mass (i.e. grains and igniter grains), which is equivalent to the one used in this document.

3.2.5
ejected mass
sum of the consumed propellant mass, the ejected pressurant gases, the instantaneously jettisoned masses and continuously jettisoned masses

NOTE 1 Not all propellants are ejected with the same velocity.

NOTE 2 Example of consumed pressurant gases is the pressurant gas sometimes ejected by spacecraft operating in blow-down mode.

NOTE 3 Examples of instantaneously jettisoned masses are burst membranes and consumable igniters.

NOTE 4 Examples of continuously jettisoned masses are erosion and ablation products, and lost oil from TVC systems.

3.2.6
propellant mass
sum of the masses of the main propellant, the gas generator and starter propellants, the propellants for attitude control and the igniters propellants

NOTE Note that some of these propellants do not contribute to a velocity increment of the propulsion system.

3.3 Abbreviated terms

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

Abbreviation	Meaning
AIT	assembly, integration and test
AOCS	attitude and orbit control system
BOL	beginning-of-life
CoM	centre of mass
DCG	document content's guideline
DRD	document requirements definition
DRL	document requirements list
EMC	electromagnetic compatibility
EMI	electromagnetic interference
EOL	end-of-life
FEEP	field emission electric propulsion
FOS	factor of safety
GEO	geostationary orbit
GSE	ground support equipment
GSO	geo-synchronous orbit
MDP	maximum design pressure
MEOP	maximum expected operating pressure