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

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National foreword

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

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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 documents 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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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT), see the following URL: Foreword — Supplementary information.

The committee responsible for this document is ISO/TC 20, *Aircraft and space vehicles*, Subcommittee SC 14, *Space systems and operations*.

Introduction

This International Standard provides customers, designers, and manufacturers of liquid rocket engines with general provisions to the parameters measured under firing stand tests, under break-in, and flight tests. Parameters subjected to be measured are determined in the design documentation and are used under the analysis of reliability and quality control of liquid rocket engines.

The determination of common requirements to the parameters of liquid rocket engines measured at firing stand and flight tests on a global scale was developed:

— to provide the required quality and reliability of rocket engines being created and used;

— to compare tests results and engines impartially;

— to provide safety of final items and environmental protection.

This International Standard will allow the development of a common criteria of evaluating and comparing of liquid rocket engines created by different countries according to the results of firing stand and flight tests.

INTERNATIONAL STANDARD ISO 16694:2015(E)

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

1 Scope

This International Standard applies to all types of liquid rocket engines for expendable launch systems and satellites:

a) Combustible fuel (including cryogenic);

b) Large-thrust, multiple component engines, with and without afterburning;

c) Low-thrust engines, one component (mono-propellant) and two-component (bi-propellant).

This International Standard establishes a list of parameters to be measured and registered with the firing stand and flight tests of serial LRE.

The order of preparation and carrying out of stand and flight tests, methods of processing, and analysis of tests results of liquid rocket engines, also measurement accuracy requirements are not regulated by this International Standard. Measurement accuracy requirements are established by engine designer.

Parameters listed in this International Standard characterize performance attributes of liquid rocket engines and are used for evaluating of technical state of engines (operative, inoperative), if they correspond to the requirements specified and possibilities of putting them into operation.

There are parameters specified in this International Standard, obligatory for registration and optional ones.

The manufacturer of liquid rocket engines can determine additional list of parameters for specific items taking into account their design and diagrammatical features.

The meaning “optional parameter” denotes (in cases when a proper unit or a component can be the part of an engine) that according to the manufacturer’s decision, measurements are allowed not to be made.

Measurement of parameters at firing stand and flight tests of liquid rocket engines is be made by means of the same sensors if possible.

2 Normative references

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

ISO 15864:2004, *Space systems — General test methods for space craft, subsystems and units*

ISO 15865:2005, *Space systems — Qualification assessment*

ISO 24917:2010, *Space systems — General test requirements for launch vehicles*

3 Symbols and abbreviations

AVR	apparent velocity regulator
BTPU	booster turbo pump
CFC	components-flow controller

CST	confirmatory sampling test
DD	design documentation
EV	electric valve
FCR	regulator of fuel components ratio in combustion chamber
IDT	interdepartmental tests
LV	launch vehicle
LRE	liquid rocket engine
LTE	low thrust engine
PA	pressure alarm
PS	propulsion system
PST	pressure stabilizer
SAT	sampling acceptance test
SST	special sampling test
SV	space vehicle
TDS	tank depletion system
TPU	turbopump
TT	technological test

4 General

4.1 Classification of measured parameters

4.1.1 The main purpose of measurement at proof tests of serial LRE (firing stand and flight tests) is to provide information for reliability analysis and quality control of engines.

4.1.2 Parameters measured at firing stand and flight tests of LRE are subdivided into the following groups:

a) parameters characterizing test operation conditions;

b) main parameters;

c) parameters characterizing the engine ability to operate without any degradation.

4.1.3 Parameters that characterize the actual test operation conditions are compared to required test operation conditions. These parameters include:

a) environmental parameters before and during the tests,

b) fuel components state before and during the tests, and

c) LRE characteristics (thrust and specific impulse).

4.1.4 The main parameters characterize the ability of an engine to fulfill requirements determined by the technical documentation of the manufacturer.

4.1.5 Parameters characterizing the ability of an engine to operate without any degradation are used to control the loads imposed over the engine elements.

