# NACA

# RESEARCH MEMORANDUM

## WIND-TUNNEL INVESTIGATION OF THE EFFECTS OF VARIOUS ASYMMETRIC CANOPY MODIFICATIONS ON THE BEHAVIOR OF DESCENDING PARACHUTES

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## SUMMARY

An investigation has been conducted in the Langley 20-foot free-spinning tunnel to study the behavior in descent of hemispherical and quasi-conical parachutes, some having various types of asymmetrical canopy modifications and each having a right circular cylinder suspended by one end below the parachute. The purpose of the tests was to determine whether a parachute could be made to lower the cylinder with a lateral component of the flight path. Eighteen 14-inch-diameter parachutes were tested.

The results of the tests indicated that the desired flight characteristics in descent could be obtained by a circular cutout in the side of the canopy of a hemispherical parachute or by a large slit cut between two panels of a quasi-conical parachute. Analysis of the results indicated that construction details such as the canopy porosity and the size of the asymmetric canopy modification may have important effects on the descent characteristics and should be given consideration in the selection of any parachute to be used in lowering a specific parcel with a prescribed descent velocity and lateral velocity.

## INTRODUCTION

The National Advisory Committee for Aeronautics has conducted an investigation in the Langley 20-foot free-spinning tunnel to study the behavior in descent of each of eighteen 14-inch-diameter hemispherical and quasi-conical parachutes, some having various types of asymmetric canopy modifications and each having a right circular cylinder suspended by one end below the parachute. In the wind-tunnel tests, the immediate purpose was to determine whether any of the eighteen parachutes could be

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made to lower the cylinder with a lateral component of the flight path. The behavior in descent of each parachute-cylinder configuration investigated is reported herein, and the general effects of each asymmetrical canopy modification are discussed.

## APPARATUS

### Wind Tunnel

The wind-tunnel tests of this investigation were made in the Langley 20-foot free-spinning tunnel. This tunnel was used because it has a vertically rising air stream in the testing area and therefore was a convenient apparatus to use in investigating experimentally the behavior in descent of the parachute-cylinder configurations. The tunnel has an airspeed range up to about 95 feet per second.

### Parachutes

The eighteen parachutes used in the investigation are listed in table I. Each parachute had a preformed canopy with a projected diameter of approximately 14 inches when inflated and had eight shroud lines attached at approximately equidistant locations around the periphery of the canopy. Sixteen of the canopies, when inflated, appeared as hemispherical, and the other two appeared as quasi-conical. One of the hemispherical parachutes was made by stitching together eight approximately triangular panels, as can be seen from the sketch and photograph in figure 1. The other fifteen hemispherical parachutes were made by stitching panels together in such a manner that the canopy appeared somewhat similar to one-half of a baseball cover; the manner in which these hemispherical parachutes were constructed is illustrated by the sketch and photograph in figure 2 and is similar to that used in making some parachutes for previous investigations in which the effects of various design variables on drag, stability, and opening characteristics of parachutes were evaluated (references 1 and 2). Sketches of various asymmetric modifications used on these parachutes are shown in figure 3. One additional asymmetric modification not shown in the figure consisted of using cloth of different porosities in the two sets of adjacent side panels. The two quasi-conical parachutes are illustrated in the sketches and photographs of figures 4 and 5 and were made by stitching together four and eight, respectively, approximately triangular panels. As can be seen in the figures, both of the quasi-conical parachutes had a slit in the side of the canopy between two panels. In addition to the modifications already discussed, the parachutes varied in two other design features which were not considered to be of importance in this investigation. These variations were: use of shroud lines 16 inches long on some parachutes and 19 inches long on others, and arbitrary use of partially free "pull-out" cords in the loop at the bottom of the canopy causing a slight gathering at the edge of the inflated canopy (illustrated in figs. 8 and 9 of reference 1). The results of a previous investigation (reference 1) did not indicate that these variations in themselves would have an appreciable effect on the attitude of the parachutes in descent, and inasmuch as they were not asymmetrical modifications, they would not be expected to cause a lateral flight component of the parachute and cylinder.

The porosity numbers listed in table I were specified by the parachute manufacturers and are given as the cubic feet of air that would pass through 1 square foot of the cloth per minute under a pressure of 1/2 inch of water. Double-thickness crown panels, such as were used on five of the hemispherical parachutes (table I), and seam construction between panels probably affected the over-all effective porosity of the parachute canopies somewhat.

### Cylinder

The cylinder used with the parachutes in this investigation was a right circular cylinder made of balsa with a length of 10.5 inches, a diameter of 3.625 inches, a sharp-edge upper surface (surface attached to parachute shroud lines) and a lower surface rounded to a radius of 0.25 inch at its edge. A sketch of the cylinder is shown in figure 6. The cylinder was ballasted with lead so that the total weight of parachute and cylinder would result in rates of descent convenient to test in the tunnel. The ballasted cylinder weighed approximately 4.1 pounds.

## METHODS AND TESTS

For the wind-tunnel tests of this investigation, each parachute in turn was attached to the top edge of the cylinder by means of four 4.125-inch lines connecting the shroud-line intersection point to four approximately equidistant points around the periphery of the cylinder. (See fig. 6.) The parachute-cylinder configuration was released to float freely in the vertically rising air stream of the tunnel and the descent velocity was recorded as the airspeed necessary to hold the parachute and cylinder at test level. Visual observations and motion pictures were made of the behavior of the parachute and cylinder, and notes were made as to whether an appreciable lateral component of the flight path was present and as to the attitude and to the motions of the parachute and cylinder during the test. A parachute was adjudged to have provided an appreciable lateral flight component when the parachute-cylinder configuration repeatedly traveled laterally across the tunnel in a consistent manner. The results were analyzed to obtain some idea as to the general effectiveness of each asymmetric canopy modification in obtaining the desired descent characteristics.

## RESULTS AND DISCUSSION

The results of the wind-tunnel tests of this investigation are presented in tabular form in table I.

When the parachutes which had no asymmetric canopy modification were used with the cylinder, they did not cause any appreciable lateral flight component. The parachute-cylinder configurations descended with irregular oscillations and inappreciable lateral motions. For these parachutes, small irregular lateral motions were sometimes obtained when the parachute and cylinder leaned to a side during an oscillation and the lateral motion was toward the side to which the parachute leaned. This behavior of the symmetrically constructed parachute and cylinder configurations appeared to be generally the same as the behavior of similar parachutes with weights used in the investigations reported in references 1 and 2. Brief tests in which the cylinder was replaced by small irregularly shaped objects of the same weight as the cylinder indicated no appreciable effects on the descent characteristics. The behavior of the symmetrically constructed parachutes is illustrated in the motion-picture strip of figure 7.

Most of the parachutes with asymmetrical canopy modifications also failed to cause an appreciable lateral flight motion of the parachute and cylinder. Indeed, some of these modifications seemed to have the effect of a deflected rudder on one side of the parachute and caused the parachute and cylinder to develop a steady equilibrium spinning motion about a vertical axis, as illustrated in the motion-picture strip of figure 8. The modifications which were most prone to cause the spinning motion were those making use of different porosities in two sets of adjacent side panels, a small auxiliary parachute tied to one shroud line, and a triangular cutout partially blocked by a flap in the side of the canopy. The parachute-cylinder combination was less prone to spin when a circular cutout partially blocked by a flap in the top of the canopy was used. When a skirt extending part of the way around the periphery below the canopy was used, no spin was obtained, but there was still no appreciable lateral motion.

