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Particularity of the Rocket Movement upon the Launcher under the Disturbance Factors Action which Appear During the Firing

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***Abstract*—Taking into consideration that during the firing, the rocket-launching device system oscillates and these oscillations may have a negative influence on the unguided rocket firing precision, it is necessary to evaluate the exactly influence of the disturbance factors on the rocket movement upon the launcher. This study presents the equations of the rocket movement upon the launcher under the disturbance factors action, taking into consideration that the rocket is the integrated part of the rocket-launching device system. Knowing the time evolution of the rocket movement, we can evaluate more accurate the the rocket-launching device system oscillations during the firing.**

***Index Terms*— launching device, oscillation, disturbance, mathematical model.**

I. Introduction

The main problems which appear during the study of the launcher devices dynamics and during the rocket launching, consist in determination of the charges that act on the rocket, in calculus of the mechanical resistance [6],[7] for the component parts from the launching device during the launch and during the motion and in evaluation of the rocket disturbances during the launch [3], [5].

Concerning the rocket launching it is imposed the determination of the disturbances for the rocket motion parameters during the launching. The deviation and the dispersal of this parameters is determined by the systematically and randomly disturbances that act on the launching device and on the rocket during the launching.

The size of the rocket motion parameters dispersal depends on the launching device parameters and on the stiffness of the different subsystems and elements of it. In the design phases we have to choose the numerical values for the launching device parameters, so that the size of the rocket motion parameter deviations during the launching must be minimized.

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II. Disturbances factors

A. Act of the gas jet

During the rocket firing, the launching device is stressed as mechanic as thermic. The hot gas jet from the rocket propulsion system has a major contribution at this stress, influencing directly the mechanical resistance for the component parts from the launching device, the stability and the oscillatory motion of this during the launching, and implicit the firing accuracy. Consequently, the acquaintance of the stresses that act on the launching device by reason of the gas jet is quite important in the design phase, in order to foresee the constructive, functional and maintenance needed actions [5].

The rocket engine gas jet during the launching is a no-isothermal, free or limited supersonic jet, according with the launching type. The concretely nature of the gas jet, as well as the own parameters effective values (velocity, density, static and dynamic pressure, debit, temperature, etc.) in different points of the jet, influences the intensity of the action on the launching device.

In the case of sloped launching the action area of gas jet is bigger, including the guide path, the other rockets, the leveling devices, etc.

In order to express the gas jet action of the rocket engine on the launching device, we use the state parameters of the jet and the value distribution of them.

B. Act of the wind

The pressure of the air stream (the wind) on the surface of the tilting platform gets out a resultant resistance force. The value of this force depends of the air friction upon the walls and of the pressure difference between the anterior and posterior parts [5].

So, the kinetic energy of the moving air is spent through friction (converted in the caloric energy) and through the development of the vortex round of the assembly (converted in the vortex kinetic energy).

C. Launching device oscillations during the firing

We consider that the launching device with the moving rocket form an oscillating system, described by an assemble of the rigid bodies (Fig. 1) bound together by elastic elements, having as main components: the vehicle chassis (upon which is laid the launching device's basis with the revolving support of the mechanisms), the tilting platform (with the containers for the rockets) and the rockets (including the moving rocket).

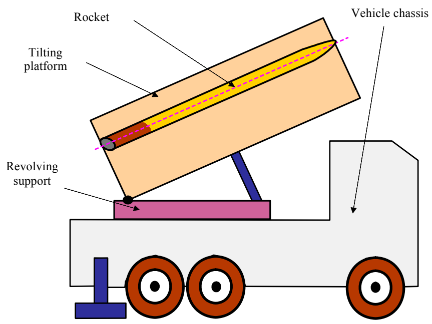

Fig. 1 The components of the rocket-launching device system

An important problem in studying the rocket launch is to determine the oscillations and their effects on the initial conditions of the rocket path. This phenomenon influences the stability of the launching device and the firing precision. The study presents the methods that allow calculating the oscillations of the launching device during firing, evaluating the dynamic stability and also computing more accurately the rocket movement elements during launch [1].

III. Forces and Moments that Act on the Rocket during Firing

To be able to approach the real analyzed phenomenon, we took into consideration all forces and moments that act upon the rocket-launching device system during firing.
We will consider separately the moving rocket in order to highlight the exterior and interior forces that act on it:

- Propulsion force:
  - rocket thrust $\overline{T}$ oriented along the $O_R x_R$ axis.
- External force:
  - rocket weight, $\overline{G}_R$.
- Connection forces and moments.

