TRAJECTORY OF THE PARACHUTE BAG DURING THE DEPLOYMENT PHASE

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Introduction

A Sailplane Parachute Recovery System requires an active device such as a rocket or a mortar to deploy the parachute. A computer simulation has been carried out for calculating the trajectory of the parachute bag and the lines during the deployment phase. The thrust of the rocket or the starting impulse of the mortar has to lift the deployment bag clear of the usually T-shaped tail unit of the glider. The calculation shows the effects of the thrust of the rocket, the burning period, the starting impulse of the mortar, the firing direction, the mass of the parachute and the flight velocity on the trajectory relative to the glider. The major consideration is an avoidance of any collision of the bag and the lines with part of the glider during the deployment phase. A more detailed description can be found in [1].

Recovery Systems

Three different deployment systems were simulated, all of them are actually used for recovery systems.

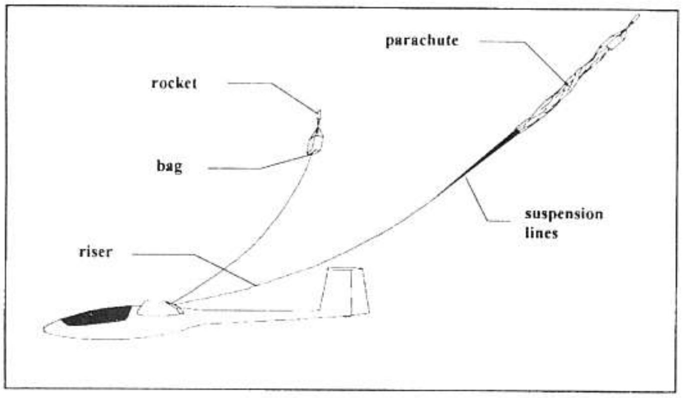

Figure 1. Rocket deployment, packed parachute.

One system is the so called "packed parachute" (Figure 1). The canopy as well as the suspension lines stay packed in a deployment bag and together with the riser they are pressed in a storage compartment. This compartment is installed into the glider near the center of gravity. A rocket pulls the bag followed by the riser out of the compartment. After the stretching of the riser the rocket slips the bag, and the suspension lines followed by the parachute are extracted out of the deployment bag. The parachute than inflates with the airstream. This deployment sequence agree with the known principle "line first deployment" and reduces the snatch and opening shock of the parachute.

The second system is the so called "stretched parachute" (Figure 2). The parachute is packed in a flexible tube and this deployment bag together with the suspension

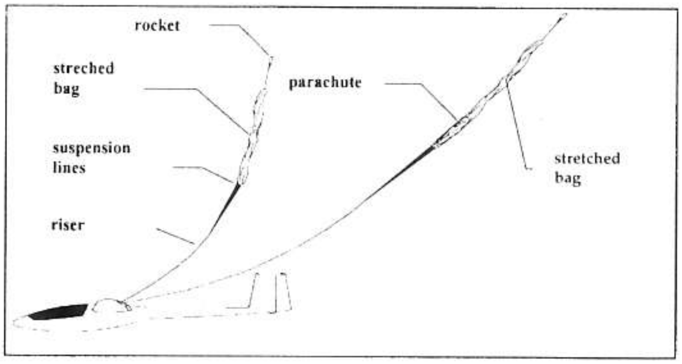

Figure 2. Rocket deployment, stretched parachute.

lines and the riser are pressed into the storage compartment. Immediately after activation the rocket pulls the parachute bag out of the compartment followed by the suspension lines and the riser. After the stretching of the bag and all the lines, the deployment bag is slipped off the parachute by the thrust of the rocket. The parachute then inflates with the airstream.

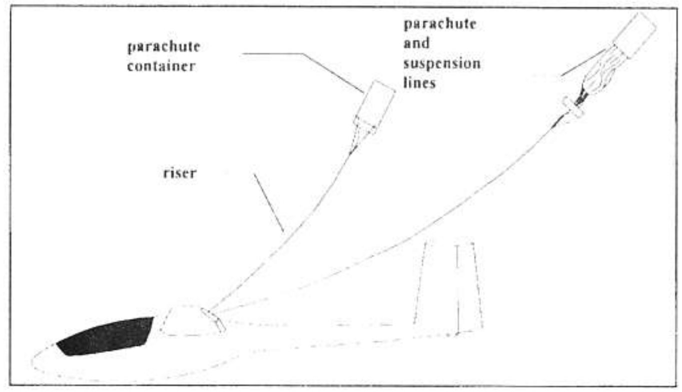

Figure 3. Mortar deployment.

