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THE TESTING OF OPERATING CHARACTERISTICS OF CLUSTER AIR WEAPONS

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In the paper, a general model for investigations of dynamical properties of cluster air weapons is presented. Flight tests were carried out in a research-development cycle. Results of simulation studies, preliminary tests in aerodynamical tunnel and in flight examination are presented. The mathematical model was verified through experimental flight tests.

Key words: flight dynamics, cluster weapon, mathematical modelling, experimental verification

1. Introduction

The practice of investigating air weapons has proved that the investigation process needs the following types of research work:

- theoretical studies, with digital and computer-simulation generated models engaged, and
- experimental efforts, i.e. ground and flight tests using material models and real objects.

Quite often, the practice of performing investigation work requires some different approach, usually a composite one. Most often, it happens while acquiring data for a simulation model, e.g. from aerodynamic wind-tunnel tests, while finding mass characteristics of a material model or a real object.

The grounds for developing new and upgrading older designs of bombing-dedicated air weapons in the NATO countries derive from rich experience effected by hostilities in Vietnam, the Middle East, and the Gulf. In the recent years, special attention has been paid to the design and construction of cluster air weapons to destroy armoured vehicles, runways, any hardware, and to suppress the hostile troops' fast moving.

The cluster weapon is a kind of air armament intended to affect the surface. This feature, being an advantage of great significance, enables more effective use of sub-munition to suppress widely dispersed objects.

Depending on the mission assigned, the cluster weapons can be filled with various sub-munitions, i.e. fragmentation, incendiary, anti-tank, anti-concrete, and with practice ones, e.g. aircraft-laid mines.

2. A mathematical model of a cluster bomb in 3D flight

A general mathematical model for any of air munitions in 3D motion can be presented in the matrix form shown below

$$\widetilde{\mathsf{M}}\dot{\boldsymbol{V}} + \mathsf{K}\mathsf{M}\boldsymbol{V} = \mathsf{Q} + \mathsf{U}\delta \tag{2.1}$$

where

— modified matrix of inertia

$$\widetilde{\mathsf{M}} = \mathsf{M} + \mathsf{M}_{\dot{\boldsymbol{W}}} \tag{2.2}$$

— acceleration vector

$$\dot{\boldsymbol{V}} = \operatorname{col}[\dot{U}, \dot{V}, \dot{W}, \dot{P}, \dot{Q}, \dot{R}] \tag{2.3}$$

— velocity vector

$$\boldsymbol{V} = \operatorname{col}[U, V, W, P, Q, R] \tag{2.4}$$

— matrix of external forces

$$\mathsf{Q} = \begin{bmatrix} \boldsymbol{F} \\ \mathsf{M} \end{bmatrix} = \operatorname{col}[X, Y, Z, L, M, N] \tag{2.5}$$

with

$$
\mathbf{M}_{\dot{W}} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & -M_{\dot{W}} & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}
\qquad
\mathbf{M} = \begin{bmatrix} m & 0 & 0 & 0 & S_z & -S_y \\ 0 & m & 0 & -S_z & 0 & S_x \\ 0 & 0 & m & S_y & -S_x & 0 \\ 0 & -S_z & S_y & I_x & -I_{xy} & -I_{xz} \\ S_z & 0 & -S_x & -I_{yx} & I_y & -I_{yz} \\ -S_y & S_x & 0 & -I_{zx} & -I_{zy} & I_z \end{bmatrix}
$$

$$
\mathbf{K} = \begin{bmatrix} 0 & -R & Q & 0 & 0 & 0 \\ R & 0 & -P & 0 & 0 & 0 \\ -Q & P & 0 & 0 & 0 & 0 \\ 0 & -W & V & 0 & -R & Q \\ W & 0 & -U & R & 0 & -P \\ -V & U & 0 & -Q & P & 0 \end{bmatrix} \tag{2.6}
$$

$$
\mathbf{U} = \begin{bmatrix} X_{\alpha zH} & X_{\delta H} & 0 & X_{\delta V} & X_{\delta T} \\ 0 & 0 & 0 & Y_{\delta V} & Y_{\delta T} \\ Z_{\alpha zH} & Z_{\delta H} & 0 & 0 & Z_{\delta T} \\ 0 & 0 & L_{\delta L} & L_{\delta V} & L_{\delta T} \\ M_{\alpha zH} & M_{\delta H} & 0 & 0 & M_{\delta T} \\ 0 & 0 & N_{\delta L} & N_{\delta V} & N_{\delta T} \end{bmatrix}
$$

