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Second edition
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Space systems — Measured parameters at firing bench and flight tests of liquid rocket engines

Systèmes spatiaux — Paramètres mesurés au banc d'allumage et essais de vol des moteurs à propergol liquide

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ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Email: copyright@iso.org
Website: www.iso.org

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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This document was prepared by Technical Committee ISO/TC 20, *Aircraft and space vehicles*, Subcommittee SC 14, *Space systems and operations*.

This second edition cancels and replaces the first edition (ISO 16694:2015), which has been technically revised.

The main changes are as follows:

— Clauses 4 and 5 are amended;

— the list of measured parameters is expanded;

— in Tables 1 and 3, the parameter “…pressure pulsation…” is split into two parameters: “…vibration amplitude…” and “…vibration frequency…”; the parameter “vibro-overloads…” is split into “vibration acceleration amplitude…” and “vibration acceleration frequency…”;

— certain parameters are moved from the category “mandatory parameters” to the category “optional”;

— superscripts and subscripts of parameter "Letter symbols" are corrected.

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

The document provides users, designers, and manufacturers of liquid rocket engines with requirements and guidance for parameters, measured during firing bench and flight tests. Parameters to be measured are used for reliability analysis and quality control of liquid rocket engines.

The parameters listed in the document characterize performance of liquid rocket engines and they are used to evaluate the technical condition of engines (operable, inoperable), their conformity with the specified requirements and whether engines are available to be delivered to a user and put into operation. ISO 15865 is used to assess conformity of liquid rocket engines to the specified requirements.

Uniform requirements for the parameters, measured during firing bench and flight tests of liquid rocket engines, ensure the following:

— quality and reliability of developed and operated liquid rocket engines;

— comparison of liquid rocket engine test results;

— end product safety and environmental protection.

The engine developer may identify an additional list of measured parameters for specific items, taking into account their design features.

This document makes it possible to develop uniform criteria for performance evaluation and comparison of liquid rocket engines, created by different countries, based on firing bench and flight tests results.

Space systems — Measured parameters at firing bench and flight tests of liquid rocket engines

1 Scope

This document specifies requirements for the list of parameters, measured during firing bench and flight tests. The requirements of the document apply to all the types of expendable liquid rocket engines supplied to the user:

a) operating on all types of propellant (including cryogenic);

b) with afterburning (with gradual burning) and without afterburning (without gradual burning);

c) low-thrust engines: one component (monopropellant) and two-component (bipropellant);

d) with a single firing or multiple firings.

The document doesn't specify firing bench test preparation and testing procedure, methods of test results processing and analysis, or requirements to measurement accuracy.

The document specifies mandatory and optional parameters.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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.

ISO 15864, *Space systems — General test methods for spacecraft, subsystems and units*

ISO 24917, *Space systems — General test requirements for launch vehicles*

3 Terms and definitions

No terms and definitions are listed in this document.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

4 Abbreviated terms

AVR	apparent velocity regulator
BTP	booster turbo pump
CFC	component-flow controller
CPT	certification periodic test
DD	design documentation

EV	electric valve
FCR	controller of the propellants ratio in a combustion chamber
IpCT	in-process control test
LV	launch vehicle
LRE	liquid rocket engine
LTE	low thrust engine
PA	pressure alarm
QT	qualification test
R&D	research and development
SC	spacecraft
SPT	special periodic test
TDS	tank depletion system
TP	turbopump

5 General

5.1 The main purpose of LRE and LTLRE parameters measurement while performing ground and flight tests is to obtain information for assessment of parameter conformity to DD requirements, reliability and quality analysis of supplied engines.

5.2 Parameters, which should be measured during fire bench and flight tests of LRE, and to which requirements of this document are applied, fall into the following groups:

a) parameters, characterizing test environment (5.3, 5.4);

b) main parameters (5.5);

c) key performance parameters (5.6);

d) parameters, characterizing the engine ability to operate without any degradation (5.7).

5.3 Parameters, characterizing test environment, include:

a) parameters of natural and artificial environmental impacts;

b) propellants status before and during tests.

5.4 Parameters, characterizing test environment, are used to evaluate conformity of physical environment and propellants status before and during tests to the requirements of the test specification, and ensure that the corrected characteristics of an engine (thrust, specific impulse) are identified.

5.5 Main parameters define how the engine performs the specified functions; and they are set by technical documentation requirements of the engine developer.

5.6 Key performance parameters characterize the engine performance and define whether a test is passed or not. Key performance parameters may be obtained either directly from measurements or from calculations. The parameters shall comply with DD requirements of the engine developer.

5.7 Parameters, characterizing the engine ability to operate without any degradation, are used to control the engine health by estimating values of loads, which act on the engine's assemblies.

This group comprises parameters, whose values cannot be determined directly by measurements, taken during assembly manufacturing process. Among these parameters are particularly ones, characterizing vibration strength and heat-resistance of the combustion chamber and the gas generator and stability of the assemblies operating process. In case of emergency, these parameters (together with the main parameters and parameters, characterizing test conditions) are used to analyse causes of emergency.