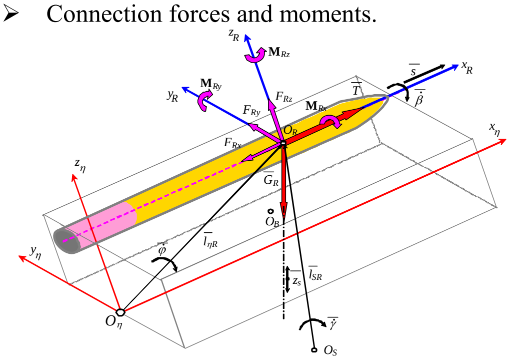

Fig. 2 The rocket forces and moments

The connection forces, including the friction force act on the all contact surface between the rocket and the tilting platform. In order to reduce the complexity of the calculus, but without limiting the studied problem generality, these forces will be reduced to resulting forces and moments in the rocket centre of masse [1], [5]:

- the connection force between the rocket and the tilting platform, $\overline{F}_R$ (force of reaction of the tilting platform on the moving rocket), has the components F_{Ry} and F_{Rz} in the transversal plan of the rocket, oriented along the $O_R y_R$ axis and respectively $O_R z_R$ axis (connection forces between the rocket and the tilting platform), and the component F_{Rx} oriented along the $O_R x_R$ axis, that consist in the withholding force $\overline{F}_{ret}$. This acts upon the rocket until the thrust overcomes the withholding force (the withholding force keeps the rocket from moving until the rocket thrust attains a certain imposed value). Additionally, the friction force $\overline{F}_f$ acts between the rocket and the tilting platform;
- the connection moment between the rocket and the tilting platform, $\overline{\mathbf{M}}_R$ (the moment of reaction of the tilting platform on the moving rocket) is given in relation with the rocket centre of masse, having the components $\mathbf{M}_{Rx}$, $\mathbf{M}_{Ry}$ and $\mathbf{M}_{Rz}$ in the rocket system of axes $O_R x_R y_R z_R$.

IV. Movement Equations of the Rocket

In the rocket-launching device system there are 6 characteristic points (Fig. 3) [1]: O_T (the fixed point bound up with the ground), O_S (the vehicle chassis centre of masse), O_Π (the centre of masse of the revolving support), O_η (the meeting point between the axle collar of the tilting platform and the longitudinal plan of the launching device), O_B (the tilting platform centre of masse) and O_R (the moving rocket centre of masse).

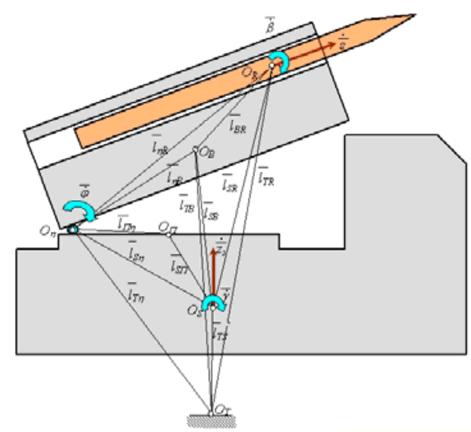

Fig. 3 The calculus diagram for the rocket-launching device system

In our study, the moving rocket system of axes moves in relation to the tilting platform system of axes, whereas the last one moves in relation to the chassis system of axes which has the ground system of axes as a reference system (fixed coordinate system) [8], [5].

To simplify the calculus, but without limiting the generality of the study, we consider the movement of the rocket-launching device system during firing being completely described by 6 state variables: the rocket linear translation in the container's guiding tube, s , two angles that define the tilting platform's position (pitch and gyration oscillation), φ_y , φ_z , other two angles that define the vehicle

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chassis pitch and rolling motions, γ_x, γ_y, and the chassis center of masse oscillating vertical displacement, z_S.

On the basis of the data presented before and using the fundamental theories of the solid mechanics (pulse theorem, etc.) we can determine the vectorial equations that describe the movement of the centre of masse and therefore the movement around it for all the 3 main components of the system.

In this manner, we obtain a system of 6 vectorial equations, respectively of 18 scalar second order differential equations, that allow determining the state variables. Following we present only the rocket movement equations, the other equations being obtained using the similar methods.

A. Movement equation of the rocket center of masse

Applying the pulse theorem and considering the system of forces presented above, we obtain the first vectorial equation that describes the rocket movement on the launching device [5]:

$$\begin{aligned} M_R\ddot{\bar{s}} &= \overline{T} + \overline{G}_R + \overline{F}_R - M_R\ddot{\bar{z}}_S - M_R\ddot{\bar{\gamma}}\times\overline{l_{SR}} + \\ &+ M_R\overline{l_{SR}}\left(\dot{\gamma}^2\right) - 2M_R\dot{\bar{\gamma}}\times\dot{\bar{s}} - M_R\dot{\bar{\gamma}}\left(\dot{\bar{\gamma}}\,\overline{l_{SR}}\right) - \\ &- M_R\ddot{\bar{\varphi}}\times\overline{l_{\eta R}} + M_R\overline{l_{\eta R}}\left(\dot{\varphi}^2\right) - 2M_R\dot{\bar{\varphi}}\times\dot{\bar{s}} - \\ &- M_R\dot{\bar{\varphi}}\left(\dot{\bar{\varphi}}\,\overline{l_{\eta R}}\right) + 2M_R\overline{l_{\eta R}}\left(\dot{\bar{\gamma}}\,\dot{\bar{\varphi}}\right) - 2M_R\dot{\bar{\varphi}}\left(\dot{\bar{\gamma}}\,\overline{l_{\eta R}}\right). \end{aligned} \tag{1}$$