The third calculated system uses a mortar for the deployment of the parachute and the lines (Figure 3). A container including the parachute and the suspension lines is ejected by the starting impulse of a mortar. This impulse may be also created by compressed air or a spring. After stretching of the riser the container continues with its path, and the suspension lines and the parachute are pulled out of the container. The parachute then inflates with the airstream.

Equations

For each part of the whole system – the riser, the suspension lines and the deployment bag – a special equation is developed. With this set of equations [1], the trajectory is calculated. Additionally, the motion of the glider and the deployment out of the compartment are simulated. The deployment phase starts with the ignition of the rocket and ends with the stretching of all components. This is the time period when the rocket pulls the line above the tail unit. During this critical phase no part of the system should touch any part of the glider. Due to the short deployment phase it was assumed that the glider flies in a level attitude.

The calculation of the trajectory of the lines and the parachute bag considers the weight, the aerodynamic drag and lift acting at all lines and the bag, the stretching of the lines and the damping. Due to the low size of the rocket or mortar these parts are simulated as mass points.

The calculation includes the translatory and rotatory degree of freedom. The equations also consider the drag and lift and the thrust of the rocket or the starting impulse of the mortar.

This results in a nonlinear set of differential vector equations which are solved numerical. More fundamentals of these equations are presented in [1]. A similar equation for towing a glider is published in [3].

Results

For evaluating the results of the calculation a box around the glider is defined (Figure 4). The upper line is parallel to the x-axis intersecting the leading edge of the stabilizer. The leading edge itself is given by the parameters x_{tail} and h_{tail}. The firing direction is defined by the angle α_o whereby $\alpha_o = 0°$ means firing with and $\alpha_o = -180°$ against the airstream. The criteria x_{box} is the distance of the deployment point to the x-position the rocket leaves the box. The height (z-axis) of the trajectory is z_{tail} while the rocket is passing the leading edge. The height of the rocket immediately after the total stretching of all lines is z_{shoot}. Up to this point the calculation is completed.

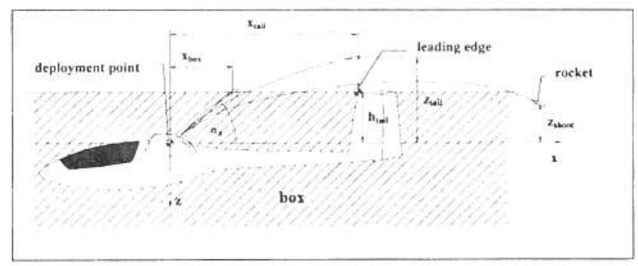

Figure 4. Trajectory criteria.

The time period from the ignition of the active device until the rocket or mortar leaves the box is called t_{box} until the device passes the leading edge t_{tail} and until the stretching of all lines t_{shoot}. If z_{tail} is smaller than h_{tail} the parachute will touch the tail unit. In case of z_{shoot} smaller than z_{tail} the rocket flies above the tail unit and looses height after passing the stabilizer.

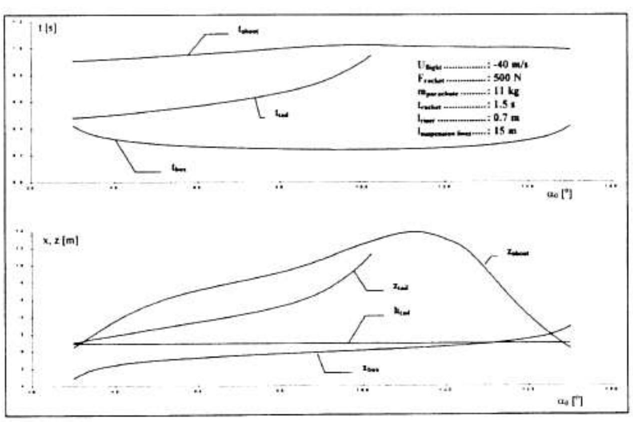

Figure 5. Characteristics values of the trajectory depending on the firing direction. Rocket deployment/packed parachute.

