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Rocket missile lift-off and flight simulator program

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The subject of this paper is a movable antiaircraft short-range rocket set. The control algorithm for a target homing short-range rocket missile by means of the proportional approach method is performed by an executive system comprising the co-ordinator and automatic pilot devices. The co-ordinator is equipped with a gyro-device and a system determining working out of the ideal, desirable signal. The automatic pilot device has a pair of double-position external vanes and internal gas control engine. A missile control, in accordance with the implemented algorithm, is achieved by using a rocket rotating motion around its longitudinal axis.

1. System model

Software realising the short-range homing rocket missile lift-off and flight simulation was compiled in the Borland C++ 3.1 language. The phenomena occuring in a launcher–missile–target system were subjected to the mathematical model process configuration. Generally, the following three stages of anti-aircraft rocket weapon system operation could be distinguished:

Stage 1: Pre lift-off phase

1.1 Target tracking down and identification

1.2 Target interception and tracking

Stage 2: Missile lift-off

2.1 Boost engine ignition and missile motion along the launcher guide

2.2 First rotary band leaves the launcher

2.3 Termination of boost engine operation and its disconnection from a missile body

2.4 The missile leaves the launcher

Stage 3: Rocket missile flight

3.1 Ballistic flight

3.2 Initial action:

– operation of an the internal gas control engine

– ignition of boost thrust force missile engine

3.3 Stationary guidance:

– ignition of sustainer thrust force missile engine

3.4 Final action.

The produced model includes all three stages of weapon system operation except the target tracking-down and identification. Controll of a missile rotating around its longitudinal axis is carried out in two feedback loops using a single-channel apparatus. The executive system comprises a co-ordinator equipped with a gyro-device and an automatic pilot forming the controlling force in a hybrid manner.

1.1. Physical model of the missile rocket-launcher-target system

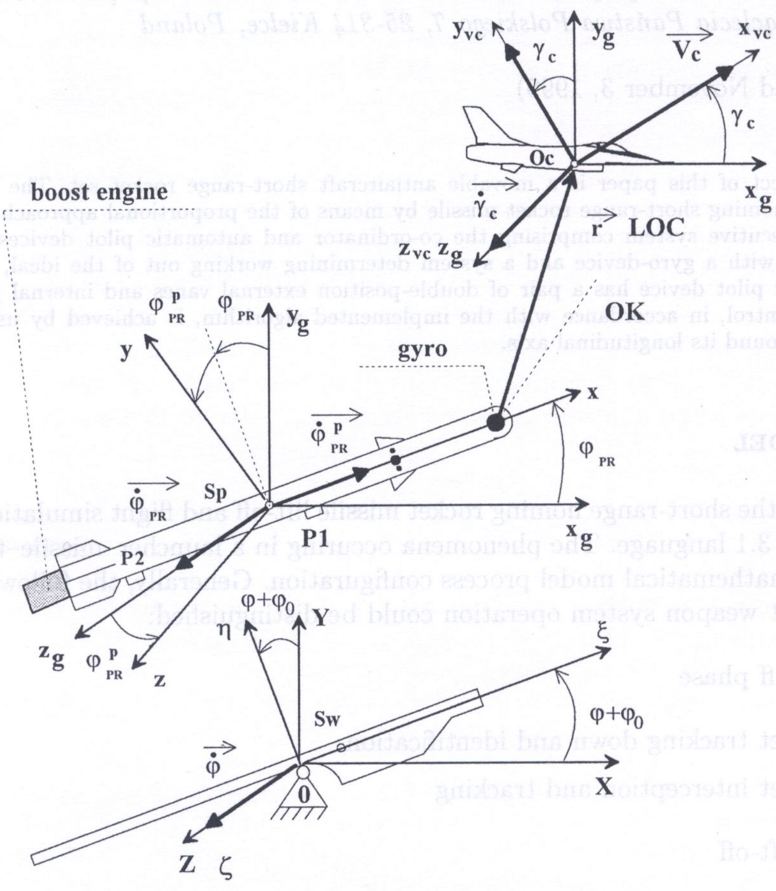


Fig. 1. Physical model of the missile rocket-launcher-target system

Inertial parameters of the system are:

m_p – rocket missile mass,

I_{px} I_{pz} – missile rocket moment of inertia,

m_w – launcher mass,

I_w – launcher moment of inertia,

m_{ss} – boost engine mass,

I_{ssx} I_{ssz} – boost engine moment of inertia.

One of the essential problems in the material system analysis is consists in establishing a model of the actual system appropriately. This is of significant importance in complex structure characteristics and in view multiplicity of physical interactions of various natures. With this regard, the actual launcher/missile rocket assembly represents a complex system. In the dynamical analysis, consideration of all structural details is limited by calculating the abilities of up-to-date digital computers as well as substantial indispensability estimated from the dynamical phenomena point of view. Not every component of both the launcher and missile rocket influences the disturbances of basic motion to the same extent. Their appropriate degeneration determines retaining by model its dynamical properties of a real structure. Not only the design of structures does require modelling, but physical phenomena taking place in the system as well. With similar regards as with structural design modelling, idealising the phenomena require the most important features to be selected. With this respect it should be emphasised that simplifications must not change dynamical phenomena in significant extent. Only mechanical interactions are involved in our discussions, consequently all the models refer to mechanical system.

