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FEASIBILITY OF MEASUREMENTS IN EXAMINATION OF AIR WEAPONS

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Abstract

Specific features of air weapons, dynamic examinations as an important component of the investigation process, examples of data recorders for parameters of the combat mean under test, telecommunication system for on-line data transmission with the assumption that the system should be composed of components and subassemblies that are commercially available from the market, system for RF transmission of flight parameters in the real time mode are presented in the paper. The system is made up of a transmitter and rpm sensors embedded into the head of the S-7 uncontrolled missile. Signals from the telecommunication module are received and decoded by means of a transducer with the sensitivity of about 2μV and stored in the memory of the TDS 3020 digital oscilloscope from Tektronix as well as in a four-channel digital recorder. The data acquisition system is triggered at the moment when the transmitter installed on the missile head was switched on. The missile was launched several seconds later. The paper includes among others workflow for examination of combat means, composition of measuring instruments for flight tests, data recorders for flight parameters installed on avionic bombs, signal waveforms recorded from rotation sensors and rotation speed variations for the S-7 missile during the flight

***Keywords**: aircraft, air combat means, flight tests of combat means, data recorders for parameters of air combat means, avionic bombs, on-line data transmission systems*

1. Specific features of air weapons as an object of investigations

Avionic combat means represent a set of components that make up a system of air weapons [6] and are designed for execution of a combat task by an impact onto an object of attack, support to combat missions of aviation and execution of tasks for the sake of other army troops as well as for trainings. Due to specific construction and application area, these combat means are classified in the following way:

- irreparable – designers do not provide any possibility to have them repaired,
- two-state operability status – can be either in service or out of service,
- feature long time of storage (shelf life) and short time of operation,
- one-shot use things – they can be applied only once according to their intended use,
- demonstrate sophisticated structure of reliability parameters.

Specific properties of avionic combat means as an object of investigations [7-9] impose specific requirements related to:

- development of such a model for investigations that enables acquisition of maximum possible information from a single trial,
- providing safe conditions for execution of tests, i.e.
  - direct handling with combat means,
  - execution of ground tests and test flights,
  - use of weapons for military purposes.

The relationship between the foregoing conditions and expenses on the investigations seems obvious. It is the reason why still more and more efforts are put onto modelling and simulation studies, which should lead to reduction of the expenses for research studies in general.

While keeping in mind the specific features of the investigation object as well as entailed requirements, it seems possible to suggest a workflow for examination of avionic combat means in

order to achieve the key objectives. Such a workflow should comprise the following milestones:
– development of action plans,
– making process,
– development of documentation for studies,
– preparations,
– execution of investigations and research studies,
– compiling reports and follow-up conclusions

The foregoing model is of general nature and refers both to ground investigations and flight tests. The effective legislative documents related to execution of research and development studies as well as other investigations dedicated to subsequent phases of technical equipment lifetime distinguish and structure ground investigations and flight tests, i.e. prior to commencement of flight tests it is mandatory to prove that ground tests have been successfully completed and passing results are available.

The workflow for investigation of avionic combat means imposes defined relationships between theoretical investigations and experimental studies. On one hand, experimental studies provide input information for any simulation model, i.e. aerodynamic characteristics, weight and geometrical parameters; on the other hand, the follow-up experiments verify and validate the already developed mathematical model [2, 15, 16].

Sophisticated nature of avionic combat means entails a very broad scope of investigations, which is shown in Fig. 1. In addition, these means are not a separated object of research studies since they are incorporated into an overall avionic system.

