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TECHNICAL NOTE

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DRAG CHARACTERISTICS AND DYNAMIC STABILITY IN DESCENT OF A ROTARY PARACHUTE TESTED IN A VERTICAL TUNNEL

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SUMMARY

An investigation was conducted in the Langley 20-foot free-spinning tunnel at low speeds to determine the drag characteristics and dynamic stability in descent of a 64-inch-diameter rotary parachute. The drag coefficient of the basic rotary parachute was approximately 1.7 based on total cloth area; cutting cloth away from the tips of the parachute permitted it to rotate faster and gave a somewhat higher drag coefficient of about 2.1. In general, the rotary parachute was extremely stable in descent, with oscillations of probably less than 1°. Small changes in rigging had no appreciable effect on the performance of the parachute.

INTRODUCTION

The National Aeronautics and Space Administration Langley Research Center is conducting a research program to evaluate different types of recovery systems for aircraft, spacecraft, and boosters. As part of this program, an investigation has been made to evaluate the drag and stability characteristics of a rotary parachute. The parachute tested has four gores, or panels, and is designed to operate in a manner similar to helicopter rotor blades in vertical autorotation. According to the results in references 1, 2, and 3, such a rotary parachute has the ability to provide greater drag per unit cloth area than conventional parachutes. Inasmuch as the drag coefficients are based on the total cloth area and the cloth area determines the parachute volume and weight, this area is an extremely important factor in evaluating the effectiveness of the parachutes in producing drag. Although in the past other parachutes have been designed to rotate to improve stability characteristics, none have produced any significant increase in the drag characteristics. (See ref. 4.)

The present investigation was undertaken because the amount of data available on rotary parachutes was very meager. In this investigation, two slightly different configurations of the rotary parachute were tested in free descent in the Langley 20-foot free-spinning tunnel, a vertical wind tunnel.

SYMBOLS

$C_{D,o}$ — drag coefficient of parachute based on total cloth area and rate of vertical descent, $\frac{D}{qS_o}$

D — drag of parachute (at terminal rate of descent in tunnel, drag is equal to total weight of parachute plus its load), lb

ΔP — difference in length of leading-edge and trailing-edge pitch lines, positive when ΔP produces a clockwise rotation of parachute when viewed from above, in.

q — dynamic pressure, $\frac{\rho V^2}{2}$, lb/sq ft

ρ — air density, slugs/cu ft

V — rate of vertical descent (free-stream velocity), ft/sec

S_o — total cloth area of canopy, sq ft

W — total weight of parachute plus load, lb

Ω — rotational speed of parachute, rpm

APPARATUS

The tests were conducted in the Langley 20-foot free-spinning tunnel, which is an atmospheric wind tunnel with a vertically rising airstream in the test section; the maximum airspeed of the tunnel is approximately 98 feet per second. For further details, see reference 5. For these tests, Pioneer Parachute Company, Inc. provided two rotary parachutes which were similar except that the basic configuration was modified by having cutouts at the tips. This particular parachute is referred to hereinafter as the modified parachute.

A sketch showing two adjacent gores of the rotary parachute with identifying nomenclature is shown in figure 1. The canopy of the parachute has four gores, or panels, and four short lines, referred to as pitch lines, which are connected to the tips of these panels. Four suspension lines are attached to the pitch lines. A center line extends downward from the center or apex of the canopy and joins the point where the suspension lines are connected to a swivel, which supports the load. An interpanel line connects each panel to maintain fixed distances between the individual panels during operation.

The parachute is made to rotate by the proper positioning of the attachment points of the suspension lines along the pitch lines. If the attachment points are positioned so that one side of each pitch line is shorter than its other side, the tips of the panels connected to the shorter sides of the pitch lines are lowered and the parachute rotates in the direction of its lowered panel tips. Thus, the short sides of the pitch lines are referred to as the leading-edge pitch lines.

Photographs of the basic and modified rotary parachutes undergoing tests in the tunnel are shown in figures 2 and 3, respectively. A downstream view of the rotary parachute is shown in figure 4 and sketches of the gore patterns are presented in figure 5. The diameter of both parachutes when laid out flat is 64 inches. The total cloth area of the basic parachute is 7.85 square feet; with the tips cut out the area is 6.20 square feet. The panels of the parachute are made of acrylic-coated nylon and have approximately zero porosity.

METHODS AND TESTS

The method of testing the rotary parachute was to hold it erect near the side of the tunnel until it became inflated and to push it toward the center of the tunnel. The parachute then floated freely in the vertically rising airstream of the tunnel, and the descent velocity was recorded as the airspeed necessary to hold the parachute at test level. Visual observations and motion pictures at a camera speed of 64 frames per second were made of the behavior of the parachute. A stroboscopic light was used to "stop" the rotation of the parachute in order to study the panel shaping and to measure the rate of rotation.

The rotary parachute was tested at speeds ranging from approximately 25 ft/sec to 65 ft/sec. This variation of rate of descent was accomplished by varying the load attached to the parachute in approximately 10-pound increments up to a total of approximately 40 pounds. In order to determine the best rigging combination for obtaining the highest $C_{D,o}$, the length of the suspension lines was varied from approximately 30 inches to 63 inches and the center-line length was varied from approximately 55 inches to 75 inches. The pitch of the panels was varied manually to change the rate and direction of rotation by altering ΔP (that is, the difference in the length of the leading- and trailing-edge pitch lines) from 16 inches to -16 inches.

Brief free-fall tests were performed at the Langley Research Center on a 32-foot-diameter rotary parachute to determine its opening and stability characteristics. The parachute was packed in a bag and released from a helicopter hovering at an altitude of about 2,000 feet.