This group consists of parameters whose values cannot be determined directly with measurements made during the assembly production process. Among these parameters are ones characterizing strength and heat-resistance of the combustion chamber and gas generator and the stability of working process in these assemblies. In case of an emergency situation these parameters (together with the main parameters and parameters characterizing the conditions of test operation) are used for the reasons of emergency process analysis.

4.2 Firing stand and flight tests operation conditions

4.2.1 Qualification tests of LRE are carried out in order to verify a safety margin beyond the expected life in accordance with the manufacturer of LV (SV) in consideration of the environmental factors and engine operation modes.

4.2.2 Technological tests are carried out under values of the environmental factors and engine operation mode with operating time necessary for measurement of parameters.

4.2.3 Sampling acceptance tests are performed for checking lifetime which is agreed upon with the manufacturer of LV (SV) under values of the environmental factors and engine operation modes.

4.2.4 Confirmatory Sampling Test (CST) is carried out within the guarantee limits of the lifelength and operation conditions of LRE. It is allowed to carry out CST above guarantee limits one at a time or under any system of operation conditions of LRE.

4.2.5 Special tests of LRE are carried out in accordance with special programs defined by a designer or a manufacturer of LRE and ratified by both enterprises.

4.2.6 Flight tests of LRE are carried out in a LV (SV) at the real conditions of operation with the purpose of verifying conformance of LRE with specifications and determination of readiness of use.

4.2.7 Purposes and objectives of flight tests are presented in details in ISO 24917.

4.2.8 General methods of tests of spacecrafts, subsystems, and units are presented in ISO 15864.

4.2.9 Flight test analysis is performed according to the requirements of ISO 15865.

5 The measured parameters at tests of LRE

The measured parameters at firing stand and flight tests of LRE are presented in the respective tables.

LRE with afterburning (staged combustion cycle) and without afterburning (gas generator cycle/expander cycle/pressure fed cycle) used in launch vehicles and space vehicles are represented.

Parameters measured under tests of LRE are subdivided into the following groups:

a) obligatory;

b) supplemental, depending on situation;

c) interchangeable, obligatory to be measured.

In the "Note" column in Tables 1 to 3, some necessary clarifications and additions to the specific parameters are given.

5.1 The measured parameters at firing stand test of LRE

5.1.1 The measured parameters at commissioning and sampling tests (CTT, CST, and SST) of LRE are presented in Table 1.

5.1.2 Table 2 is additional to Table 1 and contains parameters measured at qualification tests of LRE.

5.2 The measured parameters at flight tests of LRE

5.2.1 The measured parameters at flight tests of LRE are presented in Table 3.

The following symbols are used in the tables:

○ required parameter subjected to be obligatory measured;

• measuring of a parameter does not regulated by this International Standard;

Δ supplemental, depending on situation;

X_m interchangeable parameter to be measured where *m* is a serial number of a parameter in the respective table which can be used instead of the specified one in the clause.

Table 1 — The measured parameters at TT, SAT, CST, and SST

Description of a parameter	LRE type				Note
	without afterburning		with afterburning		
	for LV	for SV	for LV	for SV	
1. Parameters characterizing test operation conditions					
1.1 Ambient pressure	○	○	○	○	
1.2 Ambient temperature	○	○	○	○	
1.3 Ambient humidity	Δ	Δ	Δ	Δ	
1.4 Direction and speed of air	Δ	Δ	Δ	Δ	
1.5 Fuel components temperature in the place of flow rate meters installation and at the engine inlet	○	○	○	○	
1.6 Chemical composition of the fuel components	○	○	○	○	
1.7 Specific weight of the fuel components (except cryogenic)	○	○	○	○	
1.8 Content of solute gases in fuel components with a process of forced gassing	Δ	Δ	Δ	Δ	
2. Main parameters					
2.1 LRE thrust	○	○	○	○	
2.2 Mass outflow of fuel components through the engine (engine nozzle) per second	○	○	○	○	
2.3 Combustion chamber pressure	$X_{3.8}$	$X_{3.8}$	$X_{3.8}$	$X_{3.8}$	

