DEVELOPMENT OF PARACHUTE RECOVERY SYSTEM FOR SOUNDING ROCKETS

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Abstract

Re-usability of different types of spacecraft and others aerospace vehicles is nowadays very important task (due to reducing usage costs). Therefore reliable designed recovery system is crucial for those kinds of projects. In this paper the development and test of a parachute recovery system for sounding rockets are described. The system consists of three parachutes (drogue, pilot and main chute) and pyrotechnic initiation device activation system. Low volume (space of diameter about 150 mm), low mass, low cost and re-usability were the main design criteria. Different solutions for ejection are presented and discussed. This paper also discussed designing and testing pyrotechnic initiation device for parachute ejection. Calculations for determination parachute canopy geometry are given. Several tests in wind tunnel were performed and results are compared with analytical data. Test stand and data acquisition system is also covered. The main goal was to calculate snatch force of main parachute what is one of the key elements in designing parachute recovery systems. For reduction of those forces different reefing systems are discussed and presented.

Nomenclature

C_d	Drag coefficient
C_X	Opening force coefficient (infinite mass)
D_o	Nominal diameter of parachute canopy
F_C	Constant force, steady-state drag force
F_R	Reefed opening force
F_S	Parachute snatch force
F_X	Parachute maximum opening force
L	Length of cross parachute arm
L_e	Effective suspension-line length
N_G	Number of canopy gores
n_{sl}	Number of suspension lines
S_o	Surface area of parachute canopy including vent and slots
S_V	Surface of canopy vent
SC_d	Effective drag area of parachute related to canopy surface area
SrC_d	Parachute drag area, reefed
W	Width of cross parachute arm
q_{dyn}	Dynamic pressure
λ_T	Total porosity of parachute canopy
μ	Constructed angle between canopy radials and horizontal
X_1	Opening-force-reduction factor

1. Introduction

Institute of Aviation (IoA) in Poland is currently developing sounding rocket that enables low cost access to high parts of the atmosphere (100 km) for payloads up to 5 kg. To meet the needs of this construction, parachute recovery system was designed and preliminary tests were performed in wind tunnel at Warsaw University of Technology. Although presented system is being designed for specific requirements it is relatively easy to utilize it in other, similar types of sounding rockets. The idea was to develop system as flexible as possible while maintaining high reliability.

1.2 Design of the rocket

Designed rocket is the technology demonstrator for hybrid rocket motors that use 98%+ hydrogen peroxide (HTP) as an oxidiser and its main task is to launch scientific payloads to altitude around 100 km (above Karman Line). It uses two solid rocket motors (total impulse 14900 Ns) as boosters in first phase of flight and main hybrid motor. Total take-off weight of the rocket is about 140 kg and dry mass (recovery mass) around 60 kg and diameter of main stage is 220 mm. Conceptual model of the construction is presented in the Figure 1.

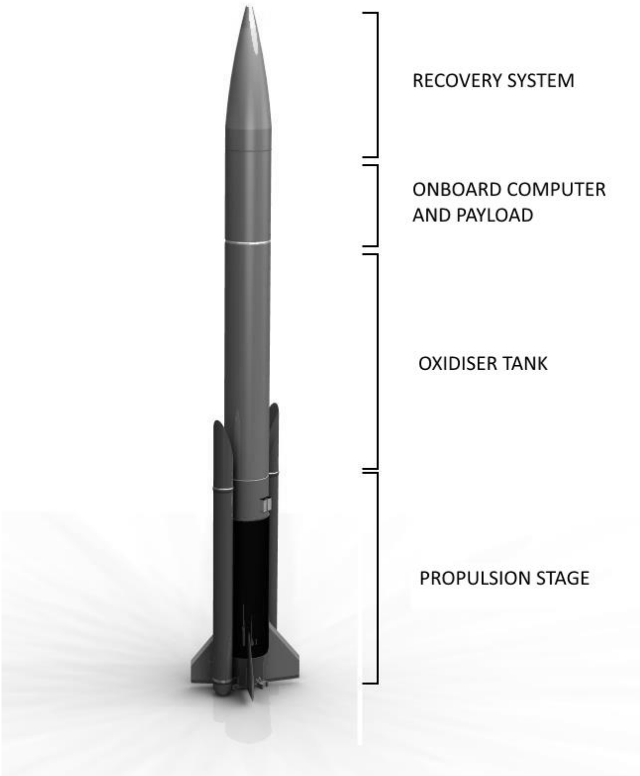


Figure 1: Render of the rocket model and sections.

2. Recovery system design

In first stage of the project some requirements were determined. Recovery system should be as simple and inexpensive as possible, highly reliable, lightweight and compact, and should assure low drift of the rocket and final rate of descent not greater than8 m/s. To meet the requirements different types of configuration were considered. Finally it was decided to use design that consists of 2 parachutes (drag and main one).

