DESIGN OF A PILOT RESCUE SYSTEM FOR THE GLIDER D-43

Andreas Cremer

Presented at the XXVI OSTIV Congress, Bayreuth, Germany, 1999

INTRODUCTION

At present, the Akaflieg Darmstadt is developing and building the two seated training glider D-43. Since there have been many accidents during the last years, where the pilots did not manage to escape the glider, the Akaflieg develops a rescue system that enables the pilots to successfully exit the aircraft in an accident especially in low altitudes, which are common during training flights.

The regular parachute is a safe rescue device, once deployed. But especially in low altitudes pilots often do not succeed in leaving the glider in time and therefore they are not able to activate their parachute. The problem is the loss of altitude while the pilot drops the canopy, opens the seat belts and tries to exit the cockpit. which can be difficult in an emergency. Thus a pilot rescue system has to minimize the time between accident and opening of the parachute. This can be achieved by an active transportation of the pilot out of the cockpit

ROCKET EXTRACTION SYSTEM

The concept of a rocket extraction system is to extract the pilot from the cockpit with a defined force and to safely descent him to the ground with a parachute. The principle is similar to an ejection seat, which can not be used in a glider due to its dimensions and weight.

A rocket extraction system uses a rocket that is connected to the pilot's parachute harness with a flexible line. After automatic canopy release and belt opening the rocket is ejected from the glider with a mortar.

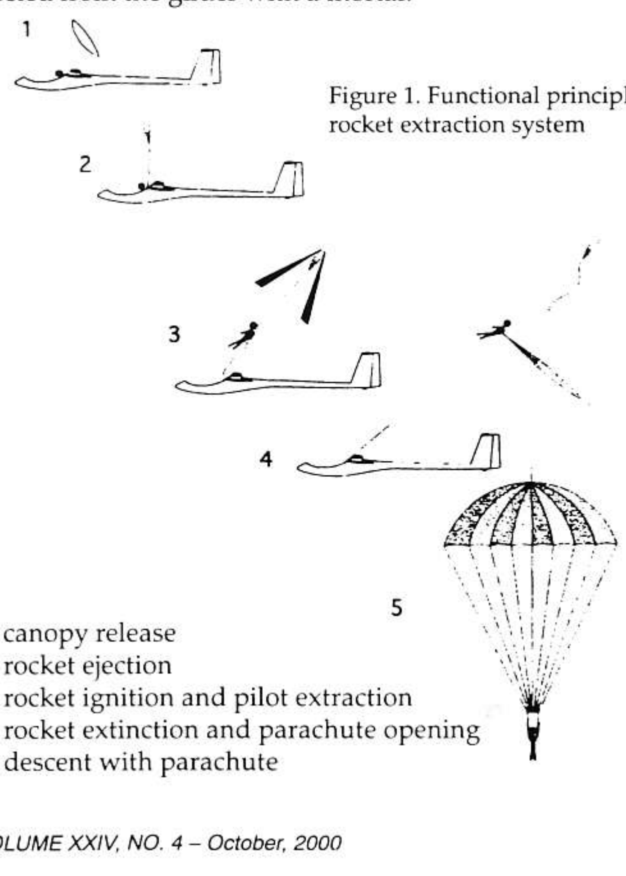

Figure 1. Functional principle rocket extraction system

1. canopy release
2. rocket ejection
3. rocket ignition and pilot extraction
4. rocket extinction and parachute opening
5. descent with parachute

Upon tightening of the line between pilot and rocket, the rocket ignites and extracts the pilot out of the glider cockpit. When the rip cord of the automatic parachute is tightened, the parachute opens and the pilot can land safely on the ground.

In the past, a pilot extraction system was realized by the American company UPCO. This Ranger Rocket Extraction system was successfully used in light military aircraft. It is not available any more and its dimensions do not allow a simple integration into a glider. Therefore a new design of a rocket extraction system which meets the special requirements of soaring is necessary.