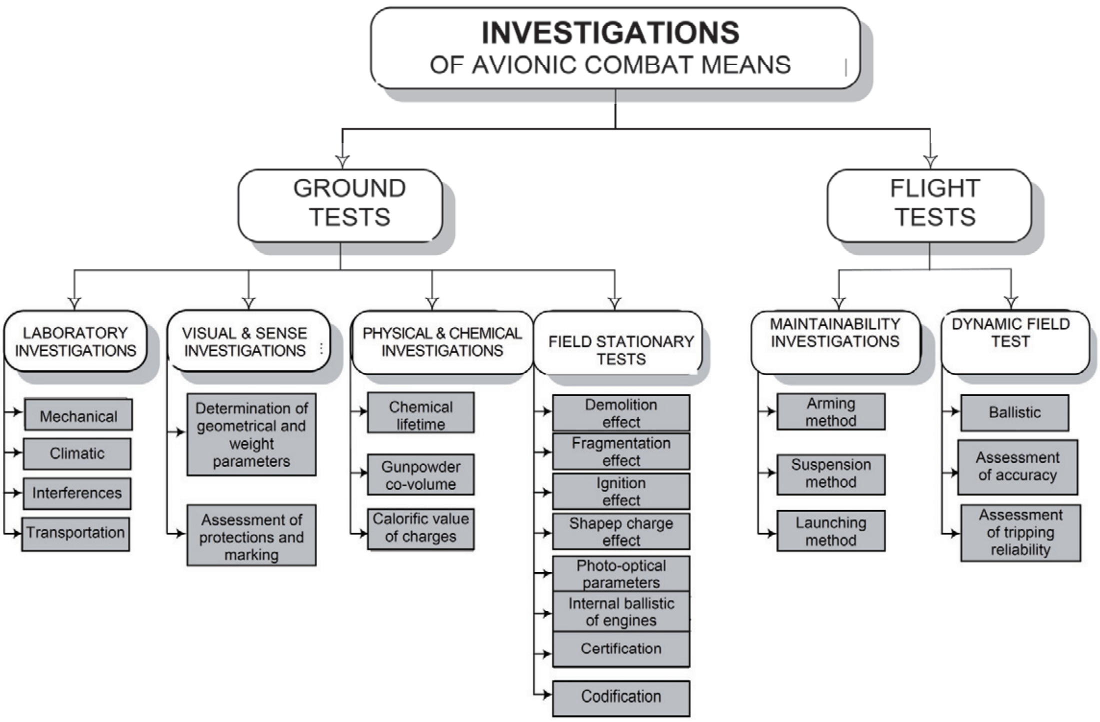


Fig. 1. Workflow for examination of combat means

2. Dynamic examinations as an important component of the investigation process

Dynamic field tests and flight tests represent a substantial component of the investigation process dedicated to avionic combat means [15, 16] since only the test of product operability under real condition of application enables final and dependable assessment of the investigation object. Due to specific features of such investigations they require the following preconditions:

- development of a correct model for investigations,
- broad and sophisticated preparations for studies,
- deep and detailed knowledge about the investigation subject,
- setting up an appropriate arrangement of measuring instruments.

In-flight field test of avionic combat means are defined as a sequence of organizational and technical measures aimed at evaluation of tactic, technical and operational characteristics for various types of weapons under real conditions of their applications.

Scheduling of in-flight tests is carried out according to the already adopted action plan of investigations adjusted to the specific needs that reflect the specific milestone of research studies. The action plan of investigations is based on crucial information related to such issues as the scope of investigations, a research organization, a subcontracting client, an aircraft, number and duration of flights, schedule and location of tests. The indispensable condition for commencement to flight tests is incorporation of the test program to the effective action plan and that fact should be referred to in key documents that kick off the research procedure.

Flight tests can be commenced provided that the subcontracting client for these tests is made familiar in due time in advance with approved schedule and program of flights as well as with the scope of research studies. The basic document of the documentation package is the workflow of studies that defines the objectives and scope of investigations as well as sets up the schedule of experimental flights.

The methodology of research studies comprises also a broad scope of simulation tests dedicated to dynamic properties of the investigation object [1, 2, 7, 16] since familiarity with aerodynamic, ballistic and other characteristics of avionic combat means is indispensable for organization of flight tests. The characteristics obtained from simulations make it easier to draw up the right investigation workflow, a program for test flights, organization of a system for tracking of flights and keeping records on the test results as well as many other organization activities.

In contrary to aircrafts, combat means are one-shot (disposable) objects. Acquisition of information from their flights depend on many factors, including the stochastic ones, as well as on organization of experimental flights, skills and competences of the pilot, conditions of the missile launching or bomb drop, weather conditions, etc.

The mentioned specific features of the investigation object impose unique requirements to the set of research instruments (Fig. 2) that should enable acquisition of information related to the following issues:

- conditions for use of aircraft combat means;
- the way how the means are detached from the carrier under combat conditions,
- parameters of the flight path and the final destination point of the aircraft combat mean,
- behaviour of the combat mean down its flight path,
- impact of the combat mean onto the appointed targets.

3. Examples of data recorders for parameters of the combat mean under test

Determination or evaluation of ballistic characteristics demonstrated by avionic combat means is one of the most important investigation objectives that are carried out over various phases of its lifetime. The term of *ballistic* or *dynamic characteristics* refers to a set of physical parameters that define physical status of the object, i.e. its geometry and weight, aerodynamic and kinematic parameters of its movements, forces and G-loads acting during the flight, etc. [1, 5, 16].

