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Tests of a final control element in flight tests of a ground-to-ground missile search support system
Badania członu wykonawczego układu wspomagania poszukiwań pocisków ziemia-ziemia w testach lotnych

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Abstract: *Searches for test flight missiles are usually based on data collected and transmitted by the on-board telemetry system of the missile. If this fails, the chances of finding the missile's landing site are significantly reduced. To provide an emergency solution, work has been undertaken to develop a search support system. Its role as a final control element is performed by an ejector using an explosive material capable of propelling loads containing devices which facilitate finding the missile's touchdown point. The research conducted on the system included the selection of the mass of black powder required to perform the task, testing of the design solutions and measuring the ejection velocity of the loads. Four different amounts of black powder were tested. The results obtained showed some potential for the proposed solution.*

Streszczenie: *Poszukiwania pocisków rakietowych, wystrzeliwanych do lotów testowych, odbywają się zwykle w oparciu o dane zgromadzone i przekazane przez układ telemetrii znajdujący się na pokładzie rakiety. W przypadku jego awarii, szanse znalezienia miejsca lądowania pocisku znacznie maleją. Aby zapewnić rozwiązanie awaryjne, podjęto prace nad systemem wspomagania poszukiwań. Rola członu wykonawczego jest w nim realizowana przez wyrzutnik wykorzystujący materiał wybuchowy, zdolny do miotania ładunków zawierających urządzenia ułatwiające odnalezienie miejsca przyziemienia pocisku. Wykonane badania nad układem obejmują dobór ilości prochu czarnego, umożliwiającej wykonanie zadania, testy rozwiązań konstrukcyjnych oraz ocenę prędkości wylotowej ładunków. Przetestowano cztery różne naważki prochu czarnego jako materiału napędowego. Uzyskane wyniki pokazały pewien potencjał zaproponowanego rozwiązania.*

Keywords: *missile, flight test, launcher, search support system*
Słowa kluczowe: *pociski. loty testowe, system wspomagania poszukiwań*

1. Introduction

A key step in the missile technology design process is usually the flight testing of the proposed missile. Such tests constitute the ultimate trial of the integrity of the structure and performance of the on-board systems under actual loads acting on the missile. Despite numerical calculations being so advanced today [1] these tests are essential for the experimental verification of the calculations of the missile's motion, range and stability,. When it comes to test missiles, which are equipped with extensive measurement equipment, enormous amounts of data are generated and collected on board [2], not all of which is transmitted via a radio link. Therefore, the need arises to have a system for recovering the missile as a whole if possible or, when this is not cost-effective, to recover the collected measurement data. When it comes to the missile, whose main task is to carry a specific combat charge into the enemy territory, flight tests should be carried out in a configuration as close as possible to the final configuration. Then, one of the possible solutions in preserving as much data as possible which cannot be transmitted by radio, is to use an ejected cartridge with data carriers, before the missile hits the ground, which usually involves the destruction of the structure. Another equally important option is to eject a locator in the form of a radio or Global Navigation Satellite Systems (GNSS) module by parachute just before impact to locate the missile debris. This paper describes initial work on a cartridge which could function both as a locator ejector and a memory card cartridge.

2. Ejector concept

The concept of the ejector emerged during testing of the 70 mm Artemida rocket test platform, whose main task at the current stage of development, is to conduct flight tests of different main engine designs using new compositions of reduced smoke solid propellant . The missile contains a telemetry system called Ariadna, which is designed to measure flight parameters and transmit them via a radio link to a base station. The test design of this missile also makes it possible to measure the working pressure in the main engine chamber during flight. The measurement is carried out at a frequency of 2 kHz. This high sampling rate makes it impossible to send the data by radio link, so it is necessary to store it on a memory card. Its recovery can be carried out in two ways: securing the memory on board to protect it against the enormous overload of ground impact or ejecting the cartridge containing the memory card and GNSS locator. The second method, using a form of parachute, makes it possible to significantly reduce the dynamic loads to which the memory card will be subjected.