— control vector

$$
\boldsymbol{\delta} = \mathrm{col}\,[\alpha_{ZH}, \delta_H, \delta_L, \delta_V] \tag{2.7}
$$

— kinematic relations can be shown in the following form

$$
\dot{\boldsymbol{r}} = \mathrm{col}\,[\dot{x}_1, \dot{y}_1, \dot{z}_1, \dot{\phi}, \dot{\theta}, \dot{\psi}] = \boldsymbol{F}[U, V, W, P, Q, R, \phi, \theta, \psi] \tag{2.8}
$$

This paper has been intended to show characteristic results of analysis of a math model of a small-size bomb (bomblet) and an aircraft-laid mine.

3. Simulation-based and aerodynamic studies

3.1. Tests of a small-size aerial bomb (bomblet)

Subject to tests was a small-size aerial bomb (bomblet) (Fig. 1a).

While studying the dynamics of bombs (Fig. 1) with elastic braking-and-stabilising systems, deformations of fins have been taken into account in such a way that aerodynamic characteristics have been changed (Fig. 2) depending on the angles of attack α and side-slip β, and the initial velocity V_0. Real objects under investigation are featured with a decrease in drag coefficient C_x

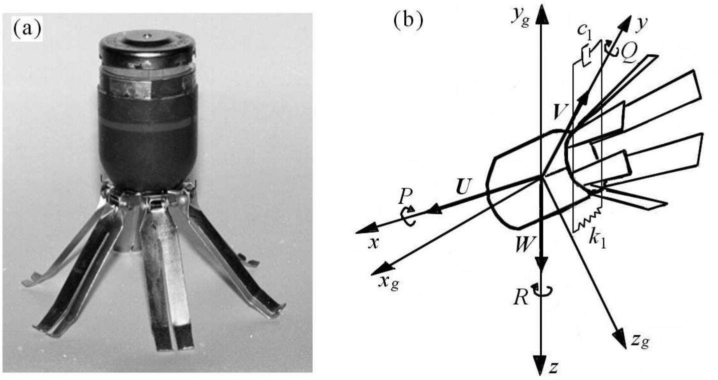

Fig. 1. (a) A small-size aerial bomb (bomblet): weight – 0.8 kg, diameter – 70 mm, length – 95 mm; (b) a model of the small-size bomb (bomblet)

as the flow velocity of the medium increases (Fig. 2a). This happens due to fin deflections (decrease in the angle of fin opening), decrease in local angles of attack and changes in the effective face surface.

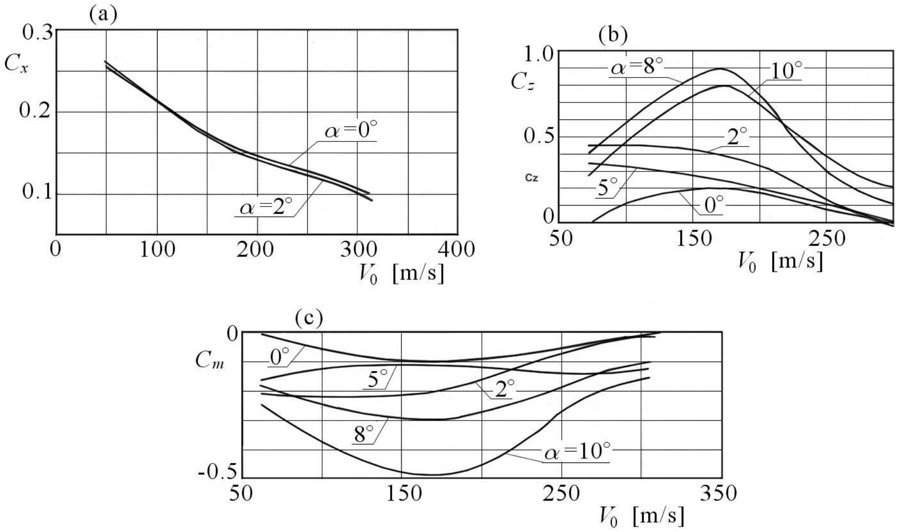

Fig. 2. Change of the: drag coefficient $C_x(\alpha, \mathrm{Ma})$ (a), aerodynamic lift $C_z(\alpha, \mathrm{Ma})$ (b) and pitching-moment coefficient $C_m(\alpha, \mathrm{Ma})$ (c)

Tests of a real-size model within the range of operating velocities provided a reliable aerodynamic representation. While examining the dynamics of a bomb with elastic braking-and-stabilising systems, the effect of release velocity on the properties of bomb motion has been given consideration.