5.8 It is recommended to use sensors of the same type to measure similar parameters during static fire and flight tests.

6 List of parameters, measured during LRE tests

6.1 General

Parameters, measured during firing bench and flight tests of the engine, are summarized in the corresponding tables.

Static fire tests of launch vehicles shall be conducted in accordance with the general requirements in ISO 24917.

Goals and objectives of flight tests shall be as specified in ISO 15864.

Depending on their importance, parameters, measured during an engine test, fall into the following groups:

a) mandatory;

b) optional;

c) interchangeable.

The term "optional parameter" means (in cases, when a corresponding assembly or a unit is a part of the engine) that, according to the approved decision of a liquid engine developer, its measurement is not mandatory, as opposed to a mandatory parameter, which shall be measured and recorded.

Additions may be made to the set of parameters, which are measured during LRE QT, in accordance to the QT program, agreed upon with the engine developer.

The "Comment" column provides required clarifications and additions to certain parameters.

6.2 List of parameters, measured during LRE firing bench test

The list of optional and mandatory parameters to be measured during in-process control test, certification periodic test and special periodic test (IpCT, CPT and SPT) of LRE is provided in Table 1.

Table 1 — Parameters, measured during IpCT, CPT, SPT

	LRE type						Comment
	Letter symbol	Measurement unit	Without afterburning		With afterburning		
			For LV	For SC	For LV	For SC	
1 Parameters, characterizing test environment							
1.1 Ambient pressure	P_{amb}	kPa	**O**	**O**	**O**	**O**	
1.2 Ambient temperature	T_{amb}	K (°C)	**O**	**O**	**O**	**O**	
1.3 Ambient humidity	H_{amb}	%	**Δ**	**Δ**	**Δ**	**Δ**	
1.4 Air flows direction and speed	W	m/s	**Δ**	**Δ**	**Δ**	**Δ**	
1.5 Propellants temperature at flow sensor locations and at the engine inlet	t^{p}_{inlet}	K (°C)	**O**	**O**	**O**	**O**	
1.6 Propellants density (except cryogenic)	ρ	kg/m^3	**O**	**O**	**O**	**O**	
1.7 Dissolved gases content in propellants when performing tests with forced gas saturation	v^{gas}_{p}	%	**O**	**O**	**O**	**O**	
1.8 Propellants pressure at the engine inlet	P^{ox}_{inlet} P^{fuel}_{inlet}	mPa (kgf/cm^2)	**X$_{4.10}$**	**X$_{4.10}$**	**X$_{4.10}$**	**X$_{4.10}$**	Sensors are used, which make it possible to measure pressure during transient processes: at start and during the change of the engine operating mode
2 Main parameters							
2.1 LRE thrust	R	N (kgf)	**O**	**O**	**O**	**O**	
2.2 Mass outflow of oxidizer and fuel through the engine per second	$\dot{m}_{ox}$ $\dot{m}_{f}$	kg/s	**O**	**O**	**O**	**O**	
2.3 Mass outflow of oxidizer and fuel through the engine chamber nozzle per second	$\dot{m}_{ox.n}$ $\dot{m}_{f.n}$	kg/s	**O**	**O**	**O**	**O**	
2.4 Fuel pressure upstream of the chamber injectors	$P_{f.A}$	mPa (kgf/cm^2)	**O**	**O**	**O**	**O**	Sensors are used, which make it possible to measure pressure for parameters 2.4 to 2.7 during transient processes: at start and during the change of the engine operating mode
2.5 Oxidizer pressure upstream of the chamber injectors	$P_{ox.A}$	mPa (kgf/cm^2)	**O**	**O**	**O**	**O**	For LRE without afterburning

Key

O — mandatory parameter

• — parameter measurement is not regulated by the document

Δ — optional parameter

X$_m$ — interchangeable parameter subject to mandatory measurement, where m is the numerical order of a parameter in the corresponding table, which can be used instead of the parameter, specified in parameter m in this table

Parameters, which characterize test environment, shall be measured before the engine is fired.

NOTE 1 Certain parameters, specified in the parameter table, can be controlled by measuring other parameters, specified in DD, if the customer is satisfied with control accuracy.

NOTE 2 Such parameters as pressure upstream(downstream) of PA, FCR, CFC, TDS are to be measured if the specified parameters are necessary to determine the estimated values of the main (specified) LRE characteristics.

NOTE 3 When performing test of cryogenic engines, in addition parameters are measured, which characterize the aggregate state of propellants (temperature, pressure).