Initially, an ejector was designed which in a separate housing, would contain a locator based on a GNSS satellite signal and a band of lightweight polyester material acting as an aerodynamic brake to stabilise and slow down the rate of descent [3, 4] of the locator while increasing the chance of surviving the hard impact part. Figure 1 shows the ejector body along with black powder chamber, load housing and GNSS locator, while Table 1 contains the main numerical parameters. The commercially available location devices used in testing transmit their position signal every few minutes, allowing them to operate continuously for several days. The use of the polyester band was chosen due to it being a simpler and more compact solution than a parachute, although its n aerodynamic drag is lower [5]. A lightweight plastic fabric was chosen for use in the design layout. It was cut into bands measuring 1.5 m in length with approximately the same width as the locator (approx. 40 mm). The bands were attached to the locator using cyanoacrylate glue. The locator ejector is shown in Figure 2. The combustor chamber, filled with the selected mass of black powder, which is initiated by an electrical signal from the control system, is used to eject the locator body.

Figure 1. Ejector body (left), load housing (centre) and ejected Global Positioning System (GPS) locator (right)

Due to the design of the Artemida missile, the ejector is subject to dimensional constraints to ensure the integrity of this module within the missile support structure. Due to the relatively small calibre of the missile compared to the space required to accommodate the propelled load and the chamber, unidirectional ejection in the plane perpendicular to the ar axis of the missile is the only viable solution. Black powder with a small grain size – type ZS1 0.25-0.50 mm – was used as the propellant. The device is intended to be mounted directly into the missile body using holes prepared for this purpose. Space is reserved in the electronics module for the remaining components of the system: microcontroller and DC power supply. For static testing, a copy of the ejector was made equipped with an additional port for connecting a pressure sensor.

Table 1. Design restrictions for the ejector concept

Load dimensions	ø28×45 mm
Load type	Portable GPS locator
Outer diameter of the system	66 mm
Ejection parameters	Unidirectional, in the planar axis of the missile
Propelling charge	Black powder, ZS1, grain size: 0.25-05 mm
Powder chamber volume	4 cm^3
Load housing	Separated from the load after launch

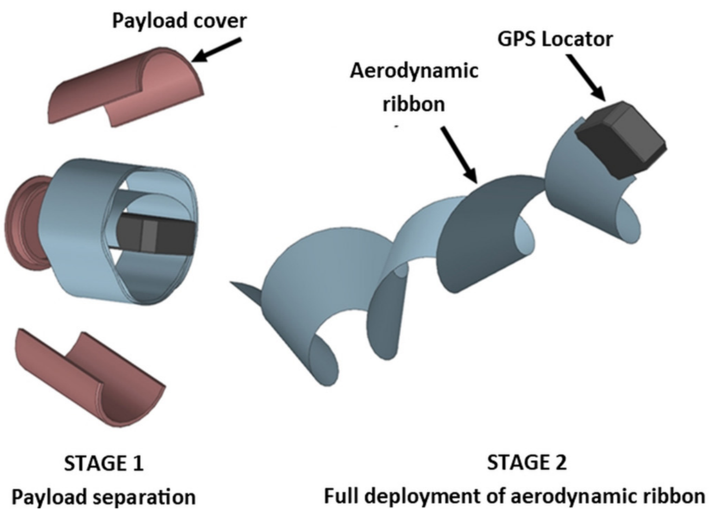

Figure 2. Schematic showing the load just after separation of the housing (left) and after full band release (right)

3. Experimental tests

Preliminary testing of the ejector was concentrated on qualitatively assessing the performance of the developed system with varying propelling charge mass. The main parameters used to evaluate the ejector's performance were the maximum pressure in the combustion chamber, the ejection velocity of the load and the approximate range over which it is ejected. The testing station was designed as a stationary stand to hold the ejector pointing at an angle of about 60° from the horizontal, similar to the angle of the final phase of flight.

The measuring instruments consisted of a high-speed camera – set up to record 2,000 frames per second (fps) – and a pressure sensor. These were connected to a National Instruments USB 6356 measurement card, timer and triggered simultaneously with the application of power to the primer. Pressure waveforms were recorded at a sampling rate of 5 kHz. A diagram of the measurement station is shown in Figure 3. For the initial tests, portions of black powder were prepared with 3 different amounts ranging from 2 to 4 g. The exact mass is shown in Table 2. The testing was carried out at a military ground range. Figure 4 shows the pressure waveforms recorded during experiments.