The increase in the bomb's initial velocity V_0 results in:

- extension of the range x_1; however, the increments keep getting smaller and smaller,
- lower loss of the altitude $z_1(t)$ (Fig. 3a),
- faster decrease in the total velocity V_0 (Fig. 3b),
- slower increase in the angle of pitch $\Theta(t)$ at the initial stage of flight (Fig. 4a),
- increase in both frequency and amplitude of variations of the angle of attack $\alpha(t)$,
- increase in the relative distance $\Delta l(t)$ between the bomb and the carrier (Fig. 4b).

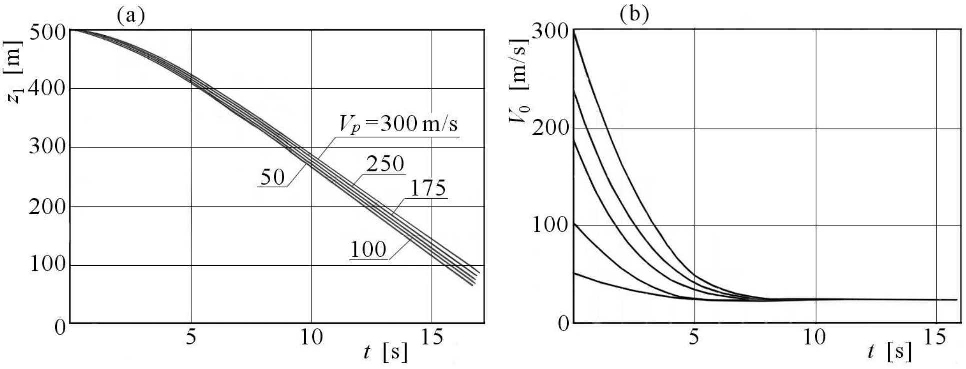

Fig. 3. Change of the flight altitude $z(t)$ for various velocities V_p (a) and total flight speed $V_0(t)$ (b)

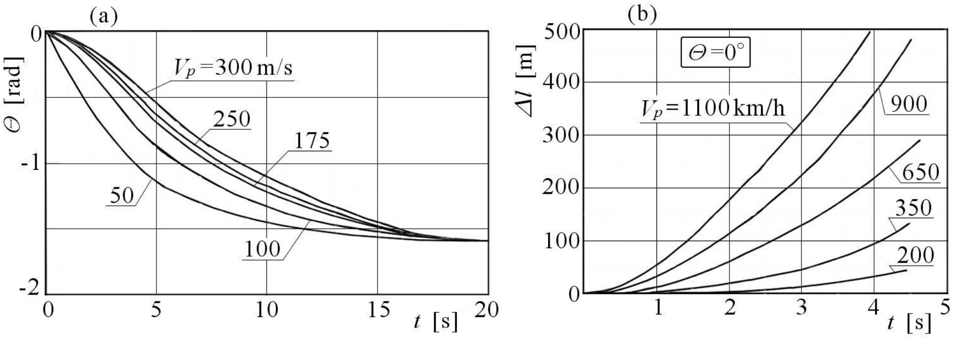

Fig. 4. Change in the angle of pitch $\Theta(t)$ (a) and relative distance between the carrier and the bomb (b)

The initial rate of bomb release does not affect the time of reaching both the critical rate of descent V_{cr} (Fig. 3b) and the angle of pitch $\Theta = 90^\circ$ (Fig. 4a).

What occurs at the initial stage of flight is an increased variation in the angle of pitch $\Theta(t)$, and the bomb can instantaneously show a positive angle of pitch Θ. These are moments when collision of the carrier and the bomb is quite possible.

The elastic control-and-braking system used to reduce the bomb's rate of motion is featured with:

- reduction of the drag coefficient $C_x(\mathrm{Ma})$ as the speed of flight increases,
- fast attainment of the critical rate of descent V_{cr}, independently of the initial (release) velocity V_0,
- strong attenuation of bomb oscillation.

The initial stage of the bomb's flight is the most important stage of bomb's motion, since two things occur during that time: decrease in velocity and flight-path curving.

3.2. Tests of a small-size aircraft-laid mine

Subject to tests was a small-size aircraft-laid mine (Fig. 5).

