IAF MICROGRAVITY SCIENCES AND PROCESSES SYMPOSIUM (A2)
Fluid and Materials Sciences (2)

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USING MATHEMATICAL MODELING WITH EXPERIMENTAL VALIDATION FOR THE DEVELOPMENT OF PROPELLANT CONTINUITY ASSURANCE EQUIPMENT

Abstract

When a launch vehicle is lifting a payload to its orbit, the propellant tanks of launch vehicle stages experience the lateral disturbing forces caused by different factors such as the operation of the stabilization system, changes in the operating mode of engines, engine start and cutoff, separation of stages, programmed maneuvers, etc. The presence of the lateral disturbing force causes the launch vehicle to drift in the transverse direction in space and spin around its center of gravity, which, in turn, disturbs the propellants in tanks. If the fuel reaches its critical level point due to moving, the pressurization gas can get into the engine supply line, which will cause the emergency engine cutoff. Therefore, two main problems have to be solved when designing the propellant continuity assurance equipment: 1) calculating the amount of propellant residue in the hydraulic circuit under the static conditions; 2) evaluating the effect of the lateral disturbing force on the amount of hydraulic-circuit propellant residue, i.e. calculating the dynamic component of the hydraulic-circuit propellant residue. To calculate the static and dynamic components of the hydraulic-circuit propellant residue, engineers use the empirical and semi-empirical relationships for determining the main parameters of the motion of liquids. However, having been obtained through experiments, these empiric relationships are applicable only for a limited circle of problems where the initial and boundary conditions are similar to those in which these relationships have been obtained. Experiments should be run therefore to confirm that the parameters of the continuity assurance methods have been calculated correctly. The full-scale tanks and their scale models (trial designs) are chiefly used as the continuity assurance equipment in the hydrodynamic tests carried out on the ground. To confirm the similarity of hydrodynamic processes, development tests are run with different scale models of different size and with different liquids used in these models. The present-day computing equipment and numerical methods of solving the differential equations of liquid motion make it possible to conduct computing experiments being more accurate than the empirical relations used almost everywhere. This, in some situations, allows reducing the quantity of the trial designs used, the duration of development tests, and, consequently, the costs of the materials and equipment used. This paper discusses the results of the experimental determination of the hydraulic-circuit propellant residue and its dynamic component. The dynamic component values were determined for the different values of the linear lateral acceleration (min, nom, max) occurring due to the disturbing lateral force in the trial designs of launch vehicle tanks with the central propellant intake, and by the numerical simulation using 3D and 2D mathematical models of trial designs (of the same size). The author has developed a method of computational experiments that allows verifying the results of numerical simulation and ensures the required accuracy of conducted studies. The proposed approach makes it possible to improve the traditional experimental procedure of determining the hydraulic circuit propellant residue and its dynamic component for the development of propellant continuity assurance equipment, as well as to reduce the scope and the material and equipment costs of development tests.