Journal of KONBiN 2024
Volume 54, Issue 1
DOI 10.5604/01.3001.0054.4460

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DESIGN AND APPLICATION OF A PARACHUTE DEPLOYMENT MECHANISM FOR SOUNDING ROCKETS BASED ON COMMONLY AVAILABLE AND AFFORDABLE COMPONENTS

Projekt i zastosowanie mechanizmu wyzwalania spadochronów dla rakiet sondujących opartego na ogólnodostępnych i przystępnych cenowo elementach

Abstract: *Sounding rockets must be equipped with a proper recovery system enabling the safe return of all rocket modules to the ground. This requirement is achieved by a parachute recovery system triggered by various types of deployment mechanisms. The paper presents the process of designing and implementing a low-cost parachute deployment mechanism for use in sounding rockets. The design of the mechanism is based on commercially available CO_2 cartridges, electric igniter and the original housing structure made using 3D printing technology. As a result of a number of experimental tests, the design details of the device were improved. Finally, successful verification tests were carried out on the operation of the developed parachute deployment mechanism on the finished sounding rocket structure.*

Keywords: sounding rocket, parachute recovery system, ballistic deployment

Streszczenie: *Rakiety sondujące muszą być wyposażone w odpowiedni system odzyskiwania, umożliwiający bezpieczny powrót wszystkich modułów rakietowych na ziemię. Wymóg ten jest spełniany przez spadochronowe systemy odzyskiwania uruchamiane przez różnego rodzaju mechanizmy. W artykule przedstawiono proces projektowania i implementacji taniego mechanizmu wyrzucania spadochronów do użytku w rakietach sondujących. Projekt mechanizmu opiera się na dostępnych w handlu nabojach CO_2, zapłonnikach elektrycznych i oryginalnej konstrukcji obudowy wykonanej w technologii druku 3D.*

W wyniku szeregu testów eksperymentalnych usprawniono szczegóły konstrukcji urządzenia. Ostatecznie, przeprowadzono pomyślne testy weryfikacyjne działania opracowanego mechanizmu wyrzucania spadochronu na gotowej konstrukcji rakiety sondującej.
Słowa kluczowe: rakieta sondująca, spadochronowy system odzysku, uruchomienie balistyczne

Received: February 5, 2024 / Revised: February 13, 2024 / Accepted: February 19, 2024 / Published: March 28, 2024

1. Introduction

The basic design assumption of sounding rockets is to recover their most important components after a successful flight. This is mainly due to the desire to collect flight data, payload recovery, or safety requirements in the rocket landing area. Most organizations such as NAR (National Association of Rocketry), TRIPOLI (Tripoli Rocketry Association) or PTR (Polish Rocketry Society) do not allow high-power rockets to fly unless they are equipped with a proper recovery system enabling the safe return of all rocket modules to the ground [1-3]. For most high-power rockets, this requirement is achieved by a parachute recovery system triggered by various types of deployment mechanisms that separate the rocket into multiple parts during descent. We can divide parachute deploying mechanisms into two groups: pushing and pulling devices [4] - described in Table 1.

Table 1

Types of parachute deployment mechanisms

	Deployment mechanism	**Method of operation**
Pushing devices	Spring	Uses pre-loaded spring released by servo, boltcutter, wirecutter etc.
	Hot gas	Ballistic/mortar system that uses the force of gases produced during combusion
	Cold gas	Ballistic/mortar system that uses the force of compressed gas
	Actuator	Uses the force generated by linear actuator
Pulling devices	Pilot parachute	Uses small parachute to extract the main (larger) parachute
	Slug gun	Ejecting mass that generate the momentum, which pulls the parachute out of the rocket body
	Tractor rocket	Uses small rocket motor to extract the parachute from rocket body

The most frequently used method of parachute deploying is a mortar system based on the use of gas energy from the combustion of a black powder charge activated by on-board electronics [5]. The main advantage of this solution is its simplicity, it does not require a feeding system, it is lighter, smaller, and does not have a complicated activation mechanism - its activation results from the combustion reaction caused by the electric igniter. Such a system, however, must meet much higher requirements regarding the strength of its housing, requires the use of explosives, and hot gaseous combustion products may damage the coatings of the parachute being thrown [6]. Currently, there is only one commercial device on the world market for deploying parachutes in high-power rocketry. The system is based on a mechanism that puncture the CO_2 cartridge, which separates the rocket into two parts and pulls out a parachute [7]. Since this device is relatively expensive (€1000) and impossible to obtain on the Polish market this article will present the process of designing and implementing a low-cost cold gas parachute ejection mechanism for use in sounding rockets.

