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e-mail: [1]odnikolayev@gmail.com; [2]ibloha@i.ua; [3]khoryak@i.ua

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To execute program motions, the space stages of liquid-propellant launch vehicles are equipped with re-startable propulsion engines. On the shutdown of the propulsion engine of a space stage, the liquid propellant in the tank in microgravity conditions moves by inertia upwards as far as possible away from the intake. This results in the potential possibility of the pressurizing gas penetrating into the engine inlet in quantities that make an en-

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gine restart impossible. Because of this, motion parameter determination for a liquid moving in propellant tanks in microgravity conditions is a topical problem to be solved in the designing of liquid-propellant rocket engines. This paper presents a technique for the calculation of the parameters of motion of the gas–liquid interface in the propellant tanks of modern liquid-propellant launch vehicle space stages in microgravity conditions (between a start and a shutdown of their propulsion engines) taking into account the design features of in-tank propellant management devices. The technique is based on the use of the finite-element method, the volume-of-fluid method, and modern finite-element CAE systems. It allows one to determine the parameters of motion and the shape of the free liquid surface in the tank, the parameters of free gas inclusions formed in the liquid, and the efficiency of the in-tank propellant management devices in the passive portion of the launch vehicle flight for the normal operation of the propulsion system.

For the conditions of motion of a prototype propellant tank with a liquid in a drop tower, which simulates microgravity, the motion of a liquid in a cylindrical tank was simulated numerically accounting for the deformation of its free surface. The computed motion parameters of the liquid and the gas–liquid interface agree with the experimental data.

The technique developed will allow one to reduce the extent of testing of newly developed and upgraded launch vehicle space stages.

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[2, 3, 6, 7, 8, 9].
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[7]   CZ-3A   -
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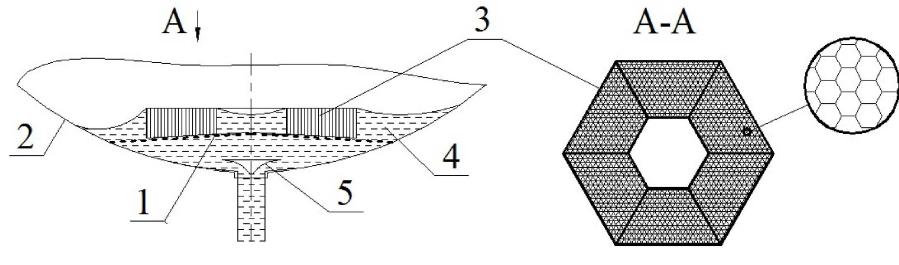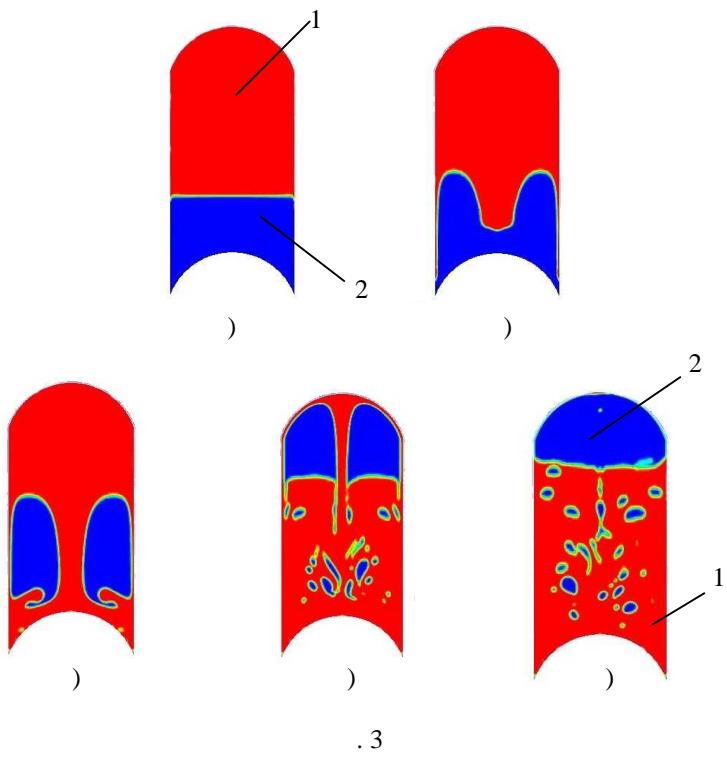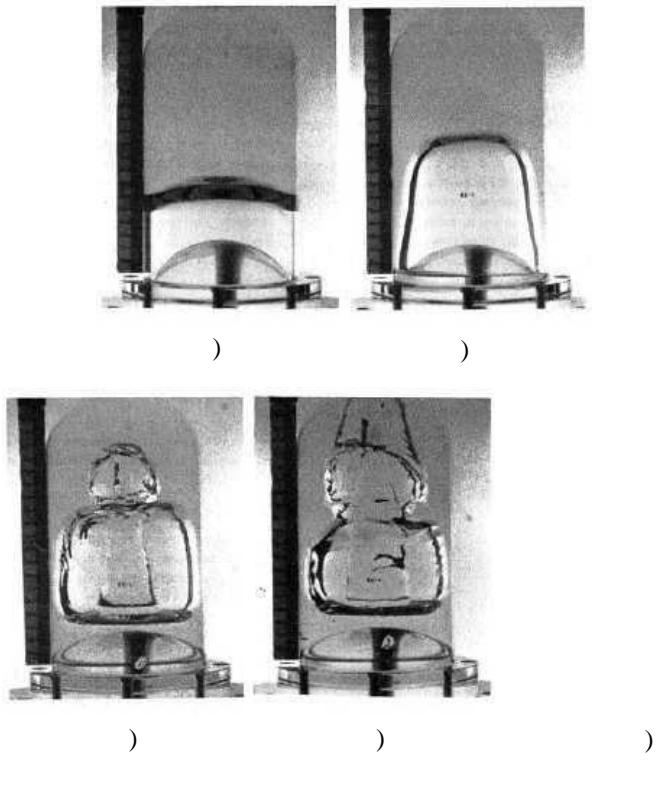   -
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$$\nabla V = 0,$$ (1)