Table 1 *(continued)*

Description of a parameter	LRE type				Note
	without afterburning		with afterburning		
	for LV	for SV	for LV	for SV	
1. Parameters characterizing test operation conditions					
2.4 Fuel components pressure at the engine inlet	○	○	○	○	
3. Parameters characterizing the ability of an engine to operate without any degradation					
3.1 Oxidizer pressure after the pump	○	○	○	○	Parameters 3.1 and 3.2 are subjected to be measured after final stage (for multi-stage pumps and after booster stage).
3.2 Fuel pressure after the pump	○	○	○	○	
3.3 Oxidizer pressure after the booster pump of oxidizer	Δ	Δ	Δ	Δ	Parameter 3.5 is measured by means of sensors allowing to measure pressure change under the transient process. Under sampling acceptance tests of engines without afterburning, parameter 3.5 is subjected to be measured if the engine construction provides the ability of the respective sensors installation.
3.4 Fuel pressure after the booster pump of fuel	Δ	Δ	Δ	Δ	
3.5 Gas pressure in the gas generator (at the turbine inlet)	Δ	Δ	Δ	Δ	
3.6 Igniter chamber pressure	Δ	Δ	Δ	Δ	
3.7 Propellant pressure at the input to steering actuators	Δ	Δ	Δ	Δ	
3.8 Propellant components pressure before the combustion chamber injectors	$X_{2.3}$	$X_{2.3}$	$X_{2.3}$	$X_{2.3}$	
3.9 Gas pressure after the turbine	Δ	Δ	Δ	Δ	
3.10 Gas pressure in gas generators of the pressurization system of tanks	Δ	Δ	Δ	Δ	Parameter 3.10 belongs to gas generator pressurization system of tanks.
3.11 Pressure drop on the flow regulator of a propellant	Δ	Δ	Δ	Δ	
3.12 Driving pressure in the regulator assembly	Δ	Δ	Δ	Δ	

Table 1 *(continued)*

Description of a parameter	LRE type				Note
	without afterburning		with afterburning		
	for LV	for SV	for LV	for SV	
1. Parameters characterizing test operation conditions					
3.13 Fuel pressure pulsations before injectors of the combustion chamber	$X_{3.14}$	$X_{3.14}$	$X_{3.14}$	$X_{3.14}$	Parameters 3.13 and 3.14 under Sampling Acceptance Test of the engines without afterburning are subjected to be measured if the engine construction provides the capability of the respective sensors installation. Measure pressure results are used for assessment of working process stability in chamber and gas generator.
3.14 Oxidizer pressure pulsations before injectors of the combustion chamber	$X_{3.13}$	$X_{3.13}$	$X_{3.13}$	$X_{3.13}$	
3.15 Fuel pressure pulsations before injectors of the gas generator chamber	Δ	Δ	Δ	Δ	
3.16 Oxidizer pressure pulsations before injectors of the gas generator chamber	Δ	Δ	Δ	Δ	
3.17 Pressure pulsations in the combustion chamber and the gas generator (at the turbine inlet)	Δ	Δ	Δ	Δ	
3.18 Pressure pulsations of fuel components in the engine inlet	Δ	Δ	Δ	Δ	
3.19 Vibro-overloads of the LRE chamber on the plane which is parallel to the main axis of the chamber	$X_{3.20}$	$X_{3.20}$	$X_{3.20}$	$X_{3.20}$	The decision for parameters 3.19 to 3.21 are to be measured obligatory for new types of LRE is taken according to the results of the development work.
3.20 Vibro-overloads of the LRE chamber on the plane which is perpendicular to the main axis of the chamber	$X_{3.19}$	$X_{3.19}$	$X_{3.19}$	$X_{3.19}$	
3.21 Vibro-overloads of the gas generator on the plane which is parallel to the main axis of the gas generator	Δ	Δ	Δ	Δ	
3.22 Vibro-overloads of the gas generator on the plane which is perpendicular to the main axis of the gas generator	Δ	Δ	Δ	Δ	The decision for parameters 3.22 to 3.24 are to be measured obligatory for newly-designed LRE is taken according to the results of the development work of LRE.
3.23 Vibro-overloads of the TPU on the plane which is parallel to the main axis of the TPU	Δ	Δ	Δ	Δ	
3.24 Vibro-overloads of the TPU on the plane which is perpendicular to the main axis of the TPU	Δ	Δ	Δ	Δ	
3.25 Gas temperature at the gas generator exit (before the turbine)	Δ	Δ	Δ	Δ	Parameter 3.25 under Sampling Acceptance Test of the engines without afterburning is subjected to be measured if the engine construction provides the ability of the respective sensors installation.