2.1 Drag parachute

Drag parachute was designed to decrease rate of descent of the rocket and enable proper inflation of the main parachute. Due to high velocities of the falling rocket in vertical position it was decided to obtain flat spin and increase drag acting on the body. It enables to decrease sink velocity of payload to Mach number about 1.5 at altitude 15 000 m and allows proper deployment of the drag parachute. For this design conical ribbon parachute was selected due to its low geometrical porosity, low action loads and correct operation up to Mach 2. To enable rate of descent about 50 m/s at altitude 1 000 m, nominal surface area was selected to 0.76 m^2. Parameters of this parachute are presented in Table 1.

Maximum inflation load was preliminary calculated to 9.84 kN for Mach 1.5 at altitude 15 000 m. It was determined based on the following equation [2]:

$$F_X = q_{dyn} \cdot SC_d \cdot C_k \tag{1}$$

Where $C_k = X_1 \cdot C_x$, for given type of parachute**.**

Table 1: Drag parachute parameters.

Parameter	**Value**
S_o	0.76 m^2
D_o	0.983 m
L_e/D_o	1.5
λ_T	25 – 26%
N_G	20
S_V	< 7.1×10^{-3} m^2
μ	30°
C_k	1.3

2.2 Main parachute

As main descent parachute cross type was selected with nominal surface area 21.5 m^2. It has beenproven that this geometry gives smallest possible oscillation (about 3 deg) and is relatively inexpensive in production [3 – ARIM]. To obtain maximum loads of reefed parachute following equation was used [2]:

$$F_R = q_{dyn} \cdot SrC_d \cdot C_X \cdot X_1 \tag{2}$$

Force reduction parameter X_1 was assumed as 1 for worst case scenario. For 1 000 m and velocity 50 m/s it gives 8 kN of reefed force. Reefing ratio was selected to 31%.

The Geometry of canopy was designed with arm width to length ratio of 0.264 that gives lower parachute loadings and increases stability (due to greater geometric porosity then canopy with 0.333 ratio). To reduce rotation of the cross parachute, webbing connecting skirt of arms was designed. Parameters of the main parachute can be found in Table 2.

Table 2: Main parachute parameters.

Parameter	Value
S_o	21.5 m^2
D_o	5.237 m
L_e/D_o	1.5
n_{sl}	12
N_G	5
C_x	1.1 – 1.2
C_d	0.66 – 0.85

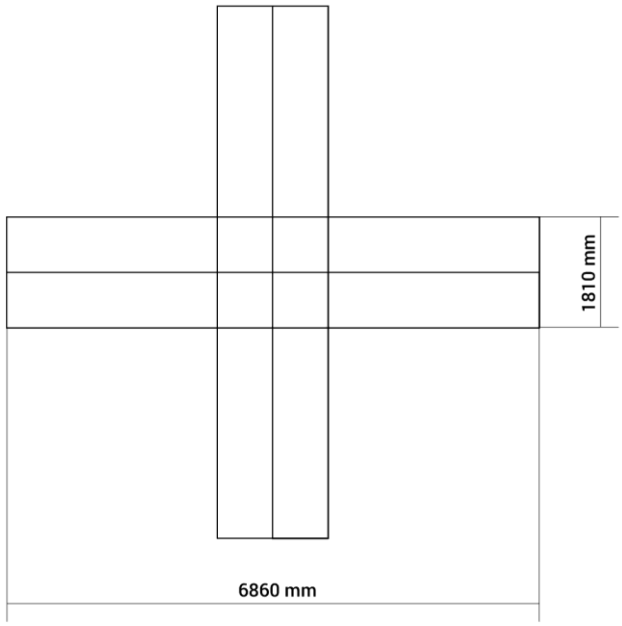


Figure 2: Constructed shape of main parachute.

2.3 System outline

Two types for ejecting parachute were considered:

a) Side ejecting

In this case (diameter 220 mm) such solution has several disadvantages. Although it does not require to separate structure in two pieces it causes weakness in construction (due to need of making slot in the core structure for parachute ejection). Also it is often wasteful in terms of volume of the system (slot width is rather smaller than maximum diameter). In so small volume only possibility is to use pilot chute combined with spring and due to the need of ejecting into good airstream it is insufficient solution.

b) Parallel ejecting

This solution requires splitting rocket in two pieces but it enables easier access to the system and often gives more reliable parachute inflation (due to ejection into good airstream). It is also better in case of volume usage and enables usage of mortar or/and slug gun.

Ultimately parallel type combined with drogue gun method was selected. Using mortar in this case would result in high reaction forces as well as relatively large mass and occupation of large volume. For slug, nose cone was used forced by spring mounted underneath it. Both parachutes lie in canister tube (diameter 166 mm and length 400 mm) that is located partly in main core and head of the rocket. Nose cone is connected to rest of the construction by pyrotechnic separation ring which firing starts recovery sequence. At an altitude of about 15 000 m, after separation, ejected head pulls pilot chute of drag parachute which stabilize rocket. Then, after reaching 1 000 m, pyrotechnic riser cutter releases drag chute (that works now as a pilot) and pulls main parachute from its container. Payload descents 5 seconds with reefed parachute and then on-board computer actuates two reefing cutters and canopy opens fully. In case of unsuccessful deployment of drag or main parachute, emergency system is launched. Piston actuated by pyrotechnic charge and placed on the bottom of the canister pushes whole system out of the rocket. Detailed scheme is shown in Figure 3.