2. Requirements for the specific recovery system

The main motivation for attempting to develop a new parachute deployment mechanism was the need to find a solution for use in a simultaneously designed sounding rocket intended to carry small research payloads. Technical data of designed rocket and the requirements that the recovery system had to meet are presented in Table 2.

Table 2

Basic technical data of the designed rocket

Parameter	Value
Length [mm]	2600
Diameter [mm]	90
Rocket mass without engine [kg]	6.3
Rocket take-off weight [kg]	7.8
Assumed ceiling [m]	approx. 1500
Rocket engine	hybrid with a total impulse of 1500 Ns
Recovery system	dual deployment (ejecting drogue parachute at the apogee and main parachute at an altitude of 300 m)
Method of deploying parachutes	cold gas parachute ejection mechanism

Based on the technical data of the designed rocket, it was assumed that it would be best to use the double deployment recovery system, which involves ejecting a smaller drogue parachute at the apogee and then deploying the second, main parachute at a specific height, as shown in Fig. 1. The geometry of the parachutes for the specific flight requirements of the rocket was calculated based on a specially developed application [8]. The data resulting from the calculations were used to make prototypes of parachutes, the parameters of which determined the requirements for the mechanism responsible for their effective ejection. The finished drogue parachute for the designed rocket had a mass of 75 g, and the main parachute weighed approximately 425 g. The main task of the ejection mechanism will be to effectively eject these parachutes by separating the rocket sections at the appropriate stage of its flight.

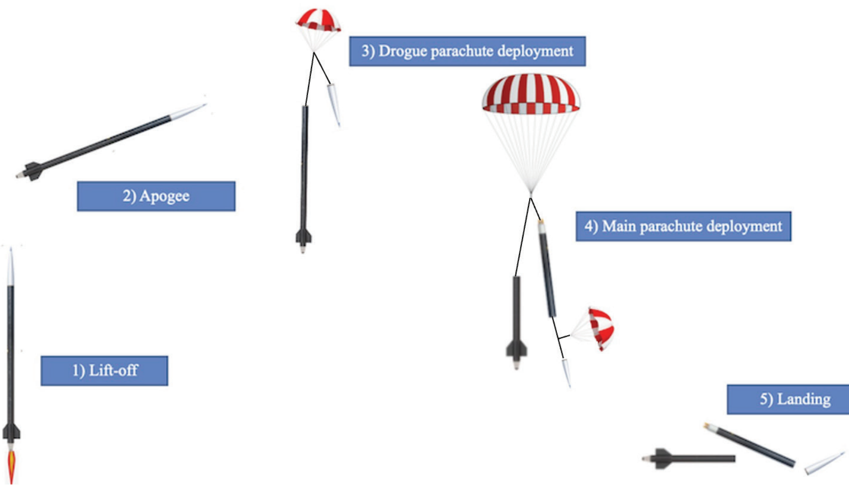


Fig. 1. Sounding rocket dual deployment recovery flight sequence [6]

3. Development of the concept of operation of the mechanism

To ensure the success of the previously proposed method of recovering the designed rocket, it is necessary to declare the sequence of activities of the individual rocket subsystems. We assume the following subsystem operation process:

a) on-board computers will send an impulse to the electric igniter in the appropriate phase of the rocket's flight;
b) the developed cold gas parachute ejection mechanism will operate correctly;
c) the gas released in the rocket body will force selected sections of the rocket to separate by shearing the nylon screws;
d) parachutes thrown during the separation of the rocket sections will open without entangling the support lines.

The method of separating the rocket sections and the location of the designed parachute ejection mechanisms (PEM) in the avionics compartment is shown in Fig. 2.