Table 1 *(continued)*

Description of a parameter	LRE type				Note
	without afterburning		with afterburning		
	for LV	for SV	for LV	for SV	
1. Parameters characterizing test operation conditions					
3.26 Gas temperature in the injector cavity of the combustion chamber	Δ	Δ	Δ	Δ	
3.27 Temperature of the cooling component pumped to the combustion chamber injector	Δ	Δ	Δ	Δ	
3.28 Temperature of propellant component in elements of its input to steering actuators	Δ	Δ	Δ	Δ	
3.29 Structural components temperature of the engine under the heat-shielding material in the area of the heat flows effect	Δ	Δ	Δ	Δ	
3.30 Engine Structural components temperature which are under active temperature control	Δ	Δ	Δ	Δ	
3.31 Gas temperature at the exit from the gas generator of the pressurization system	○	○	○	○	Parameter 3.31 belongs to the gas generator air pressurization systems of tanks.
3.32 Fuel flow rate in the gas generator	Δ	Δ	Δ	Δ	Parameters 3.32 and 3.33 are subjected to be measured if the engine construction provides installation of the flow rate meters of acceptable accuracy. Otherwise, the user should install stands flowmeter the required accuracy (at SST).
3.33 Oxidizer flow rate in the gas generator	Δ	Δ	Δ	Δ	
3.34 Flow rate through the flow regulator	○	○	○	○	
3.35 Rotational velocity of the TPU rotor shaft	○	○	○	○	For restartable space engines (impulse engines) the control system of which doesn't provide the information of the rotational velocity of the TPU rotor shaft, measuring of parameter 3.35 is optional.
3.36 Rotational velocity of the BTPU rotor shaft	Δ	Δ	Δ	Δ	
3.37 Angle of rotation of AVR and FCR system drive	○	○	○	○	
3.38 Angle of rotation of throttle of TDS	○	○	○	○	
3.39 Angle of rotation of steerable chambers of LRE	○	○	○	○	

Table 1 *(continued)*

Description of a parameter	LRE type				Note
	without afterburning		with afterburning		
	for LV	for SV	for LV	for SV	
1. Parameters characterizing test operation conditions					
3.40 Force on the actuators of the rocking chambers of LRE	Δ	Δ	Δ	Δ	
3.41 Deviation angle of the thrust vector (measuring of side force)	$X_{3.40}$	$X_{3.40}$	$X_{3.40}$	$X_{3.40}$	For engines with gas blowing to the combustion chamber
3.42 Pressure of the blown gas	$X_{3.39}$	$X_{3.39}$	$X_{3.39}$	$X_{3.39}$	For engines with gas blowing to the combustion chamber
3.43 Fuel flow continuity in front of the pump	○	○	○	○	
3.44 Oxidizer flow continuity in front of the pump	○	Δ	○	Δ	
3.45 LRE operational capacity at the test	○	○	○	○	
NOTE 1 Control of separate specified parameters can be realized by means of measuring of other parameters specified in DD if the customer is satisfied with the precision. NOTE 2 Such parameters as pressure in front of (after) PA, FCR, CFC, TDS are subjected to be measured in case that the specified parameters are necessary to determine the calculated values of the main (specified) LRE characteristics. NOTE 3 When testing the engines to cryogenic fuels further measure parameters that characterize the aggregate state components fuel (temperature, pressure).					