1.2. Model of missile loads with inertial forces

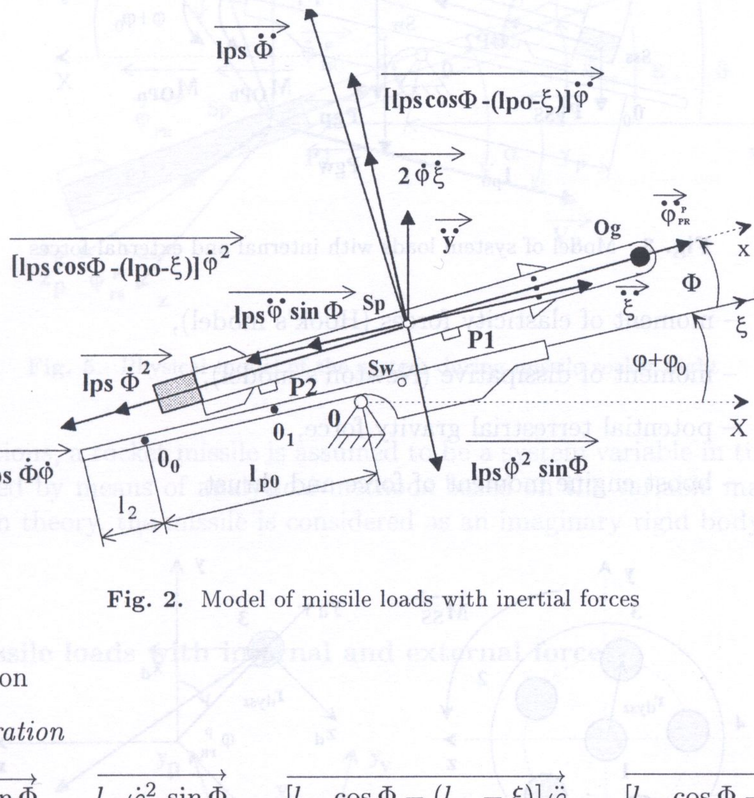


Fig. 2. Model of missile loads with inertial forces

Climbing acceleration

Climbing acceleration

$$\vec{\ddot{y}} \quad \overrightarrow{l_{ps}\ddot{\varphi}\ \sin\Phi} \quad \overrightarrow{l_{ps}\dot{\varphi}^2\ \sin\Phi} \quad \overrightarrow{[l_{ps}\ \cos\Phi - (l_{po}-\xi)]\,\ddot{\varphi}} \quad \overrightarrow{[l_{ps}\ \cos\Phi - (l_{po}-\xi)]\,\dot{\varphi}^2}$$

Relative acceleration

$$\vec{\ddot{\xi}} \quad \overrightarrow{\ddot{\varphi}^P_{PR}}$$

Coriolis acceleration

$$\overrightarrow{2\dot{\varphi}\dot{\xi}}$$

Relative acceleration

$$\overrightarrow{l_{ps}\ddot{\Phi}} \quad \overrightarrow{l_{ps}\dot{\Phi}^2}$$

Coriolis acceleration

$$\overrightarrow{2l_{ps}\dot{\Phi}\dot{\varphi}}$$

Notation of vector quantities presented in the figures are as follows: arrows stand for physical vector quantities, the moduli of which are assigned to scalar relationships given under the arrow mark; scalar relationships should be regarded as vector quantity signs.

1.3. Model of system loads with internal and external forces

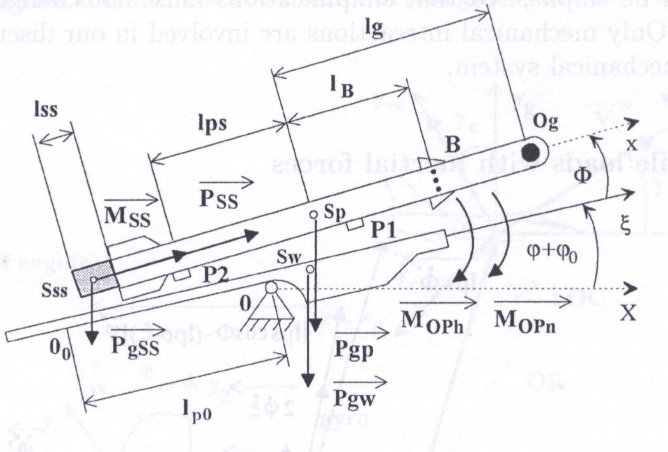


Fig. 3. Model of system loads with internal and external forces

$\overrightarrow{M_{OPh}}$ – moment of elasticity forces (Hook's model),

$\overrightarrow{M_{OPn}}$ – moment of dissipative (Newton's model),

$\overrightarrow{P_{gp}}$ $\overrightarrow{P_{gw}}$ $\overrightarrow{P_{gSS}}$ – potential terrestrial gravity force,

$\overrightarrow{P_{SS}}$ $\overrightarrow{M_{SS}}$ – boost engine moment of force and thrust.

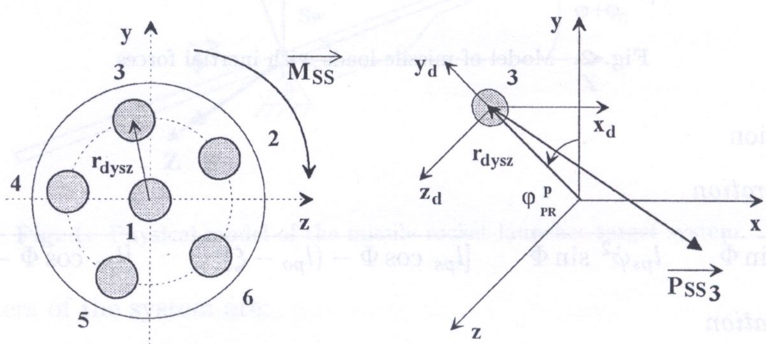


Fig. 4. Space orientation of the boost engine jet axes

Classification of the system of equations of motion derived on the basis of analytical mechanics and mathematics provides some initial data on the analysed system. From the mechanical point of view, rocket missile launching dynamics is difficult to analyse not only due to variable mass distribution of the launcher/rocket missile assembly but in view of its variable mass as well. Moreover, with rocket missile and launcher modelling vlewed as discrete systems, the established model needs to be described mathematically using strongly non-linear, differential equations which do not have accurate analytical solutions. Even though they have been linearized, equations with variable coefficients are obtained the solutions of which are burdened with errors in comparison with their non-linear equivalents. The source of nonlinearity is exclusively of geometrical nature.

