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Method for Steerable Clustered Round Parachutes

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The U.S. Army is currently pursuing a low-cost parachute system for precision airdrop of cargo. Low-cost clusters of round parachutes are being considered as a potential candidate for such a system. A method is presented that provides a glide and steering capability for a cluster of round parachutes for precision airdrop. The method involves partially connecting two round parachutes that have openings and pulldown skirts on their canopies. Glide and steering are achieved by maneuvering the pulldown skirt. This method was developed and tested first using a cluster of two one-quarter-scale G12 cargo parachutes. System glide and turn were demonstrated on a cluster of two full-scale G12 parachutes. Currently, the method is being applied to a cluster of two G11 parachutes for precision airdrop of a 4,540 kg load.

Introduction

THE U.S. Army is currently actively pursuing advanced parachute and airdrop technologies to develop high-altitude aircraft survivable precision airdrop systems.[1] High-altitude delivery significantly reduces aircraft vulnerability to ground fires, and precision airdrop provides rapid, precise delivery of payloads to where they are needed. These systems will also reduce drop zone sizes and load dispersion for quick airdrop mobility. Ram-air parafoils have been investigated extensively for precision airdrop.[2] Because of their high manufacturing costs, recently there is an interest in exploring using lower cost circular parachutes for guided precision airdrop. Circular parachutes inherently do not provide a glide capability, but physical modifications of the canopy have been used to provide some glide capability.[3–14] These modifications include openings on the canopy and canopy deformation. Each of these modifications has been investigated separately on a single round canopy. For heavy cargo delivery, clusters of round parachutes are needed. The glide and control of clustered parachutes have never been investigated. This paper presents a new method that provides a capability for gliding and trajectory control of clustered round parachutes.

Description of Method

Previous studies on clustered parachutes have shown that the motion of clustered parachutes is highly random, depending on the flow interaction among the individual parachute canopies and the prevailing wind conditions. Individual glide and steering methods applied to each canopy may work by themselves, but when the canopies are clustered together, the random geometry of the cluster, the complicated flow conditions of the canopies, and their interaction make it almost impossible to exert glide and control for the cluster as a whole. To circumvent this difficulty, the present new method consists of partially connecting the canopies of a cluster and implementing glide and steering for each canopy and the cluster as a whole.

Figure 1 shows the present method applied to a two-parachute cluster. To illustrate the method, two 24-gore canopies are used. The six gores between A and D of each canopy are connected at the skirt. The skirt of the six leading gores of canopy 1 between C and D is pulled down toward the confluence point. A typical amount of pulldown is 5% of the canopy circumferential diameter. A circumferential rectangular opening is cut near the skirt on the six gores from A to B, directly opposite to the six pulldown gores. Exactly the same modifications are made on canopy 2, as shown in Fig. 1. A perspective view of the two-parachute cluster is shown in Fig. 2. The canopy pulldown and release mechanism is shown as M1 for canopy 1 and M2 for canopy 2. When the six leading gores (C–D of canopy 1) are pulled down, the inflated canopy is deformed (Fig. 2) to create a high-velocity air jet emerging from the opposite side of the canopy (A–B for canopy 1). The slot opening near the skirt enhances this jet effect. The net result of these modifications is a thrust to glide canopy 1 forward, as shown by the arrow. A similar thrust is also generated for canopy 2. Because the two canopies are connected together, the cluster will glide forward together as a whole. During the steady glide, if a turn toward canopy 1 is desired, the pulldown of canopy 1 will be released by the release mechanism M1 (actuator). In this unsymmetrical configuration, canopy 2 has a higher forward thrust than canopy 1. This creates a counterclockwise torque for the cluster (Fig. 1), which rotates it to the left. Similarly, if a right turn is desired, the pulldown of canopy 2 will be released to achieve the turn. To restore the steady forward glide after the left turn, the pulldown mechanism M1 will be activated to pull the skirt down so that both canopies will have the same forward thrust. Thus, by partially connecting two modified round canopies, glide and steering of the cluster is achieved.