All the completed investigation of design parameters demonstrated by avionic combat means (missiles, bombs, gliding containers, etc.) were carried out to reveal flight parameters of these objects, such as speed, G-loads, rotation, flight duration, since the knowledge about these parameters is necessary to assess whether or not the assumed design solution had been justified and correct [7, 11, 13].

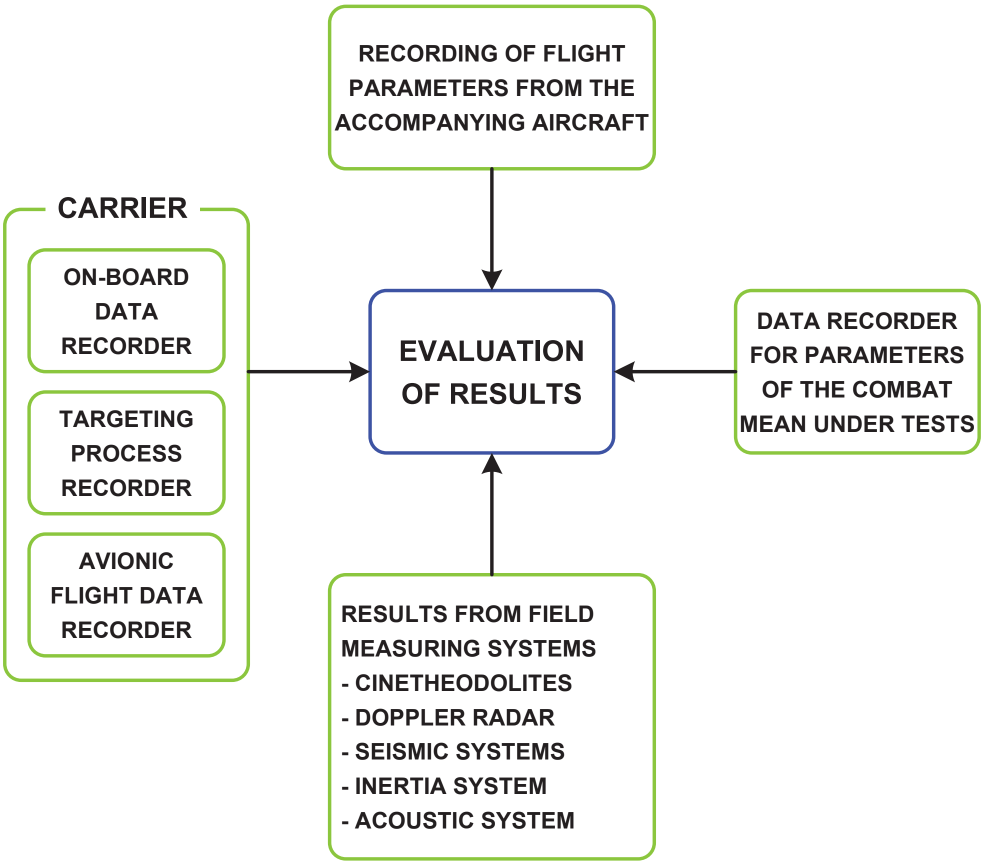


Fig. 2. Composition of measuring instruments for flight tests

To benefit from recorded information stored in flight data recorders it is necessary to find the launched or dropped object, which is only possible when the final destination point where the object hits the ground can be determined with the accuracy of several dozen meters.

The developed recorders (Fig. 3) are dedicated for research studies on avionic weapons [12] and enable data acquisition for the following parameters:

- G-loads:
  - during undisturbed flights,
  - upon activation of the deceleration system,
  - when the bomb hits an obstacle,
- timings and waveforms for control systems,
- technical parameters of fuse systems,
- effect of aerodynamic heating, electrostatic charging, and others.