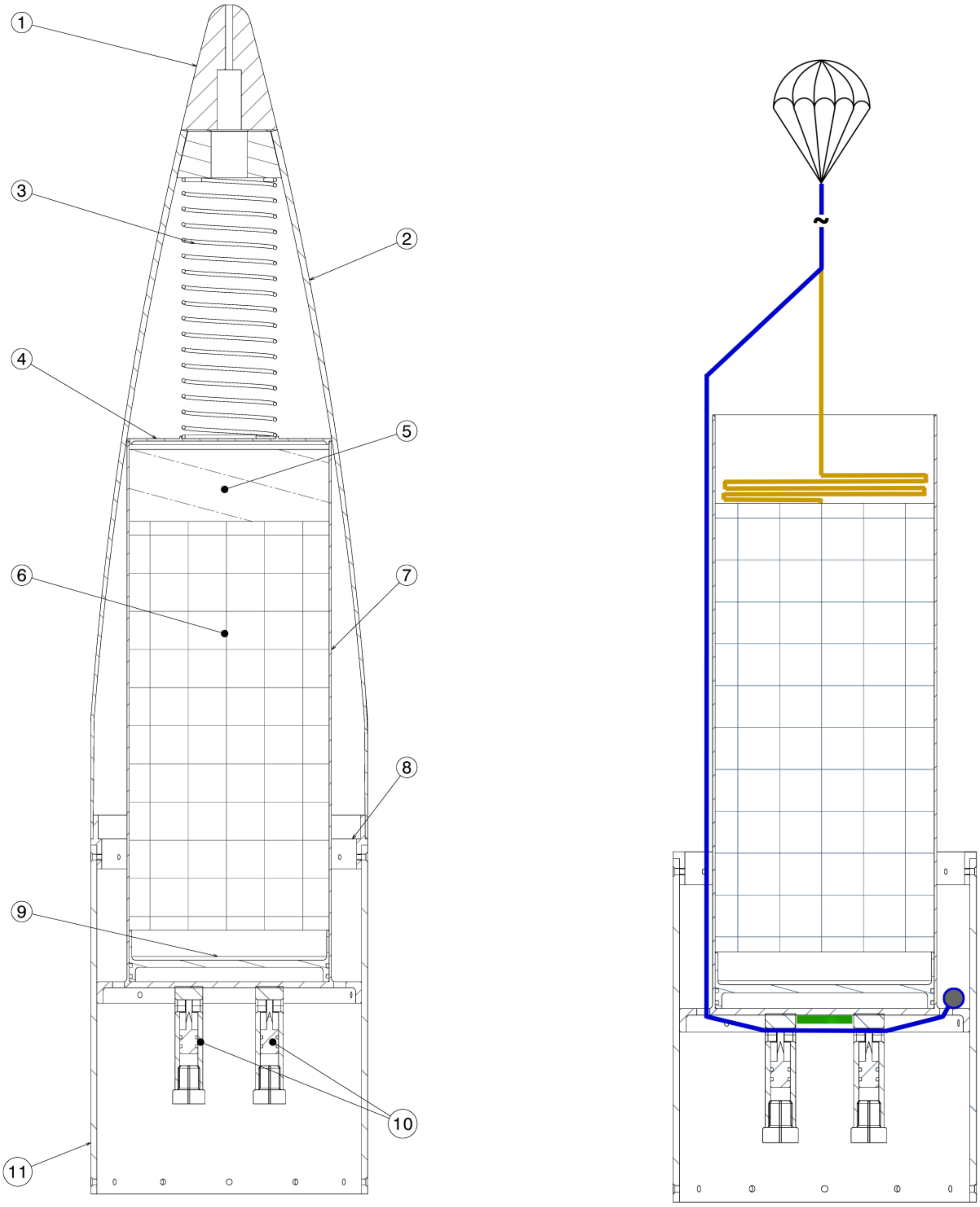


Figure 3: Complete scheme of the system before deployment (left) and with deployed drag parachute (right). 1 – top of the nose cone, 2- heat shield, 3 – spring, 4 – canister cover, 5 – drag parachute with pilot chute , 6 – main parachute, 7 – canister, 8 – pirotechnic separation ring, 9 – piston, 10 – riser cutters, 11 – rocket body. Blue line – drag parachute riser, orange – main parachute bridle to drag chute, green – main parachute riser.

2.4 Riser cutter

Riser cutters are mounted underneath parachute container and are responsible for deploying main parachute. For redundancy, two are used and they fires one after another. Design criteria for them were short reaction time, high reliability, low mass and resistance for high loads.