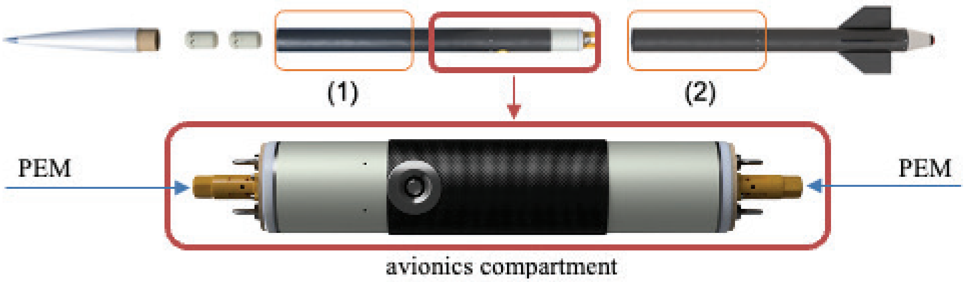


Fig. 2. Method of separation of the rocket sections: (1) – drogue parachute compartment; (2) – main parachute compartment

It was decided to develop a cold gas parachute ejection mechanism, the low price of which was to result from the use of commercially available CO_2 cartridges and the housing made using 3D printing technology. Considering the experimental nature of the work, the use of a printed structure turned out to be extremely effective due to the possibility of rapid prototyping and further testing of subsequent iterations of mechanisms. Based on the analysis of existing solutions and the requirements for the designed mechanism, an original concept of the parachute ejection mechanism was proposed, which is presented in the Fig. 3.

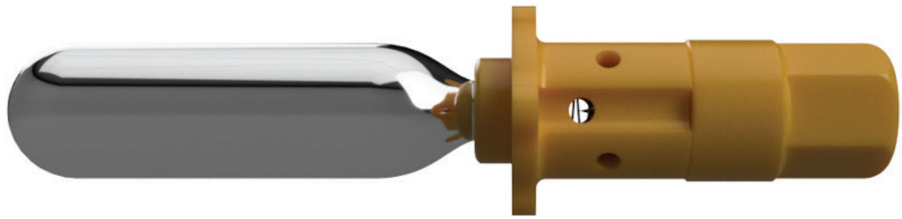


Fig. 3. Designed cold gas parachute ejection mechanism

The way the mechanism works is based on puncturing a hole and quickly releasing the gas compressed in the CO_2 cartridge. The piston with the firing pin is pulled back by a spring, protecting the mechanism against accidental operation. Under the influence of an electrical impulse from the on-board computer, the electric igniter is triggered, which generates powder gases causing the piston to move forward. The driven piston with the firing pin puncture the lid of the CO_2 cartridge, causing the gas to be released through special holes. The method of operation of the mechanism is shown in the cross-sectional drawing (Fig. 4).

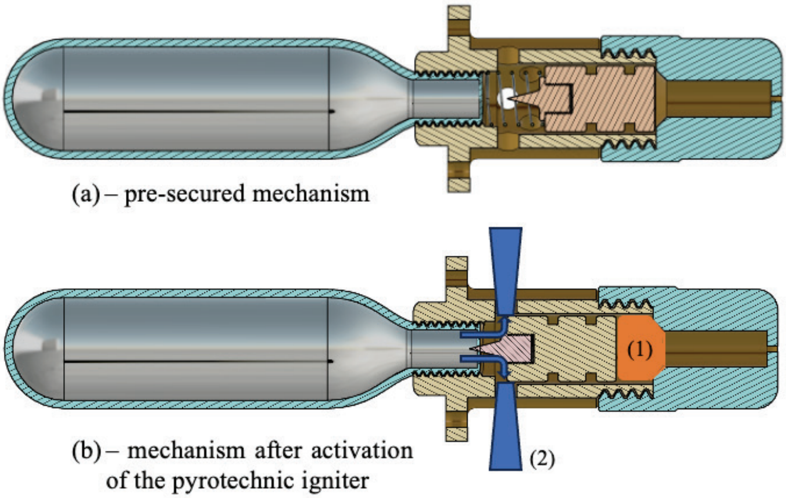


Fig. 4. A cross-section showing the principle of operation of the mechanism: (1) – combustion gases; (2) - compressed CO_2 released as a result of membrane puncture

CO_2 cartridges can be attached to the mechanism using the threaded collar located on the cartridge. The detailed structure of the parachute ejection mechanism is shown in the Figure 5.