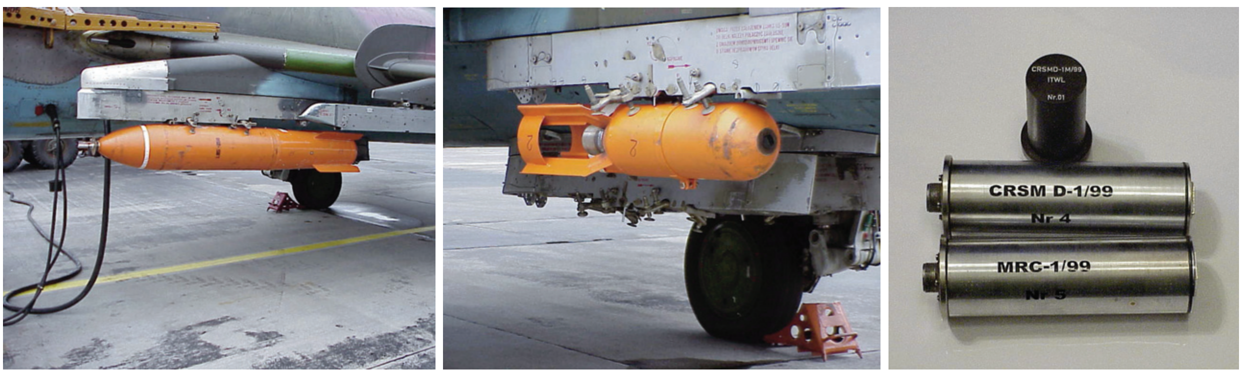


Fig. 3. Data recorders for flight parameters installed on avionic bombs with standard weight of 250 and 50 kg

G-loads are considered as one of the most important dynamic factors that affect combat means. It is why G-loads were carefully measured with the use of a miniaturized silicon accelerometer encapsulated within a casing of a typical integrated chip. Such an accelerometer comprises an integrated signal amplifier, a filter and a circuit for thermal compensation.

Such accelerometers, offered by leading manufacturers, including MOTOROLA and ANALOG DEVICES for the measurement range of ±50 (G) are perfectly suitable for autonomous measuring and data recording units due to their miniature dimensions (the size of a typical integrated circuit package) and precise compensation and calibration that is performed at the factory during the manufacturing phase. Such accelerometers can be embedded into combat means of compact dimensions. However, lack of facilities for direct readouts imposes the need to develop dedicated devices for digital acquisition of measured figures in order to store the recorded parameters (G-loads) in high capacity non-volatile semiconductor memory units. Provision of a combat mean with such a system for measurement and data acquisition makes it possible to download the recorded information by means of dedicated interface facilities enabling transfer of data to a computer and reproduction of timing waveforms for the monitored parameters. Small dimensions of accelerometers allow applying many of them to measure G-loads down various degrees of freedom and to find out variations of monitored parameters for 3D movements.

High accuracy and precise linearity of the aforementioned sensors offer the possibility to measure G-loads down all axes of a 3D coordinate system. Further integration of the acceleration waveforms makes it possible to calculate key parameters of movements.

Measurements for a higher range of G-loads (exceeding 500 G) are possible with the use of piezoelectric G-load sensors from PIEZOTRONICS. Such sensors, also offered in miniature packages, are provided with an embedded amplifier of signals. They are commercially available as either single sensors or combined units that enable application thereof for measurements of G-loads down three coordinate axes. Properties of these sensors make it possible to use them for measurements of G-loads that appear when a combat mean hits an obstacle.

Typical results for recorded G-loads and rotation of a bomb down the falling trajectory are shown in Fig. 4-7.

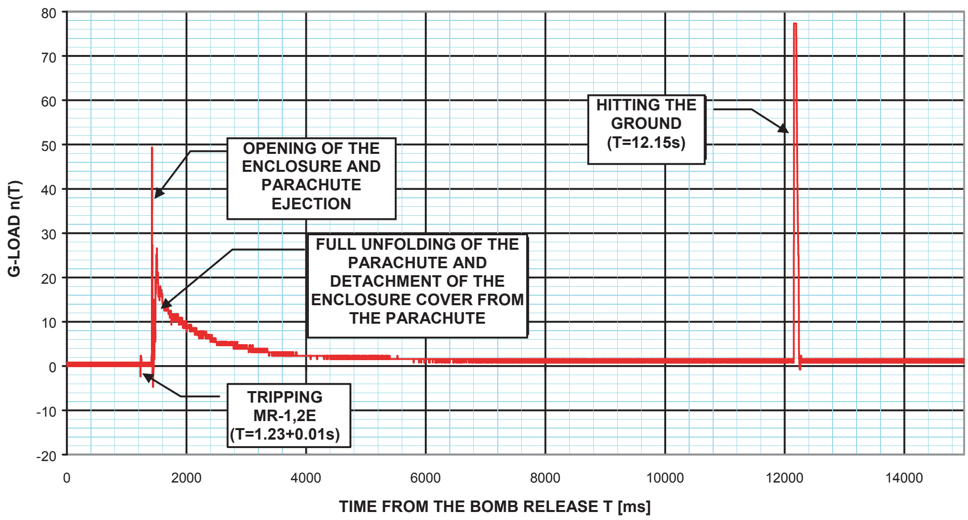


Fig. 4. The G-load (nx) waveform recorded for trajectory of a bomb with the standard weight of 250 kg and provided with a deceleration system

The results obtained from experiments demonstrated good consistence between the measured values of the G-force n_x and:

- the values calculated from (1) – for a bomb with a decelerating parachute (Fig. 4),
- the reference figures sourced from available literature (2500-3000 G, depending on the ground properties) – for a conventional bomb (Fig. 7).