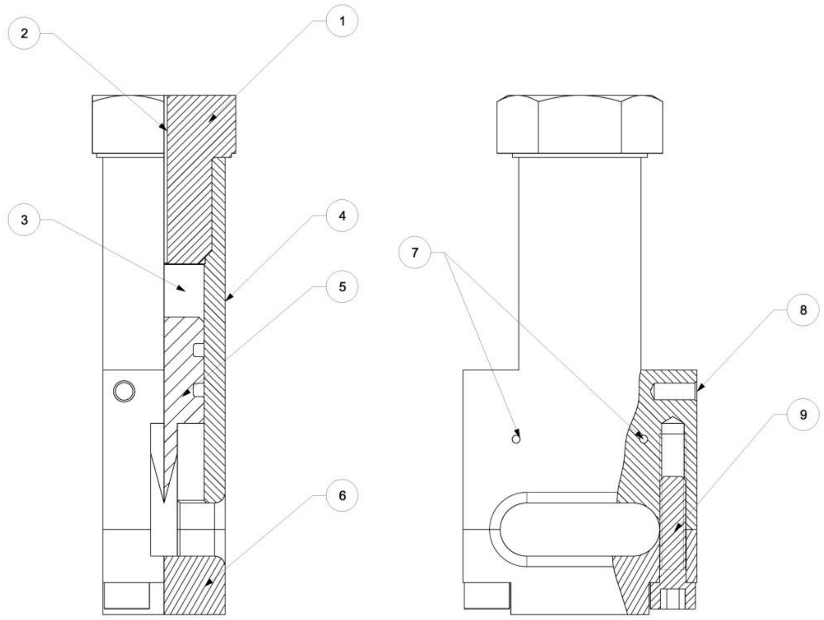


Figure 4: Scheme of designed riser cutter. 1 – plug, 2 – igniter channel, 3 – chamber, 4 – body, 5 – cutting knife, 6 – base, 7 – braking pins, 8 – mounting hole, 9 - connecting bolt.

2.5 Separation ring

Pyrotechnic separation ring was selected due to its high reliability, short reaction time, small size and high repeatability. In first phase of development process pyrotechnic bolts were considered for separation of the nose cone from rest of the body, but they did not fulfil the requirement of small size. For blasting material PETN was selected mainly due to its low critic detonation diameter and high propagation detonation wave (about 8 km/s). Two igniters, placed on opposite sides, are used to ensure proper separation (fired one after another with 1 second delay).

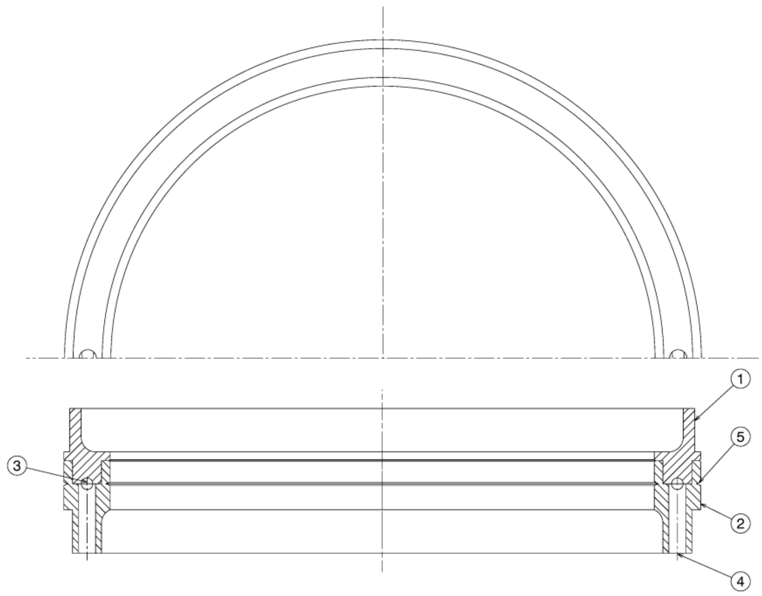


Figure 5: Pyrotechnic separation ring. 1 – top part, 2 – bottom part, 3 – PETN, 4 – mounting of detonating cap, 5 – weakening notch.

Table 3: Recovery system sequence

Altitude [km]	Action
100 – 15	Flat spin and slow down to Mach 1.5.
15	Firing nose cone and deployment of pilot chute for drag parachute, stabilization payload from flat spin.
15 – 1	Descent on drag parachute.
1	Riser cutter releases drag parachute that deploys reefed main parachute (or if needed, emergency system is launched)
1	Decent for 5 seconds with 30% reefed main parachute. Then reefing cutter deploys enabling canopy fully fill and slows down payload to rate of descent 8 m/s.
0	Touchdown.

3. Wind tunnel tests

To obtain proper parameters of parachute it is commonly recommended to perform true tests. There are two main methods of testing parachutes, one usually called *finite mass opening* and second *infinite mass opening*. First one is obtained with true air drop test when velocity of air stream drops with deployment of parachute and second one is conducted in wind tunnel when velocity is relatively constant. Differences between those two types are shown in Figure 6. Due to rather great complexity and relatively high costs of drop test it was decided to use wind tunnel.