Two asymmetrical modifications which caused appreciable lateral flight motions of the parachute and cylinder were a circular cutout in the side of a hemispherical canopy (parachutes H-15 and H-16) and a slit in the side of one of the quasi-conical canopies (parachute Q-2). The lateral flight motion obtained is illustrated in the motion-picture strip of figure 9. The lateral motions were in a direction away from the side of the parachute having the circular cutout or the slit and therefore appeared to be due to a jet-reaction effect of the air flowing through these apertures. Of the two hemispherical parachutes with circular cutouts in the side of the canopy, the results indicated that one (parachute H-15) was somewhat more prone than the other (parachute H-16) to continue in steady lateral flight. Inasmuch as the construction of these two parachutes had been specified as being the same except that the former was made of porosity 150 cloth and the latter of porosity 200 cloth, it appears that using the lower-porosity cloth was more favorable for the purpose of obtaining a more consistent lateral flight motion. It appears then, that the presence of a larger ratio of air flow through the circular cutout to the air flow through the canopy made the circular cutout more effective in causing a lateral motion. By similar reasoning, the fact that the slit in quasi-conical parachute Q-2 caused a lateral flight motion whereas the slit between two side panels of the remaining quasi-conical parachute (Q-1) and an especially cut slit in the side of one of the originally symmetrical hemispherical parachutes (parachute H-2; see table I) failed to cause a lateral flight motion may perhaps be explained on the basis that the former slit was larger in length than were the two latter slits and therefore allowed relatively more air to flow through it. As noted in table I, the (smaller) slit in quasi-conical parachute Q-1 did become effective in causing an appreciable lateral flight motion when the weight of the cylinder was reduced approximately one-eighth.

During the tests of the hemispherical parachutes having circular cutouts in their sides, it was noticed that the parachute and cylinder, while traveling laterally, remained in a near-vertical attitude with small occasional oscillations of $\pm 10^{\circ}$. However, during the tests of the quasi-conical parachute with the large slit between two side panels (parachute Q-2), it was noticed that the parachute and cylinder trimmed at about $25^{\circ}$ from vertical, leaning in the direction of its lateral travel. It should be noted (table I) that the ratio of lateral to vertical velocity was about two and one-half times higher for the latter parachute than for the former two parachutes.

The test results, summarized generally, indicate that design details such as canopy porosity, size of the asymmetric modifications, and weight of the suspended parcel are important factors affecting the effectiveness of an asymmetrical canopy modification in causing a lateral flight motion, even for the two apparently most promising types of modification.

## CONCLUDING REMARKS

An investigation has been conducted in the Langley 20-foot free-spinning tunnel to study the behavior in descent of each of eighteen 14-inch-diameter hemispherical and quasi-conical parachutes, some made with various types of asymmetrical canopy modifications in an attempt to obtain a lateral flight component during the descent. Each parachute had a right circular cylinder suspended by one end below the parachute. The results of the wind-tunnel tests indicated that a lateral flight component during descent could be obtained by use of a circular cutout in the side of the canopy of a hemispherical parachute and by use of a large slit cut between two panels of a quasi-conical parachute. The results also indicated that construction details such as the canopy porosity and the size of the asymmetric canopy modification may have important effects on the descent characteristics and should be given consideration in the selection of any parachute to be used in lowering a specific parcel with a prescribed descent velocity and lateral velocity.

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## REFERENCES

1. Scher, Stanley H., and Gale, Lawrence J.: Wind-Tunnel Investigation of the Opening Characteristics, Drag, and Stability of Several Hemispherical Parachutes. NACA TN 1869, 1949.

2. Scher, Stanley H., and Draper, John W.: The Effects of Stability of Spin-Recovery Tail Parachutes on the Behavior of Airplanes in Gliding Flight and in Spins. NACA TN 2098, 1950.

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TABLE I.- PARACHUTES USED AND TEST RESULTS OF INVESTIGATION OF EFFECTS OF ASYMMETRIC CANOPY MODIFICATIONS ON BEHAVIOR OF DESCENDING PARACHUTES

| Parachutes | | | | Behavior of parachute-cylinder configuration during descent | | | | |
|---|---|---|---|---|---|---|---|---|
| Type | Number (a) | Canopy porosity (ft$^3$/ft$^2$/min) | Asymmetric canopy modification (see figs. 3, 4, and 5) | Descent velocity (fps) | Lateral motion | Description of motion of parachute and cylinder | Approx. oscillation angle, degrees from vertical | Approx. spin attitude, degrees from vertical |
| Hemi-spherical | [b]H-1 | 125 | None | 53.7 | Not appreciable | Made irregular oscillations and inappreciable lateral motions | ±25 | — |
| | [c,d]H-2 | 125 | None | 63.6 | | [f]Same as parachute H-1 | ±20 | — |
| | [c,d]H-3 | 125 | None | 61.0 | | Same as parachute H-1 | ±20 | — |
| | [c,e]H-4 | 300 | None | 62.1 | | Made very slight irregular oscillations and occasional slight lateral motion | ± 5 | — |
| | [c,e]H-5 | 300 | None | 56.0 | | Same as parachute H-1 | ±15 | — |
| | H-6 | 200 | None | 55.8 | | Same as parachute H-1 | ±25 | — |
| | H-7 | 125 and 300 | Two adjacent side panels and crown of 125-porosity; other side panels of 300 porosity | 54.4 | | Remained in spin about vertical axis approximately through cylinder-shroud line attachment point | | 45 |
| | H-8 | 150 | Auxiliary parachute tied to one shroud line | 53.7 | | Same as parachute H-7 | — | 25 |
| | H-9 | 200 | Auxiliary parachute tied to one shroud line | 53.7 | | Same as parachute H-7 | — | 25 |
| | H-10 | 150 | Partially flap-blocked triangular cutout in side of canopy | 54.4 | | Same as parachute H-7; also, occasionally same as parachute H-1 | ±25 | 25 |
| | H-11 | 200 | Partially flap-blocked triangular cutout in side of canopy | 52.4 | | Same as parachute H-7 | — | 25 |
| | H-12 | 150 | Partially flap-blocked circular cutout in top of canopy | 53.7 | | Same as parachute H-1; also, occasionally same as parachute H-7 | ±20 | 20 |
| | H-13 | 200 | Partially flap-blocked circular cutout in top of canopy | 54.4 | | Same as parachute H-1 | ±20 | -- |
| | [c]H-14 | 150 | Skirt attached to bottom of canopy and to shroud lines; covers 25 percent of periphery | 52.4 | | Generally same as parachute H-1; somewhat more prone to continue lateral motion than parachute H-1 | ±20 | — |
| | H-15 | 150 | Circular cutout in side of canopy | 55.1 | Appreciable | Made occasional small oscillation from vertical while traveling laterally in direction opposite side having cutout in canopy; velocity of lateral flight component approximately 5 feet per second | ±10 | — |
| | H-16 | 200 | Circular cutout in side of canopy | 55.1 | | Generally same as parachute H-15; however, appeared to be somewhat less prone to continue in steady lateral flight and to have a slightly greater tendency to oscillate | ±10 | — |
| Quasi-conical | Q-1 | 125 | Slit between two of total four approximately triangular side panels | 57.1 | Not appreciable | [g]Same as parachute H-1 | ±20 | — |
| | Q-2 | 125 | Slit between two of total eight approximately triangular side panels | 45.4 | Appreciable | Trimmed in attitude approximately 25° from vertical with slit on upper side and traveled with a steady lateral motion and no noticeable oscillations; velocity of lateral flight component approximately 12 feet per second in direction away from slit side | — | — |

[a]H signifies hemispherical; Q signifies quasi-conical.
[b]Parachute differed in construction from other 15 hemispherical parachutes; see figures 1 and 2.
[c]Parachute had double-thickness crown panel.
[d]Parachutes had different manufacturers.
[e]Parachutes made of different materials (nylon and rayon).
[f]Behavior of parachute not appreciably affected when $5\frac{1}{2}$-inch slit cut in side of parachute canopy.
[g]When weight of cylinder was reduced by one-eighth, an appreciable lateral flight motion was obtained.

