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EMERGENCY BAIL-OUT FROM AIRCRAFT LANDING WITH PERSONAL RESCUE PARACHUTES

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Summary. The article is devoted to the issue of saving the lives of persons in aviation using personal emergency parachutes. Apart from the general introduction, the article is providing a detailed analysis of the final stage of an emergency bail-out-landing. Defined are the factors affecting safety of landing with the Personal Rescue Parachute (PRP) along with its quantification.

Keywords: personal rescue parachute; speed of descent; force of impact; overload at landing; para-roll

1. INTRODUCTION

Despite of reliability of current aviation technology and backups provided for each vital system of aircraft, there comes to inflight situations when immediate interruption of the flight is required and emergency landing is impossible to carry out. Or, there comes to critical situations when controlled flight is turning into an uncontrolled movement/fall. When in a situation like that, the only solution is to deploy the rescue parachute systems, which is available during flight, thereby substituting the failing system (aircraft) by a highly reliable system to save human lives.

Among the situations requiring deployment of a rescue parachute system are particularly [1]:

- Failure of the aircraft controls making further flight of the aircraft impossible,
- Losing control over the aircraft, ur being unable to recover the aircraft into normal mode of flying,
- Destruction of the airframe (e.g. breaking off the wings),
- Fire (e.g. the one that cannot be extinguished or fire in the cockpit making further control of the aircraft impossible),
- Loss of navigation or spatial orientation,
- Inability to carry out emergency landing due to poor visibility or unsuitable terrain.

Currently, the following types of rescue parachute systems are used [1]:

- Personal rescue parachutes (closer described in the article).
- Rescue parachute systems for aircraft:

Rescue parachute systems for aircraft (RPSA) are designed for saving lives of aircrews, while the persons aboard stay sitting on their seats and the aircraft as a whole is hovering down on a rescue parachute. Currently, the RPSA are manufactured for aircraft not exceeding the total weight of about 1800 kg. They are installed into powered aircraft, gliders, hang-gliders and parachute gliders. Currently, RPSA are available for speeds up to about 320 $km.h^{-1}$. Ideally, the parameters of RPSA correspond to the entire flight envelope of the aircraft. Minimal altitude for applying RPSA depends of a great number of factors and falls between 50 m to 200 m over the terrain. The RPSA can be applied at any actual position of the aircraft, be it in a spin or inverted flight. They are installed directly into the fuselage (on the body) and it is important for the rescue parachute to be anchored at places designed to withstand sufficiently high dynamic loads generated when the parachute turns open.

- Emergency parachute ejection systems:

The Emergency Parachute Ejection Systems (EPES) are used mostly in military aviation. However, the latest era is witnessing their increased use in the civil sector, mostly on aerobatic aircraft. Currently the only known manufacturer of EPES for civil aviation is the Russia-based RD&PE ZVEZDA system termed as CKC-94 for the SU-31M aircraft. Conditions of successful ejection based on the CKC-94 are for the speed intervals between 70 and 400 km.h^{-1} at minimum height of 5 m above the terrain. Use of the RPSA in an aircraft is to be considered already during the design stage as an additional installation of such a system is next to impossible.

2. PERSONAL RESCUE PARACHUTES

A Personal Rescue Parachute (PRP) is designed to ensure saving the life of an individual when it comes to in-flight emergency-exiting of an aircraft. The first models of parachutes were developed in the beginning of the 20th century in parallel with the appearance of aircraft and have remained the most-frequently used tools of emergency bail-out in civil aviation till now. In view of the positioning on the human body, they are known as back-pack, seat-pack or belly-pack parachutes. They can practically be integrated in any kind of seats without adversely affecting the comfort of sitting. Due to minimized size, they can be compared to wearing a „rougher sweater". Development, manufacturing and verification of PRPs is currently under the control of the technical normalization order of TSO-C23d „Personnel parachute assemblies" and the related norm known as the SAE AS8015 "Minimum performance standards for personnel parachute assemblies and components", or the TSO-C23e and the PIA TS 135. The operational norms laid down by the aforementioned standards are as follows [4]:

- Minimal operational load 100 kg,
- Resistance of the parachute assembly during opening to the effects of forces generated by the airstream at a speed of minimally 278 km.h^{-1} EAS at the very moment of opening the parachute canopy,
- Maximal allowable time for inflating the parachute canopy sleeve from the moment of opening the parachute canopy is 3 sec. Or, the maximum allowable loss of height between the moment of opening the parachute sleeve and the complete inflation of the parachute canopy is 91,5 m,
- Average vertical speed of falling is up to 7,3 m.s^{-1} at maximal operational weight during the last 30 m by the MSA.