RESULTS AND DISCUSSION

For a given payload, the rate of vertical descent of a nonrotating parachute is controlled by the drag of the parachute. In the case of the rotary parachute, the rate of vertical descent is controlled by the resultant of the vertical components of the lift and drag forces acting on the parachute panels. This resultant vertical force is the drag of the rotary parachute since it is parallel to the free-stream velocity. At its terminal rate of descent, this drag force is equal to the total weight of the parachute and its load.

Effect of Rigging Changes

Variation of ΔP.- The effect of varying ΔP on the drag characteristics of the basic and modified rotary parachutes is shown in figure 6. For these tests the center-line length and the suspension-line lengths were set equal at a value of $63\frac{1}{8}$ inches. The results of tests of the basic parachute indicated that for small values of ΔP (0 or ± 2 inches) the parachute did not rotate, or if it did, rotation was slow and erratic and the drag coefficient $C_{D,o}$ was approximately constant at 0.8. At the low rotational speeds, the panels were not fully inflated and therefore were producing very little lift. When ΔP was increased to ± 4 inches, rotation increased greatly and there was a large increase in the drag coefficient to about 1.7. As ΔP was further increased to ± 8 inches, rotation increased only slightly and the drag coefficient remained approximately constant. As ΔP was increased still further to ± 16 inches, rotation increased further but the drag coefficient decreased somewhat. At these large ΔP values, it was noted that the panels, although fairly well developed, became flattened and wrinkled near the leading edge, thus probably accounting for a loss in lift.

The results for the modified parachute indicate that for a ΔP value of zero, two ranges of drag coefficient exist. Either the parachute did not rotate and the drag coefficient averaged about 0.8, or the parachute rotated steadily and the drag coefficient averaged about 2.0. When ΔP was increased to ± 4 inches, there was an increase in $C_{D,o}$ to an average value of about 2.1 which remained approximately constant as ΔP was increased to ±8 inches. There was a much greater loss in lift for this parachute than for the basic parachute when ΔP was increased to 16 inches. The wrinkled and flattened condition near the leading edges of the panels was observed for the higher values of ΔP as previously noted for the basic parachute. In general, it appears that there is an optimum range of ΔP values from approximately 5 inches to 10 inches where the drag coefficient is relatively high and approximately constant. Results indicated that the modified parachute had a greater tendency to rotate than the basic parachute. This tendency was noticed during the test program in that it was very difficult to prevent rotation of the modified parachute by adjustment of ΔP, whereas for the basic parachute, ΔP could be easily adjusted to prevent rotation. It can be seen from figure 6 that direction of rotation did not have an appreciable effect on the results of either parachute, although $C_{D,o}$ was slightly higher for the clockwise rotation. This slight difference can be attributed to asymmetry in panel configuration.

The parachutes were very stable in descent, with oscillations of probably less than 1° over a range of ΔP values of ±12 inches, with the exception of the small range of ΔP values from ±2 inches where the parachute did not rotate properly.

Variation of center-line length.- The effect on $C_{D,o}$ of varying the center-line length from approximately 55 inches to a maximum of about 75 inches is shown in figure 7. The suspension-line lengths were held fixed at $63\frac{1}{8}$ inches and ΔP was arbitrarily held fixed at 8 inches, since this value was within the range in which good performance of the parachute was obtained. It can be seen from figure 7 that there is an optimum range of center-line lengths from approximately 60 inches to 66 inches. In general, when the center line was too short, the parachute canopy became distorted and the panels continually changed shape. Conversely, when the center line was too long, the panels, although generally having a fairly smooth contour, were wrinkled at the tips. Also, the interpanel lines were so taut that they caused a V-shaped depression in the panels, and in some cases, the parachute would not rotate. All of these conditions tended to reduce panel lift and overall drag, as well as stability of the parachute.

Variation of suspension-line length.- The effect on $C_{D,o}$ of varying the suspension-line length from approximately 30 inches to a maximum of about 63 inches is shown in figure 8. The center-line length and ΔP were fixed at $63\frac{1}{8}$ inches and 8 inches, respectively. This figure indicates that there is an optimum range of suspension-line lengths from approximately 47 inches to 63 inches. For suspension-line lengths of less than 47 inches the parachute was very unstable; the panels oscillated up and down and the interpanel lines were alternately taut and slack. Under these conditions, of course, panel lift, and thus the overall drag of the parachute, was reduced.

Effect of Velocity (Rate-of-Descent) Changes

The variation of drag coefficient with rate of descent is shown in figure 9 and no significant variation is apparent for the range tested. In figure 10, the variation of rate of rotation Ω of the parachutes with rate of descent is presented. In general, Ω varied linearly with V when the parachutes were rotating properly.

The test results, in general, indicated that the modified parachute provided the same rate of descent for a given weight as the basic parachute and therefore the modified parachute is considered more efficient as a drag device because it used relatively less cloth area. To provide the increased drag per unit of cloth area, the modified parachute rotated faster for a given rate of descent than did the basic parachute. The increased rate of rotation is apparently due to the fact that the cutouts in the modified parachute reduced the resistance of the parachute to rotation.

Correlation of Results

The results of the tests indicate that the modified rotary parachute produced approximately 2.8 times as much drag as a conventional flat circular parachute $\left(\text{assuming } C_{D,o} = 0.75;\text{ ref. } 4\right)$ of comparable total cloth area. Also, for the range of variables used, there appears to be an optimum range where the performance of the rotary parachute is not critical to small changes in the rigging of the parachute. This conclusion is based on the fact that the results indicated the existence of a considerable range of conditions where the drag coefficient was relatively high and approximately constant. For the rotary parachute tested in the present investigation, the range of the drag coefficients (approximately 1.7 to 2.1) agreed fairly well with wind-tunnel results presented in references 2 and 3, where the $C_{D,o}$ range of the rotary parachute was approximately 1.2 to 2.0. However, additional results, presented in reference 3, of free-fall tests of rotary parachutes indicated a lower $C_{D,o}$ range from approximately 0.8 to 1.5. The lower $C_{D,o}$ range probably resulted because the parachutes possibly were not rigged or adjusted properly. This reasoning is based on results of the present investigation (figs. 9 and 10) which indicated, as previously mentioned, that if the parachute was not rigged properly, in general, it was possible that either it would not rotate or would rotate slowly and erratically, thus resulting in relatively low drag coefficients varying approximately between 0.7 and 0.8.