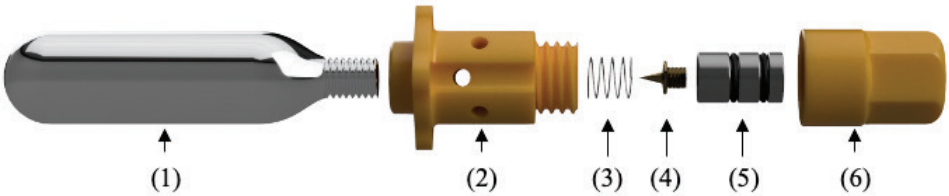


Fig. 5. Designed parachute ejection mechanism in exploded view: (1) – CO_2 cartridge; (2) – housing; (3) – safety spring; (4) – firing pin; (5) – piston; (6) – electric igniter mounting

The pressure of the gases released by the mechanism must cause the nosecone to be ejected at the apogee, and then cause the engine section to separate and the main parachute to be ejected at an altitude of approximately 300 m. Therefore, it will be necessary to estimate what size of CO_2 cartridge should be used to cut off the nylon screws located around the perimeter of the body that fasten a given segment of the rocket. Three M2 nylon screws are used to protect the rocket against premature separation of the engine segment. The method of securing the rocket segments against accidental separation and the method of shearing the nylon screws under the influence of the gas force F_g are presented in a schematic graphic (Fig. 6).

(1)

(2)

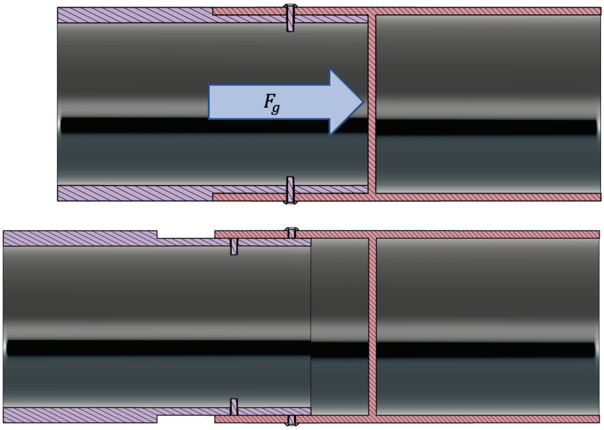
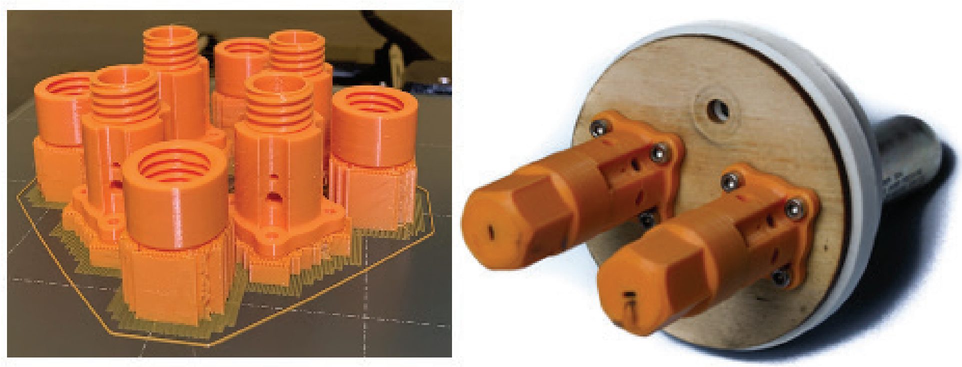


Fig. 6. Method of shearing nylon screws due to the F_g force coming from the pressure of the gas released from the CO_2 cartridge: (1) – protection against accidental separation of segments using M2 nylon screws; (2) – shearing of the screws under the influence of gas pressure and separation of the segments

Therefore, it will be necessary to estimate what size of CO_2 cartridge should be used to cut off the nylon screws located around the perimeter of the body that fasten a given segment of the rocket. Three M2 nylon screws are used to protect the rocket against premature separation of the engine segment. As previously mentioned, in high-power rockets, the energy of black powder charge gases is most often used to separate the rocket bodies. Knowing the force required to shear the nylon screw, we can approximately calculate the mass of black powder that would need to be used to separate the rocket segments by cutting off the screws securing them using the ideal gas law. Due to the universality of this solution, the manufacturer of commercially available devices using CO_2 cartridges has provided a converter for the mass of black powder into the equivalent mass of carbon dioxide compressed in the cartridge. Therefore, for the segments of the designed rocket to separate properly, a compressed carbon dioxide cartridge with a minimum CO_2 mass 6 g should be used by cutting off three M2 nylon screws. However, one should bear in mind the fact that this value is only the result of theoretical estimations, and it will be necessary to perform appropriate experiments to verify the correctness of the calculations.