When using the PRP, it is necessary to open/throw away the doors/cockpit canopy and then to release oneself from the seat by disengaging the central harness release system. At larger aircraft, usually, it is necessary to get released from the seat at first and then move to the operational area or to the emergency exit opening of the aircraft and to turn it open or throw it away. Applying one´s physical force is necessary when exiting the aircraft by bailout. Another option is to leave the aircraft by being pulled out of the aircraft as a result of a special piloting technique based using forces acting on the pilot in aerobatic manoeuvers [3].

Successful emergency exiting of an aircraft (EEoA) depends mostly on the following factors [2]:

- Speed of flight in combination of the height over terrain,
- Actual position of the aircraft,
- Position of the opening for EEoA with reference to the wings, tail units, propeller and the airstream flowing around the aircraft,
- Forces acting on the pilot during EEoA and the physical potentials of the pilot for overcoming them.
- The position of body during opening of a PRP.
- The procedure for opening the parachute (manually or by automatic activation device).
- Conditions for landing.

3. FACTORS AFFECTING LANDING WITH THE PRP

Landing with the PRP without having any theoretical coverage of the topic or any basics of practical training would not, most probably, end up without any injuries. When landing with a wind not so strong, above blowing at 3 up to 4 m.s^{-1} and on a soft, grassy surface with no barriers and observing all the elementary rules of landing is possible with minimum risks. In the rest of the cases, with insufficient theoretical knowledge and lacking sound level of practical skills will remarkably raise the level of risks involved. The basic factors affecting the process of landing with the PRP are as follows [5]:

- Speed of descent and steadiness of descent,
- Speed of the air,
- Kind of the landing area surface,
- Stability of descent and oscillation during descent,
- Direction of descent in relation to wind direction,
- Methodology of hitting the ground and its damping.

3.1. Speed and steadiness of descent on the parachute

From physical point of view, descent flight on the open PRP is defined as a braked fall. The vertical speed of fall is defined as the speed of approaching the ground surface. The vertical speed of descent of a concrete parachute in an ideally calm air is given by its design, area, geometrical shape, venting quality of the fabric, mass of the load (parachute + person) and the status of the atmosphere (air density). Rate of descent on a parachute can be determined using the expression [5]:

$$v_{des} = \sqrt{\frac{2.G}{C.\rho.S}} \tag{1}$$

where: v_{des} – rate of descent [m.s^{-1}],
G –load of the person-parachute system [N]; $G = m.g$
m – mass of the person-parachute system [kg],
g –gravitational acceleration [m.s^{-2}]; g = 9,81
C – coefficient of parachute resistance [-],
ρ – air density [kg.m^{-3}],
S – area of the parachute canopy [m^2].

The coefficient of drag for the parachutes currently available in the markets is roughly between 1,2 and 1,4. Concretely, in the follow-up calculations for the PTCH-40, ATL and JU-40, the value of C = 1,343 was used. I have managed to calculate it using the expression (1) and the parameters of parachutes presented in web-sites of the manufacturers, when the coefficient of drag remained as the sole unknown variable in expression (1). Table 1 provides the calculated values of rates of descent for the given types of parachutes at 0 altitude, density of air as by the international standard atmosphere. On can roughly define that increasing the weight by 10 % results in higher rate of descent by 5 %. By increasing the altitude of the landing area by 200 m the rate of descent increases roughly by 1 %.