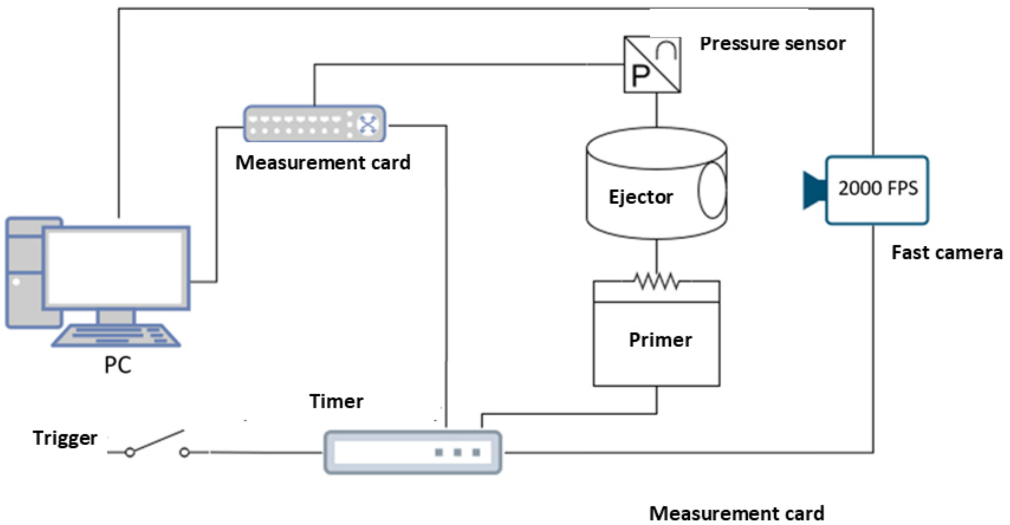

Figure 3. Diagram of the experimental station for preliminary testing

Table 2. Sizes of propelling charges used during ejector tests

Sample number	Black powder mass [g]
1	4.01 ±0.01
2	2.00 ±0.01
3	3.01 ±0.01
4	2.02 ±0.01

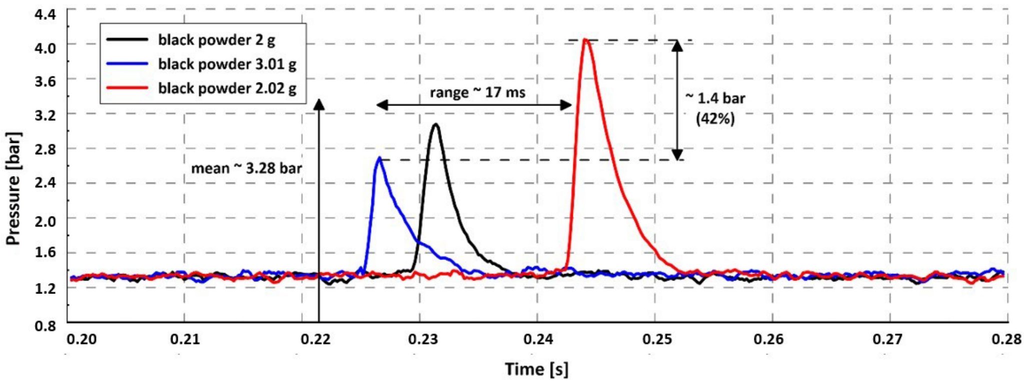

Figure 4. Ejector chamber pressure waveforms for different black powder mass

The values of the maximum pressure in the combustion chamber do not show any regularity with increasing mass of black powder in the propelling charge. Three tests were carried out in which the pressure in the powder chamber was recorded; the difference between the two values is about 1.4 bar, which is as much as 42% of the mean value of the maximum pressure of these tests. This is probably due to the unique nature of the housing of the ejected element, which was made by 3D printing. The dimensional accuracy of the parts depends on the printer settings – such as nozzle temperature, print fill rate and printing speed [6]. The dimensional tolerance of the printing process has, as was later found, an effect on the resistance to the movement of the housing along the powder chamber and consequently, on the maximum pressure values. Due to time constraints for work on the military range, only a single repetition was performed for the 2 g powder mass, while for the 4 g mass, the file recorded in the experiment was corrupted and the data could not be read. Due to the preliminary nature of the tests, the experiments used the simplest electrical initiators having a safe current of 200 mA, whose repeatability is not very high. This can be seen in the graph shown in Figure 4, where the spread is about 17 ms. All results obtained should be regarded as preliminary for the generic evaluation of the adopted concept. Figure 5 shows a sequence of selected frames recorded during the ejector experiment. The wide-angle shot shown allows one to trace how the ejection of the ejector and the deployment of the aerodynamic band take place.