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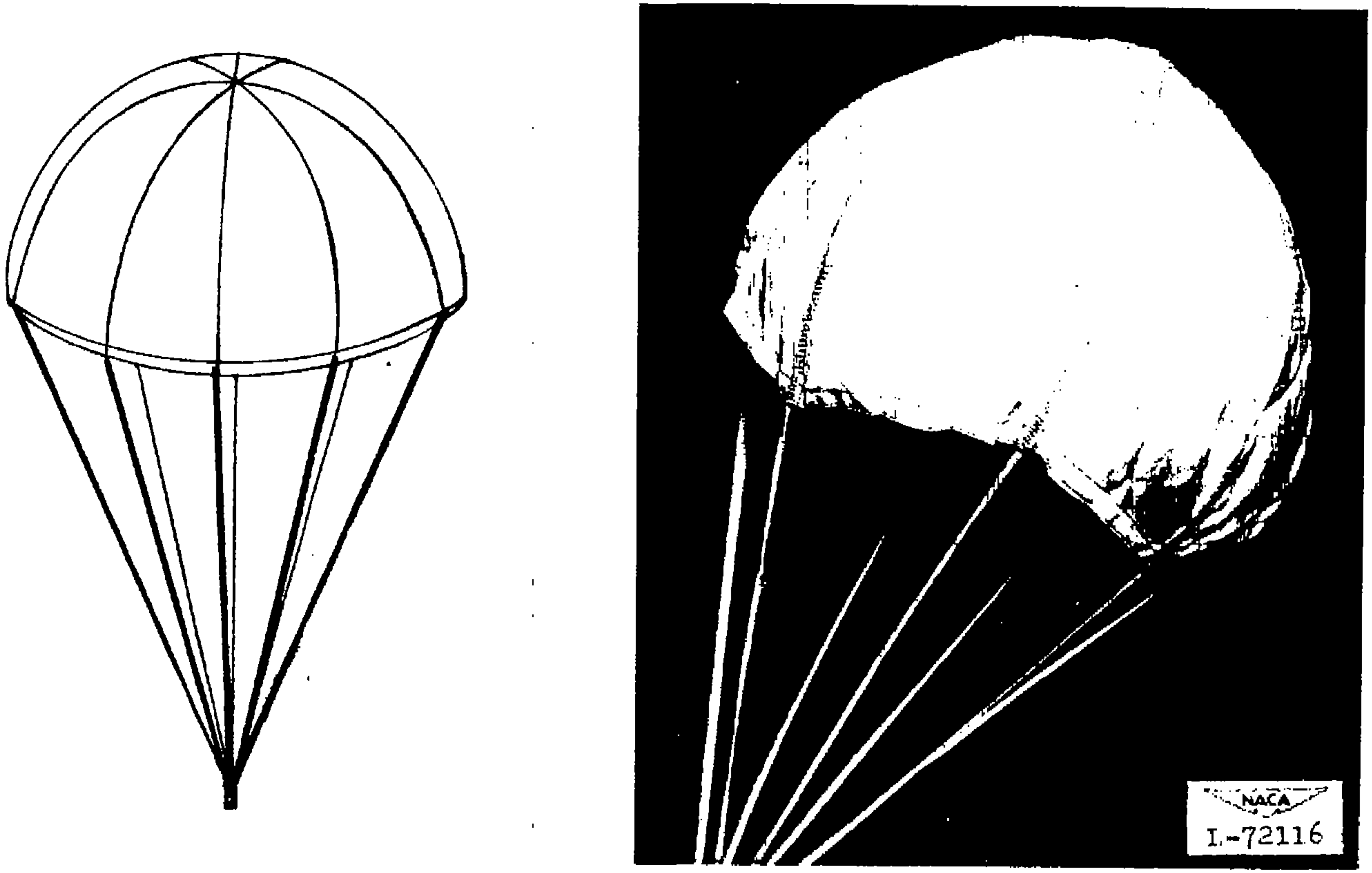


Figure 1.- Sketch and photograph of hemispherical parachute H-1 in table I.

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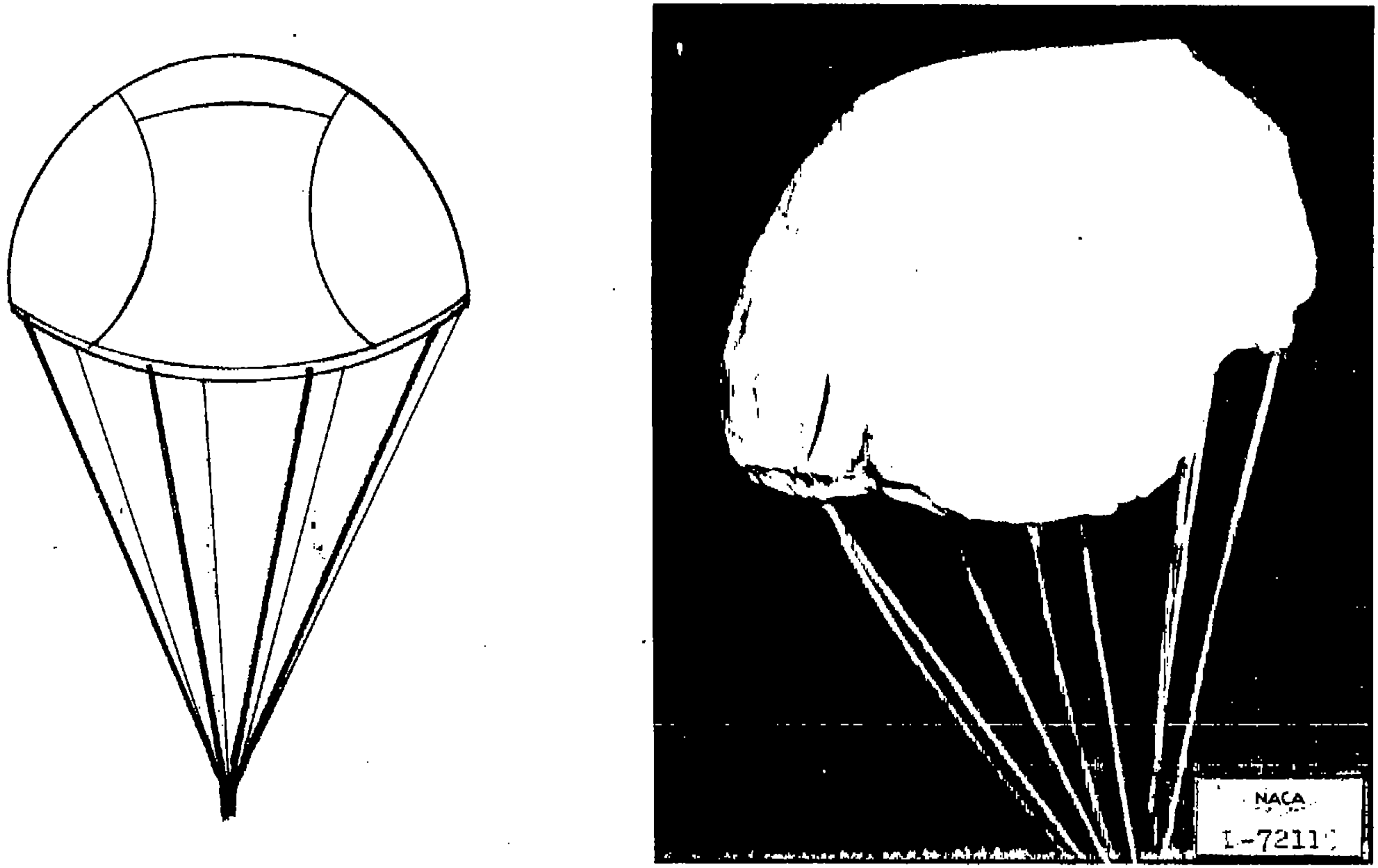


Figure 2.- Sketch and photograph illustrating hemispherical parachutes H-2 to H-16 in table I (no asymmetrical modifications shown).

