

# **Procedure for determining the effect of internal and external factors on the startup thrust spread of a liquid-propellant rocket engine**

*Institute of Technical Mechanics*

*of the National Academy of Sciences of Ukraine and the State Space Agency of Ukraine  
15 Leshko-Popel St., Dnipro 49005, Ukraine; e-mail: dolmrut@gmail.com*

Despite of the package of measures to adjust a liquid-propellant rocket engine (LPRE) to a specified operating regime, minimum acceptable spreads in the geometrical parameters and operating conditions of its units and assemblies steel remain. These internal factors together with external ones (the pressure and temperature of the propellant components at the engine inlet) govern the engine thrust spread. To provide an acceptable engine thrust spread according to the engine requirements specification, it is important to know the spread value as early as at the stage of off-engine tryout of the engine units and assemblies. The aim of this work is to develop a procedure for calculating the effect of external and internal factors on the LPRE startup thrust spread.

This paper presents a procedure for determining the effect of internal and external factors on the LPRE startup thrust spread. The procedure includes the development of a mathematical model of engine startup that accounts for the maximum number of internal factors, the choice of internal factors that produce the maximum effect on the LPRE startup thrust spread, the choice of a method for specifying the external and internal factor spread, engine startup calculations at different combinations of external and internal factor spread values, engine thrust spread determination, determining the statistical and the theoretical distributions of the 90 percent thrust time spread and the steady thrust spread, and assessing their goodness of fit using Pearson's chi-squared test.

The paper gives an example of calculating the effect of the external and internal factor spread on the LPRE startup thrust spread for a staged-combustion oxidizer-rich sustainer LPRE. Using the results of previous calculations, 12 internal factors that produce the maximum effect on the engine startup thrust spread are identified. It is shown that the calculated spread of the 90 percent thrust (combustion chamber pressure) time lies in the range  $-0.0822$  s to  $+0.0730$  s about its nominal value, and the calculated steady engine thrust (combustion chamber pressure) spread lies in the range  $-6.4$  percent to  $+6.6$  percent of the nominal thrust. Using Pearson's chi-squared test, an estimate is obtained for the goodness of fit of the anticipated theoretical distributions of the 90 percent thrust time spread and the steady thrust spread to the obtained statistical ones.

**Keywords:** *liquid-propellant rocket engine, startup, mathematical simulation, 90 percent thrust time, external and internal factors, thrust spread, goodness of fit of a theoretical distribution to a statistical one.*

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