4. Assessment of the correct operation of the developed prototype

The adopted design assumption, which was to reduce the costs of manufacturing the designed mechanism as much as possible, was fully met thanks to the use of additive manufacturing process (FDM 3D printing). The manufacturing process is shown in Fig. 7. Thanks to the possibility of rapid prototyping, it was possible to perform subsequent development versions of the device and carry out tests to verify the correctness of the introduced improvements more efficiently.



(1) (2)

Fig. 7. Additive manufacturing process of mechanism components: (1) – 3D-printed elements on the printer bed; (2) – assembled 3D-printed mechanism

The only problem was the need to verify whether the technology and materials used would be sufficient to ensure the correct operation of the mechanism when exposed to high CO_2 pressure and temperatures resulting from the combustion of the initiating charge. The final concept of the system structure presented in the previous chapter was not the first version of this mechanism developed. As a result of tests carried out to check the method of operation, it was necessary to introduce further changes and modifications to the developed mechanism concept. The final version of the mechanism is shown in Fig. 8.

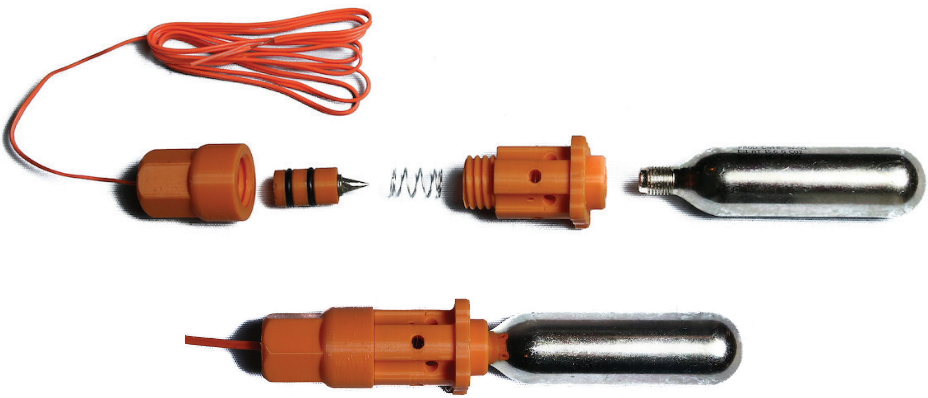


Fig. 8. The final version of the 3D-printed parachute ejection mechanism

A specially prepared platform was used to carry out the tests, and the pyrotechnic igniters were triggered remotely using an electric initiator. Due to the dynamic nature of the mechanism's operation, the tests were recorded using a camera, and then its operation was analyzed based on the collected video material. The test of the first developed version of the mechanism is presented in the photos below (Fig. 9).

(1) (2)

Fig. 9. Operation test of the first designed parachute ejection mechanism: (1) – moment of ignition of the pyrotechnic igniter charge; (2) – moment of puncture of the CO_2 cartridge membrane and release of compressed gas.

The first tests indicated the need to seal the printed threaded connection between the elements of the mechanism and to change the configuration of the compartment with the pyrotechnic igniter. About 10 development versions of the mechanism were made before a test was performed that met the requirements for the designed system. After successfully undergoing experiments on the test stand, the mechanism was implemented for final use in the rocket. In this way, it was possible to test its ability to cut off the nylon screws securing the rocket body against spontaneous disassembly and the ability to eject the parachutes. The test verifying the correct shearing of the securing screws and the method of ejecting the main parachute of the finished rocket structure is shown in the photos below (Fig. 10).