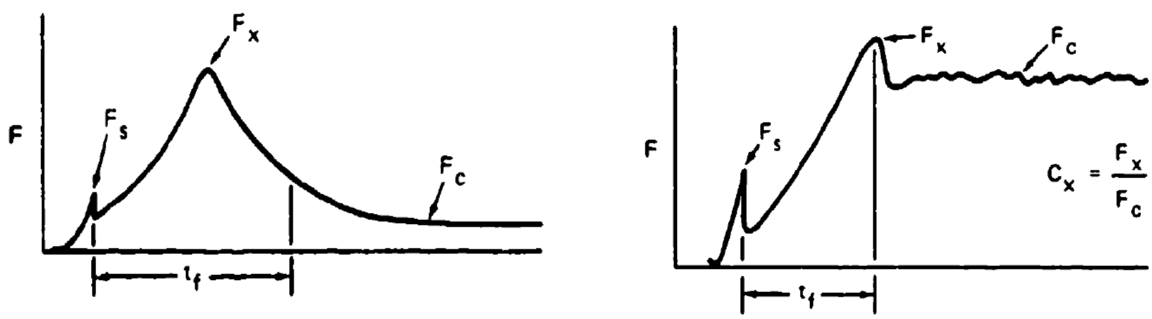


Figure 6: Differences between finite mass opening (left) and infinite mass opening [2].

3.1 Test stand

Tests were performed in closed wind tunnel with measurement space dimensions 120 cm x 90 cm and velocity up to 100 m/s. To acquire forces occurred during inflation process, parachute riser was connected to load cell. As test object, cross parachute with nominal surface area 0.46 m^2, was selected. Data were recorded with frequency of acquisition 100 kHz. To minimize drag and turbulence produced by test stand, mounting bar was covered by airfoil (NACA 0021). Inflation was also recorded by video camera placed in front of the test stand, inside the wind tunnel. It was also necessary to connect parachute by swivel to mounting bar in order to prevent twisting of the parachute. Canopy was stored in canister and ejected by mortar when expected velocity was achieved. Outline of test stand is presented on Figure 7 and 8.

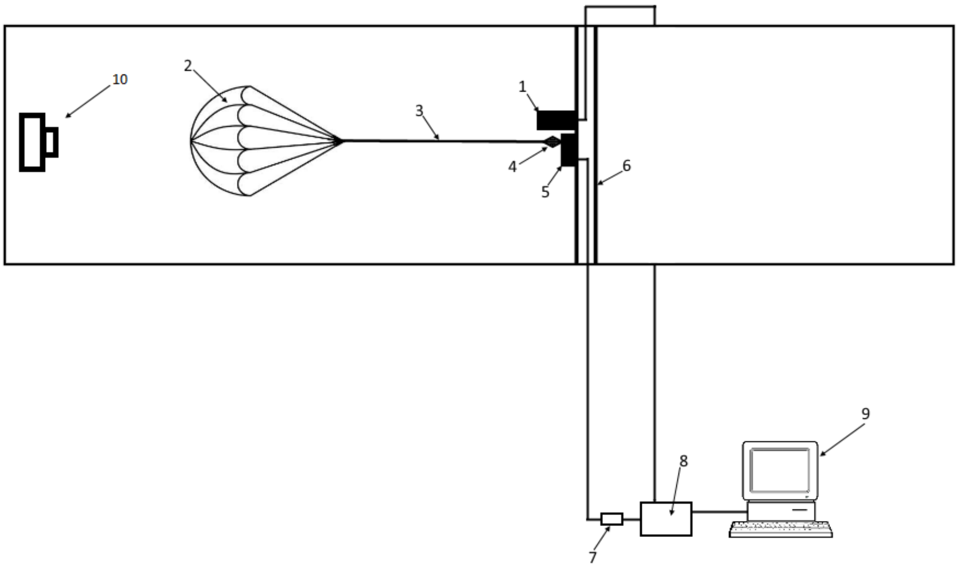


Figure 7: Scheme of test stand. 1 – parachute container, 2 – parachute canopy, 3 – riser, 4 – swivel, 5 – load cell, 6 – mounting bar, 7 – amplifier, 8 – measuring card, 9 – computer, 10 – camera.