Table 1 Calculation of the rate of descent on the PRP

Type of the parachute	m [kg]	g [m.s^{-2}]	C [-]	ρ [kg.m^{-3}]	S [m^2]	v_{des} [m.s^{-1}]
PTCH-40	85	9,81	1,343	1,225	44	4,80
ATL	77	9,91	1,343	1,225	36	5,08
JU-40	100	9,81	1,343	1,225	40	5,46

In a real air space, the rate of descent is also affected by the vertical motion taking the form of either descending or ascending streams of air caused by technical, dynamical or mechanical turbulences. The resulting vertical speed of approach to the ground $v_{des.res}$ is then the sum of vectors v_{des} and all the mentioned vertical motions of the air mass, in which the parachute is moving.

Steadiness of descent on the parachute is conditioned with a roughly constant rate of descent and elimination of oscillation of the person-parachute system (elimination of swinging). During descent on the parachute, air is accumulated in the parachute canopy, which generates overpressure, and the air is trying to escape into the surrounding area. If the design of the parachute makes it impossible to handle the process, the accumulated air is tilting the canopy in one direction, and, as a result, some air is allowed to escape from under the canopy into the surrounding environment. When accumulation is repeated, the entire process is repeated, too. This result in a cyclical change in the rate of descent the so-called pulsation of the canopy and swinging the person-parachute system. Immediately before landing, the phenomena might result in increasing the rate of descent and deviating the body from its standard position, thereby, making landing more difficult. To eliminate the negative circumstances, openings of the canopy have been introduced to enable for the excessive air to escape (pole opening of the canopy and further slots, which can be used for rotating the parachute around its vertical axis) and selecting for the proper venting quality of the canopy fabric.

3.2. Speed and steadiness of descent on the parachute

Total speed of landing is the resulting speed given by the sum of vectors of the resulting vertical rate of descent $v_{des.res}$ and the horizontal speed of the parachute movement $v_{hor.res}$. The resulting horizontal speed of the parachute $v_{hor.res}$ is a vectorial sum of the actual horizontal speed of the air mass (windspeed u) and the design of the parachute canopy, when most of currently used PRP fly at a horizontal speed of roughly v_{hor} 2 m.s^{-1}. This design-based horizontal flight is the reactional phenomenon of releasing the accumulated air put through the various canopy openings and slots located on one side of the canopy. Under ideal weather conditions, wind calm, with neither horizontal or vertical reshuffle of air, using the parachute, which be its design, allows for no horizontal speed, the overall speed of landing equals to the rate of descent v_{des} , in line with the definition by (1).

The total speed of landing and its components are illustrated in a rectangular direct-line co-ordinate system of x, y [6]:

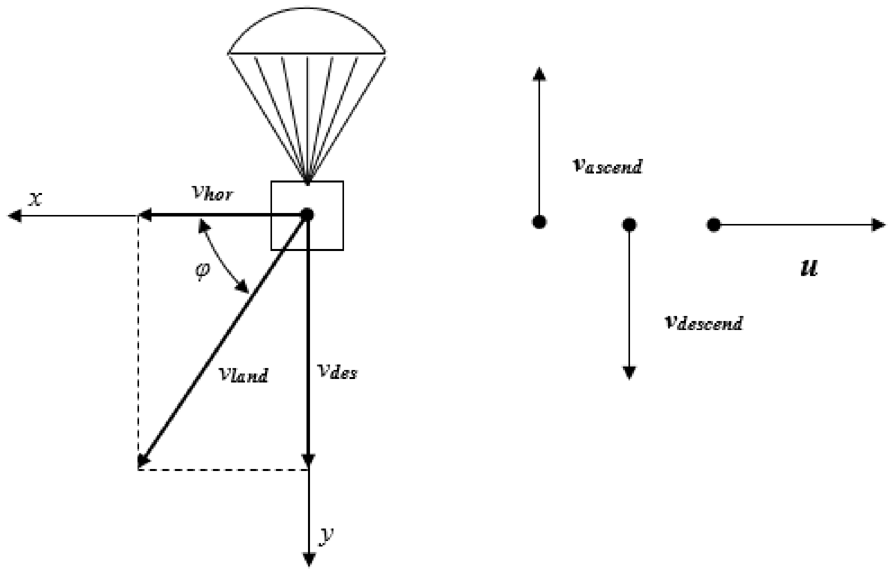

Figure 1 Vertical speed of the parachute

where: v_{land} – overall speed of landing [m.s^{-1}],
v_{des} – vertical rate of descent [m.s^{-1}],
v_{hor} – design-based horizontal forward speed of the parachute [m.s^{-1}],
v_{ascend} – speed of the ascending air stream [m.s^{-1}],
$v_{descend}$ – speed of the descending air stream [m.s^{-1}],
φ – angle of gliding [°],
u – wind speed.

For the components of total speed of landing in the co-ordinate axes it holds [6]:

$$v_{hor} = \frac{dx}{dt} = \cos\varphi \, . \, v_{land} \text{ [m.s}^{-1}\text{]}, \tag{2}$$

$$v_{des} = \frac{dy}{dt} = \sin\varphi \, . \, v_{land} \text{ [m.s}^{-1}\text{]}. \tag{3}$$

For the overall speed of landing in ideal air without any horizontal or vertical movements of the air streams, it holds [6]:

$$v_{land} = \sqrt{\left(\frac{dx}{dt}\right)^2 + \left(\frac{dy}{dt}\right)^2} = \sqrt{v_{hor}^2 + v_{des}^2} \quad \text{[m.s}^{-1}\text{]}. \tag{4}$$

Under real air conditions, the parachute is affected by ascending or descending airstreams acting in direction of the vector. The horizontal direction of the parachute flight can be affected by wind blowing at speed *u*. The total speed of landing will result from summing up the vectors [6]:

$$v_{land} = v_{des} + v_{hor} + v_{ascend} + v_{descend} + u. \tag{5}$$

In a real airspace, touching the ground surface takes place at a total rate of descent [5]:

$$v_{land} = \sqrt{v_{des.res}^2 + (u \pm v_{hor})^2} \tag{6}$$

where:
- v_{land} – overall speed of landing [m.s^{-1}],
- $v_{des.res}$ – resulting vertical speed of descent [m.s^{-1}],
- u – wind speed [m.s^{-1}],
- v_{hor} – design-based horizontal forward-speed of the parachute [m.s^{-1}].

3.3. The force of hitting the ground on landing and overload

A person jumping from above is accumulating kinetic energy by changing its potential energy derived from his altitude of jump. The kinetic energy obtained is again transformed during landing into potential energy, whereas the law of conservation of energy applies:

$$E_k + E_p = const. \tag{7}$$

where:
- E_k – kinetic energy [J]; $E_k = \frac{1}{2} m.v^2$
- E_p – potential energy [J]; $E_p = m.g.h$
- m – mass of the body [kg],
- v – speed [m.s^{-1}],
- g – graviational acceleration [m.s^{-2}]; g = 9,81 m.s^{-2},
- h – altitude of jump [m].

Hitting the ground with the body is actually losing its speed, its kinetic energy. The force of hit depends on the volume of kinetic energy loosed by the body, and the trajectory along which the loss is taking place. For this purpose of calculations, the trajectory can be replaced by a time section, too, during which the los is taking place, denoted as E_k.

The force of hitting the ground can be expressed as:

$$F = \frac{E_k}{s} = \frac{m.v^2}{2.s} = \frac{G.v^2}{2.g.s} \tag{8}$$

where: F – force of hitting the ground [N],
s – trajectory during which the bode is brought to halt definitely [m],
v – speed at hitting the ground [m.s^{-1}],
g – gravitational acceleration [m.s^{-2}]; g = 9,81 m.s^{-2},
m – mass of the body [kg]; $m = \frac{G}{g}$,
G – load of the body [N].

Overload acting on the body shows that how many times the load of the body in the moment of landing is more than the load of the body when not in motion. Overload in the moment of hitting the ground is expressed as:

$$n = 1 + \frac{v^2}{2.g.s} \tag{9}$$

where: n – overload at hitting the ground [ ].