Fig. 5. An aircraft-laid small-size mine: weight – 3.8 kg, diameter – 116 mm, length – 257 mm

While studying the dynamics of mines with rigid braking-and-stabilising systems, aerodynamic tests on real objects were carried out. Aerodynamic characteristics $C_x(\alpha, \mathrm{Ma})$, $C_z(\alpha, \mathrm{Ma})$, $C_m(\alpha, \mathrm{Ma})$ have been shown in Fig. 6.

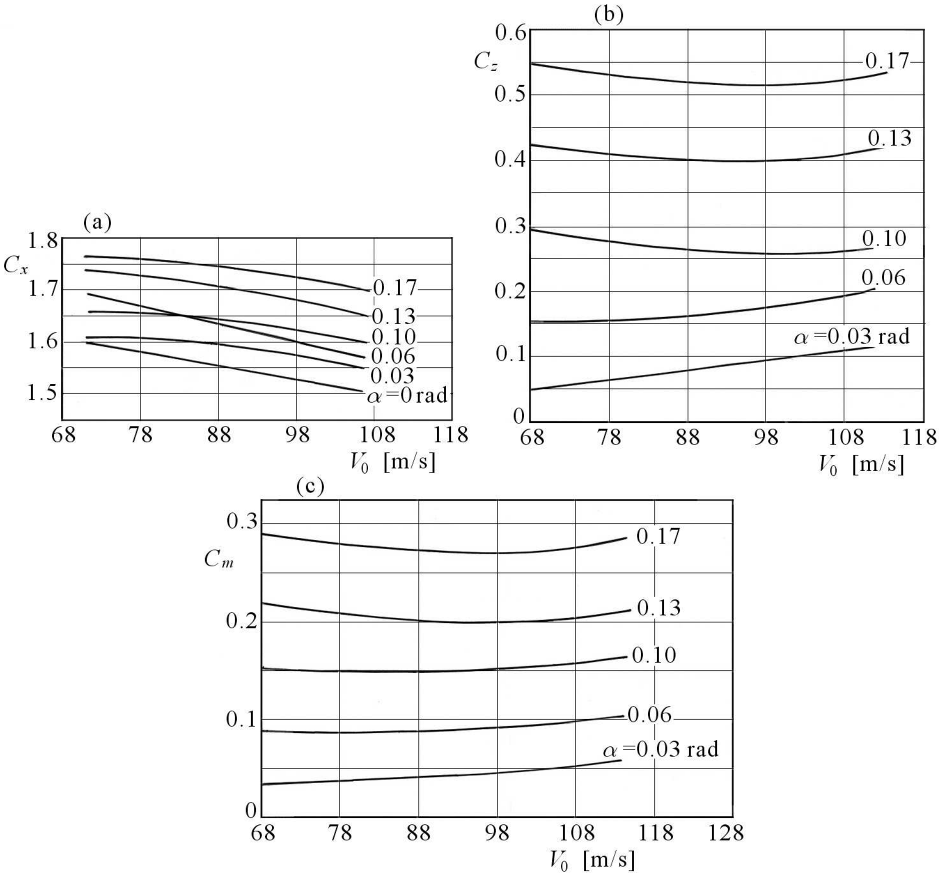

Fig. 6. Change of the drag coefficient $C_x(\alpha, \mathrm{Ma})$ (a), aerodynamic lift $C_z(\alpha, \mathrm{Ma})$ and pitching-moment coefficient $Cm(\alpha, \mathrm{Ma})$

The tests were limited to a velocity of 136 m/s, because at higher velocities of the flow of medium the plastic strain of the braking system appears (exceeds the limit of elasticity of fins).

The analysis of simulation models of mines with rigid braking-and-stabilising systems has proved what follows:

- the flight-path profile and the range of mine delivery depends first and foremost on the release velocity (Fig. 6b) and the angle of fin opening,
- mines experience decreasing variations in the angles of attack α and side-slip β (Fig. 6c),
- the critical velocity of a mine and the time needed to reach it both depend on design parameters of the braking system and remain independent of the initial release velocity V_p (Fig. 7).