In this equation we can highlight some terms having the dimensions of the forces (representing the components of the inertial forces: $-\overline{F}_t^{RS}$, $-\overline{F}_\gamma^{Rt}$, $-\overline{F}_\gamma^{Rr}$ etc), as following:

- ❖ term dues to the vertical chassis translation movement, $-\overline{F}_t^{RS} = -M_R\ddot{\bar{z}}_S$;
- ❖ term dues to the rocket translation upon the guiding tube, $\overline{F}_t^{R} = M_R\ddot{\bar{s}}$;
- ❖ terms due to the chassis rotations:
  - ✓ $-\overline{F}_\gamma^{Rt} = -M_R\left(\ddot{\bar{\gamma}}\times\overline{l_{SR}}\right)$, for the tangential acceleration;
  - ✓ $-\overline{F}_\gamma^{Rr} = M_R\,\overline{l_{SR}}\,\dot{\gamma}^2$, for the normal acceleration;
  - ✓ $-\overline{F}_\gamma^{Rc} = -2M_R\left(\dot{\bar{\gamma}}\times\dot{\bar{s}}\right)$, for the Coriollis acceleration;
  - ✓ $-\overline{F}_\gamma^{R} = -M_R\dot{\bar{\gamma}}\left(\dot{\bar{\gamma}}\overline{l_{SR}}\right)$, complementary term dues to the rotation $\bar{\gamma}$;
- ❖ terms due to the tilting platform rotation:
  - ✓ $-\overline{F}_\varphi^{Rt} = -M_R\left(\ddot{\bar{\varphi}}\times\overline{l_{\eta R}}\right)$, for the tangential acceleration;
  - ✓ $-\overline{F}_\varphi^{Rr} = M_R\,\overline{l_{\eta R}}\,\dot{\varphi}^2$, for the normal acceleration;
  - ✓ $-\overline{F}_\varphi^{Rc} = -2M_R\left(\dot{\bar{\varphi}}\times\dot{\bar{s}}\right)$, for the Coriollis acceleration;
  - ✓ $-\overline{F}_\varphi^{R} = -M_R\dot{\bar{\varphi}}\left(\dot{\bar{\varphi}}\,\overline{l_{\eta R}}\right)$, complementary term due to the rotation φ;
- ❖ terms due to the chassis and tilting platform rotations, γ and φ:
  - ✓ $-\overline{F}_{\varphi\gamma}^{R1} = 2M_R\overline{l_{\eta R}}\left(\dot{\bar{\gamma}}\dot{\bar{\varphi}}\right)$; $-\overline{F}_{\varphi\gamma}^{R2} = -2M_R\dot{\bar{\varphi}}\left(\dot{\bar{\gamma}}\,\overline{l_{\eta R}}\right)$.

In the similar manner, we note with $-\overline{F}_t^{R}$, the term dues to the rocket translation along the guiding tube, having the expression $-\overline{F}_t^{R} = -M_R\ddot{\bar{s}}$.

B. Movement equation around the rocket center of masse

In order to obtain the vectorial equation of the rocket movement around of its center of masse, we apply the kinetic moment theorem in relation with the rocket center of masse, O_R. So, we obtain the following equation:

$$\tau_R\dot{\bar{\omega}}_R + \bar{\omega}_R\times\left(\tau_R\bar{\omega}_R\right) = \overline{\mathbf{M}}_R, \tag{2}$$

where, considering that the rocket has a symmetrical form in relation with the $O_R x_R$ axis, we have

τ_R - the tensor moment of inertia:

$$\tau_R = \begin{pmatrix} J_{Rx} & 0 & 0 \\ 0 & J_{Ry} & 0 \\ 0 & 0 & J_{Rz} \end{pmatrix}, \tag{3}$$

where the transversal moments of inertia are equals, $J_{Ry} = J_{Rz} = J$;

$\bar{\omega}_R$ - the angular velocity of the $O_R x_R y_R z_R$ system of axes in relation with the $O_T x_T y_T z_T$ system of axes bound with the ground:

$$\bar{\omega}_R = \bar{\omega}_R^{(0)} = \dot{\bar{\gamma}} + \dot{\bar{\varphi}} + \dot{\bar{\beta}}; \tag{4}$$

$\overline{\mathbf{M}}_R$ - the vector of resultant moment given by the all forces that act on the rocket, calculated in relation with the point O_R.