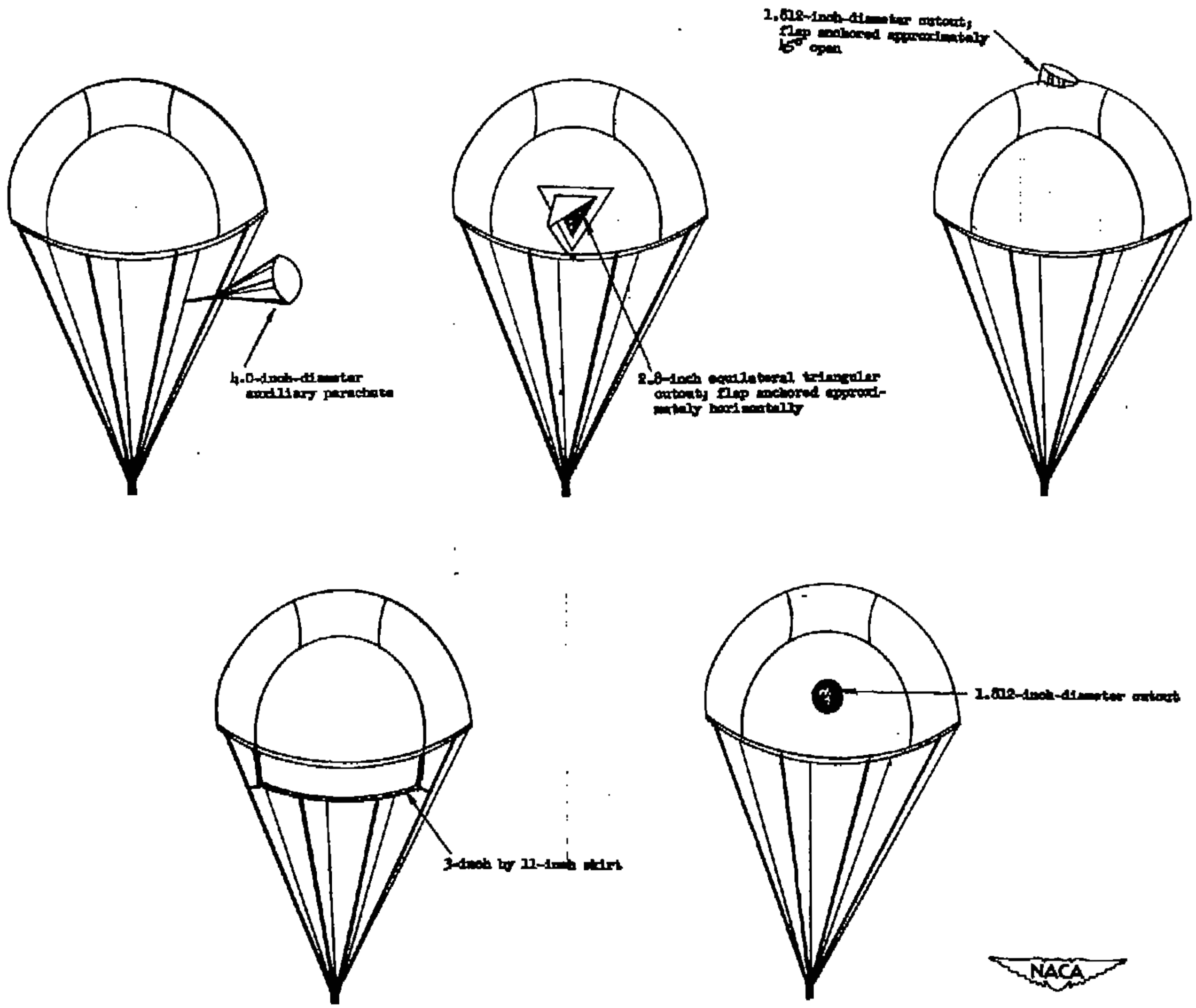


Figure 3.- Sketches illustrating various asymmetrical modifications used on hemispherical parachutes.

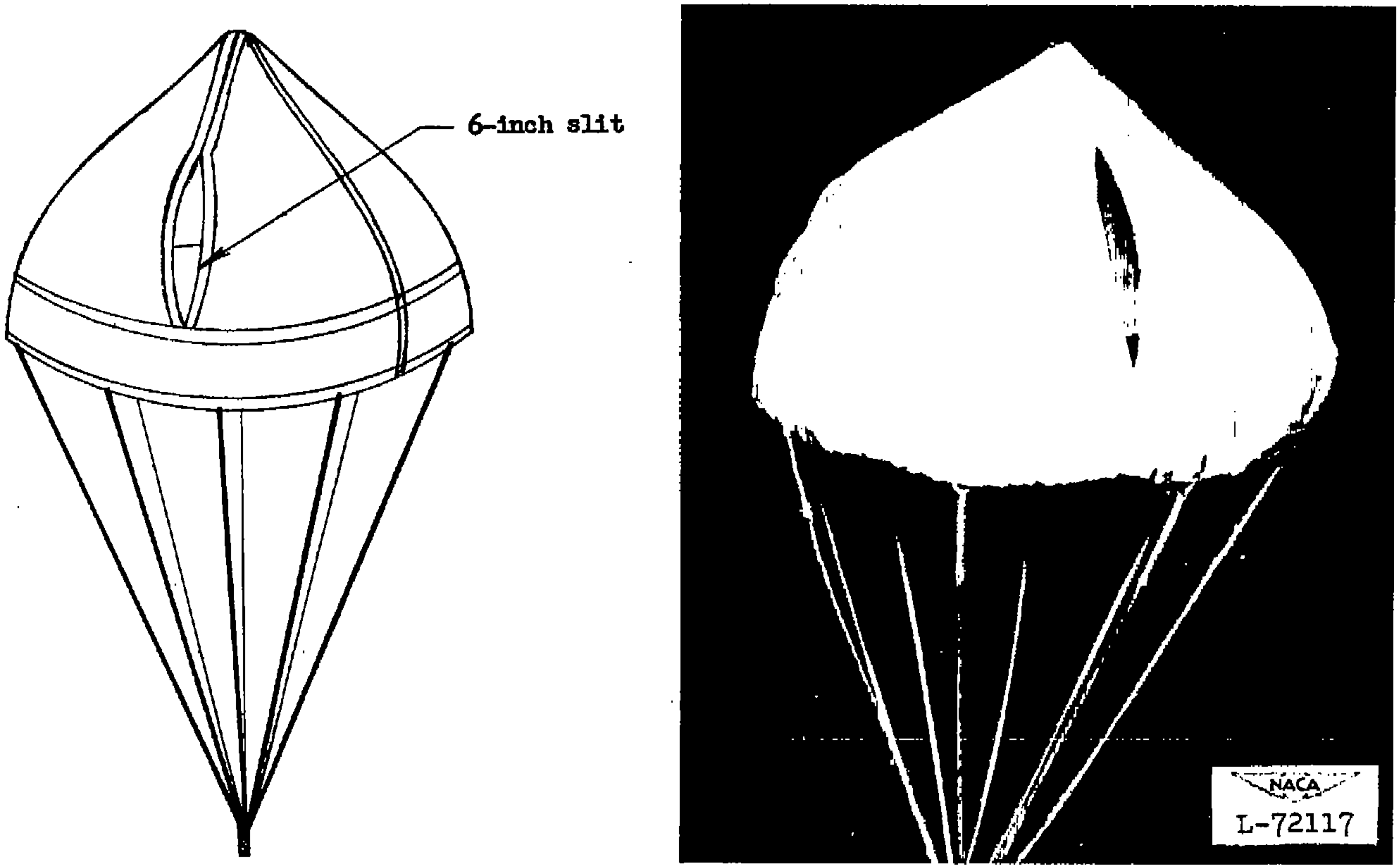


Figure 4.- Sketch and photograph of quasi-conical parachute Q-1 in table I.