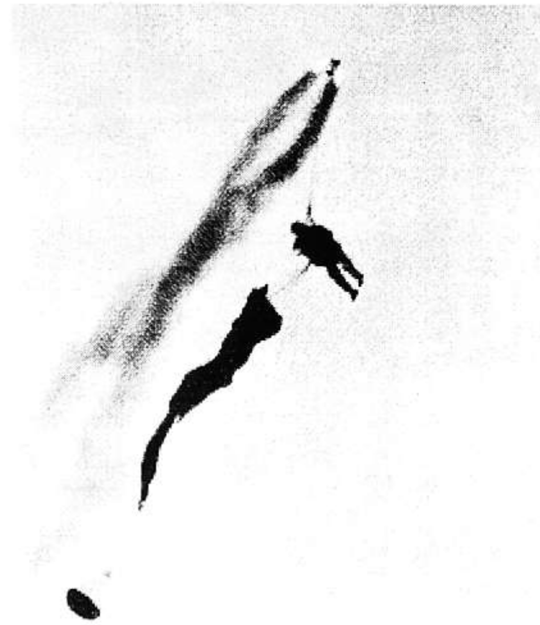

Figure 2. Ranger Rocket Extraction System

SIMULATION OF THE PILOT EXTRACTION

To gain the design data for the system components rocket, mortar and rope, and to examine the behavior of the system a numerical simulation of the pilot extraction was conducted.

Three bodies are part of the pilot extraction: the rocket, the pilot and the line.

Mass and drag of the line are small compared to rocket and pilot, therefore the system can be simplified to two rigid bodies, the rocket and the pilot. The coupling of these bodies occurs with a rope force.

The simulation is three dimensional to allow the examination of the rocket motion when the rocket is spinning around its longitudinal axis. The spinning can be achieved with a small angle of the rocket nozzles.

In the three dimensional space each rigid body has six degrees of freedom, three linear and three angular degrees of freedom.

With Newton's laws of dynamic motion related to the center of gravity of each body, six equations of motion can be formed.. In the following, bold letters designate a vector or tensor, so that one vector equation stands for three equations in the direction of the three cartesian axes in space **p** is the linear momentum, **V** is the velocity of the center of gravity, m the body mass and **F** the sum of the external forces.

$$\dot{\mathbf{p}} = \mathbf{F}$$

or

$$m\dot{\mathbf{V}} = \mathbf{F}\,.$$

With the angular momentum **L** and the sum of the external moments **M** referred to the center of gravity the equilibrum of moments is:

$$\dot{\mathbf{L}} = \mathbf{M}$$

or

$$\Theta \cdot \dot{\omega} + \omega \times \Theta \cdot \omega = \mathbf{M}$$

with inertia tensor Θ and angular velocity ω. In the following equations index R designates rocket terms and index P pilot terms.

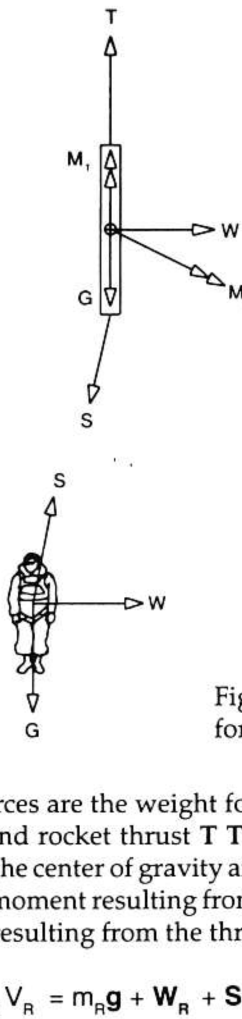

Figure 3. External forces and moments

The external forces are the weight force m**g**, drag force **W**, rope force **S** and rocket thrust **T** **T**. The external moments referred to the center of gravity are the aerodynamic moment $\mathbf{M}_W$, the moment resulting from the rope force $\mathbf{M}_S$ and the moment resulting from the thrust $\mathbf{M}_T$:

$$M_R \dot{V}_R = m_R\mathbf{g} + \mathbf{W}_R + \mathbf{S} + \mathbf{T}$$

$$\Theta_R \cdot \dot{\omega}_R + \omega_R \times \Theta_R \cdot \omega_R = \mathbf{M}_{WR} + \mathbf{M}_{SR} + \mathbf{M}_T$$

Mass and inertia tensor of the rocket are time dependent due to the fuel consumption.

$$m_R = m_R(t)$$

$$\Theta_R = \Theta_R(t)$$

The equations of the pilot do not contain thrust and the resulting moment, mass and inertia are constant.

$$m_p \dot{\mathbf{V}}_p = m_p\mathbf{g} + \mathbf{W}_p + \mathbf{S}$$

$$\Theta_P \cdot \dot{\omega}_P + \omega_P \times \Theta_P \cdot \omega_P = \mathbf{M}_{WP} + \mathbf{M}_{SP}$$

For further description of the external forces and the applied coordinate systems, refer to (1).