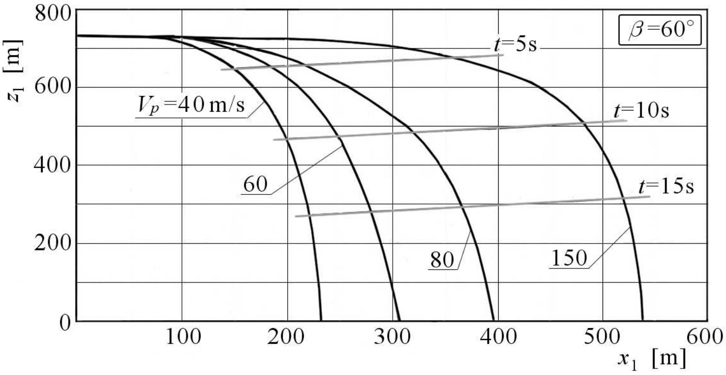

Fig. 7. Flight paths of the mine at various velocities V_p

The following parameters of motion are of the greatest significance from the standpoint of functional quality: the critical velocity V_{cr}, the time to reach it, and the angle of fall Θ_k.

The wind-tunnel and flight tests both prove that systems of that kind are very liable to deformation at higher flight speeds.

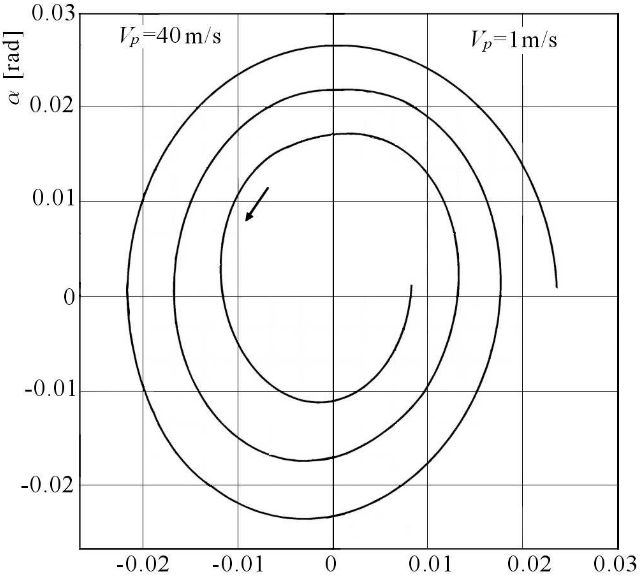

Fig. 8. Change in the angle of attack α against the angle of side-slip β

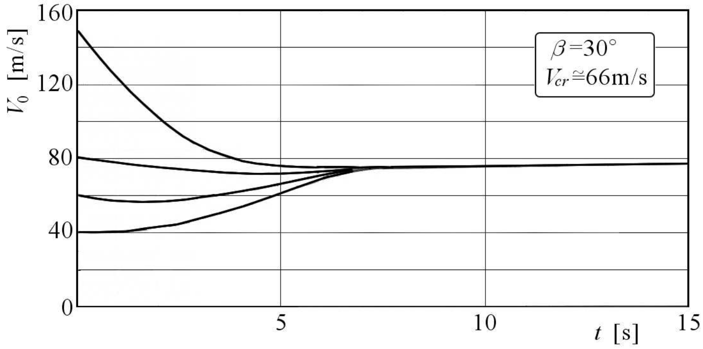

Fig. 9. Change of the total flight speed $V_0(t)$ for different initial velocities V_0

4. Experimental examination (flight tests) of a cluster bomb

A thorough R&D cycle to develop some new air weapon, cluster air weapon included, comprises the following stages:

- studies and analyses,
- preliminary design (foredesign),
- engineering design, and
- implementation.

The analysis of the R&D cycle proves that in the course of subsequent stages of developing a product, i.e. foredesign, engineering design, and implementation, the testing work is carried out, including flight tests. It should be emphasised that the testing work at different stages is aimed at different objectives.

At the stage of foredesign, a model of the product is evaluated in terms of having reached functions assumed in the Specifications.

In the course of preliminary and certification (State) tests, any prototype is subject to assessment in terms of whether the Specifications-defined requirements have been satisfied, and from the standpoint of safety of the product while transported and stored as well as in the course of combat applications and operational use.

Although beyond the R&D cycle, the stage of implementation has been presented as a logical consequence of a creative process, since the testing of a pre-production batch should offer the assessment of whether the manufacturer is well prepared and has mastered the production of goods that meet the above-mentioned specifications, in particular, those dedicated to the procedures of the manufacture and acceptance of goods.

Therefore, flight tests prove to be inherent in the investigative process, since the check-up of how the product performs under real conditions enables thorough assessment of the product under investigation/testing.

The range-based flight tests are carried out using either dynamic models of cluster air weapons under development, or real combat objects. The tests include what follows:

- evaluation of dynamic stability,
- functional tests under real conditions,
- determination of parameters of motion along the flight path and in the point of impact,
- assessment of performance effectiveness,
- investigation of how an obstacle affects the penetrating object.