Table 1 *(continued)*

	LRE type						Comment
	Letter symbol	Measurement unit	Without afterburning		With afterburning		
			For LV	For SC	For LV	For SC	
2.6 Gas medium pressure upstream of the chamber injectors	$P_{\text{gm c.inj}}$	mPa (kgf/cm^2)	O	O	O	O	For LRE with afterburning
2.7 Combustion chamber pressure	$P_{\text{c.c}}$	mPa (kgf/cm^2)	O	O	O	O	
2.8 Run-up time of heat exchangers, which are used to heat tank pressurization gases	$T_{\text{p.g.}}$	s	O	O	O	O	
2.9 Pressurizing gases pressure	$P_{\text{p.g.}}$	mPa (kgf/cm^2)	O	O	O	O	If the tank pressurization elements, heat exchanger elements are available
2.10 Pressurizing gases flow rate	$\dot{m}_{\text{p.g.}}$	kgf	O	O	O	O	If the tank pressurization elements, heat exchanger elements are available
2.11 Pressurizing gases temperature	$T_{\text{p.g.}}$	K (°C)	O	O	O	O	If pressurization elements are available
2.12 Positions of flow regulators drives, operating mode	$\phi_{\text{r.d}}$	radian	O	O	O	O	If the flow regulators drives are available
2.13 Position of mixture ratio throttle drives	$\phi_{\text{t.d}}$	radian	O	O	O	O	If the throttle drives are available
3 Key performance parameters							
3.1 Nominal engine thrust run-up	$T_{\text{run-up.nom.}}$	s	O	O	O	O	% of nominal thrust is specified by the engine developer
3.2 Engine specific impulse: — in vacuum; — on the ground	$I_{\text{spec.vac}}$ $I_{\text{spec.gr}}$	m/s	O	O	O	O	
3.3 Adjustment accuracy for propellants mass flow rate ratio	δC_{f}	%	O	O	O	O	
3.4 Adjustment accuracy for chamber pressure	δP_{c}	%	O	O	O	O	
3.5 Starting gradient of engine thrust change	V_{start}	N/s	O	O	O	O	The LV developer decides, whether maximum or average *gradient* is applied
3.6 Cutoff gradient of engine thrust change	V_{cutoff}	N/s	O	O	O	O	The LV developer decides, whether maximum or average *gradient* is applied

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NOTE 2 Such parameters as pressure upstream(downstream) of PA, FCR, CFC, TDS are to be measured if the specified parameters are necessary to determine the estimated values of the main (specified) LRE characteristics.

NOTE 3 When performing test of cryogenic engines, in addition parameters are measured, which characterize the aggregate state of propellants (temperature, pressure).

Table 1 *(continued)*

	LRE type						Comment
	Letter symbol	Measurement unit	Without afterburning		With afterburning		
			For LV	For SC	For LV	For SC	
3.7 Time difference between engines run-ups	τ_{en}^{td}	s	Δ	Δ	Δ	Δ	The LV developer decides, whether this parameter needs to be applied
3.8 Temperature of the oxidizer tank pressurizing gas	$T_{o.t.p}^{gas}$	K (°C)	O	O	O	O	
3.9 Temperature of the fuel tank pressurizing gas	$T_{f.t.p}^{gas}$	K (°C)	O	O	O	O	
4 Parameters, characterizing the engine ability to operate without any degradation							
4.1 Oxidizer pressure at the pump outlet	$P_{p.out.}^{ox}$	mPa (kgf/cm^2)	O	O	O	O	
4.2 Fuel pressure at the pump outlet	$P_{p.out}^{f}$	mPa (kgf/cm^2)	$X_{4.7}$	$X_{4.7}$	$X_{4.7}$	$X_{4.7}$	
4.3 Oxidizer pressure at the booster pump outlet	$P_{bp.out}^{ox}$	mPa (kgf/cm^2)	Δ	Δ	Δ	Δ	
4.4 Fuel pressure at the booster pump outlet	$P_{bp.out}^{f}$	mPa (kgf/cm^2)	Δ	Δ	Δ	Δ	
4.5 Gas pressure in the gas generator	P_{gg}	mPa (kgf/cm^2)	O	O	O	O	Parameter 4.5 is to be measured, when performing CPT of engines without afterburning, provided that the engine design allows for installation of respective sensors
4.6 Combustion starter chamber pressure	$P_{ch.cs}$	mPa (kgf/cm^2)	Δ	Δ	Δ	Δ	For engines, which are started, using a pyrotechnic device
4.7 Steering actuators inlet pressure	$P_{s.a}$	mPa (kgf/cm^2)	$X_{4.2}$	$X_{4.2}$	$X_{4.2}$	$X_{4.2}$	Steering actuator is a device, designed to provide engine chambers gimbaling and thrust vector control
4.8 Gas pressure at the turbine outlet	$P_{t.out}$	mPa (kgf/cm^2)	Δ	Δ	Δ	Δ	
4.9 Gas pressure in tank pressurization system	$P_{t.p}$	mPa (kgf/cm^2)	$X_{1.8}$	$X_{1.8}$	$X_{1.8}$	$X_{1.8}$	Parameter 4.9 is applicable to the gas-generating tank pressurization systems
4.10 Pressure drop at the propellants flow rate controller	$\Delta P_{fl.r.c}$	mPa (kgf/cm^2)	Δ	Δ	Δ	Δ	

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Parameters, which characterize test environment, shall be measured before the engine is fired.

NOTE 1 Certain parameters, specified in the parameter table, can be controlled by measuring other parameters, specified in DD, if the customer is satisfied with control accuracy.