Figure 3 shows the present method applied to a three-parachute cluster. Again, three 24-gore canopies are used to illustrate the method. For a more streamlined configuration, canopies 1 and 3 are connected to canopy 2 at an angle of 30 deg with respect to the center diameter EH of canopy 2. This results in a four-gore connection A–E between canopies 1 and 2, a four-gore connection H–L between canopies 2 and 3, and a four-gore opening for canopy 2. Six gores are pulled down for all three canopies, and six-gore openings are made for canopies 1 and 3. Similar to the two canopy cluster, when three parachutes are connected and modified this way, a net forward thrust is generated to glide the cluster forward. If a left turn is desired, the pulldown gores D–E of canopy 1 will be released by M1 to generate a counterclockwise torque for the turn. To restore to forward glide, M1 will pull down the skirt for a net forward thrust. Similarly, a right turn can be made releasing the pulldown skirt of canopy 3. Thus, by partially connecting three modified round canopies, glide and steering of the cluster are achieved.

Test Results

U.S. Army Cargo Parachutes

For a low-cost system, modification of current standard U.S. Army G12 (19.5 m diam) and G11 (30.5 m diam) cargo parachutes is strived for. Ultimately, the goal is to use two G11 parachutes

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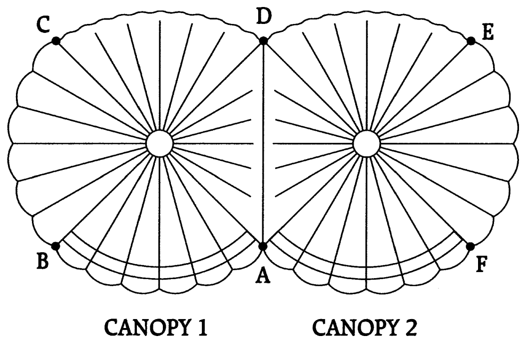


Fig. 1 Schematic of the design of a steerable cluster of two parachutes.

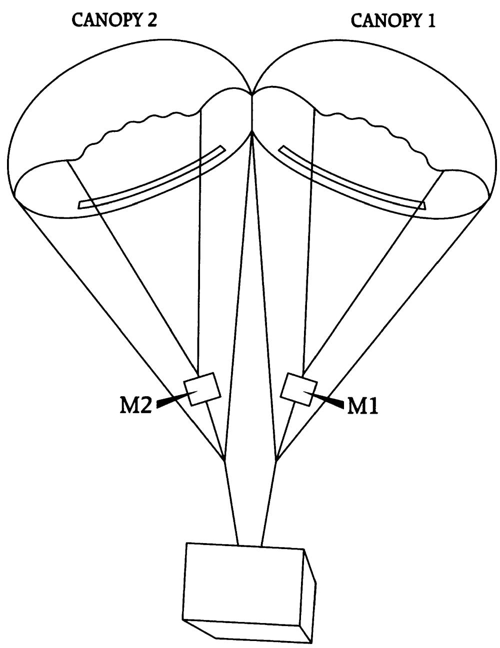


Fig. 2 Perspective view of a steerable cluster of two parachutes.

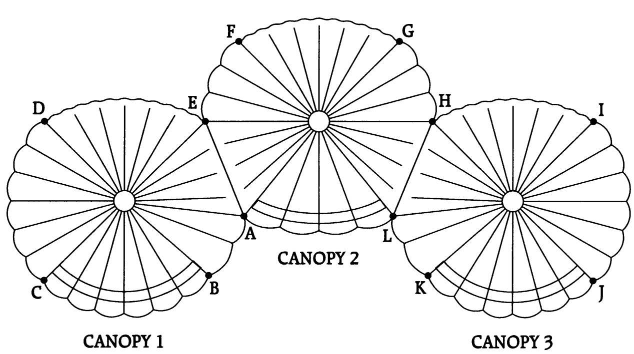


Fig. 3 Schematic of the design of a steerable cluster of three parachutes.

for a 4,540 kg low-cost cargo precision airdrop system. Before developing a full-scale G11 system, testing was conducted first with one-quarter-scale G12 parachutes to investigate the method. The method was then extended to full-scale G12s. Finally, a cluster of two G11s is currently being tested for the 4,540 kg system.