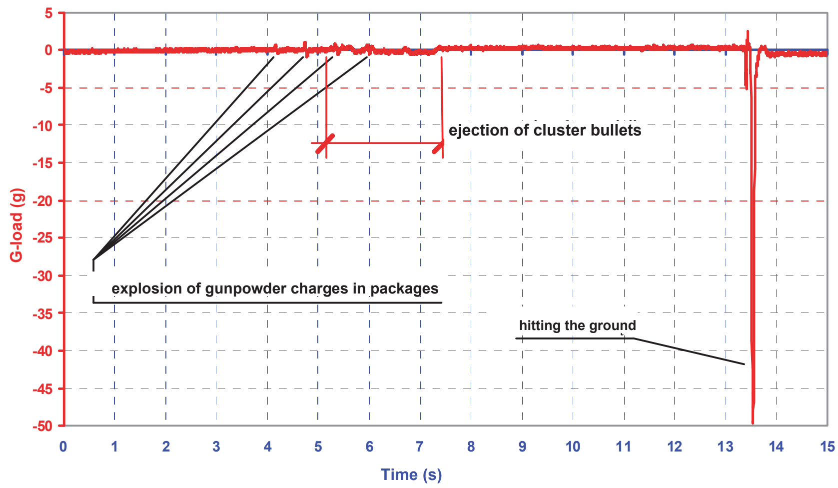


Fig. 5. The G-load (nx) waveform recorded for trajectory of a cluster (cassette) bomb with the standard weight of 250 kg

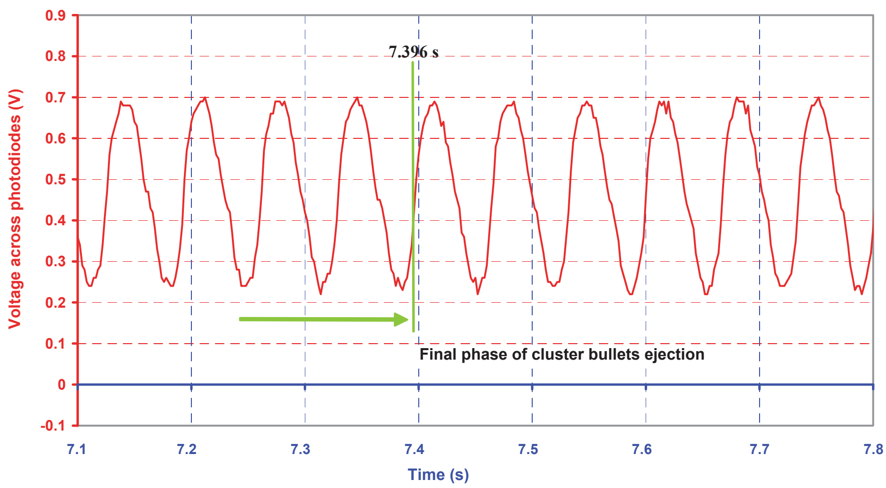


Fig. 6. Rotation of a cluster (cassette) bomb with the standard weight of 250 kg

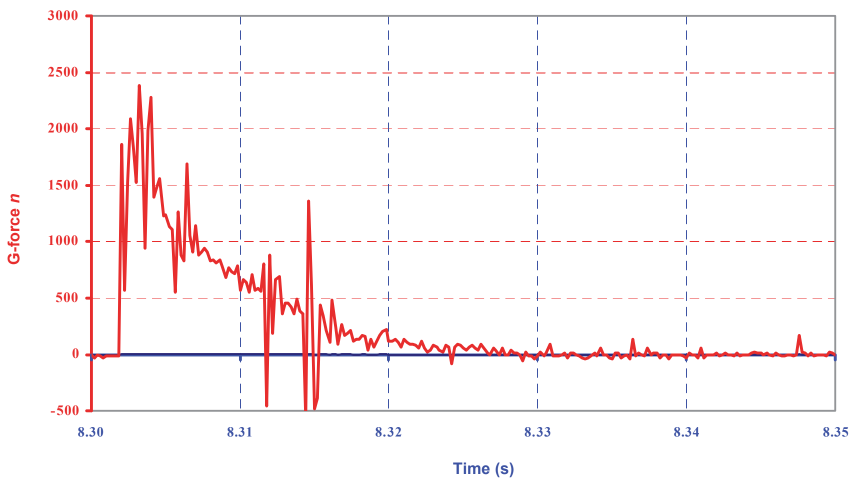


Fig. 7. The G-load (nx) waveform recorded for a conventional bomb with the standard weight of 50 kg during hitting against sandy ground

The peak G-force n_x that appears during unfolding and filling of the parachute for the decelerating and stabilizing system can be evaluated from the following relationship:

$$n_x = 1 - \left(\frac{V_0}{V_\theta} \right)^2, \qquad (1)$$

where:
V_0 – speed of the bomb release,
V_Θ – characteristic speed of the bomb.