In regard to Reynolds number effects on stability characteristics, comparison of results obtained from the present tests on the 64-inch-diameter model parachute with results of brief free-fall tests of a 32-foot-diameter rotary parachute at the Langley Research Center indicates no appreciable difference (both parachutes had oscillations of probably less than 1°). Concerning the effects of Reynolds number on $C_{D,o}$, the drag coefficient was not measured on the large parachute, but some results are available in references 2 and 3 to allow comparison with the results in the present investigation. However, the results indicate conflicting trends. Reference 2 indicates no appreciable difference in wind-tunnel-measured drag coefficients for the 32-inch-diameter and the 32-foot-diameter rotary parachutes. Reference 3 indicates that in one wind tunnel $C_{D,o}$ increased slightly with Reynolds number, whereas in another wind tunnel $C_{D,o}$ decreased slightly with Reynolds number. These results appeared to establish no definite trend in relation to the effect of Reynolds number on $C_{D,o}$.

Results of wind-tunnel tests of rotary parachutes presented in reference 2 indicated that although the opening reliability of the parachutes was good, some gore damage was sustained during some of the tests. Results of free-fall tests of rotary parachutes presented in reference 3 indicated that the opening reliability of these parachutes was only fair and that inflation characteristics of the individual gores appeared uneven, which apparently caused the severe gore damage during the tests. Data obtained from the free-fall tests conducted on a 32-foot-diameter rotary parachute at the Langley Research Center indicated that when the parachute was dropped it opened properly every time. However, these tests were brief, consisting of only eight drops. Although the test conditions used to determine the opening characteristics of the rotary parachutes were not exactly the same in the present investigation as in references 2 and 3, they were, in general, considered to be somewhat similar.

The use of a rotary parachute, such as tested in this investigation, as a recovery device appears promising. However, careful development tests to insure optimum drag and deployment characteristics should be made for any specific application.

CONCLUSIONS

An investigation has been made to determine the drag characteristics and dynamic stability in descent of a rotary parachute at subsonic speeds. The results indicated that when the parachute was operating properly the following conclusions are applicable:

1. The modified parachute (with cutouts) was more effective in producing drag than the basic configuration (without cutouts) in that the respective drag coefficients of about 2.1 and 1.7 based on total cloth area were obtained.

2. The parachute, in general, was extremely stable in descent, with oscillations of probably less than 1°.

3. Small changes in rigging had no appreciable effect on the performance of the parachute.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., June 6, 1962.

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4. Anon.: United States Air Force Parachute Handbook. WADC Tech. Rep. 55-265, ASTIA Doc. No. AD 118036, U.S. Air Force, Dec. 1956.

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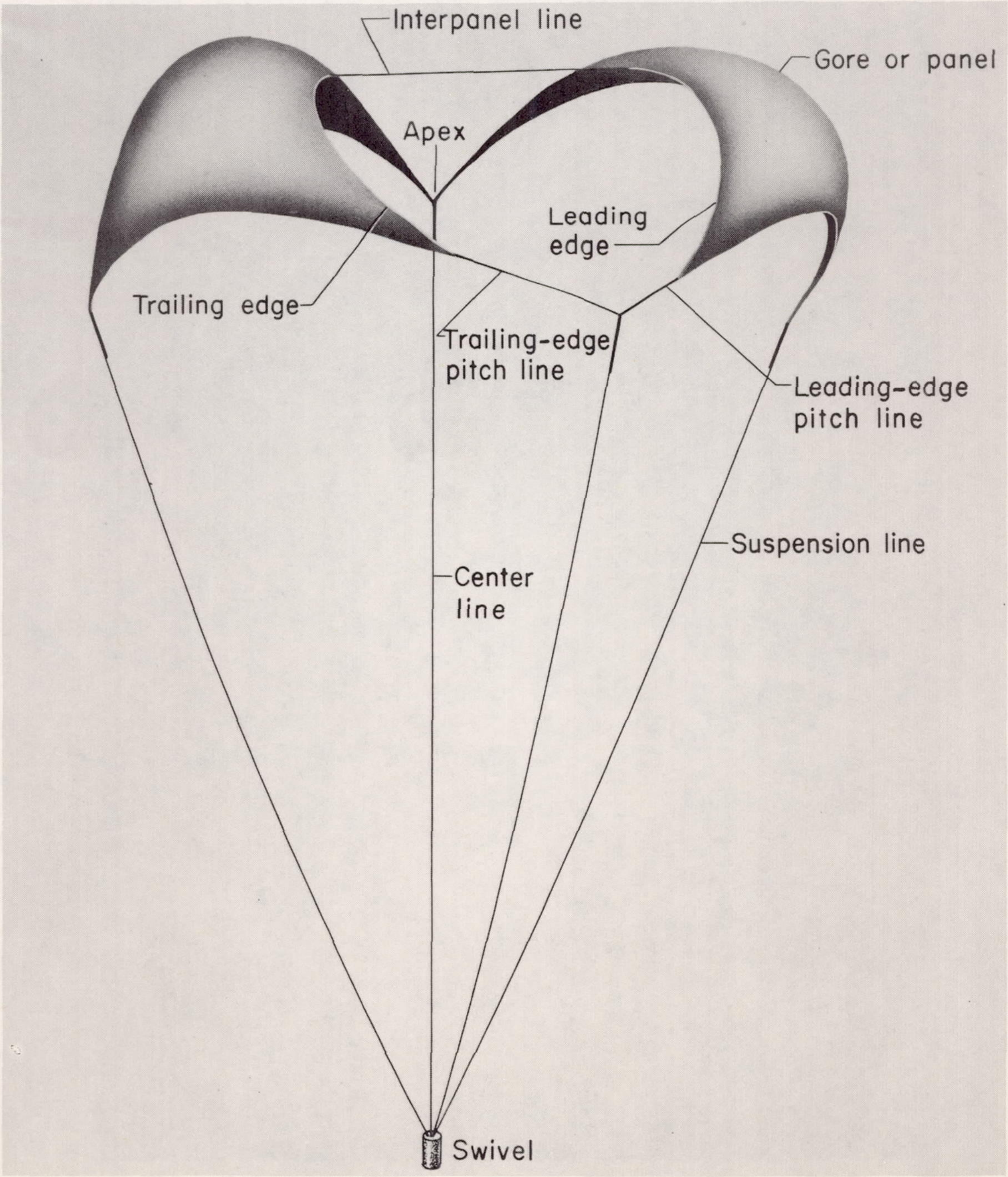