1.4. Physical model of the system during missile rocket flight

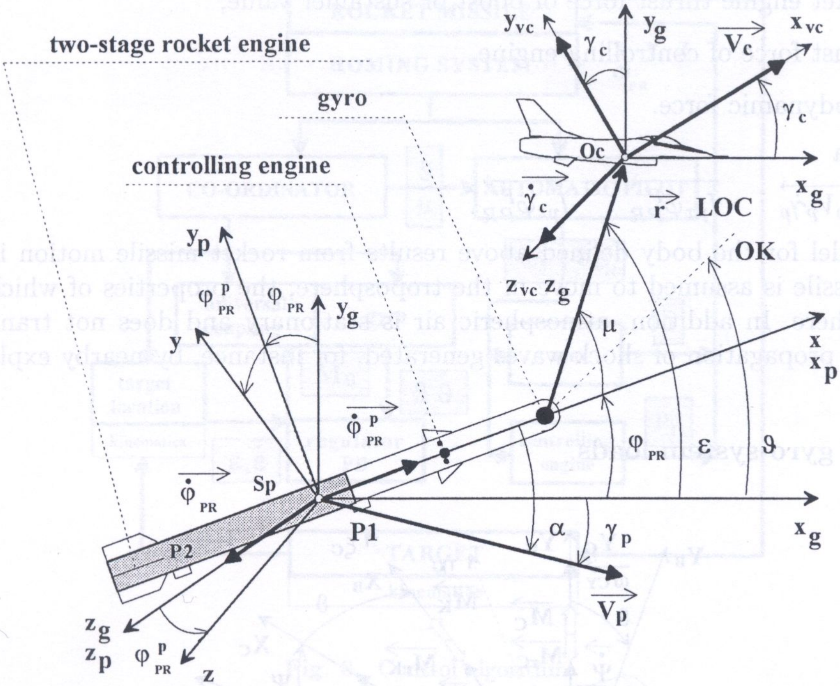


Fig. 5. Physical model of the system during missile rocket flight

In the considerations, a rocket missile is assumed to be a system variable in time. Missile motion equations are derived by means of analytical methods based on the variable mass system rigidity. According to system theory, the missile is considered as an imaginary rigid body.

1.5. Model of missile loads with internal and external forces

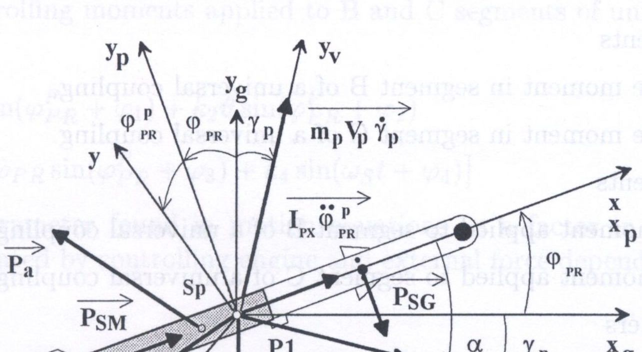


Fig. 6. Model of missile loads with internal and external forces

Internal and external forces

$\overrightarrow{P_{gp}}$ – potential terrestrial gravity force,

$\overrightarrow{P_{SM}}$ – rocket engine thrust force of boost or sustainer value,

$\overrightarrow{P_{SG}}$ – thrust force of controlling engine,

$\overrightarrow{P_a}$ – aerodynamic force.

Forces of inertia

$$\overrightarrow{m_p\dot{V}_p} \qquad \overrightarrow{m_pV_p\dot{\gamma}_p} \qquad \overrightarrow{I_{px}\ddot{\varphi}^P_{PR}} \qquad \overrightarrow{I_{pz}\ddot{\varphi}^P_{PR}}.$$

Loading model for the body defined above results from rocket missile motion in earth's atmosphere. The missile is assumed to move in the troposphere, the properties of which correspond to normal atmosphere. In addition, atmospheric air is stationary and does not transfer any disturbances, such as propagation of shock waves generated, for instance, by nearby explosions.

1.6. Model of gyro-system loads

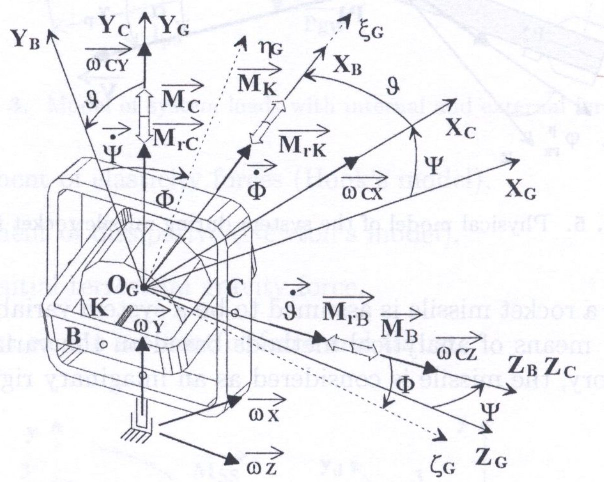


Fig. 7. Model of gyro-system loads

Dissipative forces moments

M_{rB} – friction force moment in segment B of a universal coupling,

M_{rC} – friction force moment in segment C of a universal coupling.

Controlling forces moments

M_B – controlling moment applied to segment B of a universal coupling,

M_C – controlling moment applied to segment C of a universal coupling.

Inertial system parameters

I_{Kx1} I_{Ky1} I_{Kz1} – moment of inertia of the gyro (segment K),

I_{Bx1} I_{By1} I_{Bz1} – moment of inertia of segment B of universal coupling,

I_{Cx2} I_{Cy2} I_{Cz2} – moment of inertia of segment C of universal coupling.