One-Quarter-Scale G12 Cluster Tests

A two one-quarter-scale G12 cargo parachute cluster (64 gores and 4.88 m-diam parachutes) was constructed to test the feasibility of this new method for gliding and controllable clusters. No attempt was made to investigate the design for optimum performance of the method. The one-quarter-scale G12 model parachute was made with $33.9\ g/m^2$ nylon, the same canopy fabric as that of the full scale cluster. The dimensions of the model were geometrically scaled from those of the full scale. The model design and construction guidelines were the same as those used in a previous model parachute opening study.[15,16] The canopy layout of the one-quarter-scale model is similar to that of Figs. 1 and 2. Based on the canopy design of previous single gliding parachutes and an initial conservative approach, the total slot opening area on the six gores near the skirt of each canopy is 2.3% of the constructed canopy area. The amount of pulldown of 16 gores is 5% of the canopy diameter, again, a conservative approach as compared to the larger amount of pull-down of 10% of the canopy diameter for the affordable guided airdrop system system.[3] At the skirt, 16 gores of each canopy are connected. This design and preliminary fully inflated canopy shape first were examined in the Climatic Chamber at the Natick Soldier Center. The Climatic Chamber was a $2.75 \times 2.75 \times 6.1\ m^3$ long chamber with crude airflow. It was mainly used to inflate the 4.88 m diam canopies and to examine the location of the slot opening. Flight tests were then conducted at the U.S. Army Sudbury drop zone using an ultralight aircraft. A differential global positional system (GPS) that provides one set of spatial position reading per second was used to monitor the spatial-time history of the cluster. The GPS was structurally protected in a 68.1 kg and 0.763 m wooden cube that was used as the payload. For quick and convenient tests, a pyrotechnic cutter was used in place of actuator M1 (Fig. 2). During parachute packing before a test, the 16 gores of canopy 1 were pulled down via the corresponding suspension lines. This pulldown was held in place by a 10-s pyrotechnic cutter attached at the confluence point. The 16 pulldown gores of canopy 2 were tied in place permanently at the confluence point. At the end of 10 s after parachute deployment, the pyrotechnic cutter would fire and release the skirt pulldown of canopy 1 to activate a turn. This simple technique enabled the study and demonstration of the glide and turn control of the cluster. Some tests were conducted without the cutter arrangement to investigate only the steady glide.

All tests were conducted in very low ground wind conditions of less than 5 mph. The cluster and the load were released from the ultralight aircraft at about 366 m. The cluster was static line deployed and opened quickly. After it was fully opened, it glided with the wind, and the pulldown sections of the canopies always led in the glide direction as designed. Figure 4 shows the cluster in steady glide. The pull-down skirts and the vent openings are clearly visible. Figure 5 shows the horizontal glide path (1 s between every two data points) and the vertical descent distance, respectively, of a typical test from the GPS measurement. The measurement shows that the glide was quite steady and the glide ratio was approximately 0.8 with the wind. Note that these tests were concept demonstration