Figure 1.- Nomenclature of rotary parachute. For clarity only two of four adjacent gores are shown. Rotation is clockwise when viewed from above.

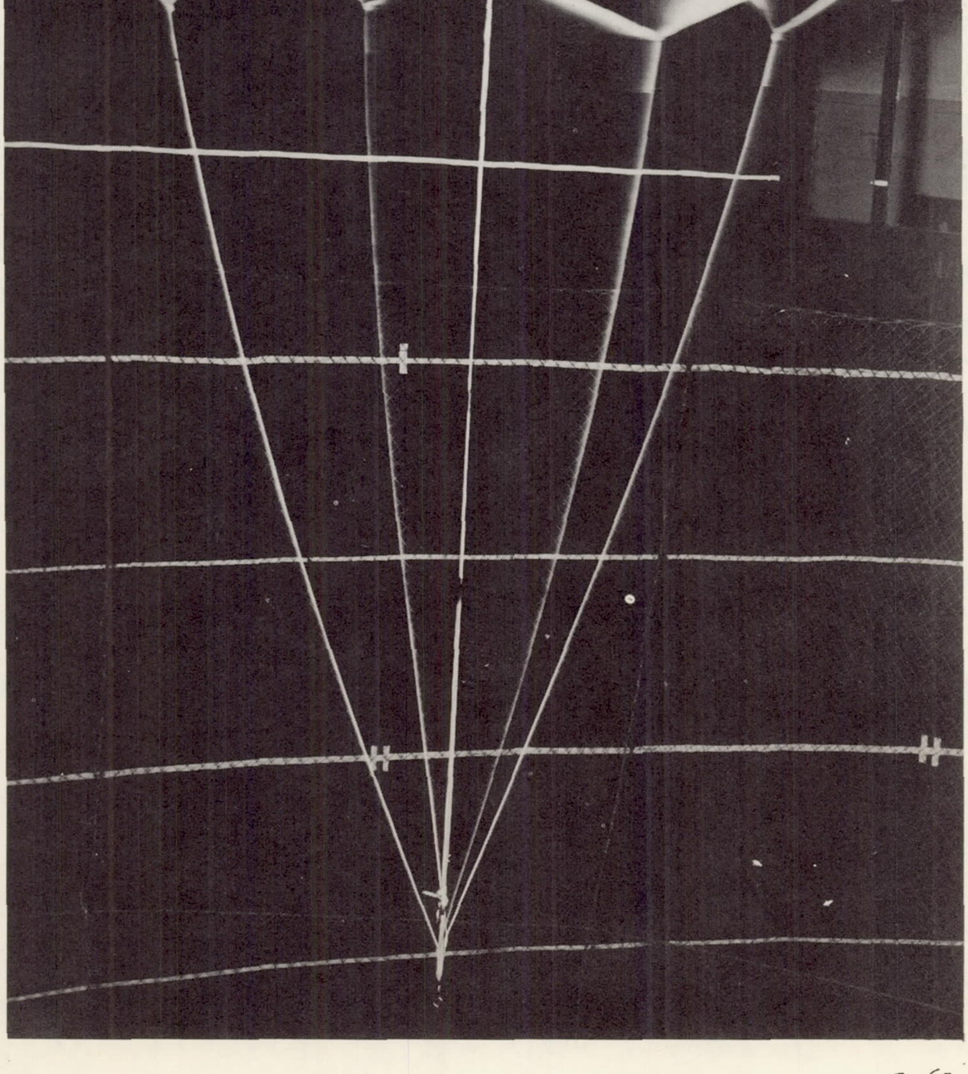

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Figure 2.- Photograph of basic rotary parachute in Langley 20-foot free-spinning tunnel. Rotation is clockwise when viewed from above.