4. Telecommunication system

In case of uncontrolled missiles with the reach of several kilometres, it is nearly infeasible to find a missile on the fire range area, which virtually excludes the possibility to use data recorders to monitor flight parameters and download the stored information.

Thus, it proved necessary to develop a system for on-line data transmission with the assumption that the system must be composed of components and subassemblies that are commercially available from the market. According to the initial suppositions, the prototype version of the system should work at the UKF frequency of 435 MHz. For that bandwidth, it is easy to purchase necessary electronic parts and components, such as transmitter modules with the power up to 10 mW, receivers and power amplifiers.

The foregoing subassemblies were then used to develop a system for RF transmission of flight parameters in the real time mode. It was also necessary to design and make up the interface units dedicated for coupling with sensors of acceleration, rotation, temperature, etc., as well as encoding modules for transmitters and decoders for receivers. Due to expected high level of interferences and substantial fluctuation in power of the signal that reaches the receiving antenna it was necessary to take advantage of modulation of the carrier frequency (FM). It is the modulation type that diminishes sensitivity to aforementioned interferences.

According to the adopted assumptions, the telecommunication system should be suitable for embedding into an uncontrolled air-launched missile with the bore of 70 mm and capable of recording the missile rotation speed (rpm), rotation direction and longitudinal G-force acting onto the missile in flight.

The foregoing requirements imposed the need of real-time multi-channel transmission. It was assumed that the signal in each of the measuring channels shall provide amplitude modulation (AM) for the subcarrier frequency. Subsequently, the superposition of amplitude modulated subcarrier signals shall provide frequency modulation for the carrier frequency of the transmitter. Upon reception, the signal shall be decomposed and decoded in individual channels tuned to the frequencies of individual subcarriers.

The adopted assumptions served as the baseline for engineering and assembling of an RF telecommunication system that is made up of a transmitter and rpm sensors embedded into the head of the S-7 uncontrolled missile. The solution that benefited from the experience gained from data acquisition for aircraft bombs with use of autonomous digital recorders assumed installation of two optical light-sensitive rpm sensors deployed on the generator line of the missile head and mutually displaced by the angle of 90º. Such arrangement of sensors enables also to unambiguously identify direction of the missile rotation.

The weight of clamping rings meant to the fix electronic modules as well as the shape and depth of the seat for the telemetric head were purposefully designed during the modelling phase so that the weight of the missile head together with the transmitter fixed thereon as well as location of its gravity centre were exactly the same as the corresponding parameters for a typical war-head.

The picture of the telecommunication module engineered and attached to the missile head as well as the head itself are shown in Fig. 8 and 9.

Signals from the telecommunication module were received and decoded by means of a transducer with the sensitivity of about 2μV and stored in the memory of the TDS 3020 digital oscilloscope from Tektronix as well as in a four-channel digital recorder.

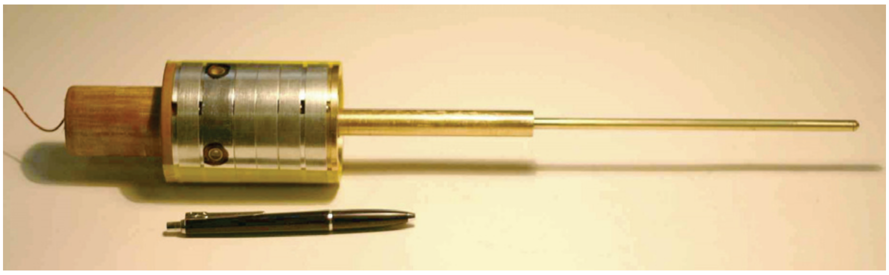


Fig. 8. Picture of the transmitter module (power supply compartment, optical sensors and antenna)