The established model includes in its structure mechanical part of the homing head co-ordinator system together with the controlling device. Mechanical part of the co-ordinator, simulated as Hooke's coupling on which a rotating ring featuring the gyro is suspended is the controlled object.

1.7. Control algorithm

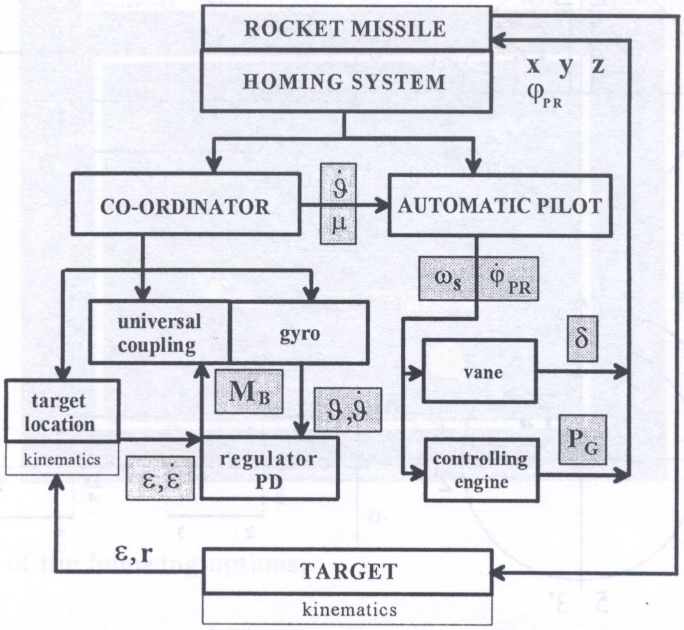


Fig. 8. Control algorithm

The controll system used is expected to assure tracking of the direction related to TOL (Target Observation Line) target tracking line by the CA co-ordinator axis. This is accomplished by establishing moments which control the gyro-axis angular position variations. Sequence of moment variations assures minimization of the actual control deviations maintaining the safety conditions. Too large values of the moments may be the reason for mechanical failure of the gyro. In the research, we use controll in closed configuration, in which a PD proportional-plus-derivative error controller is found.

Co-ordinator

$$M_B = K_1(\varepsilon - \vartheta) + K_2(\dot{\varepsilon} - \dot{\vartheta}), \qquad M_C = -K_1\psi - K_2\dot{\psi}$$

where M_B , M_C – controlling moments applied to B and C segments of universal coupling.

Automatic pilot

$$sygnal = \operatorname{sgn}\left[k_1\mu\sin(\varphi_{PR}^P + \varphi_1) + k_2\vartheta\sin(\varphi_{PR}^P + \varphi_2) + k_3\dot{\varphi}_{PR}\sin(\varphi_{PR}^P + \varphi_3) + k_4\sin(\omega_S t + \varphi_4)\right]$$

where *sygnal* – the parameter found in motion equations as a factor in components containing internal gas force generated by controlling engine and external force dependent on rotation angle of the vane

1.8. Shaping the variability course of missile controlling force

Symbols shown in the above diagram refer to the shaping of an external controlling force variability course

$\overrightarrow{P_a}$ – external force controlling a missile,

δ – angle of a vane rotation.

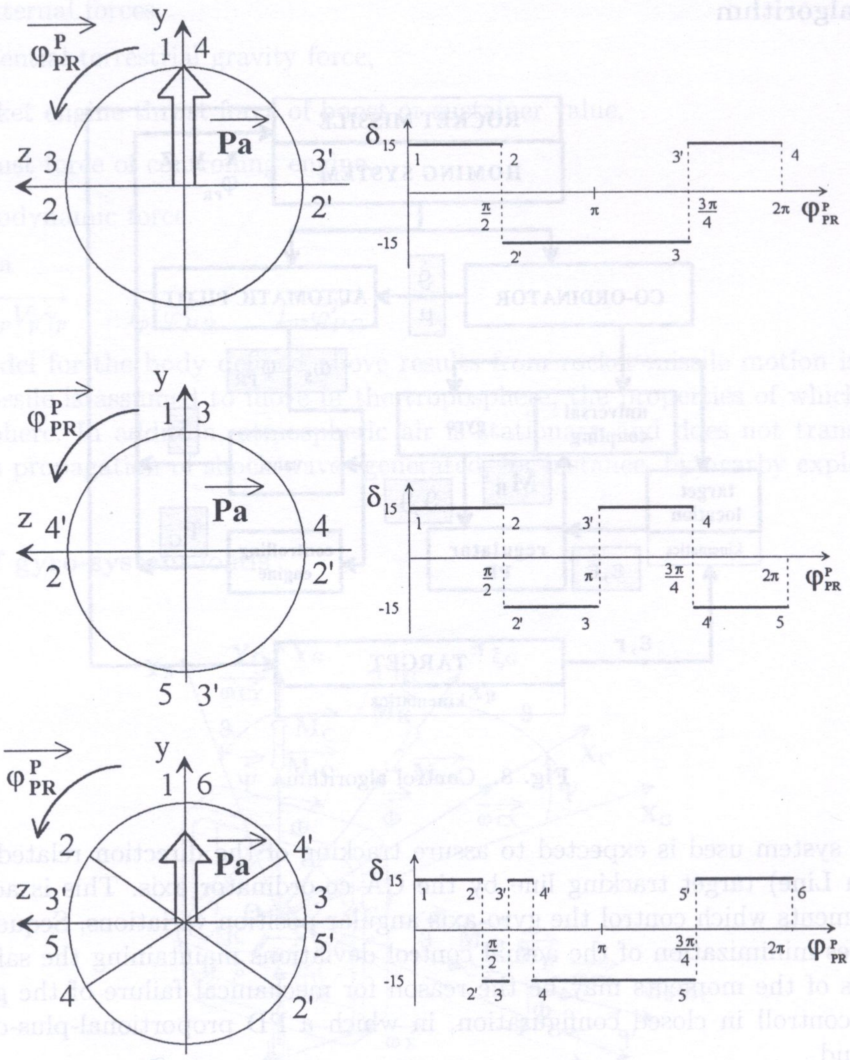


Fig. 9. Shaping the variability course of missile controlling force

In a similar way, the controlling force generated by an internal gas controlling engine is shaped. In the diagram, the following symbols correspond to the respective parameters:

$\overrightarrow{P_a}$ – internal gas controlling a missile,

δ – active controlling jet of an internal gas engine.