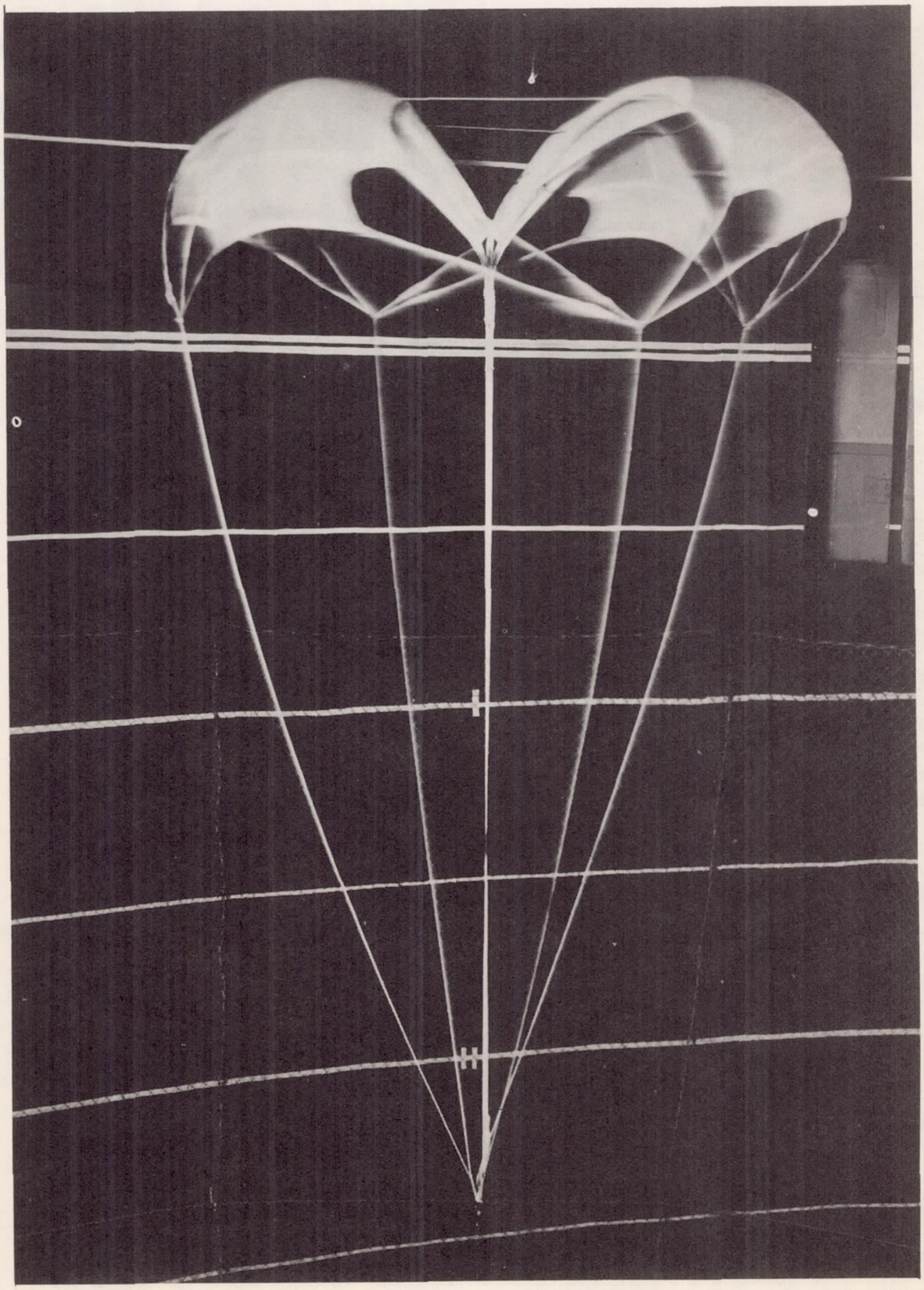

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Figure 3.- Photograph of modified rotary parachute in Langley 20-foot free-spinning tunnel. Rotation is clockwise when viewed from above.