NOTE 2 Such parameters as pressure upstream(downstream) of PA, FCR, CFC, TDS are to be measured if the specified parameters are necessary to determine the estimated values of the main (specified) LRE characteristics.

NOTE 3 When performing test of cryogenic engines, in addition parameters are measured, which characterize the aggregate state of propellants (temperature, pressure).

Table 1 *(continued)*

	LRE type						Comment
	Letter symbol	Measurement unit	Without afterburning		With afterburning		
			For LV	For SC	For LV	For SC	
4.11 Driving pressure in control assemblies	$P_{\mathbf{contr}}$	mPa (kgf/cm^2)	**O**	**O**	**O**	**O**	
4.12 Pressure vibration amplitude upstream of The chamber fuel injectors	$A^{\text{fuel}}_{\text{inj.c}}$	mPa (kgf/cm^2)	**Δ**	**Δ**	**Δ**	**Δ**	Parameters 4.12, 4.13 under CPT of engines without afterburning are to be measured, if the engine design allows for installation of respective sensors
4.13 Pressure vibration frequency upstream of the chamber fuel injectors	$f^{\text{fuel}}_{\text{inj.c}}$	Hz	**Δ**	**Δ**	**Δ**	**Δ**	
4.14 Pressure vibration amplitude upstream of the chamber oxidizer injectors	$A^{\text{ox}}_{\text{inj.c}}$	mPa (kgf/cm^2)	**Δ**	**Δ**	**Δ**	**Δ**	Parameters 4.14 and 4.15 under CPT of engines without afterburning are to be measured, if the engine design allows for installation of respective sensors
4.15 Pressure vibration frequency upstream of the chamber oxidizer injectors	$f^{\text{ox}}_{\text{inj.c}}$	Hz	**Δ**	**Δ**	**Δ**	**Δ**	
4.16 Pressure vibration amplitude upstream of the gas-generating fuel injectors	$A^{\text{f}}_{\text{inj.gg}}$	mPa (kgf/cm^2)	**Δ**	**Δ**	**Δ**	**Δ**	
4.17 Pressure vibration frequency upstream of the gas-generating fuel injectors	$f^{\text{f}}_{\text{inj.gg}}$	Hz	**Δ**	**Δ**	**Δ**	**Δ**	
4.18 Pressure vibration amplitude upstream of the gas-generating oxidizer injectors	$A^{\text{fox}}_{\text{inj.gg}}$	mPa (kgf/cm^2)	**Δ**	**Δ**	**Δ**	**Δ**	
4.19 Pressure vibration frequency upstream of the gas-generating oxidizer injectors	$f^{\text{ox}}_{\text{inj.gg}}$	Hz	**Δ**	**Δ**	**Δ**	**Δ**	
4.20 Pressure vibration amplitude in the combustion chamber and in the gas generator	$A_{\mathbf{cc}}$ A_{gg}	(kgf/cm^2)	**Δ**	**Δ**	**Δ**	**Δ**	
4.21 Pressure vibration frequency in the combustion chamber and in the gas generator	$F_{\mathbf{cc}}$ F_{gg}	Hz	**Δ**	**Δ**	**Δ**	**Δ**	
4.22 Propellants pressure vibration amplitude at the engine inlet	$A^{\text{p}}_{\text{en.inlet}}$	mPa (kgf/cm^2)	**Δ**	**Δ**	**Δ**	**Δ**	
4.23 Propellants pressure frequency amplitude at the engine inlet	$f^{\text{p}}_{\text{en.inlet}}$	Hz	**Δ**	**Δ**	**Δ**	**Δ**	

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NOTE 1 Certain parameters, specified in the parameter table, can be controlled by measuring other parameters, specified in DD, if the customer is satisfied with control accuracy.

NOTE 2 Such parameters as pressure upstream(downstream) of PA, FCR, CFC, TDS are to be measured if the specified parameters are necessary to determine the estimated values of the main (specified) LRE characteristics.

NOTE 3 When performing test of cryogenic engines, in addition parameters are measured, which characterize the aggregate state of propellants (temperature, pressure).