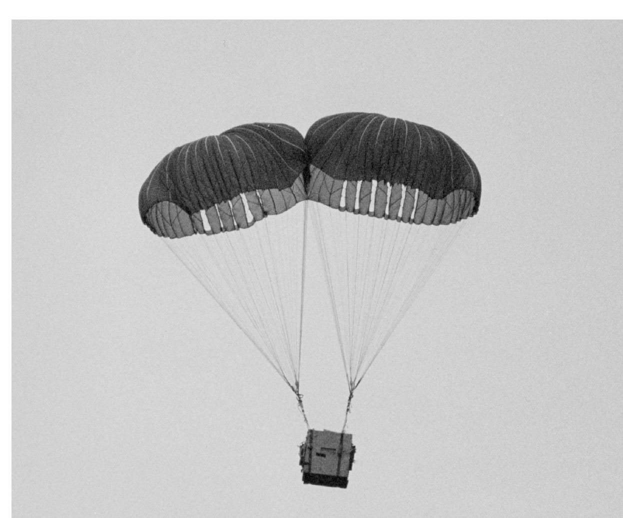
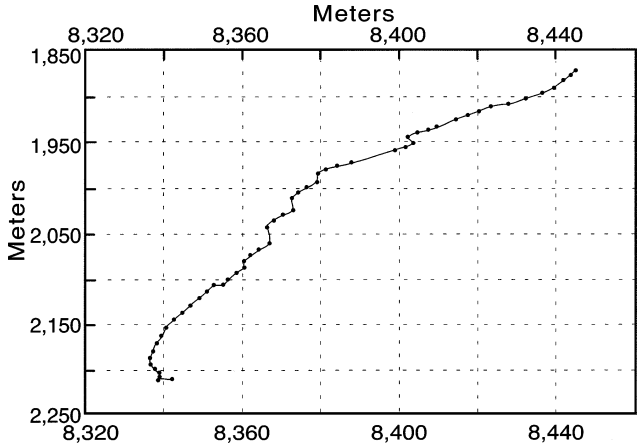
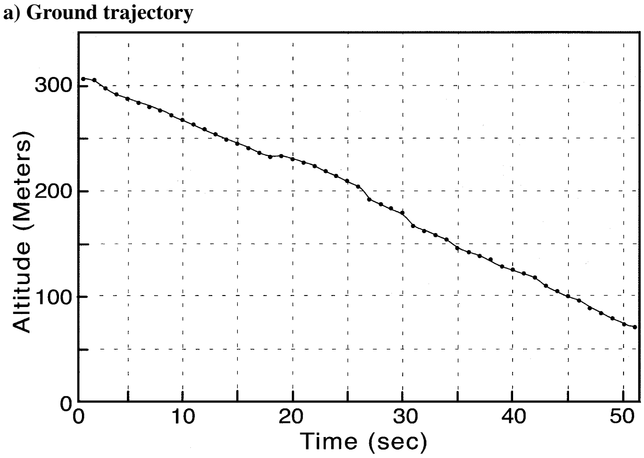


Fig. 4 Photograph of a cluster of two connected one-quarter-scale G12 parachutes during steady glide.



a) Ground trajectory



b) Vertical trajectory

Fig. 5 Trajectory measurement of a cluster of two connected one-quarter-scale G12 parachutes.

Fig. 6 Photograph of a cluster of two connected one-quarter-scale G12 parachutes during a turn.

tests. The canopy/cluster design probably was not optimum and the glide performance could be improved, for example, larger canopy opening area. For the tests equipped with a 10-s cutter, the cluster glided after opening. At the end of the 10 s, the cutter fired and released the skirt pulldown of one canopy. The corresponding cluster configuration (one fully inflated and one pulled down) is shown in Fig. 6. The cluster then made a turn accordingly. Figure 7 shows the horizontal glide path, which starts from the lower left corner of Fig. 7. After 10 s, a left turn is clearly shown.

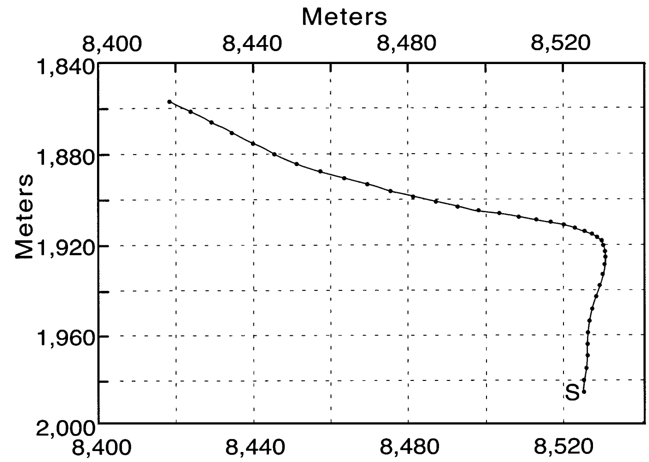


Fig. 7 Ground trajectory of a cluster of two connected one-quarter-scale G12 parachutes.

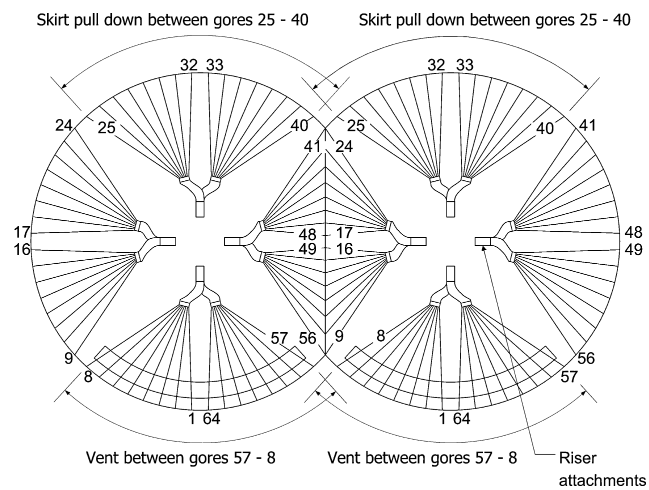


Fig. 8 Schematic of the design of a steerable cluster of two G12 parachutes.