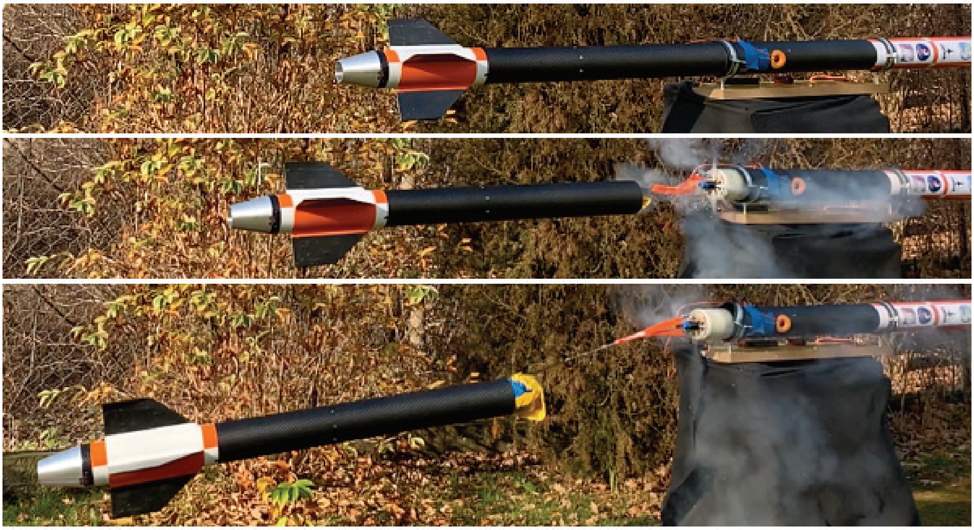


Fig. 10. A test verifying the correct operation of the parachute ejection mechanism on the finished rocket structure

To better illustrate the operation of the designed mechanism, the close – up photos below are showing the process of separation of the rocket's sections because of the energy of the released CO_2 (Fig. 11).

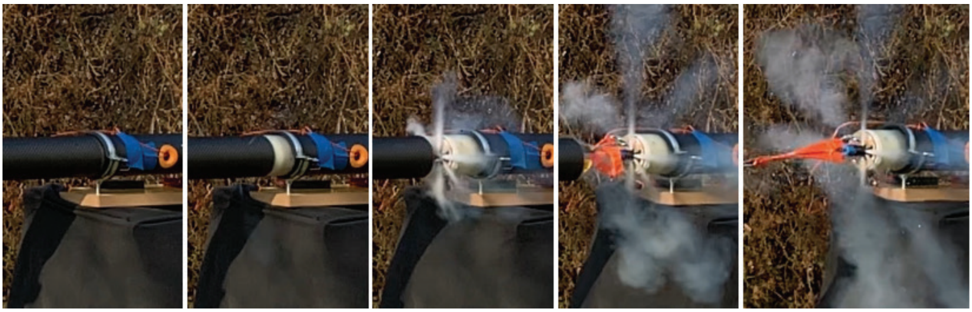


Fig. 11. Close-up photos showing how the designed mechanism works.

5. Conclusions and summary

The recovery system of a rocket is the most essential part of it because rocket structure and the gained information of the mission can be lost if the rocket crashes. The authors have developed an original mechanism design based on commonly available and affordable elements, which is particularly relevant for amateur designs as well as for professional applications. All assumed functional requirements are met in the final design. Due to the increasing popularity and availability of 3D printing, the mechanism developed and tested by the authors can be made at home by any rocket technology enthusiast. Presented in the final test parachute release system is ready to be used in every rocket whose body can accommodate the presented mechanism and on-board computer can generate an impulse to the electric igniter in the appropriate phase of the rocket's flight.

The designed mechanism was used in a rocket whose test flight took place during the Experimental Rocket Flights organized by the Polish Rocket Society at the Drawsko Pomorskie test site. A “Cangur” rocket was powered by a hybrid rocket engine (with a total impulse of 1.5 kNs). Rocket rose to a height of approximately 1289 m and performed flight was a complete success. After deployment of the drogue parachute at apogee (i.e. 1289 m) there was a free fall of the rocket with the rejected head. Then, at an altitude of 250 meters, the rocket's body was detached and the main parachute, on which all the components of the rocket fell, was released. The rocket's descent sequence, with a breakdown of the rocket's recovery process, is presented in the Authors' publication [8].

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