Table 1 *(continued)*

	LRE type						Comment
	Letter symbol	Measurement unit	Without afterburning		With afterburning		
			For LV	For SC	For LV	For SC	
4.24 Engine chamber vibration acceleration amplitude in the plane, parallel to the assembly main axis	$A^{e.c}_{par.}$	m/s^2 (g)	**X**$_{4.26}$	**X**$_{4.26}$	**X**$_{4.26}$	**X**$_{4.26}$	For newly developed LRE, decision on whether measurement of parameters 4.24-4.35 is mandatory, is based on R&D results
4.25 Engine chamber vibration acceleration frequency in the plane, parallel to the assembly main axis	$f^{e.c}_{par}$	Hz	**X**$_{4.27}$	**X**$_{4.27}$	**X**$_{4.27}$	**X**$_{4.27}$	
4.26 Engine chamber vibration acceleration amplitude in the plane, normal to the assembly main axis	$A^{e.c}_{norm}$	m/c^2 (g)	**X**$_{4.24}$	**X**$_{4.24}$	**X**$_{4.24}$	**X**$_{4.24}$	
4.27 Engine chamber vibration acceleration frequency in the plane, normal to the assembly main axis	$f^{e.c}_{norm}$	Hz	**X**$_{4.25}$	**X**$_{4.25}$	**X**$_{4.25}$	**X**$_{4.25}$	
4.28 Gas generator vibration acceleration amplitude in the plane, parallel to the assembly main axis	A^{gg}_{par}	m/s^2 (g)	**Δ**	**Δ**	**Δ**	**Δ**	
4.29 Gas generator vibration acceleration frequency in the plane, parallel to the assembly main axis	f^{gg}_{par}	Hz	**Δ**	**Δ**	**Δ**	**Δ**	
4.30 Gas generator vibration acceleration amplitude in the plane, normal to the assembly main axis	A^{gg}_{nor}	m/s^2 (g)	**Δ**	**Δ**	**Δ**	**Δ**	
4.31 Gas generator vibration acceleration frequency in the plane, normal to the assembly main axis	f^{gg}_{nor}	Hz	**Δ**	**Δ**	**Δ**	**Δ**	
4.32 Turbopump vibration acceleration amplitude in the plane, parallel to the assembly main axis	A^{tp}_{par}	m/s^2 (g)	**Δ**	**Δ**	**Δ**	**Δ**	
4.33 Turbopump vibration acceleration frequency in the plane, parallel to the assembly main axis	f^{tp}_{par}	Hz	**Δ**	**Δ**	**Δ**	**Δ**	
4.34 Turbopump vibration acceleration amplitude in the plane, normal to the assembly main axis	A^{tp}_{nor}	m/s^2 (g)	**Δ**	**Δ**	**Δ**	**Δ**	
4.35 Turbopump vibration acceleration frequency in the plane, normal to the assembly main axis	f^{tp}_{nor}	Hz	**Δ**	**Δ**	**Δ**	**Δ**	
4.36 Vibration acceleration amplitude on the engine bed at the point of its attachment to the movable stand bed in the plane, parallel to the engine axis	$A^{en.b}_{par}$	m/s^2 (g)	**O**	**O**	**O**	**O**	

Key

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Parameters, which characterize test environment, shall be measured before the engine is fired.

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NOTE 2 Such parameters as pressure upstream(downstream) of PA, FCR, CFC, TDS are to be measured if the specified parameters are necessary to determine the estimated values of the main (specified) LRE characteristics.

NOTE 3 When performing test of cryogenic engines, in addition parameters are measured, which characterize the aggregate state of propellants (temperature, pressure).

Table 1 *(continued)*

	LRE type						Comment
	Letter symbol	Measurement unit	Without afterburning		With afterburning		
			For LV	For SC	For LV	For SC	
4.37 Vibration acceleration frequency on the engine bed at the point of its attachment to the movable stand bed in the plane, parallel to the engine axis	$f_{par}^{en.b}$	Hz	O	O	O	O	
4.38 Vibration acceleration amplitude on the engine bed at the point of its attachment to the movable stand bed in the plane, normal to the engine axis	$A_{nor}^{en.b}$	m/s^2 (g)	O	O	O	O	
4.39 Vibration acceleration frequency on the engine bed at the point of its attachment to the movable stand bed in the plane, normal to the engine axis	$f_{nor}^{en.b}$	Hz	O	O	O	O	
4.40 Gas temperature at the gas generator outlet (upstream of the turbine inlet)	$T_{gg.outlet}$	K (°C)	Δ	Δ	Δ	Δ	Parameter 4.40 under CPT for engines without afterburning is to be measured, if the engine design allows for installation of respective sensors
4.41 Gas temperature in the injector cavity of the combustion chamber (downstream of the turbine)	$T_{injc.cc}^{gas}$	K (°C)	•	•	Δ	Δ	For engines without afterburning parameter 4.41 is not to be measured
4.42 Temperature of propellant cooling component upstream of the combustion chamber injectors	T_{cool}	K (°C)	Δ	Δ	Δ	Δ	
4.43 Propellant temperature at the inlet of steering actuators	$T_{st.inlet}^{p}$	K (°C)	Δ	Δ	Δ	Δ	
4.44 Temperature of engine structural elements under the heat-shielding material in the area of heat flows impact	$T_{under.hs}^{en.el}$	K (°C)	O	Δ	O	Δ	
4.45 Temperature of engine structural elements under thermal conditioning	$T_{thermal}^{en.el}$	K (°C)	O	O	O	O	
4.46 Gas temperature in the tank pressurization system	$T_{t.p}^{gas}$	K (°C)	O	O	O	O	Parameter 4.46 is applicable to the gas-generating tank pressurization systems