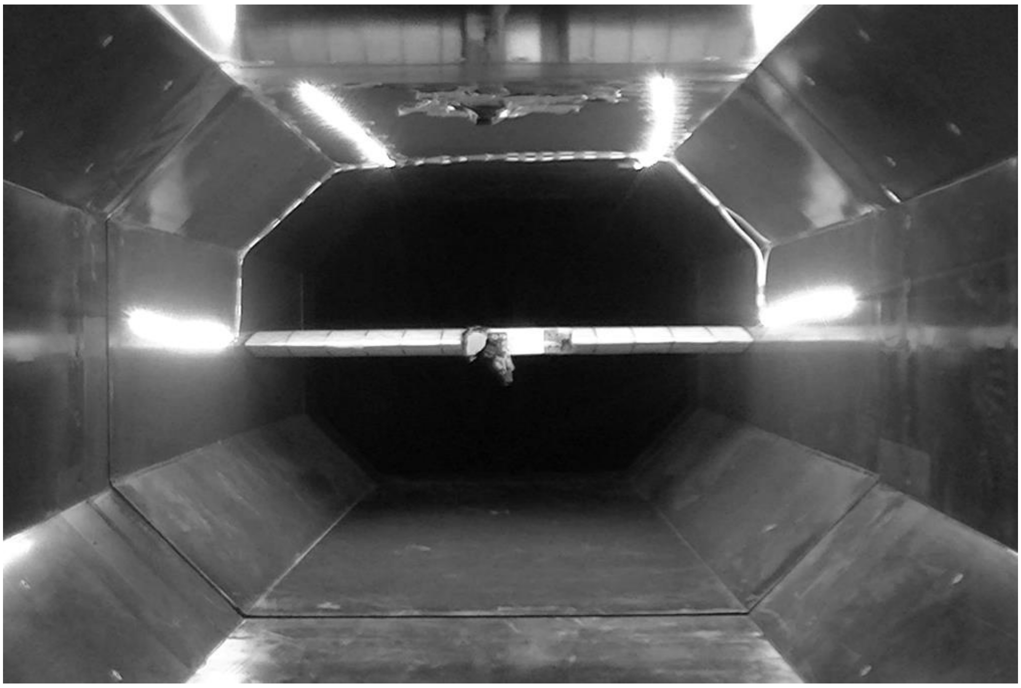


Figure 8: Picture of test stand, view from camera position.

3.2 Test results

Several tests were performed using different range of velocities and configuration. Velocity decrease after parachute opening was observed. It is caused by relatively high drag surface area of the parachute in comparison to dimensions of the measurement space.

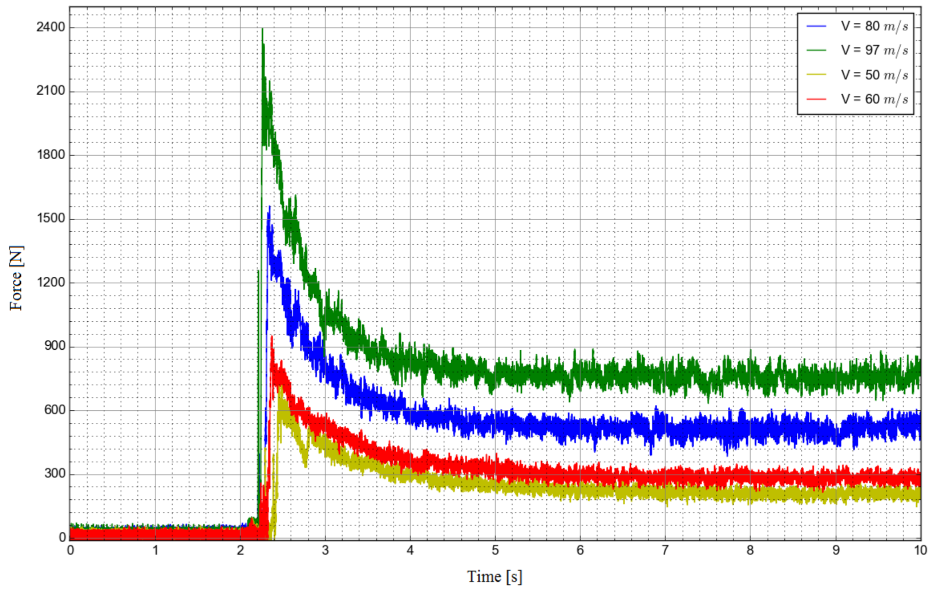


Figure 9: Measured, raw data.