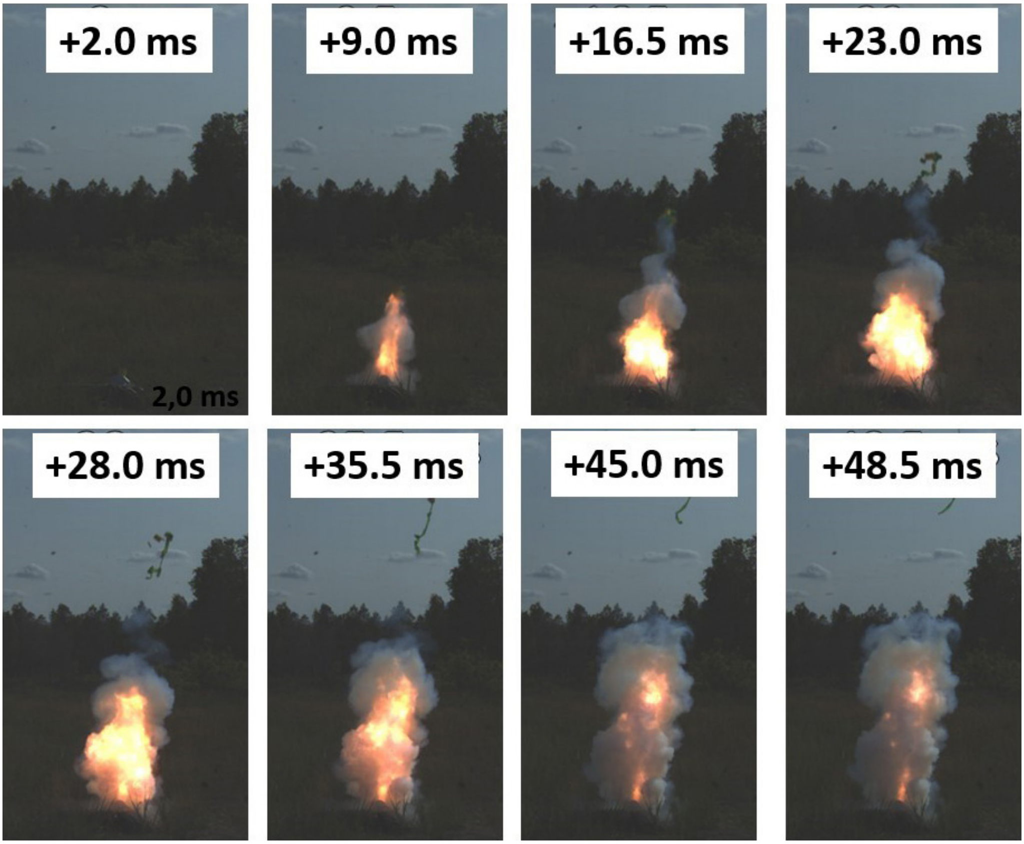

Figure 5. Shots showing selected frames during the ejector test

4. Summary and conclusions

The article presents preliminary static experimental tests of the ejector conducted at a military test range. The tests were designed to verify the concept of ejecting a cartridge from the test missile prior to impact with the ground. The cartridge may contain a locator which allows the missile to be easily found or the measurement data stored on a data carrier to be retained. The ejection of the cartridge and its impact happens at a much lower speed, which resulted in a reduction in the loads acting on the ejected components and hence the likelihood of their destruction.

A load discharge velocity of approximately 25 m/s, based on the high-speed camera images, was considered to be sufficient to safely move the locator away from the missile body before the impact with the ground. The average distance between the impact locations of the launched locators and the test site was approximately 80 m. The dimensional repeatability of the printed elements proved to be unsatisfactory, which is reflected in the pressure waveforms. The peak pressure value does not increase regularly with the increasing mass of the propelling charge. This demonstrates significant differences in the amount of clearance between the housing wall and the surface of the discharge channel during the tests. This leads to the conclusion that further work is required to improve the parameters of the 3D printing technology so as to increase the repeatability regarding firing parameters. The testing confirmed the viability of using the designed ejector in the test missile in the next phases of field tests.

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