C. Scalar equations of the rocket movement

Using the vectorial equations (1) and (2), that describe the rocket movement during the firing, and the expression for the terms of the forces and moments presented above, we obtain the scalar equation of the rocket movement written in relation with the system of axes bound with the axle collar of the tilting platform $O_\eta x_\eta y_\eta z_\eta$:

$$\begin{aligned} &\ddot{s} + \ddot{z}_S A_{13}^{\gamma\varphi 0\varphi} + \ddot{\gamma}_x\left(A_{21}^{\varphi 0\varphi} l_{SRz}^{\eta} - A_{31}^{\varphi 0\varphi} l_{SRy}^{\eta}\right) + \\ &+ \ddot{\gamma}_y\left(A_{22}^{\varphi 0\varphi} l_{SRz}^{\eta} - A_{32}^{\varphi 0\varphi} l_{SRy}^{\eta}\right) + \ddot{\varphi}_y l_{\eta Rz}^{\eta} - \\ &- \ddot{\varphi}_z l_{\eta Ry}^{\eta} + \dot{\gamma}_x^2\left(B_{\gamma 1} - l_{SRx}^{\eta}\right) + \dot{\gamma}_y^2\left(B_{\gamma 2} - l_{SRx}^{\eta}\right) + \\ &+ \dot{\gamma}_x\dot{\gamma}_y B_{\gamma 3} - \dot{\varphi}_y^2 l_{\eta Rx}^{\eta} - \dot{\varphi}_z^2 l_{\eta Rx}^{\eta} - 2\dot{\gamma}_x\dot{\varphi}_y A_{21}^{\varphi 0\varphi} l_{\eta Rx}^{\eta} - \\ &- 2\dot{\gamma}_x\dot{\varphi}_z A_{31}^{\varphi 0\varphi} l_{\eta Rx}^{\eta} - 2\dot{\gamma}_y\dot{\varphi}_y A_{22}^{\varphi 0\varphi} l_{\eta Rx}^{\eta} - \\ &- 2\dot{\gamma}_y\dot{\varphi}_z A_{32}^{\varphi 0\varphi} l_{\eta Rx}^{\eta} = \frac{T}{M_R} + \frac{F_{Rx}}{M_R} - A_{13}^{\gamma\varphi 0\varphi} g; \end{aligned} \tag{5}$$

$$\begin{aligned} &\ddot{z}_S A_{23}^{\gamma\varphi 0\varphi} + \ddot{\gamma}_x\left(A_{31}^{\varphi 0\varphi} l_{SRx}^{\eta} - A_{11}^{\varphi 0\varphi} l_{SRz}^{\eta}\right) + \\ &+ \ddot{\gamma}_y\left(A_{32}^{\varphi 0\varphi} l_{SRx}^{\eta} - A_{12}^{\varphi 0\varphi} l_{SRz}^{\eta}\right) + \ddot{\varphi}_z l_{\eta Rx}^{\eta} + \\ &+ \dot{\gamma}_x^2\left(B_{\gamma 4} - l_{SRy}^{\eta}\right) + \dot{\gamma}_y^2\left(B_{\gamma 5} - l_{SRy}^{\eta}\right) + \\ &+ \dot{\gamma}_x\dot{\gamma}_y B_{\gamma 6} - \dot{\varphi}_z^2 l_{\eta Ry}^{\eta} + \dot{\varphi}_y\dot{\varphi}_z l_{\eta Rz}^{\eta} + \\ &+ \dot{\gamma}_x\dot{\varphi}_y\left(B_{\varphi\gamma 1} - 2A_{21}^{\varphi 0\varphi} l_{\eta Ry}^{\eta}\right) - \\ &- 2\dot{\gamma}_x\dot{\varphi}_z A_{31}^{\varphi 0\varphi} l_{\eta Ry}^{\eta} + \dot{\gamma}_y\dot{\varphi}_y\left(B_{\varphi\gamma 2} - 2A_{22}^{\varphi 0\varphi} l_{\eta Ry}^{\eta}\right) - \\ &- 2\dot{\gamma}_y\dot{\varphi}_z A_{32}^{\varphi 0\varphi} l_{\eta Ry}^{\eta} + 2\,\dot{s}\,\dot{\gamma}_x A_{31}^{\varphi 0\varphi} + \\ &+ 2\,\dot{s}\,\dot{\gamma}_y A_{32}^{\varphi 0\varphi} + 2\dot{s}\,\dot{\varphi}_z = \frac{F_{Ry}}{M_R} - A_{23}^{\gamma\varphi 0\varphi} g; \end{aligned} \tag{6}$$