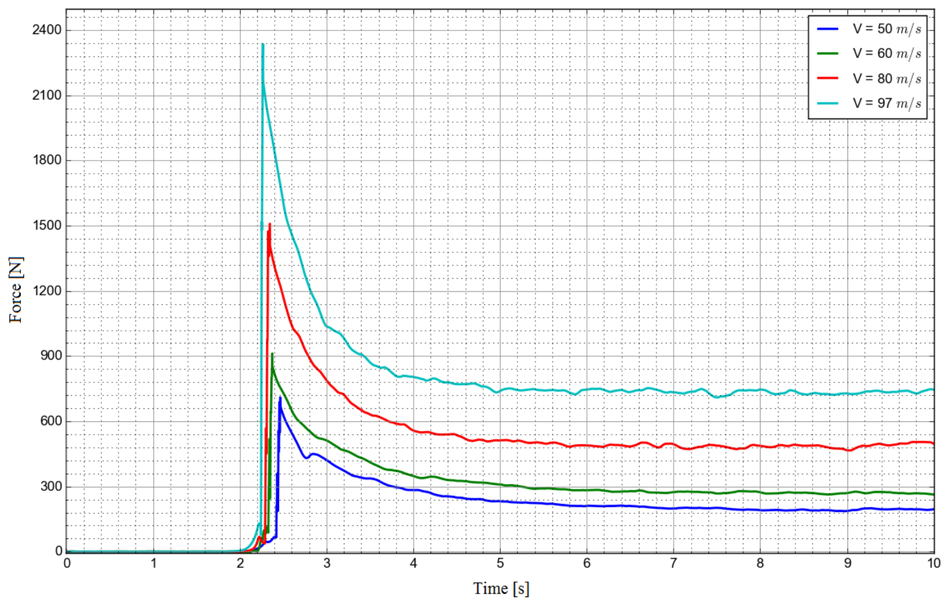
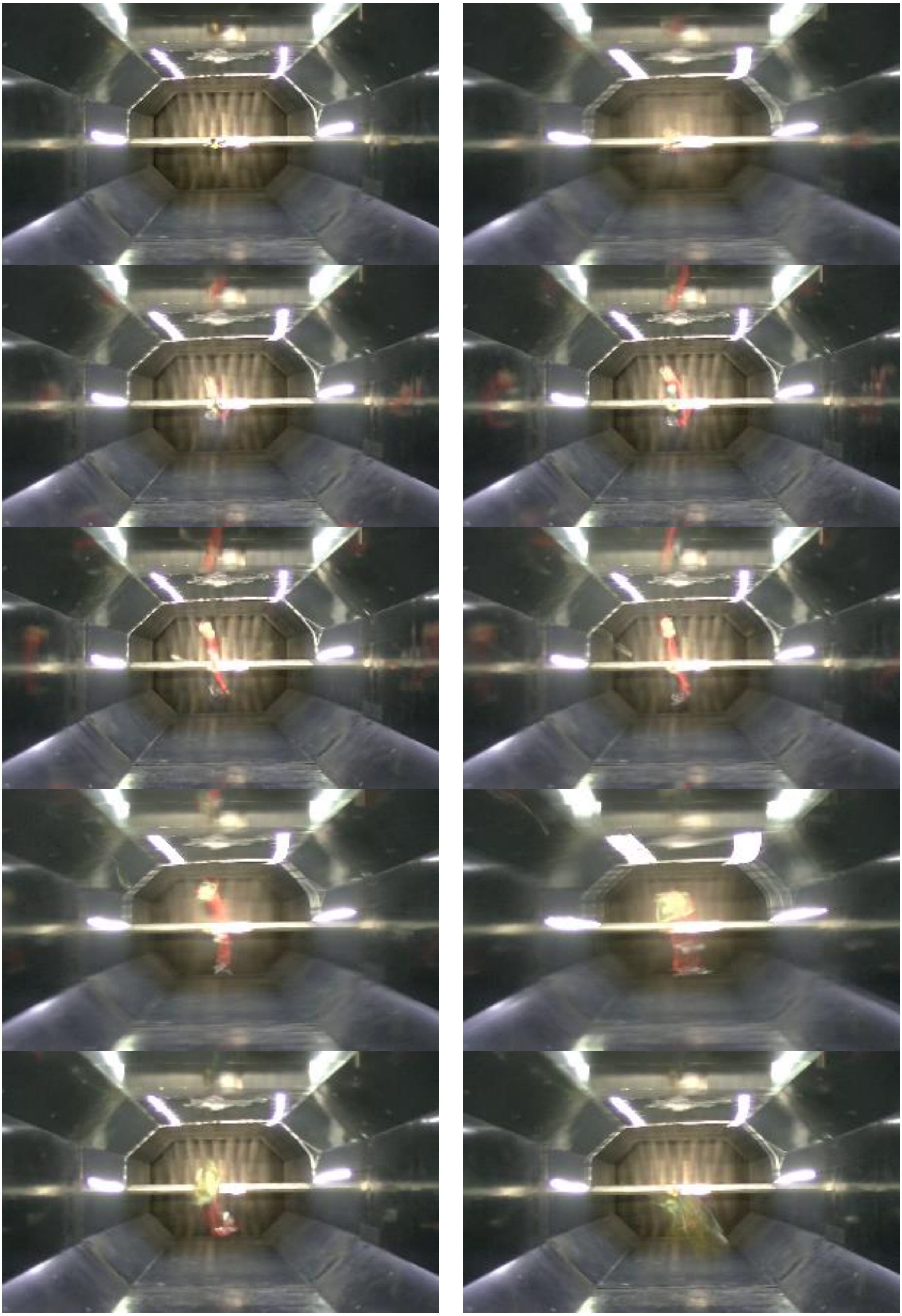


Figure 9: Measured, filtered data.