SIMULATION RESULTS

The numerical calculated solution of the equation of motion delivers the extraction trajectories for the pilot.

The following graphs show pilot trajectories for several parameter variations.

For easier interpretation the trajectories are displayed in a coordinate system that is parallel to the aircraft fixed coordinate system with the coordinate base in the location of the pilot center of gravity while sitting in the cockpit. The pilot extraction procedure requires only a short period of time, thus the aircraft trajectory can be assumed as a constant linear motion. The pilot trajectories are the pilot center of gravity trajectories relative to the aircraft. This way it can be examined if there is a danger of collision between the pilot and aircraft parts during the extraction procedure. Most important is to avoid contact of the pilot with the tail unit.

The leading edge of the horizontal stabilizer is marked with the symbol '+' . The symbol ' * ' designates the location of the pilot upon extinction of the rocket. The following part of the trajectory is ballistic.

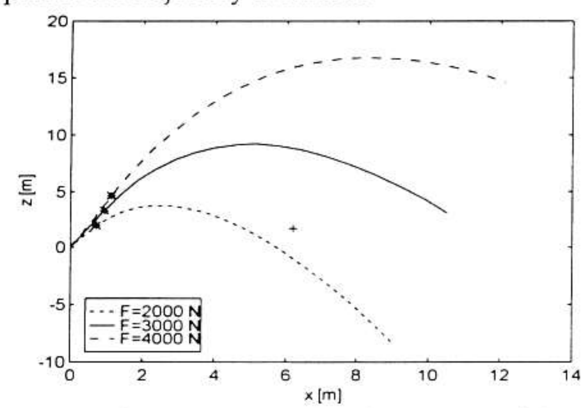

Figure 4. Pilot trajectory at 75 km/h. Variation of thrust

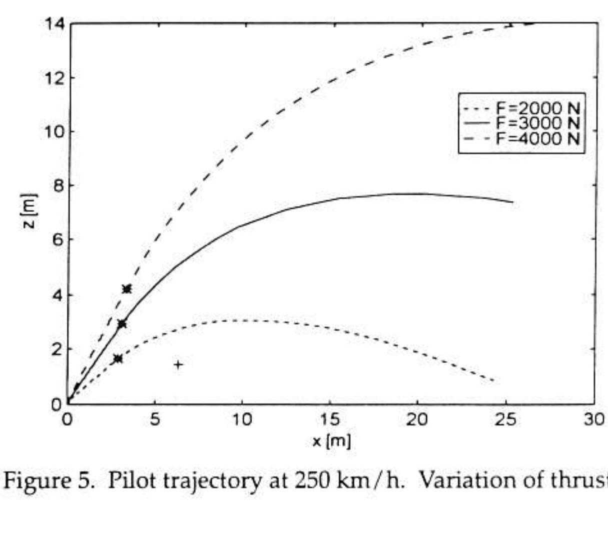

Figure 5. Pilot trajectory at 250 km/h. Variation of thrust

Figure 4 shows the effect of the variation of the rocket thrust at minimum airspeed 75 km/h. and rocket burning time 0.5s. A variation of thrust has a significant effect on the trajectory. Important for the distance between the trajectories over the tail unit is the location of the trajectory peak. Low airspeeds produce low drag forces on the pilot and the rocket., the deceleration of the pilot relative to the glider is smaller and the peak of the pilot trajectory is reached before passing the tail unit. At lower airspeeds the trajectory distances over the tail for thrust variations are much bigger than for high airspeeds, where the pilot is still in the ascending part of the trajectory while passing the stabilizer.

A possibility to stretch the trajectory over the stabilizer without increasing the thrust is an increase of burning time. An prolonged burning of 0.1 has only a small effect on the first part of the trajectory but due to the higher speed at extinction the pilot gains significantly more height above the stabilizer.