$$
\begin{aligned}
&\ddot{z}_S A_{33}^{\gamma\varphi0\varphi} + \ddot{\gamma}_x\left(A_{11}^{\varphi0\varphi} l_{SRy}^{\eta} - A_{21}^{\varphi0\varphi} l_{SRx}^{\eta}\right) + \\
&+ \ddot{\gamma}_y\left(A_{12}^{\varphi0\varphi} l_{SRy}^{\eta} - A_{22}^{\varphi0\varphi} l_{SRx}^{\eta}\right) - \ddot{\varphi}_y l_{\eta Rx}^{\eta} + \\
&+ \dot{\gamma}_x^2\left(B_{\gamma7} - l_{SRz}^{\eta}\right) + \dot{\gamma}_y^2\left(B_{\gamma8} - l_{SRz}^{\eta}\right) + \\
&+ \dot{\gamma}_x\dot{\gamma}_y B_{\gamma9} - \dot{\varphi}_y^2 l_{\eta Rz}^{\eta} + \dot{\varphi}_y\dot{\varphi}_z l_{\eta Ry}^{\eta} - \\
&- 2\dot{\gamma}_x\dot{\varphi}_y A_{21}^{\varphi0\varphi} l_{\eta Rz}^{\eta} + \dot{\gamma}_x\dot{\varphi}_z\left(B_{\varphi\gamma1} - 2A_{31}^{\varphi0\varphi} l_{\eta Rz}^{\eta}\right) - \\
&- 2\dot{\gamma}_y\dot{\varphi}_y A_{22}^{\varphi0\varphi} l_{\eta Rz}^{\eta} + \dot{\gamma}_y\dot{\varphi}_z\left(B_{\varphi\gamma2} - 2A_{32}^{\varphi0\varphi} l_{\eta Rz}^{\eta}\right) - \\
&- 2\dot{s}\,\dot{\gamma}_x A_{21}^{\varphi0\varphi} - 2\dot{s}\,\dot{\gamma}_y A_{22}^{\varphi0\varphi} - 2\dot{s}\,\dot{\varphi}_y = \frac{F_{Rz}}{M_R} - A_{33}^{\gamma\varphi0\varphi} g\,;
\end{aligned} \tag{7}
$$

$$
\mathbf{M}_{Rx} = \ddot{\gamma}_x J_{Rx} A_{11}^{\varphi0\varphi} + \ddot{\gamma}_y J_{Rx} A_{12}^{\varphi0\varphi} + \ddot{\beta} J_{Rx} \tag{8}
$$

$$
\begin{aligned}
\mathbf{M}_{Ry} &= \ddot{\gamma}_x J_{Ry} A_{21}^{\varphi0\varphi} + \dot{\gamma}_x^2 (J_{Rx} - J_{Rz}) A_{11}^{\varphi0\varphi} A_{31}^{\varphi0\varphi} + \\
&+ \ddot{\gamma}_y J_{Ry} A_{22}^{\varphi0\varphi} + \dot{\gamma}_y^2 (J_{Rx} - J_{Rz}) A_{12}^{\varphi0\varphi} A_{32}^{\varphi0\varphi} + \\
&+ \dot{\gamma}_x\dot{\gamma}_y (J_{Rx} - J_{Rz})\left(A_{11}^{\varphi0\varphi} A_{32}^{\varphi0\varphi} + A_{12}^{\varphi0\varphi} A_{31}^{\varphi0\varphi}\right) + \\
&+ \dot{\gamma}_x\dot{\varphi}_z (J_{Rx} - J_{Rz}) A_{11}^{\varphi0\varphi} + \dot{\gamma}_y\dot{\varphi}_z (J_{Rx} - J_{Rz}) A_{12}^{\varphi0\varphi} + \\
&+ \dot{\gamma}_x\dot{\beta}(J_{Rx} - J_{Rz}) A_{31}^{\varphi0\varphi} + \dot{\gamma}_y\dot{\beta}(J_{Rx} - J_{Rz}) A_{32}^{\varphi0\varphi} + \\
&+ \dot{\varphi}_z\dot{\beta}(J_{Rx} - J_{Rz}) + J_{Ry}\ddot{\varphi}_y;
\end{aligned} \tag{9}
$$

$$
\begin{aligned}
&\ddot{\gamma}_x J_{Rz} A_{31}^{\varphi0\varphi} + \ddot{\gamma}_y J_{Rz} A_{32}^{\varphi0\varphi} + J_{Rz}\ddot{\varphi}_z + \\
&+ \dot{\gamma}_x^2\left(J_{Ry} - J_{Rx}\right) A_{11}^{\varphi0\varphi} A_{21}^{\varphi0\varphi} + \\
&+ \dot{\gamma}_y^2\left(J_{Ry} - J_{Rx}\right) A_{12}^{\varphi0\varphi} A_{22}^{\varphi0\varphi} + \\
&+ \dot{\gamma}_x\dot{\gamma}_y\left(J_{Ry} - J_{Rx}\right)\left(A_{11}^{\varphi0\varphi} A_{22}^{\varphi0\varphi} + A_{12}^{\varphi0\varphi} A_{21}^{\varphi0\varphi}\right) + \\
&+ \dot{\gamma}_x\dot{\varphi}_y\left(J_{Ry} - J_{Rx}\right) A_{11}^{\varphi0\varphi} + \dot{\gamma}_y\dot{\varphi}_y\left(J_{Ry} - J_{Rx}\right) A_{12}^{\varphi0\varphi} + \\
&+ \dot{\gamma}_x\dot{\beta}\left(J_{Ry} - J_{Rx}\right) A_{21}^{\varphi0\varphi} + \dot{\gamma}_y\dot{\beta}\left(J_{Ry} - J_{Rx}\right) A_{22}^{\varphi0\varphi} + \\
&+ \dot{\varphi}_y\dot{\beta}\left(J_{Ry} - J_{Rx}\right) = \mathbf{M}_{Rz},
\end{aligned} \tag{10}
$$