Table 2 — The measured parameters at qualification tests of LRE (in addition to Table 1)

Description of a parameter	LRE type				Note
	without afterburning		with afterburning		
	for LV	for SV	for LV	for SV	
1. Pressure of subsidiary gases in the stand platform (under the using of them during the engine tests)	Δ	Δ	Δ	Δ	Composition of parameters measured under the qualification tests of LRE can be supplemented according to the schedule of qualification tests agreed upon with the designer of the engine.
2. Vibro-overloads on the engine bed in the place of sealing to the movable stand bed on the planes which are parallel and normal to the engine axis	○	○	○	○	

Table 3 — Parameters of LRE measured at flight tests

Description of a parameter	LRE type				Note
	without afterburning		with afterburning		
	for LV	for SV	for LV	for SV	
1. Parameters characterizing test operation condition					
1.1 Ambient pressure	•	•	•	•	

Table 3 *(continued)*

Description of a parameter	LRE type				Note
	without afterburning		with afterburning		
	for LV	for SV	for LV	for SV	
1.2 Ambient temperature	•	•	•	•	
1.3 Ambient humidity			○	○	
1.4 Direction and speed of air	○	○	○	○	
1.5 Fuel temperature at engine inlet and at flow rate meters (if applicable)	○	○	○	○	
1.6 Chemical composition of the fuel components	○	○	○	○	
1.7 Specific weight of the fuel components (except cryogenic)	○	○	○	○	
2. Main parameters					
2.1 Mass outflow of fuel components through the engine (engine nozzle) per second	Δ	Δ	Δ	Δ	
2.2 Combustion chamber pressure	$X_{3.4}$	$X_{3.4}$	$X_{3.4}$	$X_{3.4}$	
2.3 Fuel components pressure at the engine inlet	○	○	○	○	
3. Parameters characterizing the ability of an engine to operate without any degradation					
3.1 Oxidizer pressure after the pump	Δ	Δ	Δ	Δ	Parameters 3.1 and 3.2 are subjected to be measured after every stage (for multi-stage pumps) and after booster stage.
3.2 Fuel pressure after the pump	○	○	○	○	
3.3 Gas pressure in the gas generator chamber (at the turbine inlet)	Δ	Δ	Δ	Δ	
3.4 Propellant components pressure before the combustion chamber injectors	$X_{2.2}$	$X_{2.2}$	$X_{2.2}$	$X_{2.2}$	
3.5 Igniter chamber pressure	Δ	Δ	Δ	Δ	Parameter 3.5 belongs to the engines with the engine starting system.
3.6 Propellant pressure in the elements of vernier thruster	Δ	Δ	Δ	Δ	
3.7 Gases pressure of tank pressurization	○	○	○	○	Parameter 3.7 belongs to the gas generator air pressurization systems of tanks.
3.8 Gases pressure after the turbine	Δ	Δ	Δ	Δ	
3.9 Pressure fall in AVR	Δ	Δ	Δ	Δ	
3.10 Fuel pressure pulsations before injectors of the combustion chamber and gas generator	Δ	Δ	Δ	Δ	
3.11 Oxidizer pressure pulsations before injectors of the combustion chamber and gas generator	Δ	Δ	Δ	Δ	