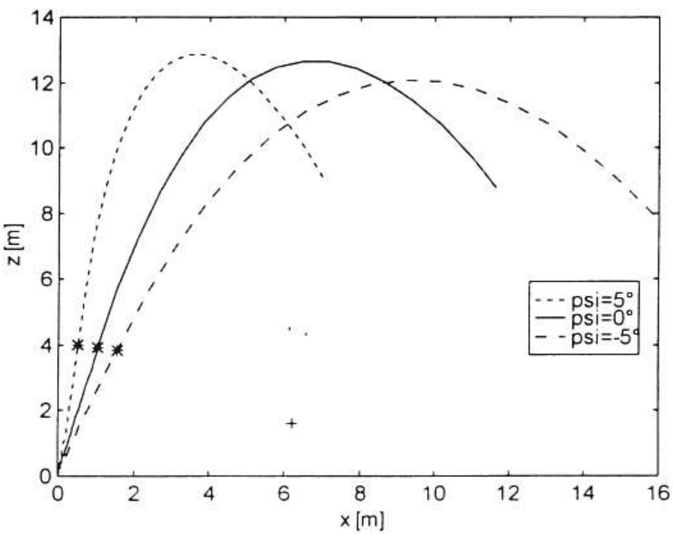

Figure 6. Pilot trajectory at 250 km/h.
Variation of rocket ejection angle

Affecting the trajectory without altering rocket performance can be achieved by changing the ejection angle of the rocket to the fuselage. If 0° means a perpendicular ejection to the aircraft longitudinal axis, a rocket ejection swept 5° forward at high airspeeds results in a small gain of distance between pilot and stabilizer on the ascending part of the trajectory. At low airspeeds the peak of the trajectory is far over the forward area of the glider and the pilot is passing the tail pretty close on his descending part of the trajectory.

A major influence on the trajectory has the pilot mass. a 70 kg mass is transported to a height almost three times as high as a 110 kg mass, Since the trajectory peak is behind the glider at high airspeeds, these differences are not so extreme when the pilot passes the tail.

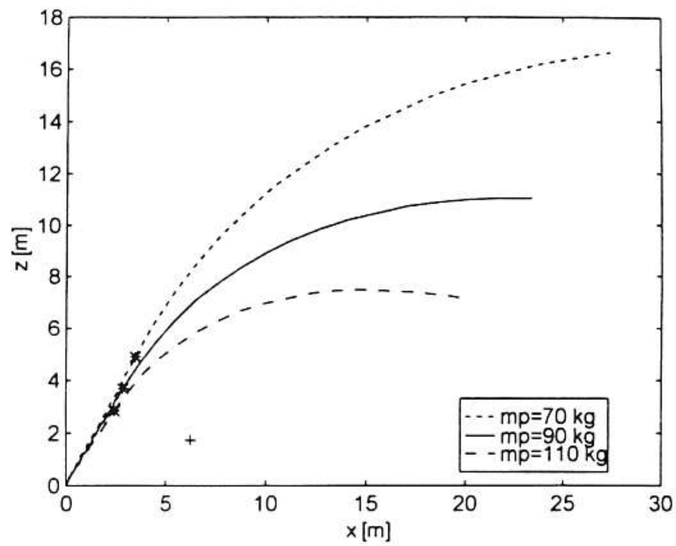

Figure 7. Pilot trajectories at 250 km/h. Variation of pilot mass

The design of the rescue systems requires not only a pilot trajectory over the tail unit, but also withstandable extraction accelerations for the pilot.

Figure 8 shows that different pilot masses result in significantly different acceleration peaks. Therefore the thrust of the rocket must be selected carefully. Heavy pilots must be transported safely over the stabilizer without exposing light pilots to extreme accelerations. When the pilot is still sitting in the cockpit he is exposed to 1 g. The rocket is ejected from the fuselage and after 0.3 s the rope to the pilot is tight and starts to extract the pilot from the cockpit. The first acceleration peak is caused by the kinetic energy of the rocket after the ejection. This energy is saved in the rope during rope expansion and results in an increased rope force. The resulting accelerations are between 5 and 7.5 g for a soft rope an, which is uncritical for the pilot safety according to (3).