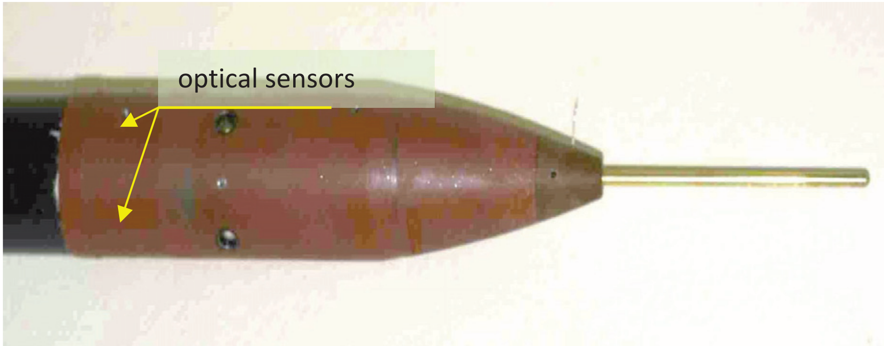


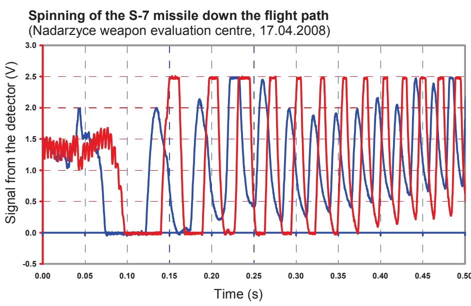
Fig. 9. Picture of the telecommunication module installed on the missile head

The field tests were carried out on a weapon range with use of a missile launcher. The elevation angle of the launcher was about 4º and the estimated range of the S-7 missile for that angle value was about 3 km.

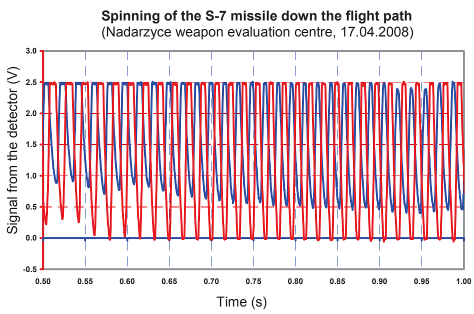
The station for receiving and acquisition of RF signals was located within about 40 m from the launcher. A directional antenna of the YAGI type with the gain of about 9 dB was positioned towards the direction of the missile path.

The data acquisition system was triggered at the moment when the transmitter installed on the missile head was switched on. The missile was launched several seconds later.

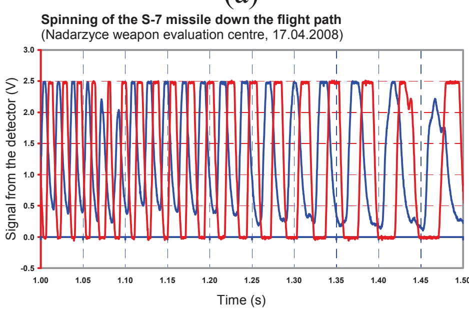
The waveforms that depict rotation speed of the missile as a function of time down the missile flight path and plotted on the basis of the signals from the rotation sensors are shown in Fig. 10.



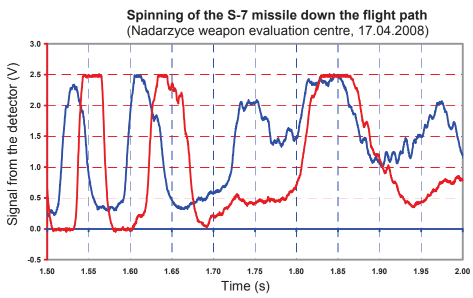
(a)



(b)



(c)



(d)