Full-Scale G12 Cluster Tests

After the successful tests of the clustered one-quarter-scale G12 parachutes, a two full-scale G12 parachute cluster was tested at Yuma Proving Ground, Yuma, Arizona. The design of the two G12s was similar to that of the one-quarter-scale G12s and is shown in Fig. 8. Each of the two canopies were divided into four quadrants. One quadrant was connected between the two canopies. Fully inflated G12 photographs from other previous studies were used to guide to the location of the vent opening on the canopy. It was found that the relatively vertical part of the canopy was 1.83 m high measured form the skirt. As a conservative approach and based on the one-quarter-scale G12 tests, a total vent area of 2.5% of the constructed canopy surface area was chosen. This resulted in a 0.458 m-high opening beginning at 0.305 m from the skirt, and the length of the opening covered the entire quarter of the canopy perimeter. The opening was cut by a hot knife, and webbings were sewn on the perimeter of the opening to strengthen the cut edges. The quadrant of the skirt opposite to the vent was pulled down. Two tests were conducted from a C130 U.S. Army aircraft. The deployment speed was 130 kn, and the drop altitude was 610 m above ground level. An onboard GPS system was used to measure the position-time profile of the load and a Windpad[14] was dropped along with the load to measure the wind profile. The horizontal wind velocity was used to correct the GPS data for the glide ratio of the G12 cluster system.

In test 1, the length of the pulldown skirt was 1.83 m. Because the standard riser of the G12 was only 1.53 m, an 2.44 m riser had to be added to achieve this. Exact standard G12 packing procedure was not followed for this test, especially along the connected skirt

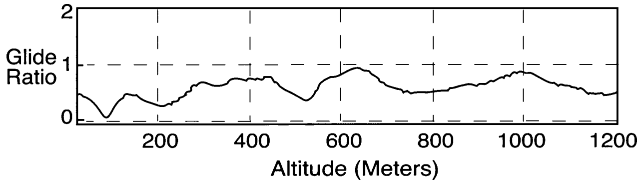


Fig. 9 Glide ratio (wind effect subtracted) of a cluster of two connected G12 parachutes.

area. The gores in that area were just lumped together without gore-by-gore packing with forced airflow. A 6.1 m riser extension was used for each G12. The two rigged G12s were packed as a single parachute in one G11 deployment bag. Standard rigging procedure was also used to rig the G12 cluster onto a 1,470 kg type V platform. Ground wind was calm at 5 kn for this test. After load release from the C130, the two connected G12s opened smoothly. After full inflation, the cluster glided toward the skirt pulldown direction as was designed. Although flow study of the connected canopies has not been analyzed or measured, it is reasonable to describe the overall canopy airflow in four flow regimes surrounding the canopies. The first flow regime is the flow into the canopy through the skirt and out of the canopy fabric due its porosity. The second one is the shedding vortex flow emanating from at the skirt of the canopy. The third one is the air ejecting from the vent opening and the raised skirt (relative to the pull-down skirt) below it. The fourth one is the impinging flow onto the front section, including the pulldown section of the canopy. For an unmodified G11, the shedding vortex flow causes the canopy to oscillate and breathe (alternate canopy deflation and inflation). Although the current G11 has been modified, these oscillatory behaviors still exist and are further complicated by the impinging flow. During canopy breathing, the air pressure inside the canopy interacts with the air pressure of the impininging flow outside the canopy. For this test, the 1.83 m skirt pulldown apparently was excessive and was pushed in quite noticeably by the impinging flow, causing pronounced canopy breathing. Because the canopy drag is a function of the canopy geometry, the drag force also oscillates. This in turn would affect the glide ratio of the G11 cluster. This was indeed observed in the measured time profile of the horizontal wind corrected glide ratio. Figure 9 shows that the glide ratio fluctuates between 0.3 and 0.9, which are reasonable values for gliding round canopies. Because the amount of the skirt pulldown was excessive, it would be decreased for the next test to get steadier and better glide performance.