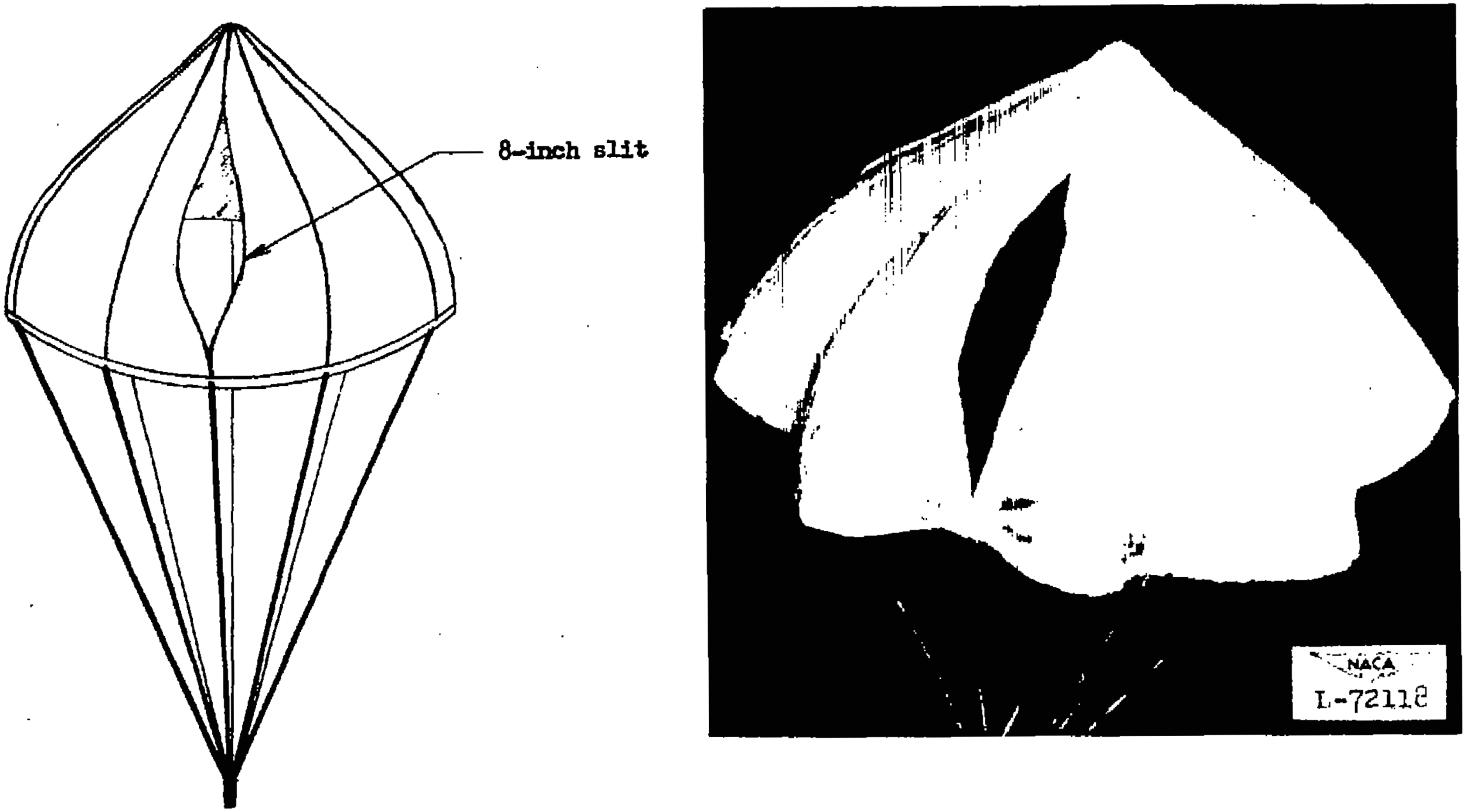


Figure 5.- Sketch and photograph of quasi-conical parachute Q-2 in table I.

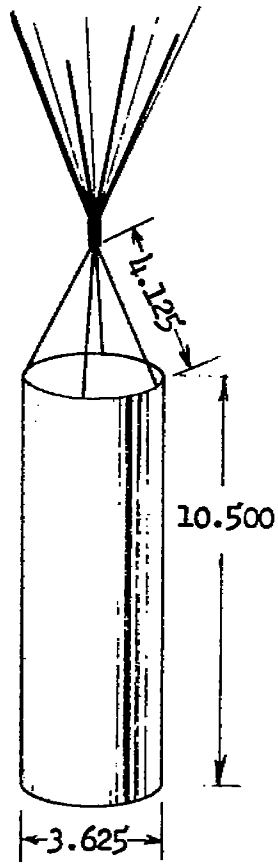


Figure 6.- Sketch of cylinder showing method of attachment to parachute shroud lines.

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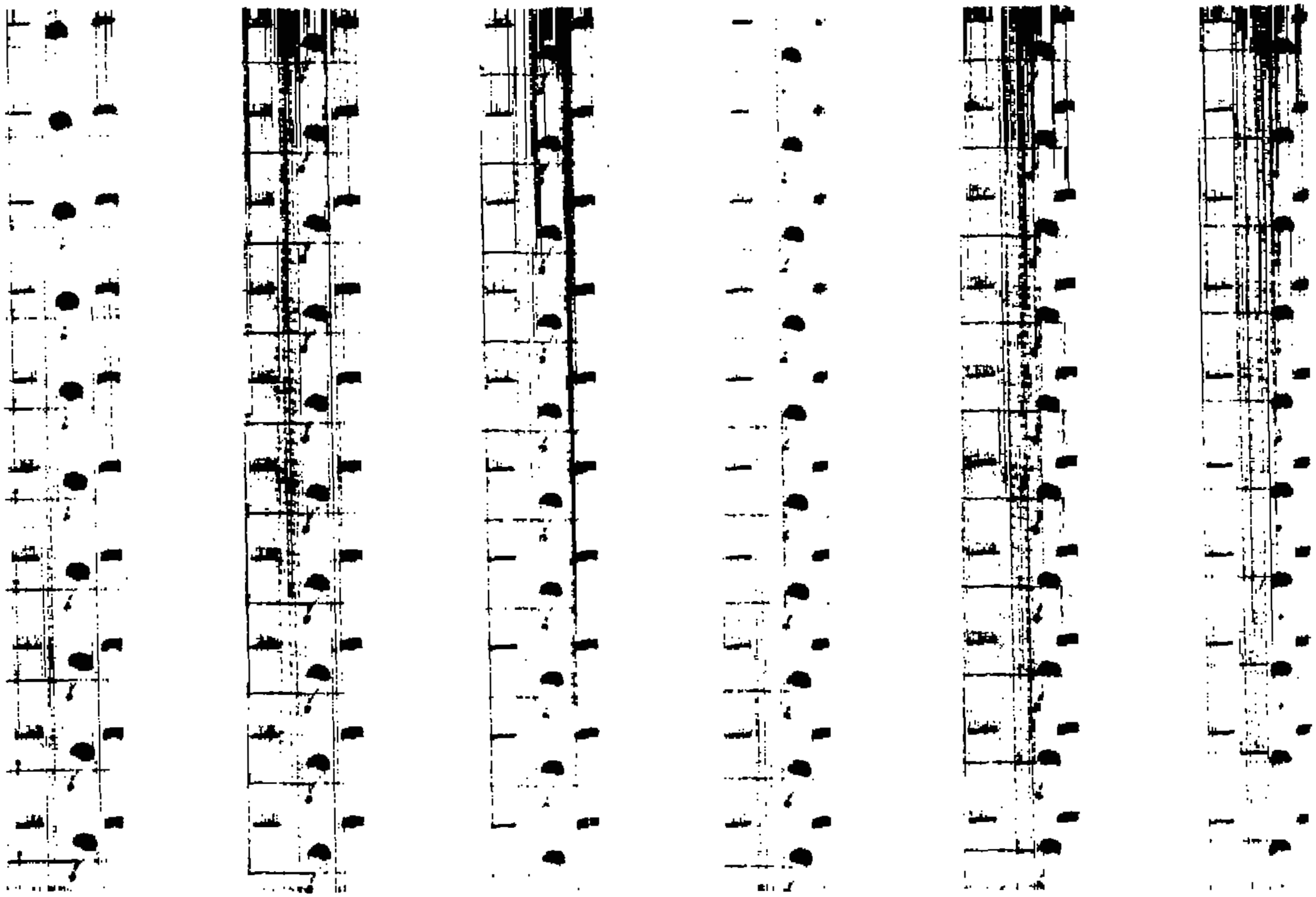

Figure 7.- Motion-picture strip illustrating irregular behavior of symmetrically constructed parachute and a weight in the Langley 20-foot free-spinning tunnel. (An irregularly shaped weight was used instead of the cylinder for these pictures.) Camera speed was 64 frames per second.