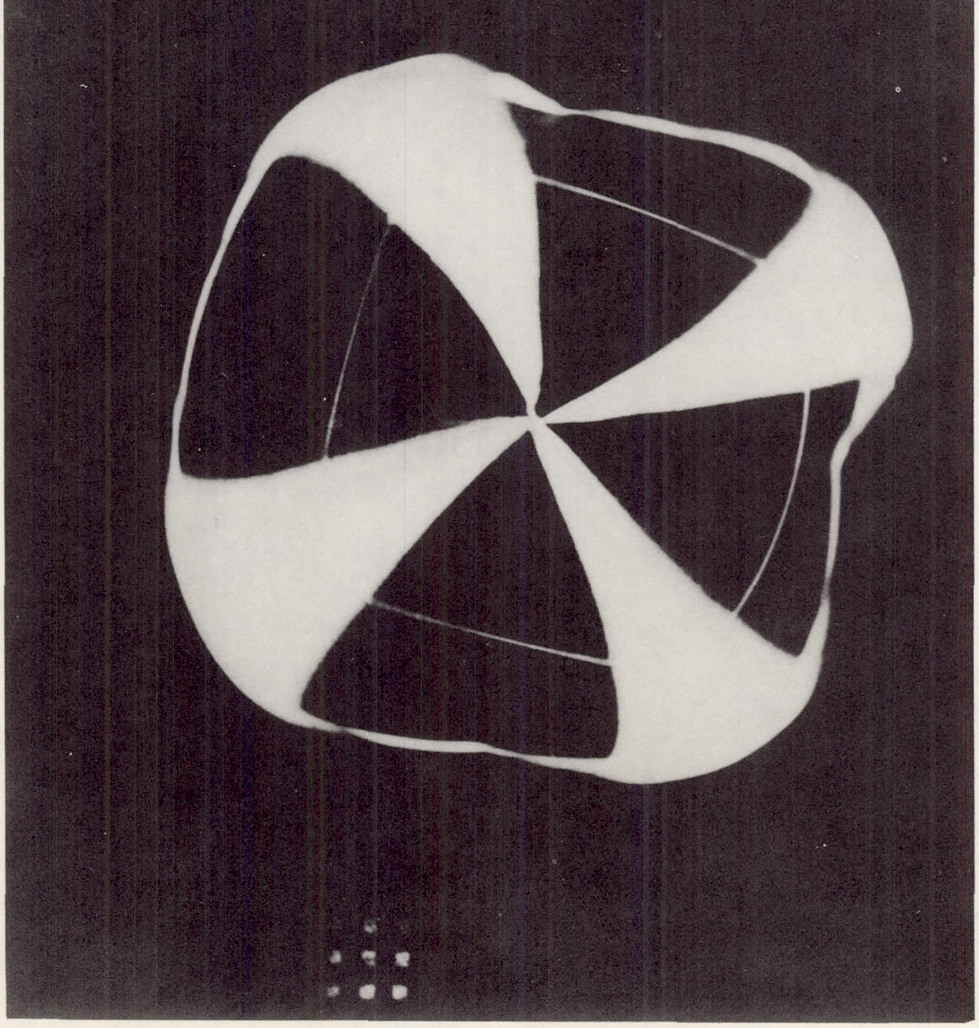

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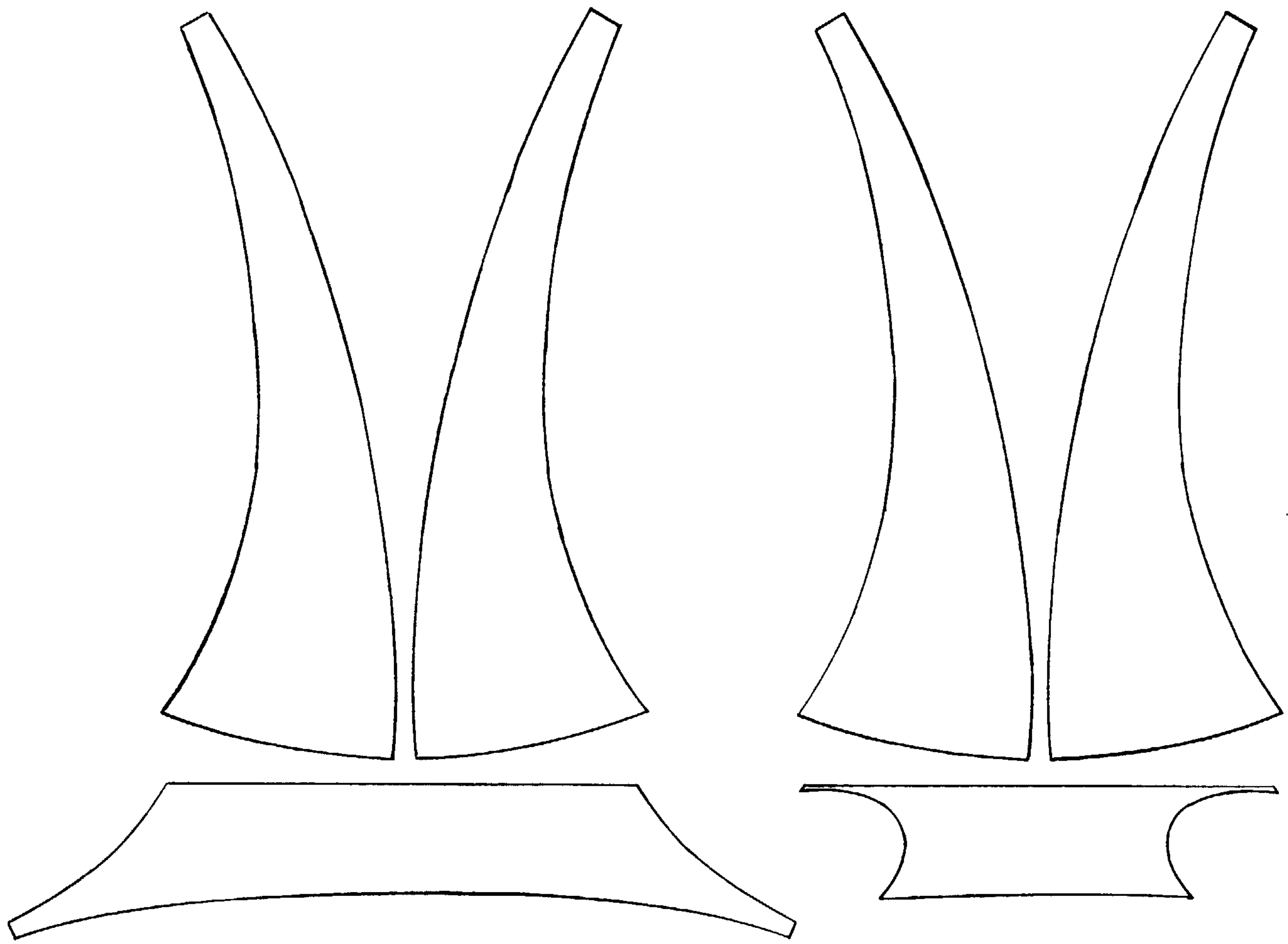
Figure 4.- Downstream view of rotary parachute in Langley 20-foot free-spinning tunnel. Rotation is clockwise.



(a) Basic (b) Modified.

Figure 5.- Gore patterns of rotary parachute laid out flat. To make one gore sew adjoining edges together. Rotary parachute has four gores. (Drawing is not to scale.)