The firing direction is the main parameter which may be changed with the installation of a parachute recovery system. In Figure 5 the values of the time periods and the values of x_{box}, z_{tail} and z_{shoot} are shown depending on the firing direction α_o. All lines are stretched in less than one second. The time period t_{shoot} needed for the stretching of all lines is reduced when firing with the airstream ($\alpha_o < 90°$). On the other hand, the time period t_{shoot} is almost independent of the firing direction when firing against the airstream ($\alpha_o > 90°$). As shown in Figure 5, the increase of the angle α_o increases the height the rocket has reached when stretching all lines (z_{shoot}). The maximum height results at an angle of 113°. Firing against the airstream at an angle of more than 113° will reduce the height drastically. Firing against the airstream results in a longer time period to stretch the lines. Increasing the firing angle from $\alpha_o = 30°$ to 90°, the time period (t_{tail}) as well as the height passing the leading edge of the stabilizer (z_{tail}) increases. At an angle above 102° (see z_{tail}) the rocket does not pass the leading edge until all lines are stretched.

As a result of examining the firing direction, one concludes that the maximum height of the deployment bag can be achieved firing upward at approximately 20° against the airstream.

In Figure 6 the values of the time periods and the distances depending on the flight velocity of the glider are shown whereby the firing direction is kept to 45°. With a high velocity, the drag of the bag and the drag of the lines support the rocket to pull the deployment bag and the lines backwards with the airstream. This accelerates the deployment of the parachute system and results in shorter time periods.

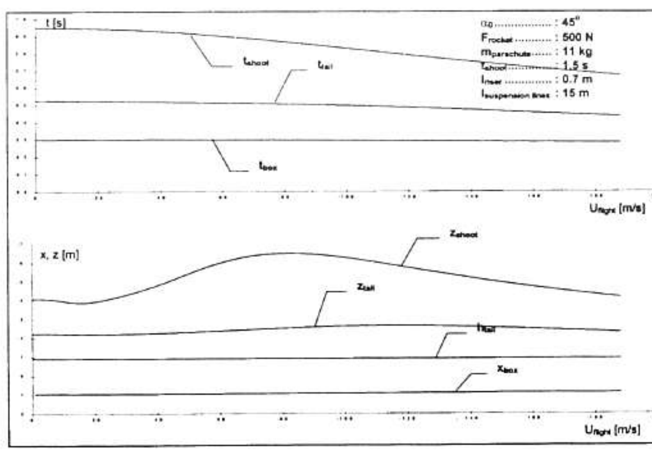

Figure 6. Characteristics values of the trajectory depending on flight velocity. Rocket deployment/packed parachute.

On the other hand, the flight velocity does not remarkably change the distance the rocket needs to leave the box (x_{box}) and the height above the leading edge (z_{tail}). Only with a very high velocity does a small change result. The drag only has a small effect on the height due to the short time period the rocket needs to pull the bag above the tail unit.

However the drag influences the height z_{shoot} reached at the end of the deployment phase. The rocket pulls the riser upwards according to the firing direction. The drag force acting at the rocket and the lines additionally shifts the whole system backwards with the airstream. At a low velocity the drag is low and the path of the rocket resulted in a convex trajectory (Figure 7). At a high flight velocity, the larger drag acting at the deployed part of the riser pulls the line backwards resulting in a concave trajectory. The sagging line turns the rocket somewhat upright and the rocket pulls the riser in a more upwards direction. The result is a larger height at the end of the deployment phase. The calculation which brings out the maximum height is achieved at a velocity of about 80 m/s. A further increase of the velocity produces a higher drag force accelerating the deployment of the bag and there is not enough time to gain height.

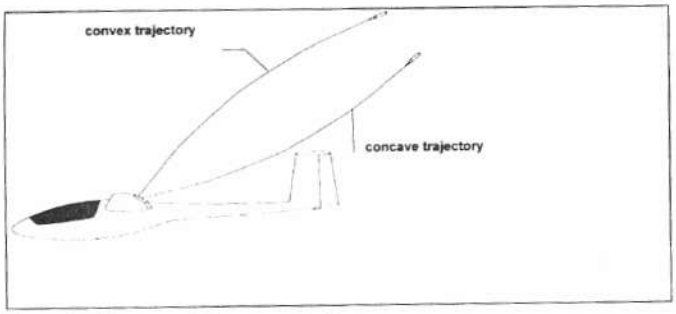

Figure 7. Convex/Concave trajectory.