The terms that express the existence of the rocket lateral movement (that contain $\dot{\gamma}_x$, $\ddot{\gamma}_x$) are due, in special, to the unlevelness distribution of the tilting platform weight and of the vehicle chassis in relation with the launching longitudinal plan.

The equations (5) – (10) with the other 12 scalar equation corresponding to the tilting platform and to the chassis form a second order differential nonlinear equations system that allows to determine the launching device oscillations using the numerical solving [1], [5].

V. SCHEDULING ALGORITHM FOR THE DETERMINATION OF THE ROCKET MOVEMENT UPON THE LAUNCHING DEVICE

The numerical application named ILANPRN [4], developed by the authors using the general mathematical model [1], [2] allows calculating the oscillations of the rocket-launching device system.

Following we present the module that allow determining the rocket movement along the guiding tube as well as the connection forces and moments between the rocket and the tilting platform.

Because the rocket is in a tube from the launching container, it will follow the movements of the tilting platform. Consequently, the rocket will receive from the vehicle chassis the rotation γ and the translation $\overline{z}_S$, and from the tilting platform the rotation φ . In relation with the tilting platform, the rocket does a translation with the velocity $\dot{\bar{s}}$, along the firing sense, and a rotation movement with the angular velocity $\dot{\bar{\beta}}$.

The connection between the rockets and the tilting platform is realized using the guiding tube concretized through the connection forces $\overline{F}_{Ri}$ and connection moments, $\overline{\mathbf{M}}_{Ri}$. In the Fig. 4 we present the calculus diagram of the rocket movement.

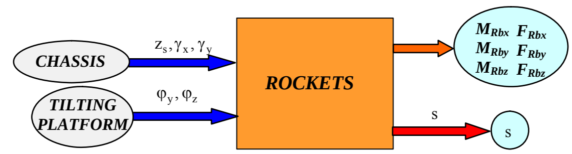

Fig. 4 The calculus diagram of the rocket movement

The initial firing parameters, among that we notice the rocket constructive characteristics, the presence of the rocket on the launching device, as well as the initial firing position (the orientation of the tilting platform along the firing direction), are some needed initial data used to solve the rocket equations. The other data category is represented by the linear and angular position variables from the tilting platform level and respectively from the vehicle chassis level.

After the calculus we can generate the values of the connection forces and moments between the rocket and the tilting platform as well as the time history of the rocket position along the launching device. These evolutions have an important influence upon all the launching device system components and, implicitly upon the rocket during the firing.

VI. NUMERICAL RESULTS

We consider a study case, based on the real situation having 2 rocket in the launching container placed in the positions 15 and 40. The first rocket is launched from the 15 position, and after 0.5 s we launch the second rocket from the 40 position.

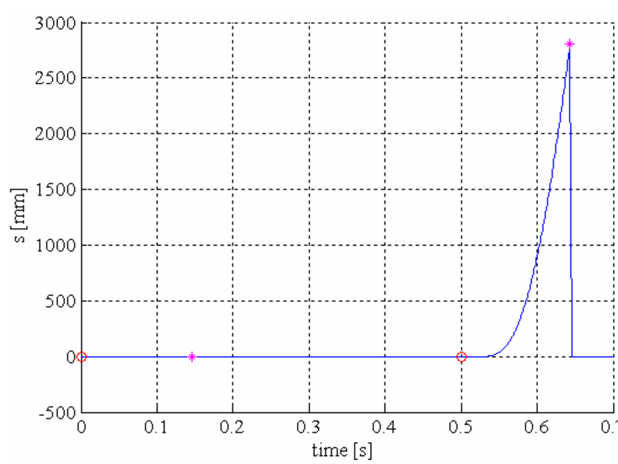

Fig. 5 Time history of the displacement s

The launching device orientation along the firing direction is given by the angles φ_{H0} and φ_{V0} equals with 45° . In the

Fig. 5 is shown the time history of the rocket center of masse displacement from the position 40, launched after 0.5 s. The election of the gap 0.5 s is made according with the stability of the launcher device during firing.

In the Fig. 6 - Fig. 9 we present the lateral components of the connection forces and moments between the rocket and the tilting platform, F_{Ry}, F_{Rz}, $\mathbf{M}_{Ry}$ and $\mathbf{M}_{Rz}$.