2. Simulator software structure – menu

The computer program includes a digital module together with menu compiled in graphic mode in the form of input and output interfaces. To parametrise the system, this menu could be used, or a batch file could be created from the level of ASCII standard text file generating editor. On entering the parameters describing specific system characteristics they are visualised in form of graphs or drawings. When calculations are being continued, the user has the possibility to see the animation of system motion at each of the discussed stages of missile weapon system operation. Therefore there is a possibility of current verification of object response, for instance when defining angular stability of performed simulation. There is also a possibility to convert results to use them in other software.

Main menu

Main menu consists of the following options:

1. **Data**
2. **Computations**
3. **Results**
4. **Subject**
5. **Exit**

Menu Options

Menu Options consists of the following options:

1. **New**
2. **File**

Option **New** makes it possible to parametrise currently the physical system and simulation process.

Option **File** uses previously established system characteristics and simulation process.

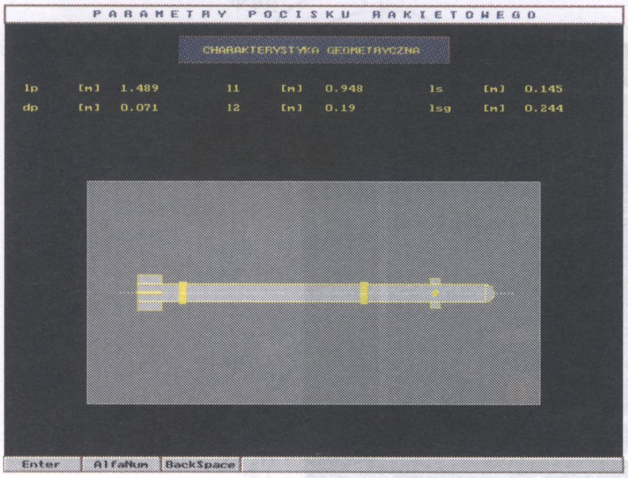
Menu Results

Menu Results consists of the following options:

1. **Graph**
2. **Chart**
3. **Grapher**

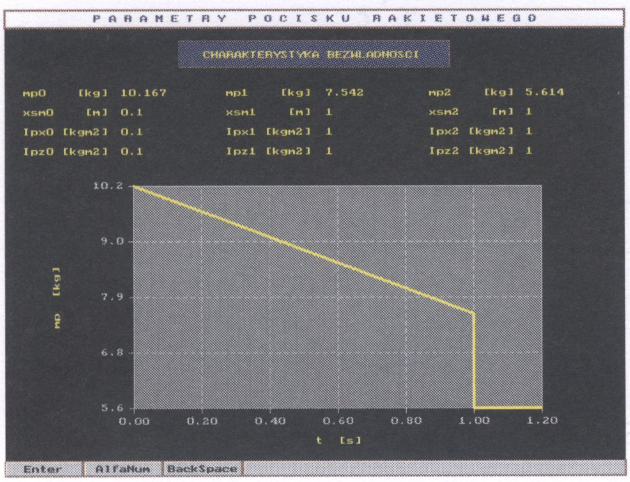
The individual options of this Menu are used to visualise the solutions obtained during the simulation process.

Geometrical characteristics



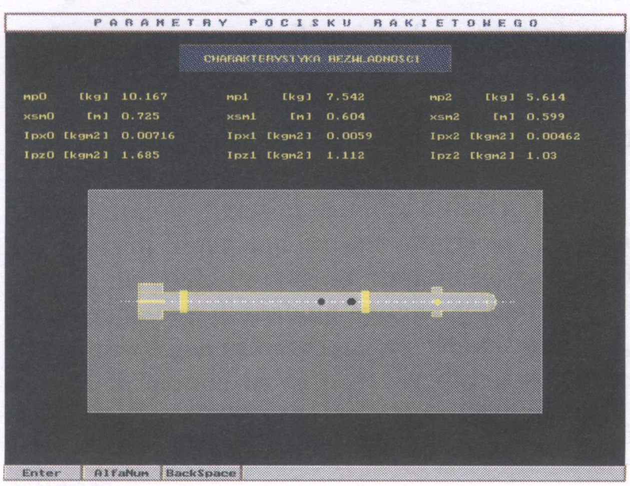
With this menu only these geometrical parameters of the rocket missile are loaded, which are used in a model describing the dynamics of the system analysed. On loading the geometrical characteristics of a missile, its shape and overall dimensions are automatically visualised. This allows to verify the assumed overall dimensions optically and to correct the values, if necessary.

Inertia characteristics



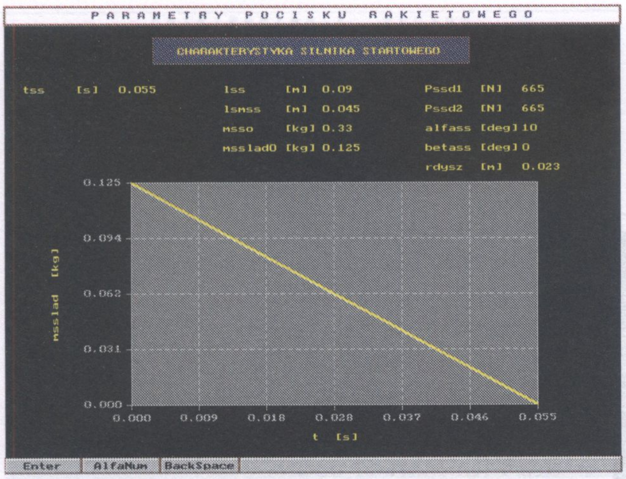
With this menu four functions describing rocket missile inertia characteristics are loaded. Graphs displayed on the monitor screen reflect the course of variability within such parameters as mass, mass centre and major central moments of inertia. The number values for the above physical quantities are determined outside the software.