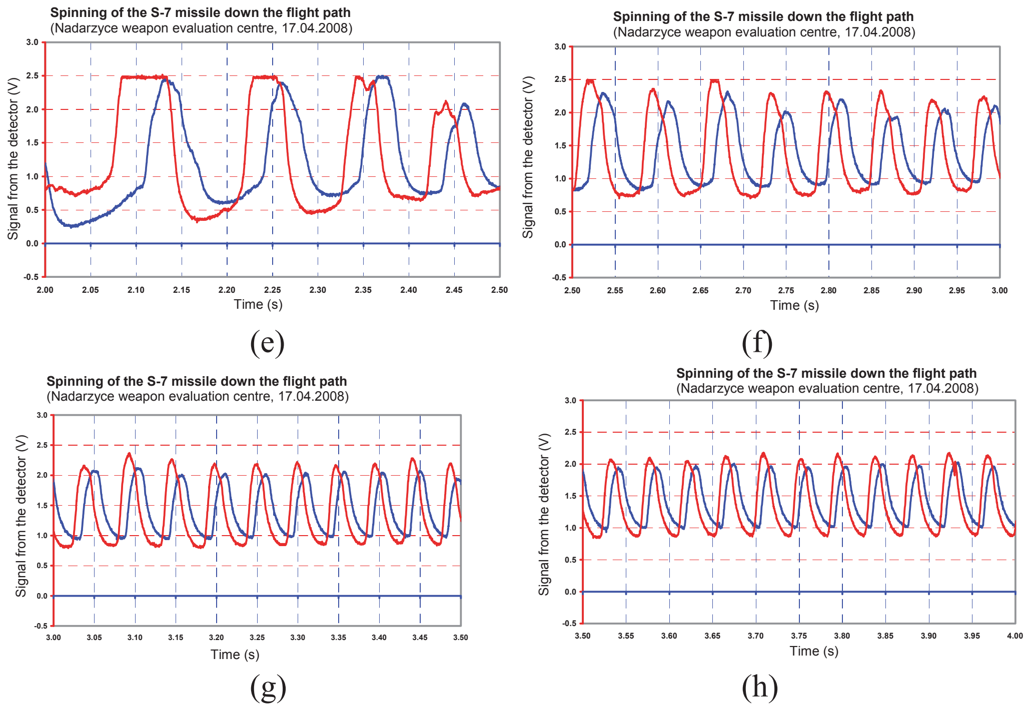


Fig. 10. Signal waveforms recorded from rotation sensors

Processing of the recorded waveforms made it possible to find out rotation speed of the S-7 missile with simultaneous detection of the rotation direction (Fig. 11).

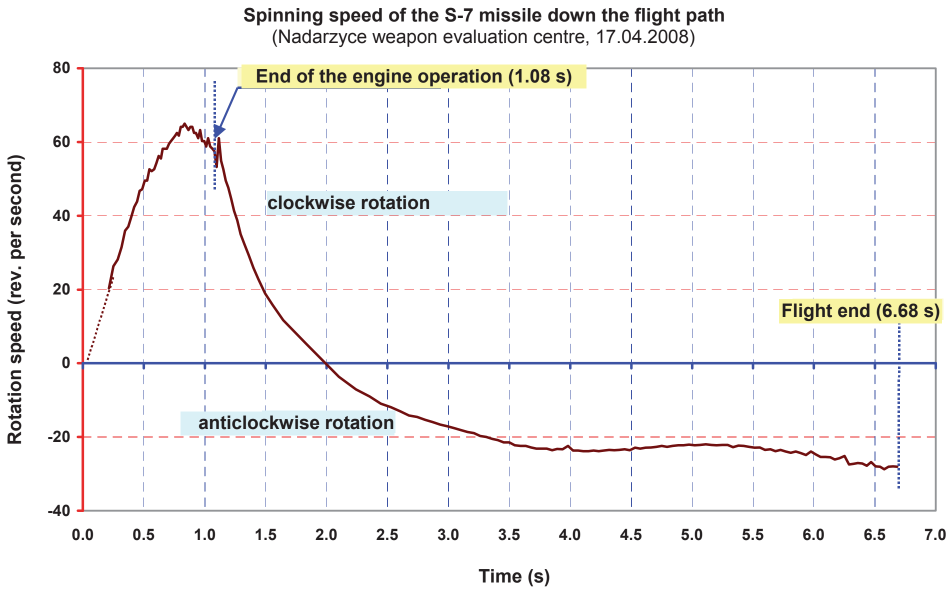


Fig. 11. Rotation speed variations for the S-7 missile during the flight

The acquired results made it possible to formulate the following findings:

- the system for RF data transmission installed on fast-moving objects (the maximum speed of the S-7 missile is V_{max} = ca. 650 m/s),
- the achieved range of the RF signal reception exceeded 3 km,
- recorded waveforms enabled to determine rotation speed of the S-7 missile down its flight path,
- the effect of the rotation speed drop was recorded at the moment about 0.3 s prior to termination of the engine operation,
- the rotation direction of the missile toggled within about 2 s. after the missile had been launched.

5. Conclusions

Specific features of combat means that are one-shot disposable objects entail an unusual approach to issues related to research studies. The key problem is instrumentation of the combat mean as an object of investigations and the acquisition of maximum possible information about the object behaviour. High price of a disposable combat mean as well as all associated measuring and data collection equipment under that assumption that they can be used only once results in acquisition of very scarce amount of information with a very high risk that the experiment fails and no data are collected.

Nowadays efforts are in progress to enhance the system for taking measurements on the object to improve quality and extend amount of information that can be gathered during experiments (e.g. use of gyroscopic platforms engineered with use of the MEMS technology) as well as techniques that facilitate data acquisition (e.g. on-line data transmission systems).

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