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Table 1 *(continued)*

	LRE type						Comment
	Letter symbol	Measurement unit	Without afterburning		With afterburning		
			For LV	For SC	For LV	For SC	
4.47 Fuel flow rate through the gas generator	$\dot{m}_{gg}^{f}$	kg/c	Δ	Δ	Δ	Δ	Parameters 4.47, 4.48 are to be measured, if the engine design allows for installation of flow meters with adequate accuracy
4.48 Oxidizer flow rate through gas generator	$\dot{m}_{gg}^{ox}$	kg/c	Δ	Δ	Δ	Δ	
4.49 Propellant flow rate through the propellant flow controller	$\dot{m}_{fr.c}^{p}$	kg/c	Δ	Δ	Δ	Δ	
4.50 TP rotor shaft speed	n_{tp}	c^{-1} (r/min)	O	O	O	O	
4.51 BTP rotor shaft speed	n_{btp}	c^{-1} (r/min)	Δ	Δ	Δ	Δ	
4.52 Angle of rotation of the AVR and FCR system drive	φ_{avr} φ_{fcr}	radian	O	O	O	O	
4.53 Angle of the TDS throttle rotation	ϕ_{TDS}	radian	O	O	O	O	
4.54 Angle of the engine steerable chambers rotation	$\phi_{s.c}$	radian	O	O	O	O	
4.55 Force at the actuators of the engine tilting chamber	$F_{t.ch}^{act}$	N $(m \cdot kg / s^2)$	Δ	Δ	Δ	Δ	
4.56 Lateral force	F_{l}	N $(m \cdot kg / s^2)$	$X_{4.57}$	$X_{4.57}$	$X_{4.57}$	$X_{4.57}$	For engines with gas injection into the combustion chamber
4.57 Pressure of the gas, injected into the combustion chamber	$P_{c.c}^{i.g}$	mpa (kgf/cm^2)	$X_{4.56}$	$X_{4.56}$	$X_{4.56}$	$X_{4.56}$	
4.58 Fuel flow continuity upstream of the pump	ρ_{f}	%	Δ	Δ	Δ	Δ	
4.59 Oxidizer flow continuity upstream of the pump	ρ_{ox}	%	Δ	Δ	Δ	Δ	
4.60 Engine firing interval	τ_{en}	s	O	O	O	O	

Key

O — mandatory parameter

• — parameter measurement is not regulated by the document

Δ — optional parameter

X_m — interchangeable parameter subject to mandatory measurement, where *m* is the numerical order of a parameter in the corresponding table, which can be used instead of the parameter, specified in parameter *m* in this table

Parameters, which characterize test environment, shall be measured before the engine is fired.

NOTE 1 Certain parameters, specified in the parameter table, can be controlled by measuring other parameters, specified in DD, if the customer is satisfied with control accuracy.

NOTE 2 Such parameters as pressure upstream(downstream) of PA, FCR, CFC, TDS are to be measured if the specified parameters are necessary to determine the estimated values of the main (specified) LRE characteristics.

NOTE 3 When performing test of cryogenic engines, in addition parameters are measured, which characterize the aggregate state of propellants (temperature, pressure).

Table 2 provides additional parameters, measured during qualification test (QT), if they are stipulated in the QT program.

Table 2 — Parameters, measured during the qualification test

Parameter title	LRE type						Comment
	Letter symbol	Measurement unit	Without afterburning		With afterburning		
			For LV	For SC	For LV	For SC	
1 Auxiliary gas pressure during the engine test bench run	$P_{aux.g}$	mPa (kgf/cv^2)	Δ	Δ	Δ	Δ	
2 Vibration acceleration amplitude on the engine bed at the point of its attachment to the movable stand bed in the plane, parallel to the engine axis	$A_{par}^{en.b}$	m/s^2 (g)	O	O	O	O	
3 Vibration acceleration frequency on the engine bed at the point of its attachment to the movable stand bed in the plane, parallel to the engine axis	$f_{par}^{en.b}$	Hz	O	O	O	O	
4 Vibration acceleration amplitude on the engine bed at the point of its attachment to the movable stand bed in the plane, normal to the engine axis	$A_{nor}^{en.b}$	m/s^2 (g)	O	O	O	O	
5 Vibration acceleration frequency on the engine bed at the point of its attachment to the movable stand bed in the plane, normal to the engine axis	$f_{nor}^{en.b}$	Hz	O	O	O	O	
Key Δ — optional parameter O — mandatory parameter							

6.3 List of parameters, measured during LRE flight test

The list of parameters to be measured during LRE flight test is provided in Table 3.

Table 3 — Parameters, measured during the flight test

Parameter title	LRE type						Comment
	Letter symbol	Measurement unit	Without afterburning		With afterburning		
			For LV	For SC	For LV	For SC	
1 Parameters, characterizing test environment							
1.1 Ambient pressure	P_{amb}	kPa	•	•	•	•	
1.2 Ambient temperature	T_{amb}	K (°C)	•	•	•	•	
1.3 Ambient humidity	H_{amb}	%	•	•	•	•	
1.4 Air flows direction and speed	W	m/s	O	O	O	O	
1.5 Propellants temperature in flow sensor locations and at the engine inlet	t_{inlet}^{p}	K *(°C)*	O	O	O	O	
1.6 Propellant components density (except cryogenic)	ρ	kg/m^3	O	O	O	O	
Key O — mandatory parameter • — parameter measurement is not regulated by the document Δ — optional parameter X_m — interchangeable parameter subject to mandatory measurement, where m is the numerical order of a parameter in the corresponding table, which can be used instead of the parameter, specified in parameter m in this table Parameters that characterize test environment shall be measured before the LV launch.							

