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REORIENTATION OF FUEL COMPONENTS TO ENSURE RESTARTING OF THE MAIN ENGINE: CALCULATION METHODS, NUMERICAL SIMULATION AND EXPERIMENTAL TESTING

Abstract

When performing launch services for putting several spacecraft into orbit, it is necessary to repeatedly turn on the main engine. The pauses between the main engines start can have a long duration, up to several days. All this time, the fuel is in conditions of almost complete zero gravity, and can freely move throughout the entire volume of the tank, occupying almost any spatial position. This movement is due to various factors caused by both “internal” (programmed turn of the stage, separation of the spacecraft, operation of the stabilization system, etc.) and “external” (pressure of the solar wind, geomagnetism, thermal effect, etc.) reasons. In order to guarantee the subsequent launch of the main engine, it is necessary to move the entire mass of fuel to the prelaunch position. The fuel is moved to the prelaunch position (reorientation) by creating longitudinal acceleration which is ensured by the operation of several low thrust engines. The time of complete movement of the fluid from one position to another is the most important parameter affecting the propellant capacity and, accordingly, the power characteristics of the stage. Theoretical calculations of the hydrodynamic processes of fuel reorientation are associated with significant mathematical difficulties caused by the difficulty of solving the hydrodynamic problems of determining the motion of a fluid with a free surface, taking into account the surface tension of the fluid, and also many other geometric, kinematic and dynamic factors. Therefore, the most reliable data on solving these problems are currently obtained only on model hydrodynamic stands, on which it is possible to simulate the behavior of liquids in tanks under conditions of variable acceleration. In this paper, we consider the traditional method of calculating the total time required to reorient the fuel components during the flight of the space stage of the rocket, and we also describe the method of selecting model parameters for experimental testing under the constraints of the existing bench base, such as the scale of the tank model and free fall time provided by the stand and acceleration which is able to provide a kinematic model. The authors have also performed the work on the numerical simulation of the fuel reorientation process with the determination of the reorientation time for various filling volumes of tank models and the magnitudes of the acceleration, as well as on verification of the results of theoretical calculations and numerical modeling by experimental results. The paper also describes the characteristics of a test bench with a kinematic model which was used during experimental testing. The use of the described complex, which consists of a theoretical technique combined with numerical modeling and subsequent confirmation by the results of experimental testing, allows us to optimize the process of determining the time necessary for the fluid reorientation, providing a more accurate determination at the initial stage of development, and thereby reducing the financial cost and time for conducting this work, as well as the required amount of reserves of fuel components for the operation of small engines, which, in its turn, allows increasing the weight of the displayed payload, thereby increasing the power characteristics of the rocket.