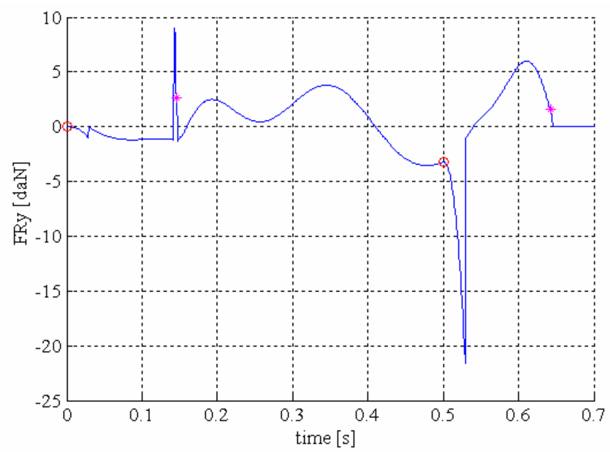

Fig. 6 Time history of the force F_{Ry}

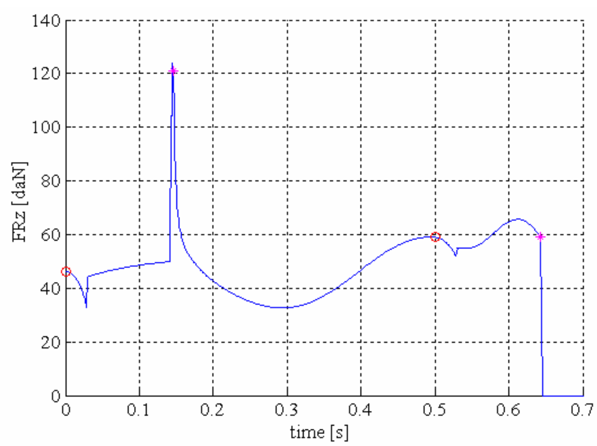

Fig. 7 Time history of the force F_{Rz}

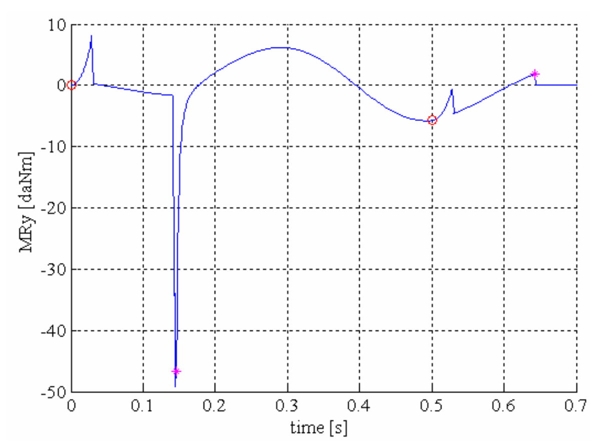

Fig. 8 Time history of the moment $\mathbf{M}_{Ry}$

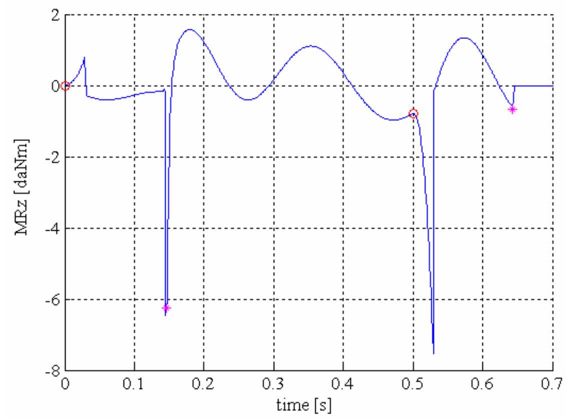

Fig. 9 Time history of the moment $\mathbf{M}_{Rz}$

The longitudinal components of these forces and moments hasn't represented because their influence are smaller. On the presented diagrams we can notice the influence of the gas jet force and of the withholding force of the rocket. The rocket movement along the guiding tube influences the stability of the whole system launching device-rocket during firing through the components of the connections forces and moments transmitted from the tilting platform [3].

Following we present the time histories of the state variables corresponding of others components of the system, respectively the oscillations φ_y, φ_z of the tilting platform and the oscillations z_s, γ_x and γ_y of the vehicle chassis.