With increasing thrust (Figure 8), the rocket leaves the box, passes the leading edge and stretches the line in a shorter time. As a result of this quick deployment the drag only has a small effect on the backwards shifting motion. Thus the trajectory mainly was influenced by the firing direction. The result is a larger height (z_{tail} and z_{shoot}) when the rocket is fitted with more thrust.

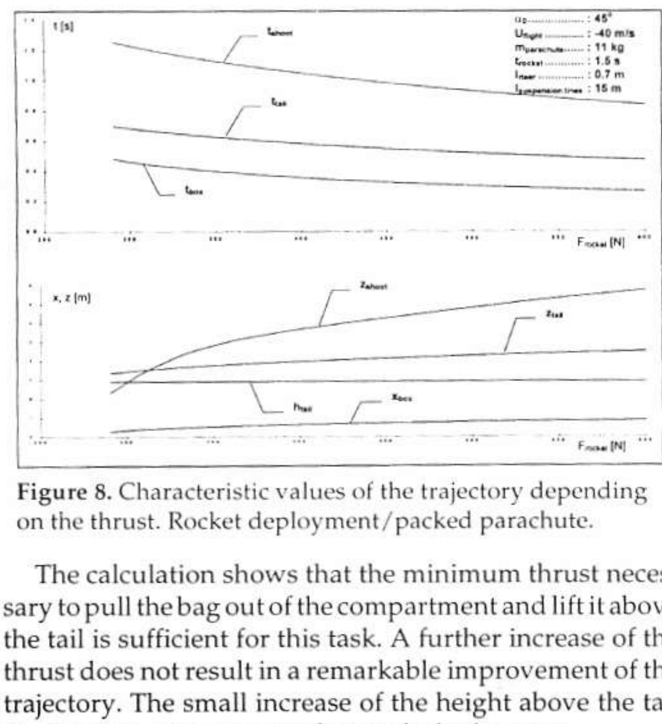

Figure 8. Characteristic values of the trajectory depending on the thrust. Rocket deployment/packed parachute.

The calculation shows that the minimum thrust necessary to pull the bag out of the compartment and lift it above the tail is sufficient for this task. A further increase of the thrust does not result in a remarkable improvement of the trajectory. The small increase of the height above the tail (z_{tail}) unit is not necessary for a safe deployment.

Compared with a rocket the deployment of the parachute and the lines by a mortar results in an important change of the trajectory. The time period to leave the box, to pass the leading edge and to stretch the lines are considerably shorter than those achieved by a rocket (Figure 9). Due to the very quick deployment, the trajectory looks like a straight line with only a small effect from the drag force. For this reason, the maximum height is obtained by firing upright at an angle of 90°. At a firing direction above 70° the container does not pass the tail until the stretching of the lines due to the limited length of the lines. All values of x_{box}, z_{tail} and z_{shoot} can be easily calculated by drawing a straight line from the firing point. The flight velocity and consequently the drag force acting at the rocket and the riser is unable to change the trajectory significantly (Figure 10).

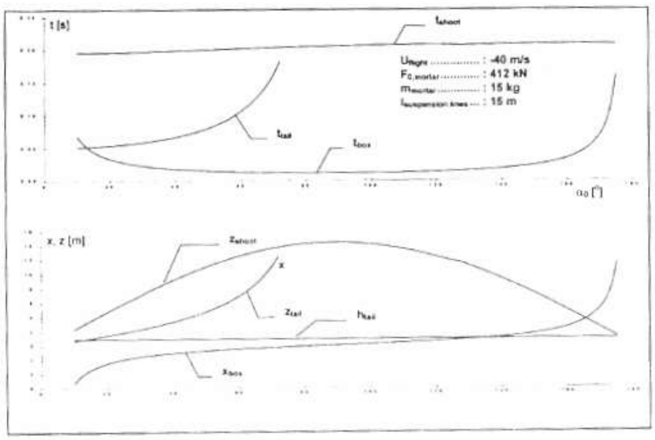

Figure 9. Characteristic values of the trajectory depending on the firing direction. Mortar deployment..