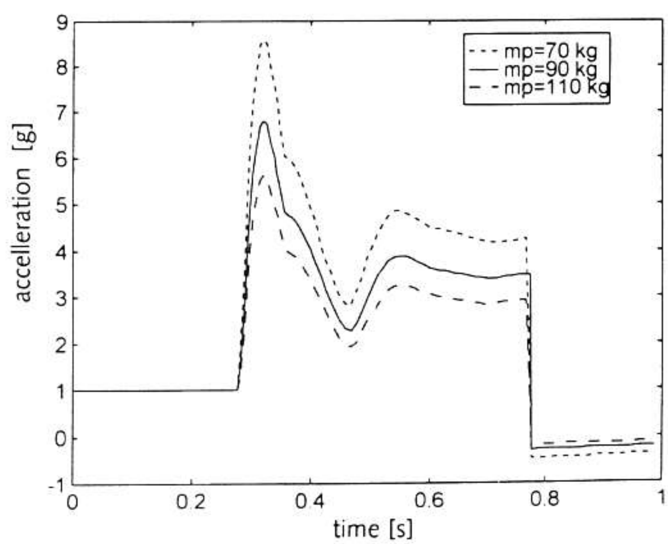

Figure 8. Accellerations during pilot extraction,
thrust=3.5kN, variation of pilot mass

Simulation of the pilot extraction at maximum and minimum airspeeds of the D-43 as well as at speeds and flight attitudes that occur during typical accidents, showed that the following design data ensures a safe pilot rescue:

Rocket thrust = 3500 N
Burning time = 0.6 s
Rocket ejection velocity = 20 m/s
Rocket ejection angle = 5° forward
Rope length = 5 m
Rope module= 10 kN

MINIMUM ALTITUDE REQUIREMENT

The rescue procedure can be divided into separate stages. Each stage contributes to the minimum altitude requirement with its altitude loss

- Reaction time
- Operating time
- Canopy release
- Rocket ejection
- Pilot extraction
- Parachute opening and deceleration

Reaction and operation time with canopy release takes about 3.5s . During that time altitude loss is dependent on the damage of the glider and the airspeed at the time of the accident. The altitude loss of the D-43 during this stage can be determined in (4). Airspeed and flight attitude at the end of that stage are used as starting data for the pilot extraction simulation. The simulation delivers the altitude loss for the stages rocket ejection and pilot extraction until the parachute rip cord is tight. The altitude loss for the parachute opening stage is determined with a special parachute calculation program (3). The following table lists the altitude loss from the accident event to a safe sink rate with the parachute for certain emergencies

These calculations for altitude loss with a rocket extraction system show that a safe rescue is possible when accidents occur even at low altitudes e.g. in the traffic circuit. The system requires a flight altitude of only about 200 meters, somewhat more at higher airspeeds.

The altitude loss for the pilot extraction itself is only about 20% to 30% of the total altitude requirement. At constant level flight attitudes with regular airspeed rescue is possible even from 0 altitude.

CONCLUSIONS

In an emergency, a pilot extraction system, pulls the pilot is out of the cockpit with a solid fuel rocket, which is connected to the pilot with a rope. After rocket extinction the pilot descents with a parachute A numerical simulation of the extraction procedure was conducted to evaluate design data and to examine the systems characteristics. A rocket thrust of 3.5 kN and a burning time of 0.6 s ensures a safe pilot extraction trajectory over the tail unit. The pilot is exposed to undangerous 5 to 7.5 g with a soft rope. A successful rescue is possible with accidents at flight altitudes of about 200 meters.

REFERENCES:

(1) Cremer, A., Konstruktion eines Pilotenrettungssystems für das Segelflugzeug D-43 Konstruktiver Entwurf, TU Darmstadt,1998

(2) Kohl, D. Auslegung von Fallschirmen bei Rettungssystemen für Segelflugzeuge, Diplomarbeit am Fachbereich Flugzeugbau Triebwerkbau und Raumfahrttechnik, FH Aachen, 1992

(3) Röger W./Conradi, M./Stabenau, P., Verbesserung der Insassensicherheit bei Segelflugzeugen und Motorseglern, Forschungsbericht an der FH Aachen, Fachbereich Flugzeugbau Triebwerkbau und Raumfahrttechnik, 1994.

(4) Zürner, J., Auslegung eines Pilotenrettungssystems fur das Segelflugzeug D-43 Konstruktiver Entwurf, TH Darmstadt, 1997

emergency, initial airspeed	altitude loss for flight trajectory	altitude loss for pilot extraction	altitude loss for parachute opening	total altitude loss
loss of horizontal stabilizer at 90 km/h	52 m	45 m	57 m	154 m
loss of tail unit at 90 km/h	60 m	41 m	50 m	151 m
loss of tail unit at 250 km/h	120 m	79 m	58 m	257 m
spinning	105m	39 m	64 m	208 m
normal flight 125 km/h	3m	-11 m	3 m	-5 m

Figure 9. Altitude loss