Table 3 *(continued)*

Parameter title	LRE type						Comment
	Letter symbol	Measurement unit	Without afterburning		With afterburning		
			For LV	For SC	For LV	For SC	
1.7 Propellants pressure at the engine inlet	P^{p}_{inlet}	mPa (kgf/cm^2)	$X_{4.7}$	$X_{4.7}$	$X_{4.7}$	$X_{4.7}$	
2 Main parameters							
2.1 Propellants mass outflow through the engine per second	m_{ox} m_f	kgf	Δ	O	Δ	O	
2.2 Propellants mass outflow through the engine nozzle per second	$m_{ox.n}$ $m_{f.n}$	kgf	Δ	O	Δ	O	
2.3 Combustion chamber pressure	$P_{c.c}$	mPa (kgf/cm^2)	$X_{4.4}$	$X_{4.4}$	$X_{4.4}$	$X_{4.4}$	
2.4 Run-up time of heat exchangers, which are used to heat tank pressurization gases	$\tau^{run-up}_{t.p}$	s	O	O	O	O	
3 Key performance parameters							
3.1 Nominal engine thrust run-up	$T_{tun-up\ nom.}$	c	O	O	O	O	% of nominal thrust is specified by the engine developer
3.2 Specific impulse in vacuum	$I_{spec.vac}$	m/s	O	O	O	O	
3.3 Adjustment accuracy for the propellants mass flow rate ratio	δK_m	%	O	O	O	O	
3.4 Adjustment accuracy for the chamber pressure	δP_c	%	O	O	O	O	
3.5 Starting gradient of the engine thrust change	V_{start}	N/m	O	O	O	O	The LV developer decides, whether maximum or average gradient is applied
3.6 Cut-off gradient of the engine thrust change	$V_{cut-off}$	N/m	O	O	O	O	The LV developer decides, whether maximum or average gradient is applied
3.7 Time difference between engine run-ups	τ^{td}_{en}	s	Δ	Δ	Δ	Δ	The LV developer decides, whether this parameter needs to be applied
3.8 Temperature of the oxidizer tank pressurizing gas	$T^{gas}_{o.t.p}$	K (°C)	O	O	O	O	
3.9 Temperature of the fuel tank pressurizing gas	$T^{Газа}_{f.t.p}$	K (°C)	O	O	O	O	
4 Parameters, characterizing the engine ability to operate without any degradation							
4.1 Oxidizer pressure at the pump outlet	$P^{ox}_{p.out.}$	mPa (kgf/cm^2	O	O	O	O	
4.2 Fuel pressure at the pump outlet	$P^{f}_{p.outlet}$	mPa (kgf/cm^2)	O	O	O	O	
4.3 Gas pressure in the gas generator	P^{gas}_{gg}	mPa (kgf/cm^2)	Δ	Δ	Δ	Δ	

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Parameters that characterize test environment shall be measured before the LV launch.