Table 4: Comparison of data and factor C_x

V [m/s]	Calculated F_c [N]	Obtained F_x [N]	C_d[a]	Calculated C_x
50	660	720	0.75[a]	1.09
60	811	900	0.64[b]	1.11
80	1397	1500	0.62[b]	1.07
97	2020	2340	0.61[b]	1.16

[a]Data obtain from tests; [b]Data taken from reference [3]



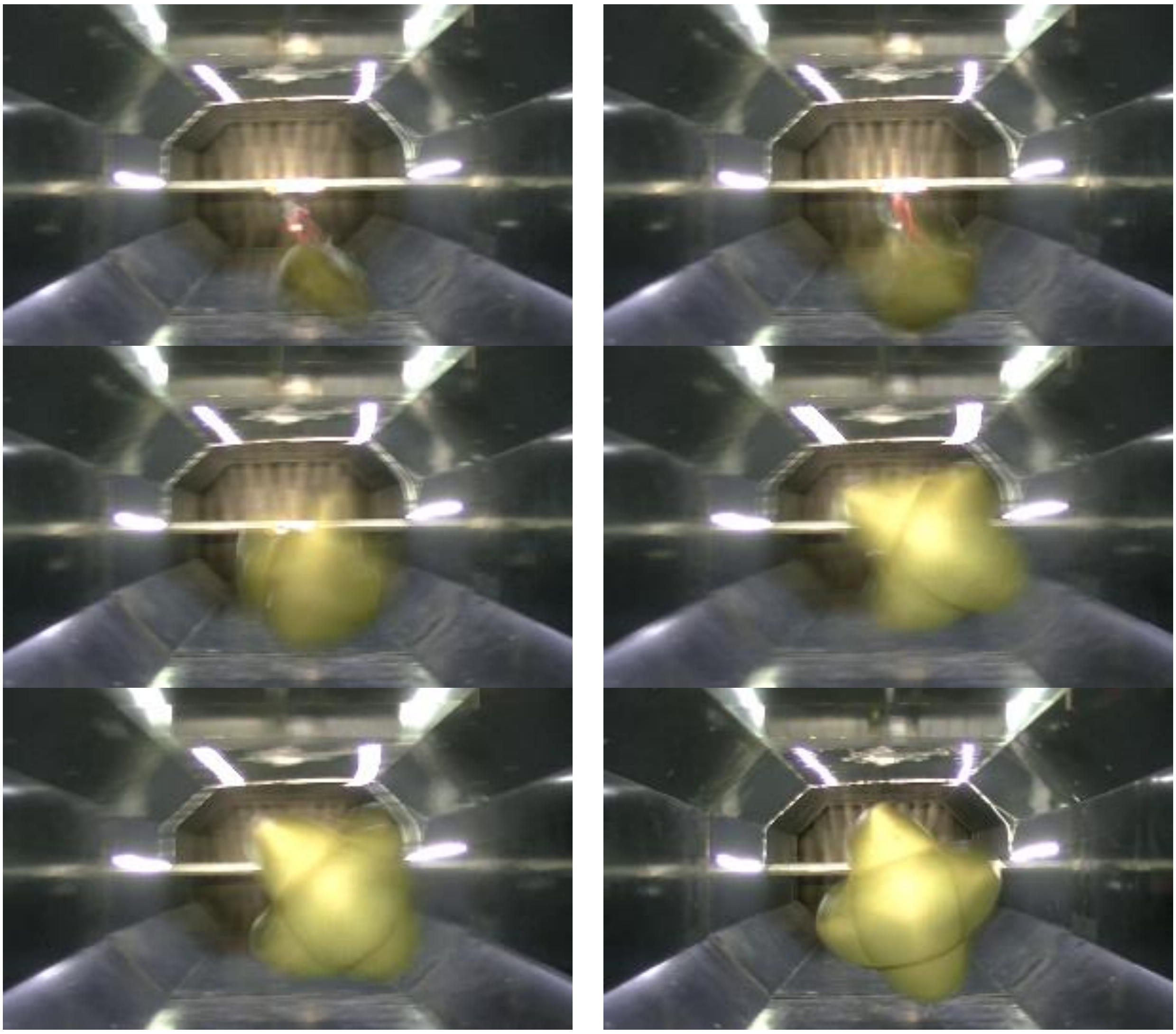


Figure 10: Inflation proces of cross parachute obtained from wind tunnel. Time interval – 0.02 s.

4. Conclusions and future plans

Presented system is relatively easy to implement in other, similar (in terms of mass and overall dimensions) sounding rockets. Simple and modular design of the system can be easily adjusted to other existing designs with minor changes in construction. However it is worth mentioning that every design has its unique, own requirements and they have to be taken into account in design process. Further tests of the Presented parachute recovery system have to be performed and its performance also has to be verified. Parts like pyrotechnic separation ring and riser cutter have to be subjected to different conditions to finally be approved for the flight.
Next phase of the research is to perform tests with smaller types of parachutes in order to resolve the issue with decreasing velocity of the air stream. In future plans it is planned to use faster and more reliable cameras and removing issue with rotation of the parachute by use of slightly different canopy geometry.

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References

[1] Marciniak, B. 2015. Rozwój systemu odzyskiwania modułów rakiet. Bachelor Thesis. Warsaw University of Technology.
[2] Knacke, T. W. T. 1991. Parachute Recovery Systems. Santa Barbara, California: Para Publishing
[3] Ludtke, W. P. 1971. Effects of canopy geometry on the drag coefficient of a cross parachute in the fully open and reefed conditions for a w/l ratio of 0.264. Silver Spring, Maryland. Naval Ordnance Laboratory.