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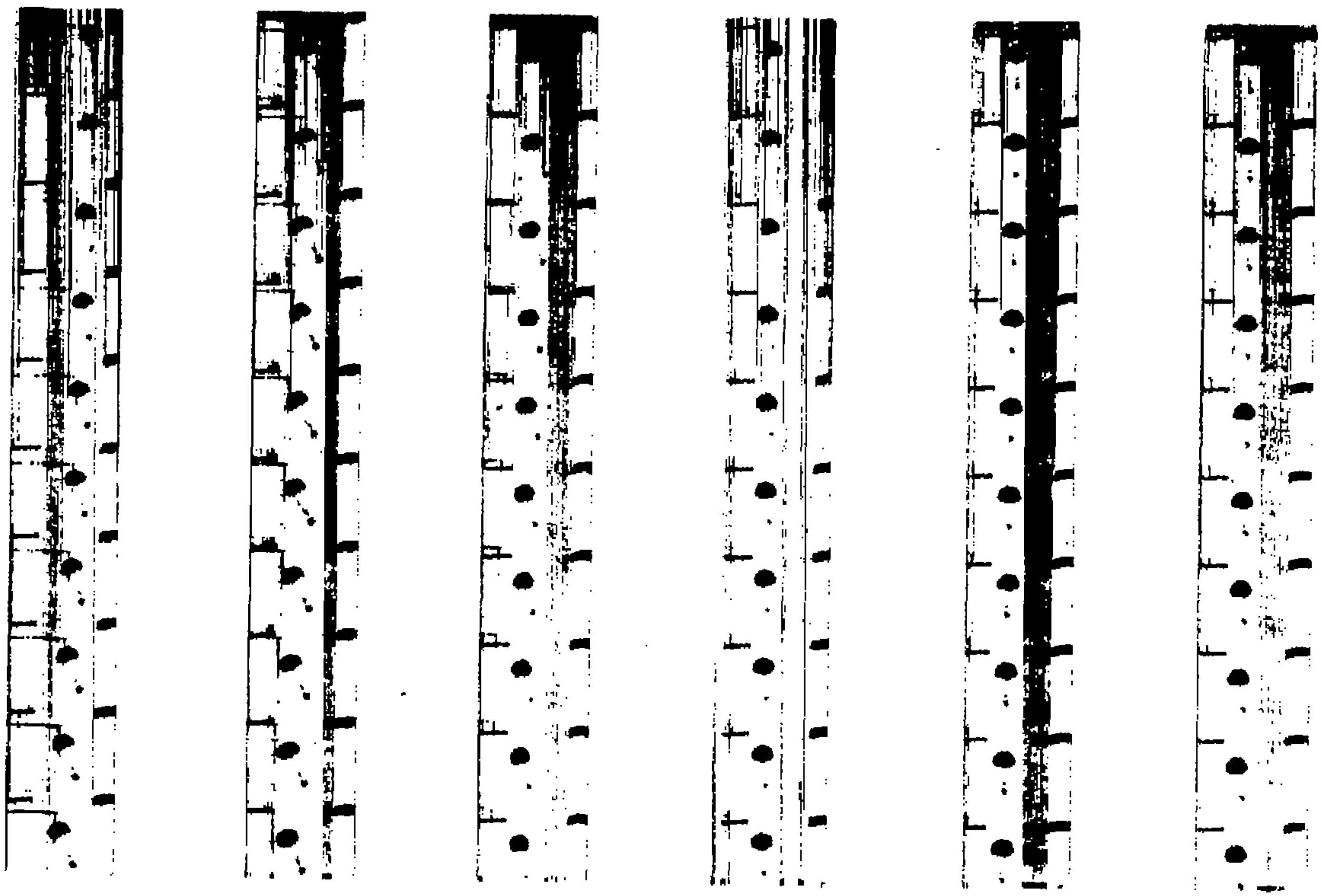

Figure 7.- Continued.

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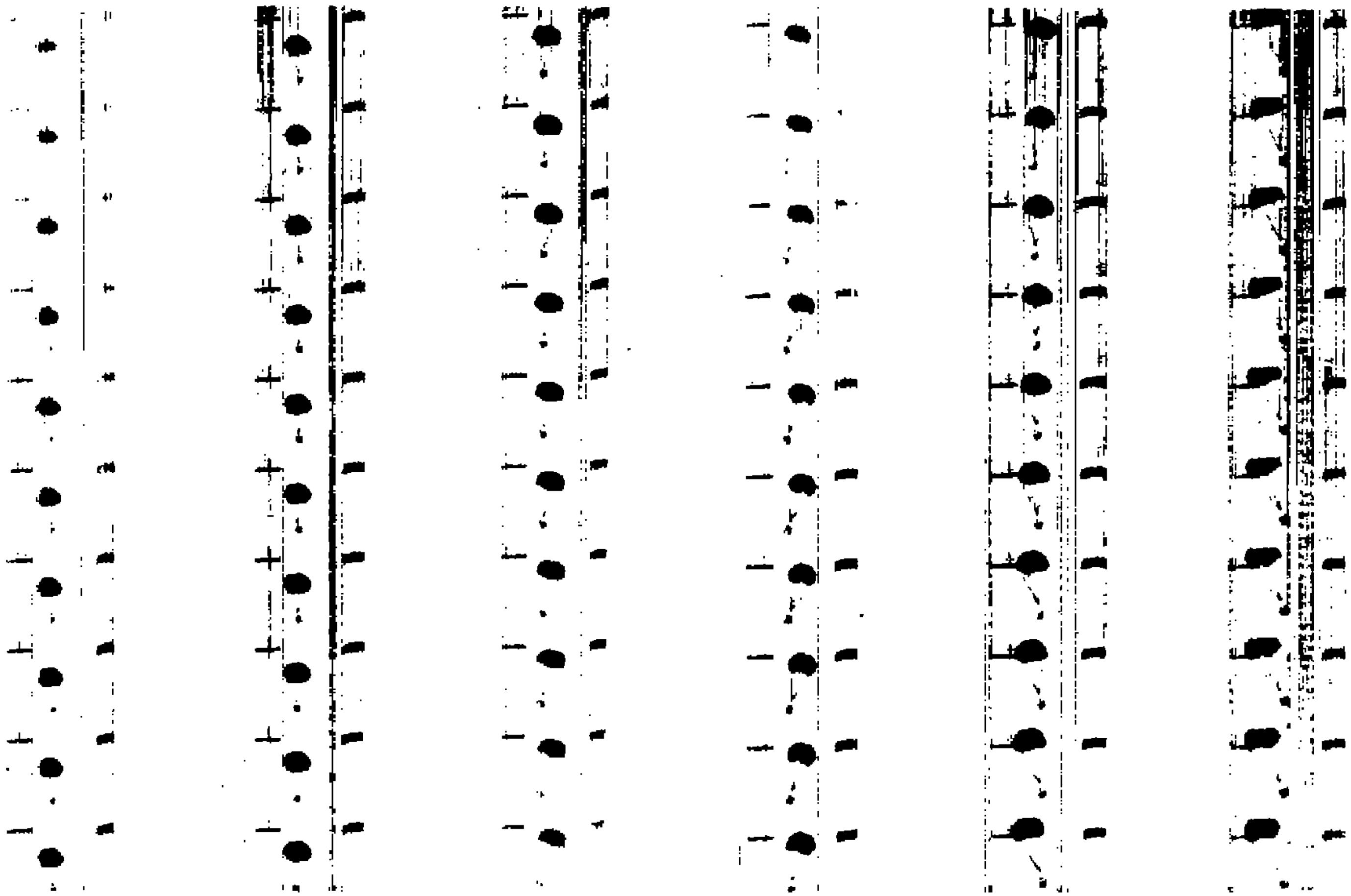

Figure 7.- Concluded.