Table 3 *(continued)*

Parameter title	LRE type						Comment
	Letter symbol	Measurement unit	Without afterburning		With afterburning		
			For LV	For SC	For LV	For SC	
4.4 Propellants (gas) pressure upstream of the combustion chamber injectors	$P^{\mathbf{f}}_{\mathbf{inj.cc}}$	mPa (kgf/cm^2)	$\mathbf{X_{2.3}}$	$\mathbf{X_{2.3}}$	$\mathbf{X_{2.3}}$	$\mathbf{X_{2.3}}$	
4.5 Combustion starter chamber pressure	$P_{\text{c.s.ch}}$	mPa (kgf/cm^2)	Δ	Δ	Δ	Δ	Parameter 4.5 is applicable to the engines, which are fired, using a starter system
4.6 Propellants pressure at the steering actuators inlet	$P^{\text{p}}_{\text{act.inlet}}$	mPa (kgf/cm^2)	Δ	Δ	Δ	Δ	
4.7 Pressure of the tank pressurizing gases	$P_{\text{t.p}}$	mPa (kgf/cm^2)	$\mathbf{X_{1.7}}$	$\mathbf{X_{1.7}}$	$\mathbf{X_{1.7}}$	$\mathbf{X_{1.7}}$	Parameter 4.7 is applicable to the tank pressurization generating systems
4.8 Pressure at the turbine outlet	$P_{\text{t.outlet}}$	mPa (kgf/cm^2)	Δ	Δ	Δ	Δ	
4.9 Pressure drop at FCR	ΔP_{FCR}	mPa (kgf/cm^2)	Δ	Δ	Δ	Δ	
4.10 Pressure vibration amplitude upstream of the combustion chamber and the gas generator fuel injectors	$A^{\text{f}}_{\text{cc.inj}}$ $A^{\text{f}}_{\text{gg.inj}}$	mPa (kgf/cm^2)	Δ	Δ	Δ	Δ	
4.11 Pressure vibration frequency upstream of the combustion chamber and the gas generator fuel injectors	$f^{\text{f}}_{\text{cc.inj}}$ $f^{\Gamma}_{\text{gg.inj}}$	Hz	Δ	Δ	Δ	Δ	
4.12 Pressure vibration amplitude upstream of the combustion chamber and the gas generator oxidizer injectors	$A^{\text{ox}}_{\text{cc.inj}}$ $A^{\text{ox}}_{\text{gg.inj}}$	mPa (kgf/cm^2)	Δ	Δ	Δ	Δ	
4.13 Pressure vibration frequency upstream of the combustion chamber and the gas generator oxidizer injectors	$f^{\text{ox}}_{\text{cc.inj}}$ $f^{\text{ox}}_{\text{gg.inj}}$	Hz	Δ	Δ	Δ	Δ	
4.14 Pressure vibration amplitude in the combustion chamber and the gas generator (at the turbine inlet)	A_{cc} A_{gg}	mPa (kgf/cm^2)	Δ	Δ	Δ	Δ	
4.15 Pressure vibration frequency in the combustion chamber and the gas generator (at the turbine inlet)	f_{cc} f_{gg}	Hz	Δ	Δ	Δ	Δ	
4.16 Propellants pressure vibration amplitude at the engine inlet	$A^{\text{p}}_{\text{en.inlet}}$	mPa (kgf/cm^2)	O	O	O	O	
4.17 Propellants pressure vibration frequency at the engine inlet	$f^{\text{p}}_{\text{en.inlet}}$	Hz	O	O	O	O	
4.18 Engine chamber, gas generator, and turbo pump vibration acceleration amplitude in the planes, parallel and normal to the assembly main axes	$A_{\text{e.ch}}$ A_{gg} A_{tp}	m/s^2 (g)	Δ	Δ	Δ	Δ	

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Parameters that characterize test environment shall be measured before the LV launch.

Table 3 *(continued)*

Parameter title	LRE type						Comment
	Letter symbol	Measurement unit	Without afterburning		With afterburning		
			For LV	For SC	For LV	For SC	
4.19 Engine chamber, gas generator, and turbo pump vibration acceleration frequency in the planes, parallel and normal to the assembly main axes	$f_{e.ch}$ f_{gg} f_{tp}	Hz	Δ	Δ	Δ	Δ	
4.20 Vibration acceleration amplitude in the direction of the item axis, on the engine bed at the point of its attachment to the item body	$A_{en.b}$	m/s^2 (g)	O	O	O	O	
4.21 Vibration acceleration frequency in the direction of the item axis, on the engine bed at the point of its attachment to the item body	$f_{en.b}$	Hz	O	O	O	O	
4.22 Gas temperature at the gas generator outlet (upstream of the turbine inlet)	T_{outlet}^{gg}	K (°C)	Δ	Δ	Δ	Δ	
4.23 Gas temperature in the injector cavity of the combustion chamber (downstream of the turbine)	$T_{cc}^{inj.cav}$	K (°C)	•	•	O	O	For engines without afterburning parameter 4.23 is not to be measured
4.24 Temperature of propellant cooling component upstream of the combustion chamber injectors	$T_{cool.}$	K (°C)	Δ	Δ	Δ	Δ	
4.25 Propellants temperature at the inlet of steering actuators	$T_{inlet}^{st.act}$	K (°C)	Δ	Δ	Δ	Δ	
4.26 Gas temperature at the outlet of the tank pressurization system gas generator	$T_{g.p.}$	K (°C)	O	O	O	O	
4.27 TP rotor shaft speed	n_{tp}	c^{-1} (r/min)	O	O	O	O	
4.28 BTP rotor shaft speed	n_{btp}	c^{-1} (r/min)	Δ	Δ	Δ	Δ	
4.29 Angle of rotation of the AVR and FCR system drive	φ_{avr} φ_{fcr}		O	O	O	O	
4.30 Angle of the TDS throttle rotation	ϕ_{TDS}	radian	O	O	O	O	
4.31 Angle of engine tilting chambers rotation	$\phi_{t.c}$	radian	O	O	O	O	
4.32 Thrust vector angle (lateral force)	$\phi_{th.v}$	radian	$X_{4.33}$	$X_{4.33}$	$X_{4.33}$	$X_{4.33}$	Parameter 4.32 may be replaced by the injected gas pressure, provided that there is a well-founded lateral force dependence on gas pressure
4.33 Pressure of gas, injected into a nozzle of the chamber (gas shaft distributor deviation angle)	$P_n^{inj.g.}$	mPa	$X_{4.32}$	$X_{4.32}$	$X_{4.32}$	$X_{4.32}$	For engines with gas injection into the combustion chamber

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Parameters that characterize test environment shall be measured before the LV launch.