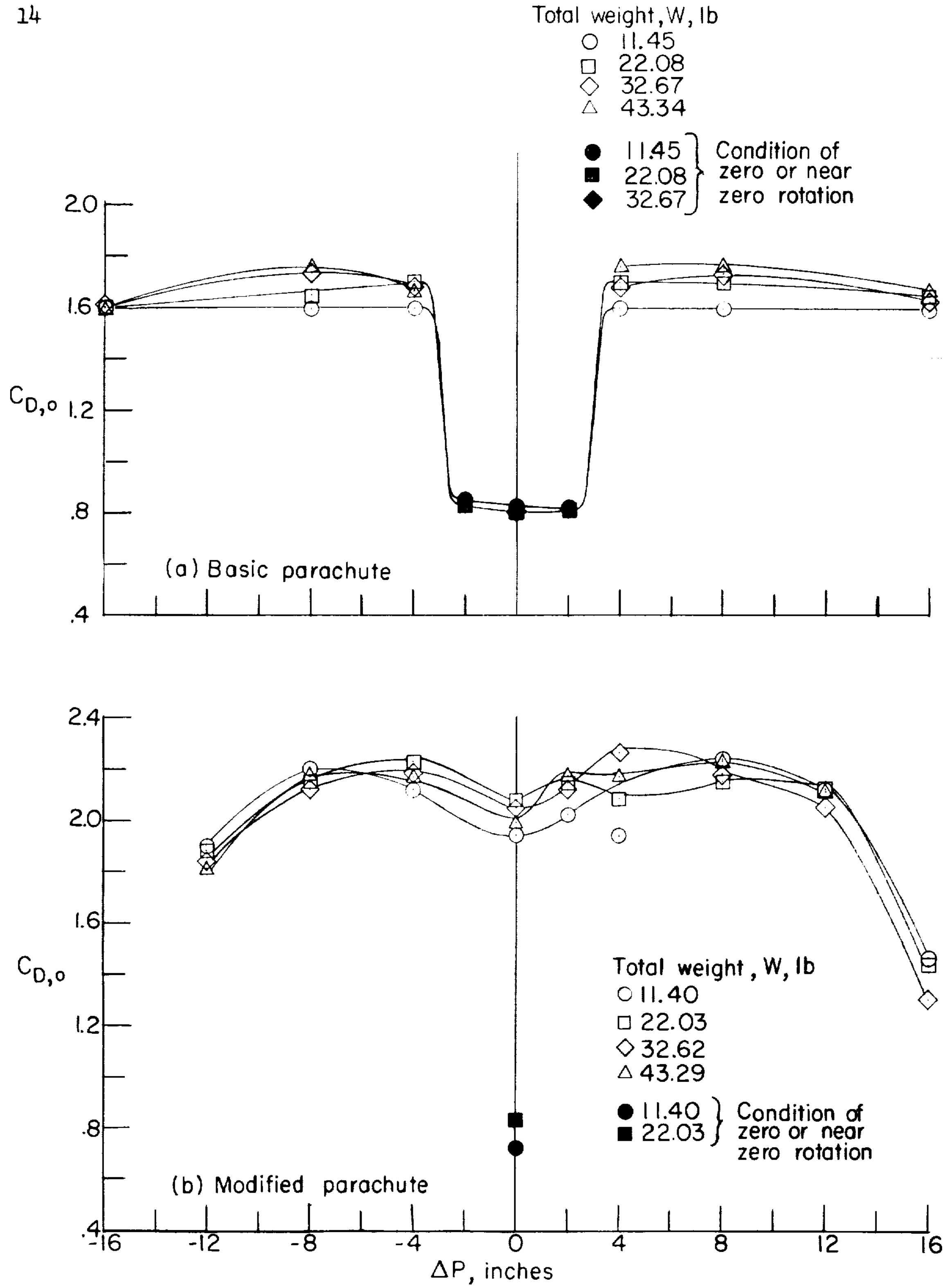


Figure 6.- Variation of $C_{D,o}$ with ΔP for basic and modified rotary parachutes. Suspension-line and center-line lengths equal $63\frac{1}{8}$ inches.