Location of mass centre



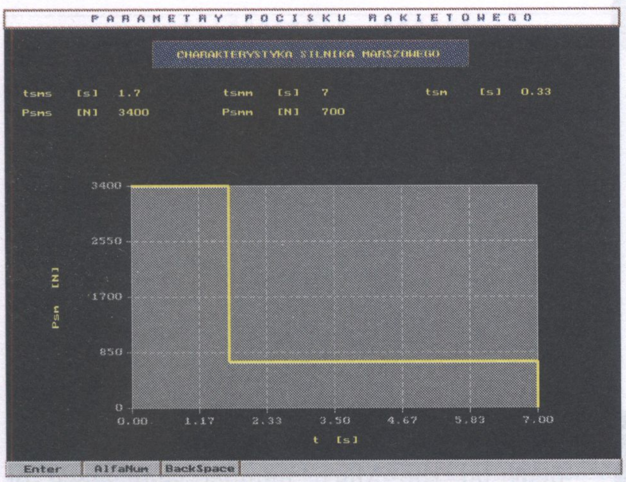
One of the parameters describing the rocket missile inertia characteristics is a of the mass centre location. Apart from the course of function variability, determining the centre of mass location in the domain of time, a picture showing the missile with marked characteristic points is displayed on the screen. The points represent linear variation of the function.

Boost engine characteristics



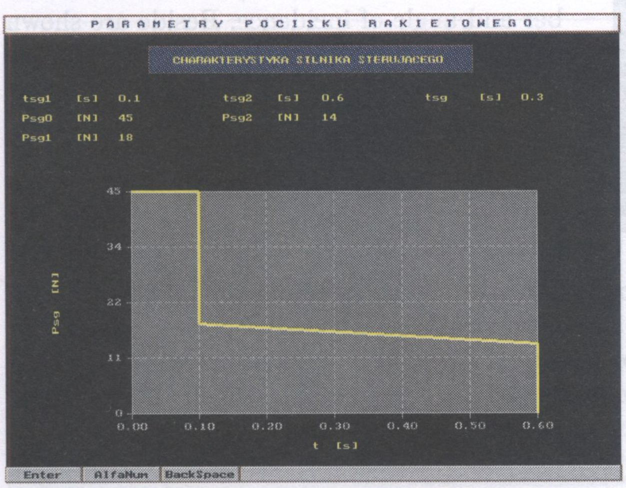
With this menu geometrical boost engine characteristics are loaded together with functions describing its inertia and distribution of thrust force. The job of a boost engine is to give the missile adequate linear and angular velocities in a tilting motion. These number values make the initial kinematic parameters of flight. In the engine geometry, space orientation of its jet axes is taken into consideration.

Rocket engine characterictics



The function of this menu is to describe the rocket missile engine thrust in the domain of time. Rocket engine is double-stage. Its job is to generate adequate thrust force to accelerate missile motion to the specified linear velocity, then to keep constant the velocity value. The missile rotation compensates some disturbances caused by deviation of action of this force from the assumed direction.

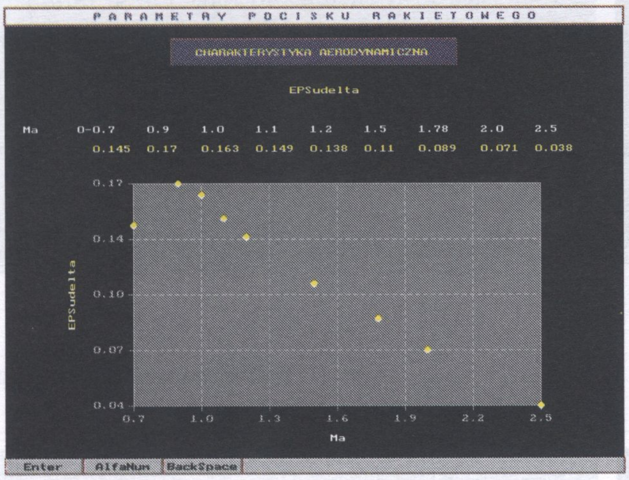
Controlling engine characteristics



The function of this menu is to describe the variation of the controlling engine thrust force in the domain of time. This engine is responsible for appropriate execution of the initial manoeuvre of a missile. The automatic pilot controls the engine using missile rotary motion. Single-channel apparatus used makes it possible to home the missile on the target proportionally.

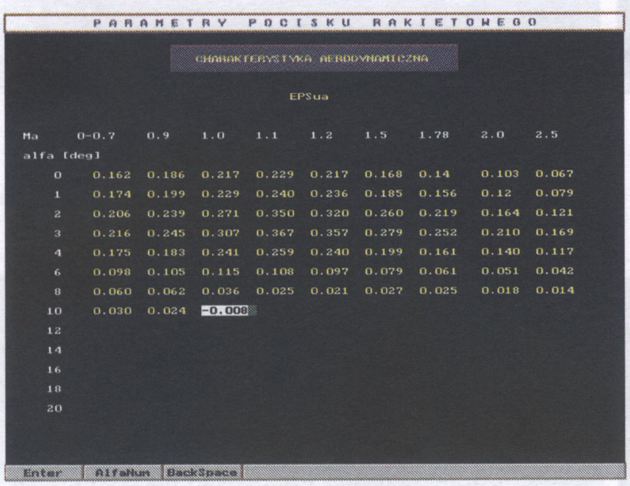
Aerodynamic characteristics

One variable function



The nine function of this menu is to describe aerodynamic characteristics dependent on Mach number. The values in nodes are determined outside the software. In the system motion simulation an interpolation between selected nodes is carried out subject to Mach number. Beside are shown characteristics with marked nodes.