Test 2 was the repeat of test 1 except for the following three differences. The two G12s were packed as closely as possible to the standard packing procedure. The connected gores were packed gore-by-gore with forced airflow. Based on the lesson learned from test 1, the skirt pulldown was reduced to 0.915 m. On one of the canopies, the skirt pulldown was tied to two 20-s pyrotechnic cutters so that the pulldown skirt would be released after 20 s from line stretch to turn the cluster. Ground wind was gusty at about 8 kn for this test. On load release from the C130, the parachute opening was not good, with excessive fabric twisting and irregular inflation, causing some fabric damage. Video of the test shows that one possible reason for the poor opening was that the well-packed connected gore area of the two canopies created air inflation by itself that interfered with the inflation of the main part of the canopy. Because of the fabric damage on the canopies, the glide ratio was not as high as test 1 but steady at about 0.5. The steadier glide ratio as compared to test 1 was because of the reduced skirt pulldown to 0.915 m. Visually, skirt pulldown was pushed in much less than test 1. After 20 s from line stretch, on firing of the cutters, the skirt pulldown of one canopy was released, as shown in Fig. 10. Subsequently, the cluster started to turn as designed. The average turn rate for a 90-deg turn measured from the video after the test was 2.5 deg/s. After landing, inspection of the parachutes showed moderate, but salvable, amount of scattered canopy fabric damage.

After the two G12 cluster tests, tow 30.5-m-diam G11 parachutes were modified based on the same modification and design as those

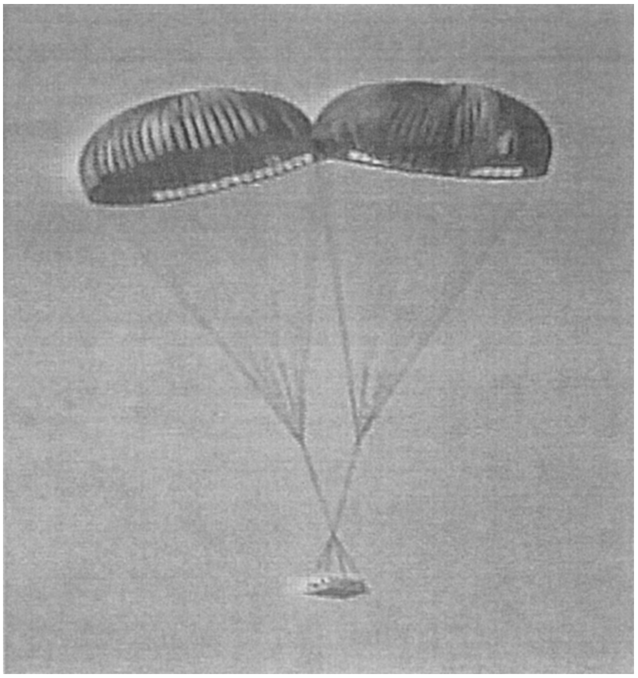


Fig. 10 Photograph of a cluster of two connected G12 parachutes during a turn.

for the two G12s. Testing of the steerable 1-G11 cluster is currently ongoing. Using the packing method used in test 1 of the G12 cluster also resulted in a good G11 cluster opening. System performance was also satisfactory. Test results will be reported at a later date.

Conclusions

A new method of providing glide and turn control of clustered round parachutes has been successfully demonstrated using a two one-quarter-scale G12 cluster and a full-scale two G12 cluster. The method involves simply pulling down part of the canopy skirt, making vent openings opposite to the skirt pulldown, and connecting the canopies. Steady glide is obtained when both canopies are pulled down. Turn control is obtained by releasing the pulldown skirt of one of the canopies. The simplicity and low-cost nature of the system makes it a viable candidate for the low-cost precision airdrop system that the U.S. Army is currently pursuing. Currently, a two full-scale cargo G11 parachute cluster with autonomous precision delivery capability is being developed and tested for a 10,000-lb system.

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