4. PROPER EXECUTION OF LANDING WITH THE PRP

The expressions regarding hits on landing and overload reveal that the magnitude of the hit is mainly influenced by the speed of hitting the ground. The force of hitting the ground and overload are functions of the square of the speed.

At a given speed, the force of hitting the ground and overload will depend on the trajectory, along which the breaking off of the body down to zero is being achieved. For mathematical purposes, in case of a parachute jump, this trajectory can be limited by the position of the body´s centre of gravity at the very moment of when the feet come into contact with the ground and the position of the centre of gravity at the moment of the hit.

Table 2 presents calculations of overload when hitting the ground for the following three ways of landing and damping:

Way 1

The ground is hit with legs fully straightened. It is, however, a purely theoretical assumption, as legs are unable to withstand jump even from a height slightly above 0,5 m and are bent or even get broken, with the latter option presented as the worst and less favourable way of landing. The trajectory along which the loss of speed is taking place while trying to land on completely straightened legs will be above 0,05 up to 0,06 m long (effect of the soft connecting tissues and body flexibility).

Way 2

The ground is hit on slightly bent and appropriately bent (squatted) legs. The trajectory at which the loss of speed is taking place during this way of landing will be above 0,8 m long.

Way 3

The ground is hit on slightly bend and appropriately flexed legs leading into a para-roll. The trajectory when the loss of speed is taking place is extended roughly to 1,5 m long.

Table 2 Overload at landing after jumping

Way of hitting the ground	Altitude of jump [m]	Speed at hitting the ground [m.s^{-1}]	Trajectory of breaking the landing [m]	Overload at landing [ ]
1 straightened legs	1	4,43	0,06	17,67
2 squatted legs			0,8	2,25
3 para-roll			1,5	1,67
1 straightened legs	2	6,18	0,06	33,44
2 squatted legs			0,8	3,43
3 para-roll			1,5	2,30

From Table 2 it follows, that damping of the hit by way of the para-roll is the most efficient way, how human body is able to cope with the dynamic and kinetic effects of hitting the ground.

Methodology of damping the hit applying the para-roll:

- Prior to hitting the ground, keep ankles and knees together, with legs slightly bent and body muscles appropriately stressed (body muscles must not be rigid of the fear from the hit),
- feet must be parallel with the ground to be hit,
- the body is to be slightly inclined forward,
- hitting the ground is to be performed on slightly bent and appropriately flexed legs and full feet areas,
- the main damping of the hit is to be performed with flexed muscles of the legs and partially those of the back,
- gradually transit into slight bending,
- from this slight squatting the body must transit into fall on the side while turning his back in direction of the horizontal components of the speed at the moment of landing.

5. CONCLUSION

The article is presenting basic information on the methodology of using the PRP in the final stage of flight on the parachute – that of landing. Current literature dealing with this area of concern is not available. Consequently majority of users of personal rescue parachutes lack fundamental knowledge on the issue of landing with the PRP, having no knowledge of the procedures for proper landing either.

6. LITERATURE LIST

[1] Kaľavský, P.: Handle crisis situations in civil aviation using recovery parachute system. Reviewed proceedings of the International Conference *Increasing safety and quality in civil and military aviation*, Žilina, 2012, ISBN 978-80-554-0519-3

[2] Kaľavský, P.: Emergency evacuation of an aircraft by personal rescue parachute. Proceedings of the International Scientific Conference *New Trends in Civil Aviation*, Ostrava, 2012, ISBN 978-80-248-2826-8

[3] Theory and Technology of the emergency exit from fast aircraft. Pom-let-13, military rule of Czechoslovak Army, Prague, 1954

[4] TSO-C23e. Personnel parachute assemblies. FAA Aircraft certification service, Washington DC, 2008.

[5] Čejpa, C.: Textbooks for parachuting. Theory and practice of parachute sport. Our troops, Prague, 1961

[6] Kaľavský, P.: Dissertation thesis, The measurement of vertical speed, Technical University of Košice, Faculty of Aeronautics, Košice, 2007