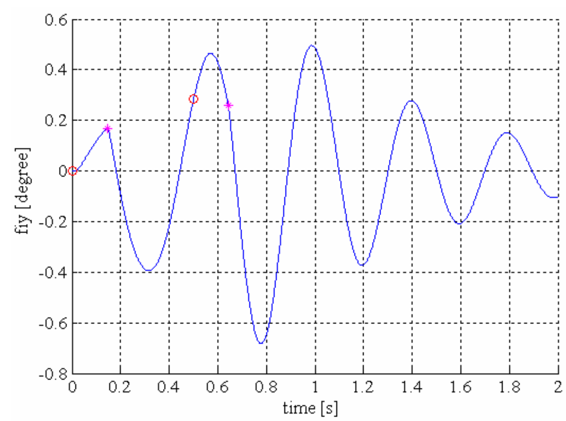

Fig. 10 Time history of the rotation angle φ_y

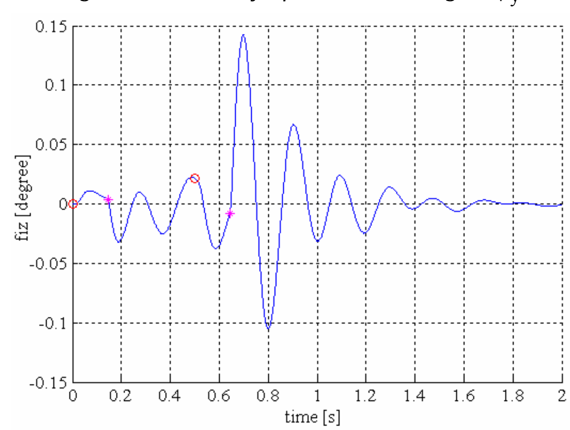

Fig. 11 Time history of the rotation angle φ_z

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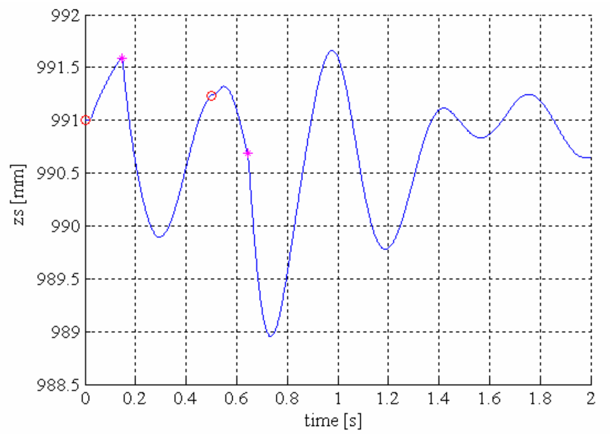

Fig. 12 Time history of the displacement z_S

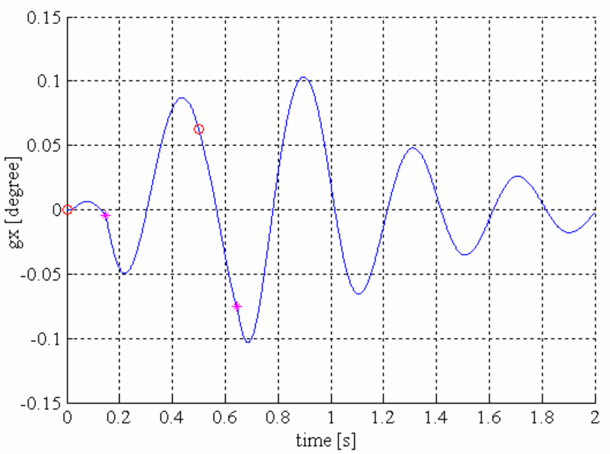

Fig. 13 Time history of the rotation angle γ_x

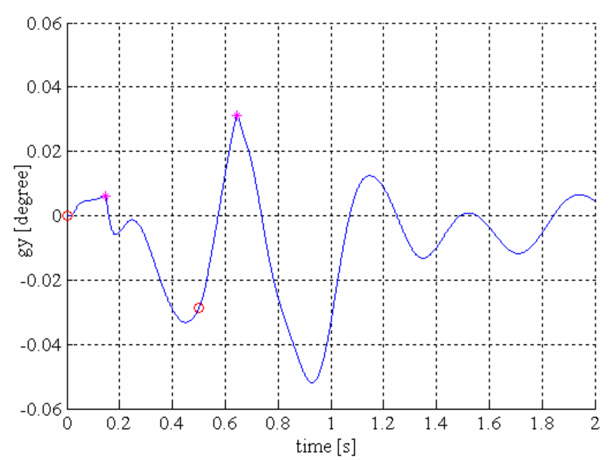

Fig. 14 Time history of the rotation angle γ_y

In the fig. 10 – 14 we notice that the state variables from the tilting platform level and from the vehicle chassis level have the damped oscillating time histories. This situation is convenient to the launching device stability in the case of firing with lots successively rockets. This thing is very important, considering also the accuracy of firing.

These oscillations have been confirmed by the experimental results which validate and lead to the improvement of the numerical scheduling algorithm.

VII. Conclusion

The evolution calculus of the rocket state variables during firing allows the evaluation of dynamic forces present at all levels of the launching device system component, and therefore the analysis of the dynamic behavior of the whole assembly system. The evaluation of the oscillation parameters of a rocket-launching device system and of their influence to the system stability during firing, such as the initial rocket flight condition, leads implicitly to evaluating the firing accuracy, a must in the design of a precise rocket-launching device system.

In conclusion, the rocket is an essential component needed to be taken into account in the launching phase design. The movement of the rocket under the action of the disturbances factors has a major influence upon the stability of whole launching device – rocket system.

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