If the minimum thrust to require lift off and to push the container above the tail is installed a further increase of the starting impulse does not result in any advantage (Figure 11). The shortening of the time periods are very small and there is no change of the values of x_{box}, z_{tail} and z_{shoot}. So an increase of the starting impulse does not improve the system.

Conclusion

Both calculated devices, a rocket or a mortar, are able to deploy the parachute of a glider recovery system.

Using a rocket the following points must be considered:

- With an increasing flight velocity the height of the trajectory above the tail decreases. Therefore, the firing direction must be determined according to the maximum velocity. A firing direction from 50° to 120° results in a sufficient height above the tail and avoids touching of the bag and the lines with the glider during the deployment phase. A firing direction greater than 120° should be avoided because the height drastically decreases at higher angles.
- The thrust has a lesser effect than the firing direction. The rocket must be fitted with sufficient thrust to keep the bag clear from the tail. A further increase of the thrust does not increase the height significantly. It is necessary to choose a sufficient long burning period to be sure that the rocket will slip the bag.

Using a mortar the following points must be mentioned:

- The trajectory is nearly a straight line. So the firing

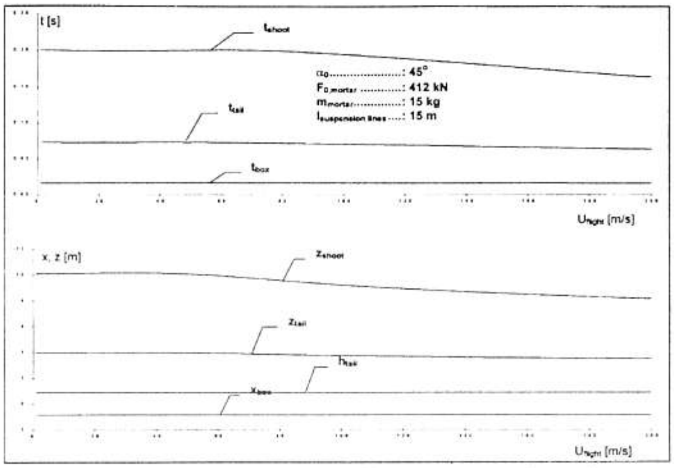

Figure 10. Characteristic values of the trajectory depending on the flight velocity. Mortar Deployment.

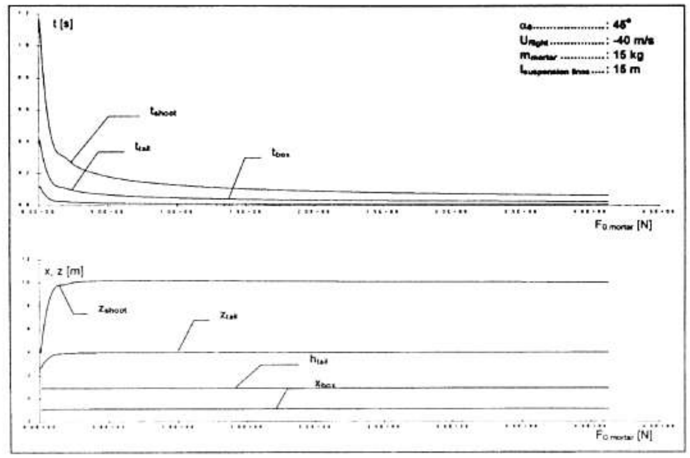

Figure 11. Characteristic values of the thrust. Mortar Deployment.

direction can be chosen according to the size of the glider. The flight velocity of the glider does not influence the trajectory. The mortar needs a starting impulse depending on the mass of the parachute. An increase of this minimum impulse does not improve the system. The structure of the glider must be designed to withstand the starting impulse.

• For flight velocities up to about 80 m/s a rocket extraction system as well as a mortar are good solutions. At higher velocities the mortar has an advantage as compared to the rocket.

References

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[2] Engeln-Mullges, G. Numerik Algorithmen mit ANSI C-Programmen Bl Wissenschaftsverlag, Mannheim, 1993, 1. Auflage.

[3] de Matteis, Longitudinal dynamics of towed sailplane. *Journal of Guidance, Control and Dynamics*, Vol. 16, No 5., 1993, S.882 - 829.