Two variable function

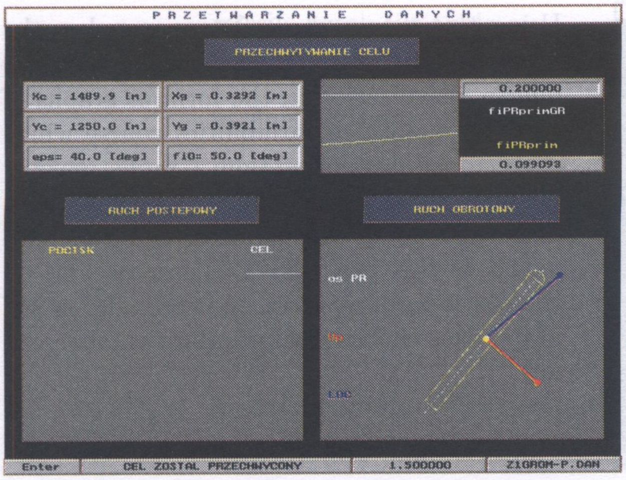


Ma / alfa [deg]	0-0.7	0.9	1.0	1.1	1.2	1.5	1.78	2.0	2.5
0	0.162	0.186	0.217	0.229	0.217	0.168	0.14	0.103	0.067
1	0.174	0.199	0.229	0.240	0.236	0.185	0.156	0.12	0.079
2	0.206	0.239	0.271	0.350	0.320	0.260	0.219	0.164	0.121
3	0.216	0.245	0.307	0.367	0.357	0.279	0.252	0.210	0.169
4	0.175	0.183	0.241	0.259	0.240	0.199	0.161	0.140	0.117
6	0.098	0.105	0.115	0.108	0.097	0.079	0.061	0.051	0.042
8	0.060	0.062	0.036	0.025	0.021	0.027	0.025	0.018	0.014
10	0.030	0.024	-0.008						
12									
14									
16									
18									
20									

With this menu eight functions are given describing aerodynamic characteristics dependent on the Mach number and angle of incidence. Values in the nodes are determined outside the software. In system motion simulation an interpolation between selected nodes is carried out, subject to Mach number and angle of incidence. Beside are shown characteristics with marked nodes.

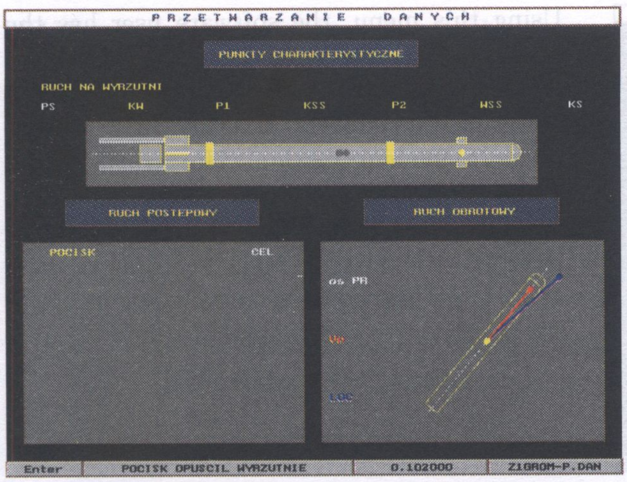
Aerodynamic characteristics are extremely substantial parameter describing the influence of environment in which a rocket missile is moving on its behaviour during flight. It is a time consuming and cost consuming operation to establish a reliable course of variability of functions loaded into the software. Empirical investigations of specifically constructed models in wind tunnels must be performed as well as additional tests during the flights on prototypes. In the design process, theoretical calculations are also carried out.

Calculations – target interception



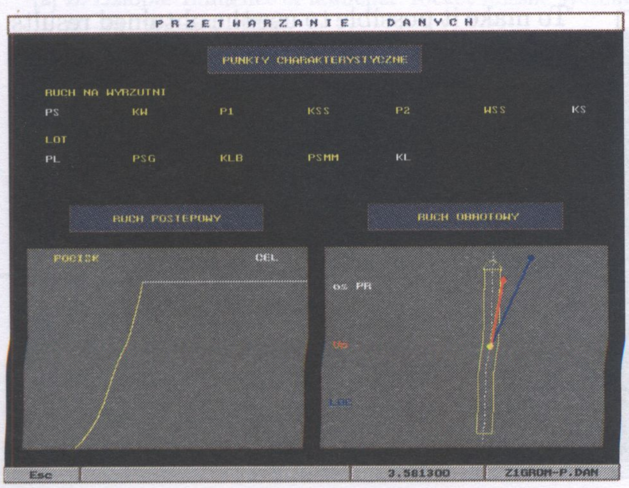
The target interception operation is performed on the launcher. A gunner locates the target and performs its identification, then he moves a launcher carried on his arm in order not to loose the target being traced. In the simulation process it has been assumed that target interception starts when target location is determined by the set and lasts until the boost engine has been activated.

Calculations – motion on the launcher



When performing the motion set simulation, special attention should be given to the behaviour of objects in some characteristic moments. These moments are interrelated with a change in system functioning, or with change of its parameters and structure. In the motion of a missile along launcher guide, the system structure is being changed two times. The missile is also subjected to natural degeneration when loosing a boost engine. On striking the launcher intercepting component, the engine becomes its integral part.