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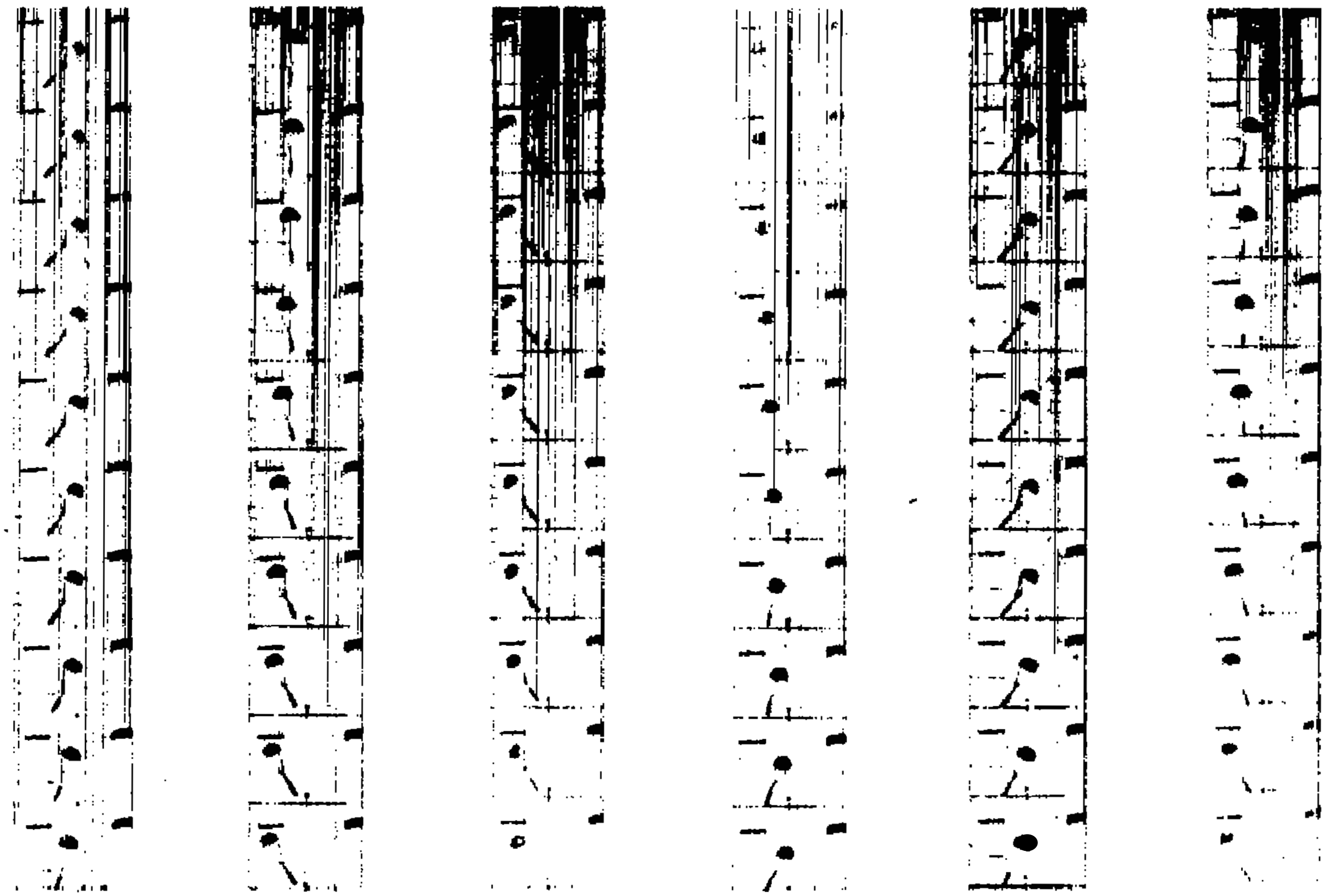

Figure 8.- Motion-picture strip illustrating equilibrium spinning motion obtained with each of several asymmetrically modified parachutes and the cylinder in the Langley 20-foot free-spinning tunnel. Camera speed was 64 frames per second.

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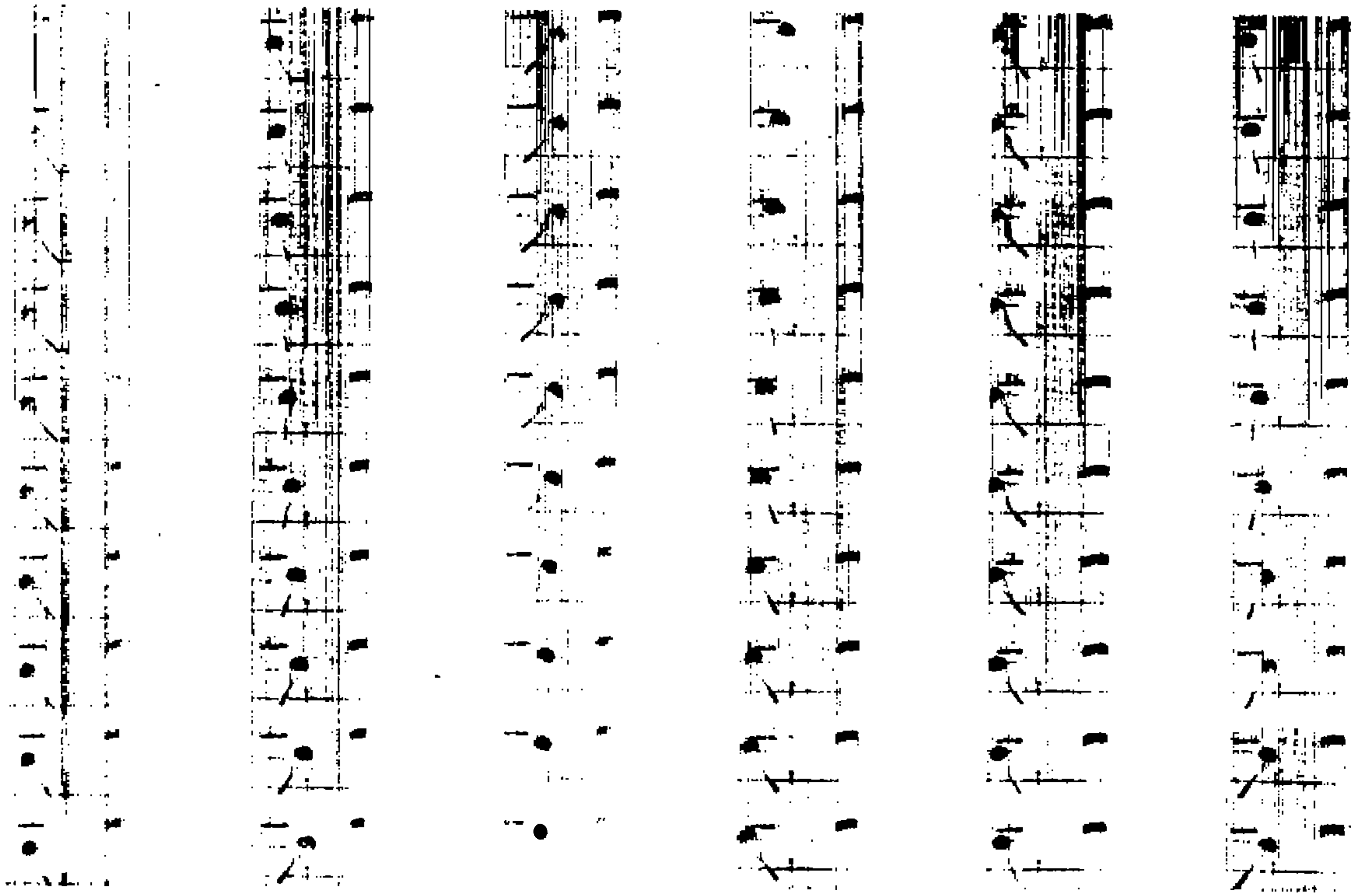

Figure 8.- Concluded.