Table 3 *(continued)*

Description of a parameter	LRE type				Note
	without afterburning		with afterburning		
	for LV	for SV	for LV	for SV	
3.12 Pressure pulsations in the combustion chamber and the gas generator (at the turbine inlet)	Δ	Δ	Δ	Δ	
3.13 Pressure pulsations of fuel components at the engine inlet	Δ	Δ	Δ	Δ	
3.14 Vibro-overloads of the LRE chamber, gas generator, and TPU on the planes which are parallel and perpendicular to the axes of units	Δ	Δ	Δ	Δ	
3.15 Vibro-overloads towards the axis of the unit on engine bed at the fixturing point to unit body	○	○	○	○	
3.16 Gas temperature at the gas generator exit (before the turbine)	Δ	Δ	Δ	Δ	
3.17 Gas temperature in the injector cavity of the combustion chamber (after the turbine)	•	•	○	○	
3.18 Temperature of the cooling component pumped to the combustion chamber injector	Δ	Δ	Δ	Δ	
3.19 Propellant component temperature in the venires thruster	Δ	Δ	Δ	Δ	
3.20 Gas temperature at the exit from the gas generator of the pressurization system	○	○	○	○	Parameter 3.20 belongs to the gas generator air pressurization system of tanks.
3.21 Rotational velocity of the TPU rotor shaft	○	○	○	○	
3.22 Rotational velocity of the BTPU rotor shaft	Δ	Δ	Δ	Δ	
3.23 Angle of rotation of AVR and FCR systems drive	○	○	○	○	
3.24 Angle of rotation of throttle of TDS	○	○	○	○	
3.25 Angle of rotation of steer able combustion chambers	○	○	○	○	
3.26 Deviation angle of the thrust vector (measuring of side force) for the engines with gas blown to the combustion chamber	$X_{3.27}$	$X_{3.27}$	$X_{3.27}$	$X_{3.27}$	Parameter 3.26 can be substituted for the pressure of blown gas if there is the valid correlation between the side force and the gas pressure.
3.27 Pressure of the blown gas (deviation angle of gas shaft distributor) for the engines with blown gas to the combustion chamber	$X_{3.26}$	$X_{3.26}$	$X_{3.26}$	$X_{3.26}$	

Table 3 *(continued)*

Description of a parameter	LRE type				Note
	without afterburning		with afterburning		
	for LV	for SV	for LV	for SV	
3.28 Discontinuities of the fuel flow in front of the pump	•	Δ	•	Δ	Parameters 3.28 and 3.29 are measured to identify fluctuations in component flow that can cause vibration in the combustion chamber.
3.29 Discontinuities of the oxidizer flow in front of the pump	•	Δ	•	Δ	
3.30 Engine operating period duration	○	○	○	○	
NOTE 1 Parameters such as pressure in front of (or after) PA, AVR, TDS, or FCR are to be measured when it is necessary to determine the values of the main (specified) engine characteristics (thrust, specific impulse).					
NOTE 2 Some parameters specified in the table can be calculated from measurement of other key parameters. If the accuracy of the calculated parameters is acceptable to the customer, these measurements can be avoided.					
NOTE 3 When testing engines which use cryogenic fuels, additional measured parameters that characterize the aggregate state of fuel components (temperature, pressure) are required.					

Table 4 — The measured parameters at firing stand-test of LTE

Description of a parameter	Letter designation	Unit measures	LTE type	
			single-component	two-component
1. Parameters characterizing test operation conditions				
1.1 Ambient pressure:				
— Pressure atmospheric;	P_{amb}	kPa	Δ	Δ
— Vacuum chamber pressure	P_{ambch}		○	○
1.2 Ambient temperature	T_{amb}	°C	○	○
1.3 Temperature of engine mount interface	T_f		○	○
1.4 Propellant inlet pressure in engine (one component engines)	P_{pp}	MPa	○	-
1.5 Propellant component entry inlet pressure in engine (Two component engines):				
— oxidizer pressure;	P_{op}		—	○
— fuel pressure.	Pf_{pp}		—	○
1.6 Propellant inlet temperature in engine (one component engines)	T_p	°C	Δ	
1.7 Propellant compo entry inlet temperature in engine (Two component engines):	t_{ox} t_f			
— oxidizer temperature;	T_o		—	○
— fuel temperature.	T_f		—	○
1.8 Voltage on heater of engine	U_h	V	•	Δ
1.9 Current of engine Heater	I_h	A	•	Δ
1.10 Lead time of engine	X_l	s	•	•
2. Main parameter				
2.1 LTE thrust	F_{ap}	N	○	•
2.2 Combustion chamber pressure	P_{pch}	MPa	Δ	Δ