Calculations – flight of the rocket missile

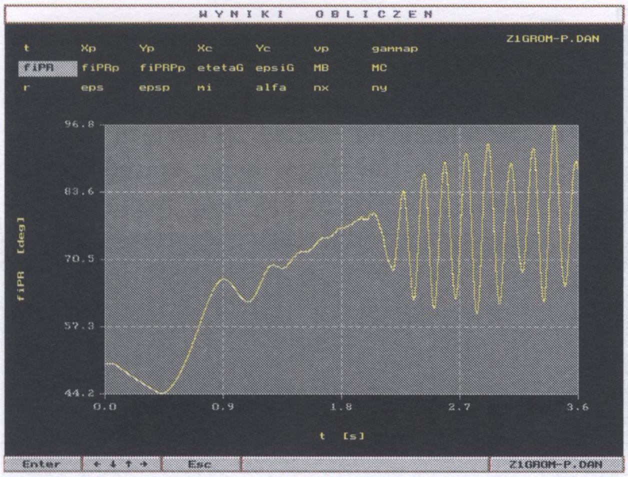


The flight of a rocket missile is performed in four stages:

1. Ballistic flight,
2. Initial manoeuvre,
3. Stationary homing,
4. Final manoeuvre.

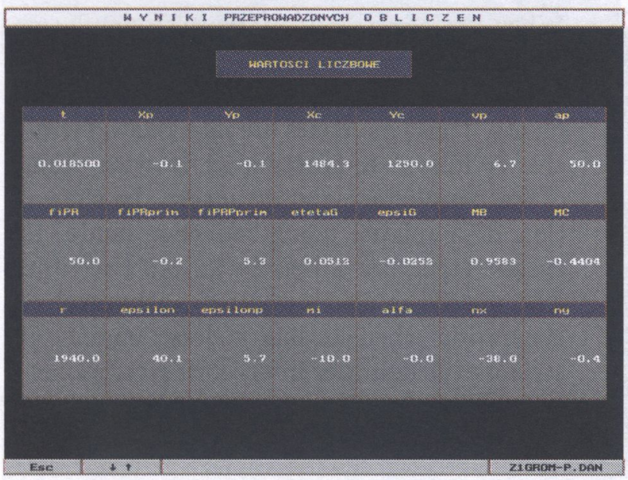
In the first phase stage, an internal gas controlling engine and first stage of the rocket engine are being activated. In third phase, second stage of the rocket engine of sustainer thrust force is activated.

Results – graph



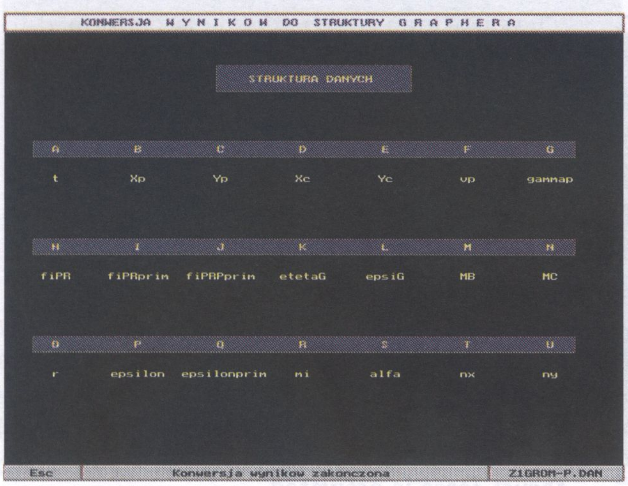
Using this menu, the software user has the possibility to interpret the obtained results due to visualisation in the form of graphs of physical quantities variabilities course which characterise system motion. Graphs make it possible to carry out a quantitive analysis efficiently. Twenty one variables could be subjected to this analysis. The user decides on the selection of abscissa and ordinate on the graph axes choosing appropriate number values.

Results – chart



Using this menu, the software user has the possibility to interpret the obtained results due to numerical presentation of physical quantities variabilities course which characterise a system motion. Numerical values make it possible to carry out a quantitive analysis. Twenty one variables could be subjected to this analysis. The scrolling of variables is performed in accordance or in opposite direction to the change of time.

Results – conversion



To make it possible to use the obtained results in another software, their conversion could be carried out. When using this menu, the file containing calculated physical quantities in the Golden Software's SURFER postprocessor standard is obtained. Data in this standard are saved in form of a text file of ASCII format.

3. Symbols and co-ordinate system

φ_{PR} – missile trunk tilt angle,

φ_0 , φ – initial and current launcher guide inclination angle,

ϕ – inclination angle of the missile towards 2nd support (item P2),

V_p , γ_p – modulus and direction angle of the rocket missile velocity vector,

V_c , γ_c – modulus and direction angle of the target velocity vector,

δ, α – angular displacement and angle of incidence of external vane,

ϑ, ψ, Φ – nutation, precession and specific rotation angles of the gyro,

r, ε – modulus and direction angle of target surveillance line vector,

ω_x , ω_y , ω_z – kinematic input function resulting from missile trunk movement,

K_1 , K_2 – PD regulator amplification coefficients in the coordinator model,

S_p – missile mass centre,

S_w – launcher guide mass centre,

O_c – mathematical point describing target motion,

XYZ – inertial reference system related to earth: origin of co-ordinates in initial position overlaps launcher guide joint centre, Y axis overlaps the gravity force direction operation,

$\xi\eta\zeta$ – non-inertial reference system related to launcher guide: origin of co-ordinates in initial position overlaps launcher guide joint centre, ξ axis is directed along launcher guide,

xyz – non-inertial reference system related to missile: origin of co-ordinates in initial position overlaps the missile centre of inertia, x axis overlaps the direction of longitudinal rocket axis,

$x_g y_g z_g$ – non-inertial reference system related to missile: origin of co-ordinates in initial position overlaps the missile centre of inertia, y_g axis overlaps the gravity force direction operation.

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