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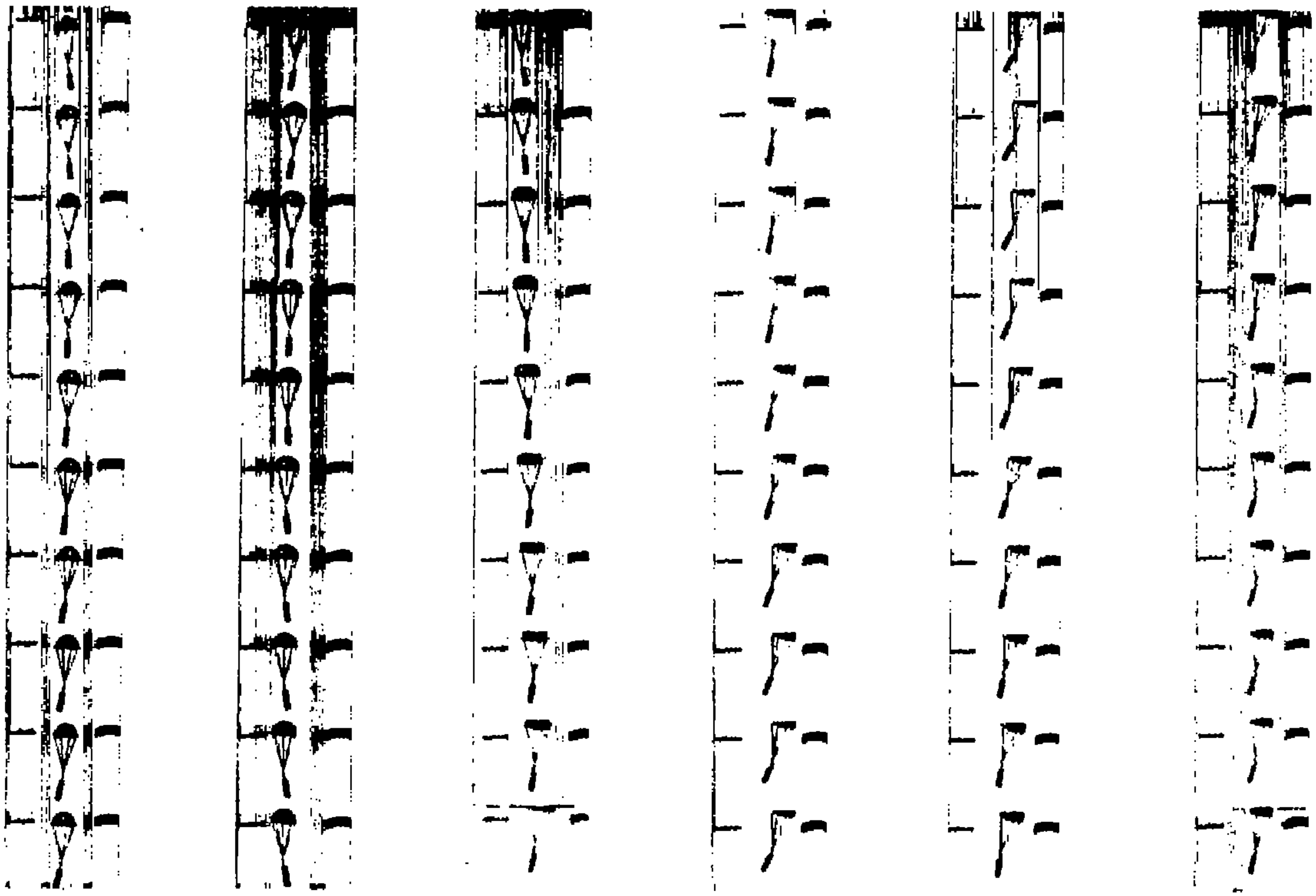

Figure 9.- Motion-picture strip illustrating lateral flight motion obtained with each of two asymmetrically modified parachutes and the cylinder in the Langley 20-foot free-spinning tunnel. In these pictures, the canopy modification consisted of a circular cutout in the side nearest the camera, and the direction of the lateral motion is away from the camera. Camera speed was 64 frames per second.

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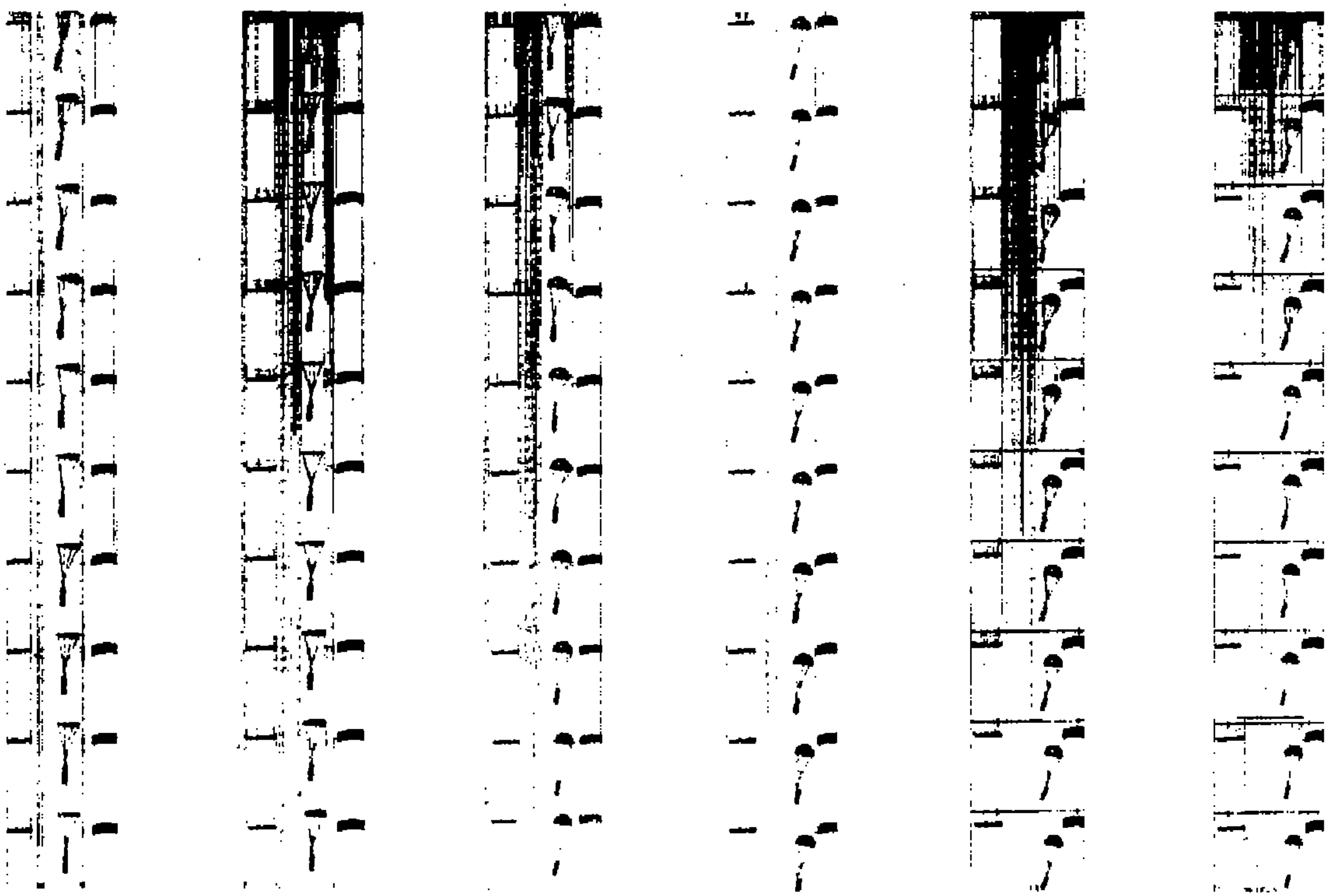

Figure 9.- Concluded.

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SECURITY INFORMATION



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