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$$\frac{\partial}{\partial t}(\rho V) + \rho(V \cdot \nabla)V = -\nabla p + \mu \nabla^2 V + F_s + \rho a_z, \qquad (2)$$

–

$$\frac{\partial C}{\partial t} + V \cdot \nabla C = 0, \qquad (3)$$

∇ –   ; V –   ; p, ρ, μ ,

F_s –   ,   ,

; a_z –   .

(3)   :

$= 0$ –   ,

$= 1$ –   , $0 < \ < 1$ –   -

.

VOF –   CSF-   -

F_s

$$F_s = \sigma k \nabla C, \qquad (4)$$

k –   «   –   »   -

; σ –   ,   «   –   ».

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[12, 13].   ,   -

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, $\vec{n}$ -

«   –   –   »

[13]:

$$\vec{n} = \vec{n}_w \cos \theta_W + \vec{t}_W \sin \theta_W, \qquad (5)$$

θ_W –   ,

«   –   »; $\vec{n}_W$ $\vec{t}_W$ –   -

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(5)   -

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[2, 5, 14].   . 1   -

[14]: 1 –   ; 2 –

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                                                (5).

A-A

Рис. 1

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            ,   :

$$K = \frac{\Delta P}{\rho V^2 \, \Delta l},\qquad(6)$$

ΔP –   ; V –
                                        ; Δl –
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                        ΔP -
            ,   -
        F S [15, 16]:

$$\Delta P = F \quad / S.\qquad(7)$$

                    [15, 17]

$$F \quad = a_* \cdot \sqrt[4]{\frac{\rho \sigma^3}{a_g}} \cdot V \cdot \Pi,\qquad(8)$$

        Π –   ; a_* –
($a_* = 0{,}182$).

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ξ ,

[18, 19]:

$$\xi = \alpha + \beta/\mathrm{Re} \ , \qquad\qquad\qquad (9)$$

α , β – ; Re – .