Another thing to be strongly emphasised is very specific nature of flight tests of any air weapons. The tests are very expensive, that is why development of an algorithm of the testing work and a suitable set of measuring equipment is very important. Unlike the aircraft, air weapons are single-use objects. Hence, any set of information is a function of many variables, including a set of measuring equipment, organisation of test flights, flying skill's and experience of a pilot, weapons launch (release) conditions, weather conditions, etc.

The measuring equipment should provide capabilities to record:

- carrier's flight parameters at the moment of weapon launch/release,
- the flight path and the point of impact of the weapon under testing,
- how the object performs along the free-flight path.

The recorders designed and developed at ITWL (Air Force Institute of Technology) and intended for investigation and tests of bombing weapons enable, among other things, the recording of:

- overloads (excessive loads):
  - in the course of free flight,
  - during engagement of the braking system,
  - at the moment the bomb hits an obstacle,
- transient responses (performance) of control systems,
- technical data (parameters) of fuses (fuse systems),
- parameters of aerodynamic heating, etc.

Figures 10 and 11 show typical effects of overloads and bomb's rotations while following the flight path.

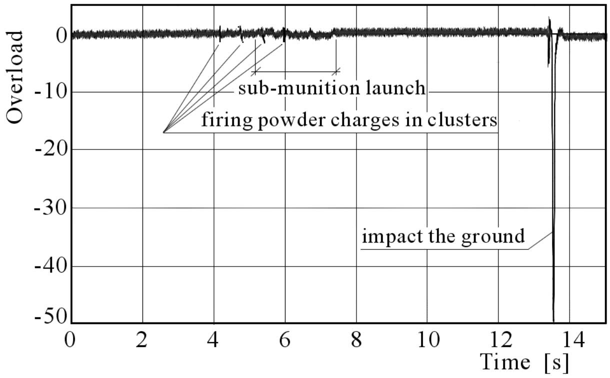

Fig. 10. The overload n_x of a cluster bomb (weight 250 kg) recorded at the moment of impact on the target (sandy soil)

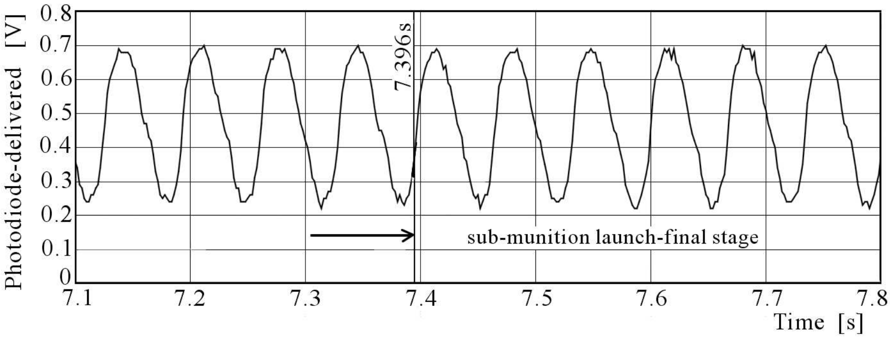

Fig. 11. Rotations of a cluster bomb (weight 250 kg) while following the flight path

5. Conclusions

The above-presented methodology of investigating/testing dynamic properties of air weapons enables analysis of motion of any system of any structural configuration, and at the same time, it provides continuous delivery of information on changes in the flight-path parameters.

The outcome of theoretical studies has been confirmed in the course of flight testing of real objects. General compliance of both calculation- and experiment-effected results verifies the generated model (algorithm) of the testing work.

The presented investigating/testing method and results gained give good grounds for claiming that theoretical analyses of the object's model should be used during both the research stage and that of preliminary design.

The research/testing team keeps making efforts to apply new measuring methods to find and/or verify at least some of dynamic parameters.

The above-specified issues would enable the team to formulate a possibly complete, generalised model of an air weapon in terms of investigating/testing dynamic properties thereof.

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Badania charakterystyk eksploatacyjnych lotniczych środków kasetowych

Streszczenie

W pracy przedstawiono ogólny model badań własności dynamicznych lotniczych środków kasetowych. Umiejscowiono doświadczalne badania w locie w cyklu prac badawczo-rozwojowych. Zaprezentowano wyniki badań symulacyjnych, badań doświadczalnych w tunelu aerodynamicznym i w locie. Model matematyczny zweryfikowano eksperymentalnymi badaniami w locie.

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