Table 4 *(continued)*

Description of a parameter	Letter designation	Unit measures	LTE type	
			single-component	two-component
2.3 Mass flow rate of actuating medium — continuous value:				
a) of propellant (One component engines)	$\dot{m}_p$	g/s	Δ	-
b) of oxidizer (Two component engines)	$\dot{m}_o$		—	○
c) of fuel (Two component engines)	$\dot{m}_f$		—	○
— in pulse mode behaviour: a) of propellant (one component engines)	$\dot{m}_{pp}$	g/p	○	—
b) of oxidizer (two component engines)	$\dot{m}_{op}$		—	○
c) of fuel (two component engines)	$\dot{m}_{fp}$		—	○
2.4 Full impulse	$I_{0,9}$	s	Δ	○
2.5 Unit impulse	I_1		○	○
2.6 Residual impulse	I_r		Δ	○
2.7 Starting operation time	$X_{0,9}$	s	○	○
2.8 Ignition delay	$X_{0,1}$		○	○
2.9 On-time	X_{on}		○	○
2.10 Off-time	X_{of}		○	○
2.11 The engine chamber temperature	T_{ch}	°C	○	○
3. Parameters characterizing the ability of an engine to operate without any destruction				
3.1 Current through the electro-valve (EV)	I_{EV}	mA	○	○
3.2 Current through the pressure indicator (PI)	I_{PI}		Δ	○
3.3 Starting current	I_p			○
3.4 Supply voltage of electro-valve	U_{EV}	V	○	○
3.5 Complex $\beta = \frac{P_{ch} \cdot F_{cr}}{\dot{m}}$	β	$\frac{\text{kgs} \times \text{s}}{\text{kg}}$	Δ	○
3.6 Thruster ignition frequency	f	Hg	Δ	○
3.7 vibration(al) frequency in combustion chamber	f_{ch}			
3.8 Combustion chamber pressure oscillation amplitude (with respect to nominal pressure)	A	%	Δ	○
3.9 Total opening time of EV from the moment of issuing the command signal	X_{op}	s	Δ	
3.10 Total closing time of EV from the moment of issuing the command	X_{sh}		Δ	○
3.11 Reaction time of PI from moment issuing the command electric	X_{PI}		Δ	○

Table 5 — Parameters of LTE measured during flight tests

Description of a parameter	Letter designation	Unit measures	LTE type	
			single- component	two- component
1 Parameters characterizing test operation conditions				
1.1 Ambient pressure	P_{amb}	kPa	•	•
1.2 Ambient temperature	T_{amb}		•	•
1.3 Temperature of engine mount interface	T_f	°C	Δ	•
1.4 Propellant inlet pressure in engine (one component engines)	P_{pp}	kPa	Δ	•
1.5 Propellant component entry inlet pressure in engine (Two component engines):				
— oxidizer pressure;	P_{op}	MPa	—	Δ
— fuel pressure	Pf_{pp}		—	Δ
1.6 Propellant inlet temperature in engine (one component engines)	T_p	°C	Δ	•
1.7 Propellant compo entry inlet temperature in engine (Two component engines):				
— oxidizer temperature;	T_o	°C	—	Δ
— fuel temperature	T_f		—	Δ
1.8 Lead time of engine	X_l	s	Δ	•
2. Main parameter				
2.1 On-time	X_{on}	s	Δ	Δ
2.2 Off-time	X_{of}		Δ	Δ
2.3 Engine Chamber Temperature	T_{ch}	°C	Δ	Δ
3. Parameters characterizing the ability of an engine to operate without any destruction				
3.1 Supply voltage of electro-valve	U_{EV}	V	Δ	Δ
3.2 Reaction time of PI from moment issuing the command electric	X_{PI}	s	Δ	Δ
3.3 Total opening time of EV from the moment of issuing the command signal	X_{op}	s	•	•
3.4 Total closing time of PI from the moment of issuing the command	X_{Pld}	s	Δ	•
3.5 Period of time PI is switched off while in impulse mode	X_{PI}	s	Δ	Δ
3.6 Total closing time of EV from the moment of issuing the command	X_{sh}	s	•	•

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