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[21]. AMG -

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AMG - -

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«   » [9, 22, 23].

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«   »,   [9, 22].   -

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. H –   ($H = 11{,}015$ с);
L, R –
($L =16{,}3$ с ; $R =5{,}5$ с ; $R1 =5{,}782$ с).   -
FC-78,

$\sigma =13{,}2*10^{-3}$ Н/ , $\rho =1720$ / ^{3},
$\mu =8{,}2*10^{-3}$ /   .   -
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CAE–   (ANSYS)   FLOTRAN CFD   ANSYS
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(.3,), 4,)); Т 2 –

« » (.3,), 4)); Т 3 – « »

(.3,), 4,)); Т 4 –

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(1) – (9) -

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« » (.3,), 4)) $t = 1,9$ -

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P–P ,

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-7,98
-15,96
-23,94
-31,92
-39,90
-47,88
-55,86
-63,84
-71,82
-79,80

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P–P ,

19,0
10,10
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-7,70
-16,6
-25,50
-34,4
-43,30
-52,2
-61,10

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$P-P$,   ,

, $P-P$ < 0 (. 5,)).

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a_z,   .

.6,)   2 («   »).

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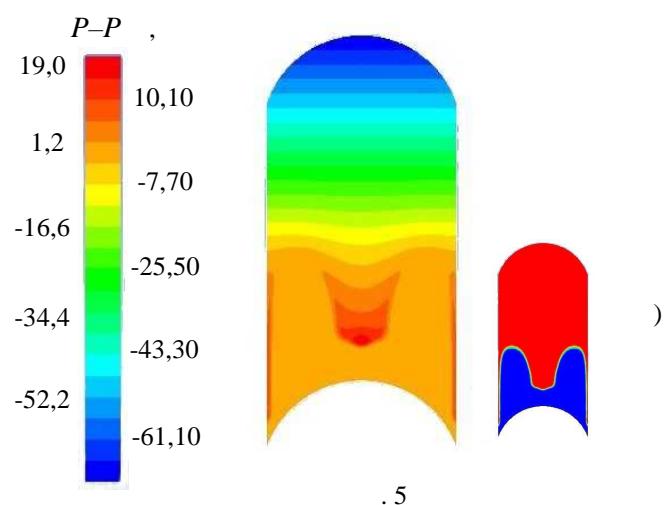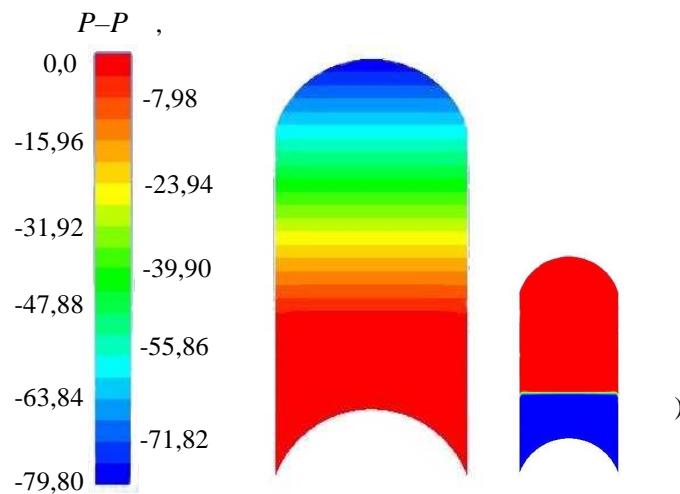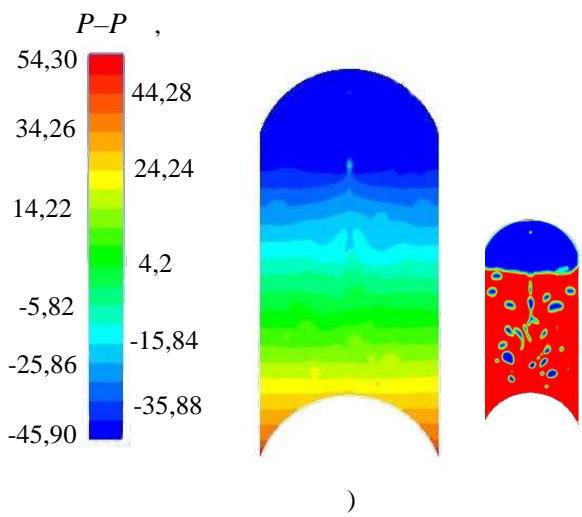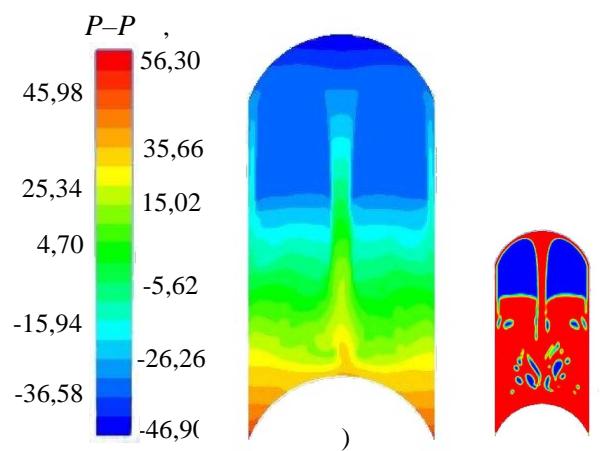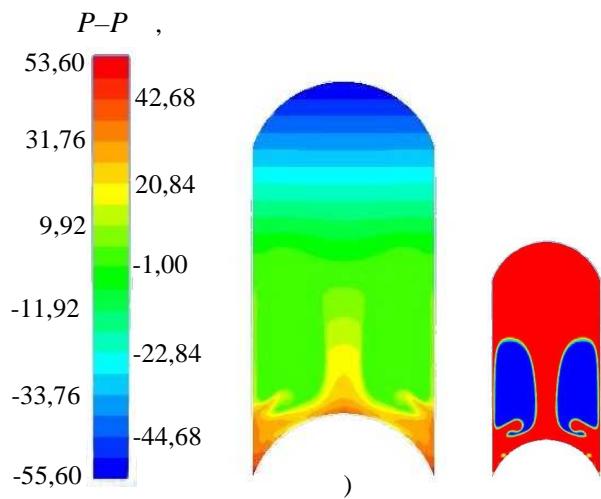
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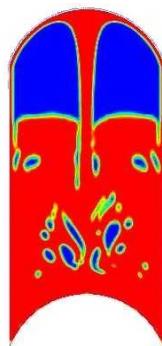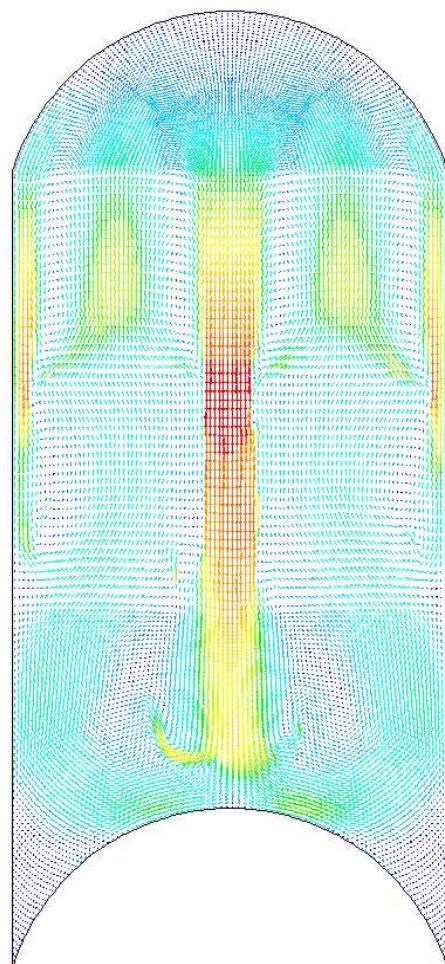
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