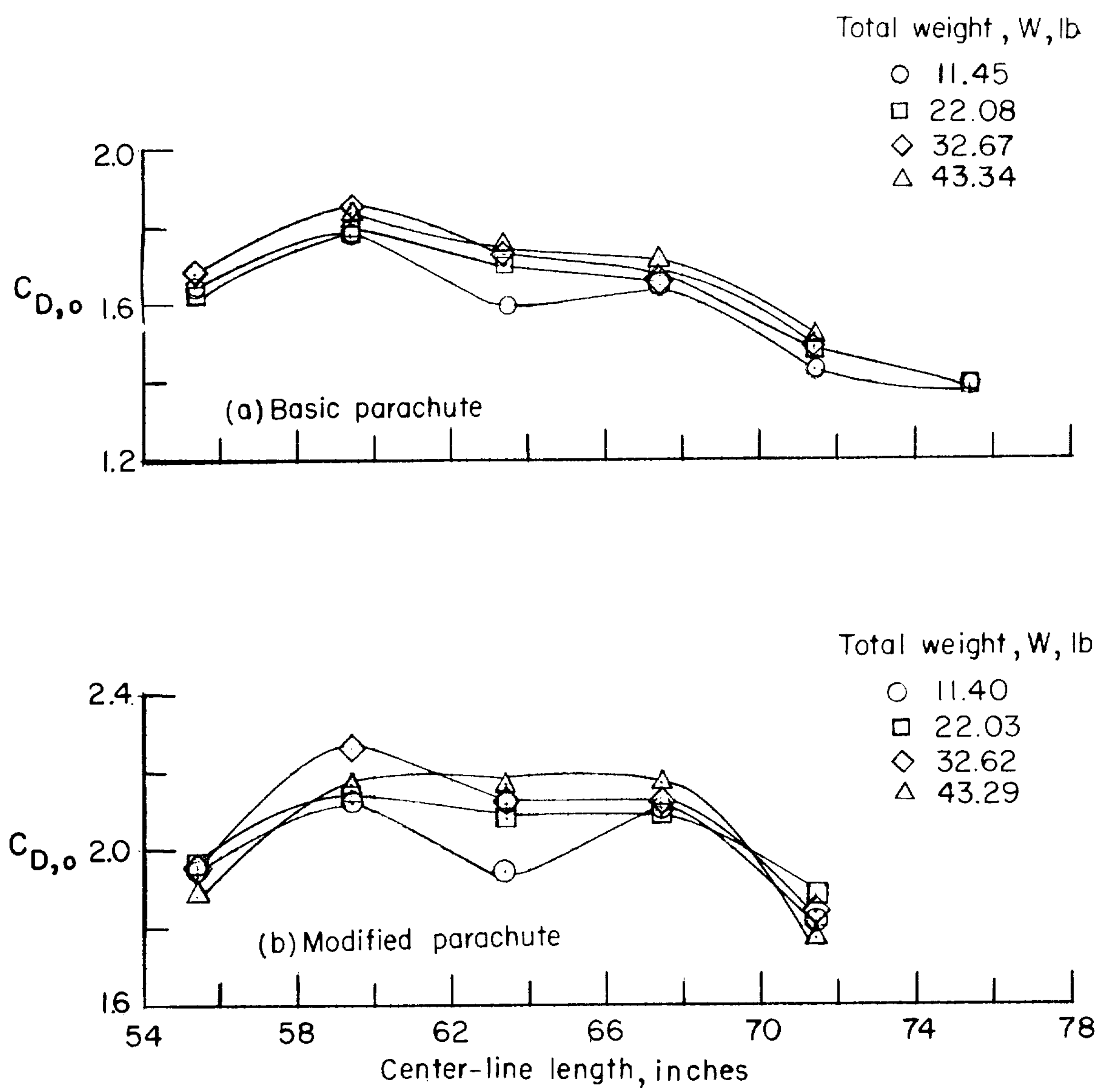


Figure 7.- Variation of $C_{D,o}$ with center-line length for basic and modified rotary parachutes. Suspension-line length equals $63\frac{1}{8}$ inches; ΔP = 8 inches.

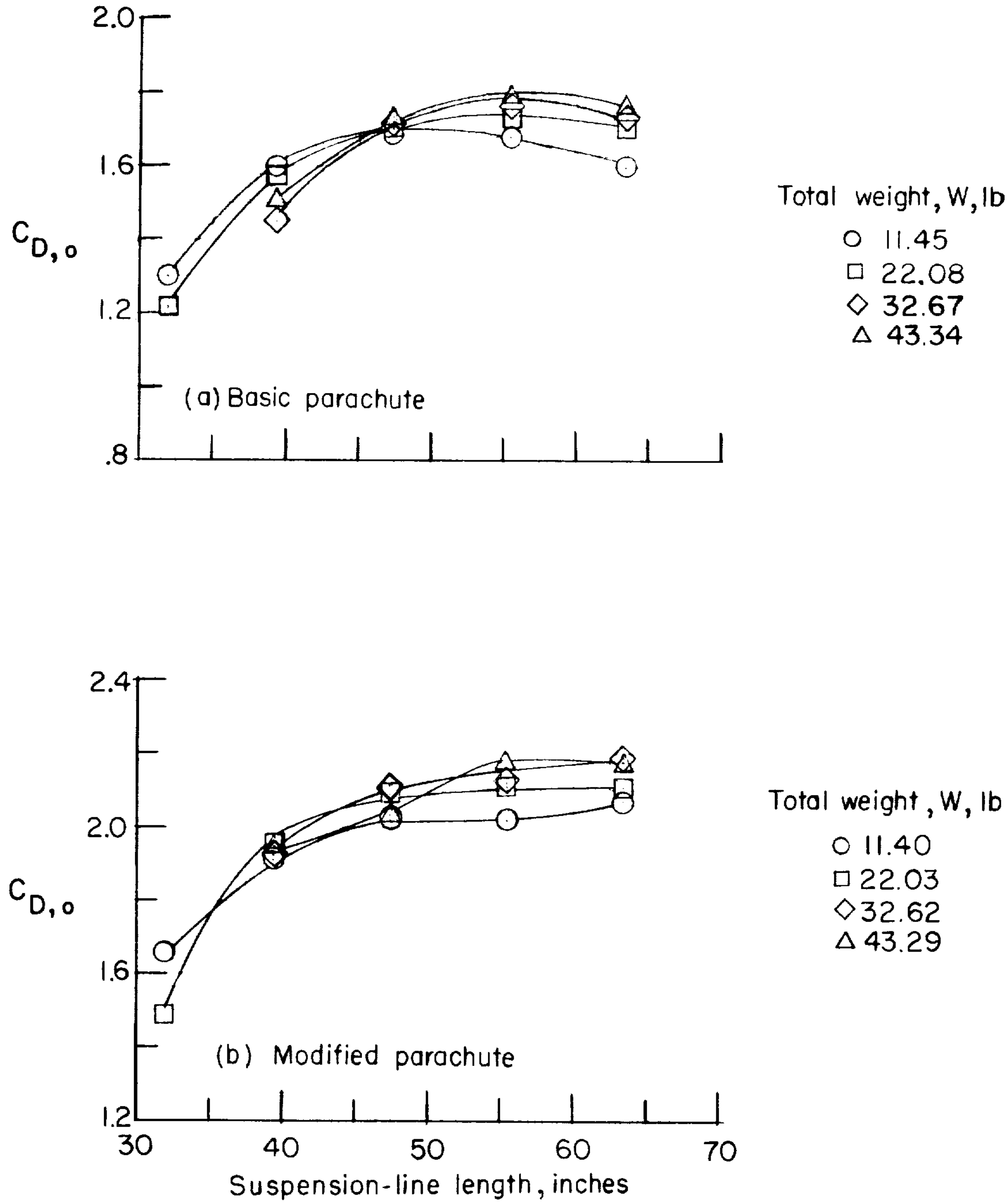


Figure 8.- Variation of $C_{D,o}$ with suspension-line length for basic and modified rotary parachutes. Center-line length equals $63\frac{1}{8}$ inches; ΔP = 8 inches.

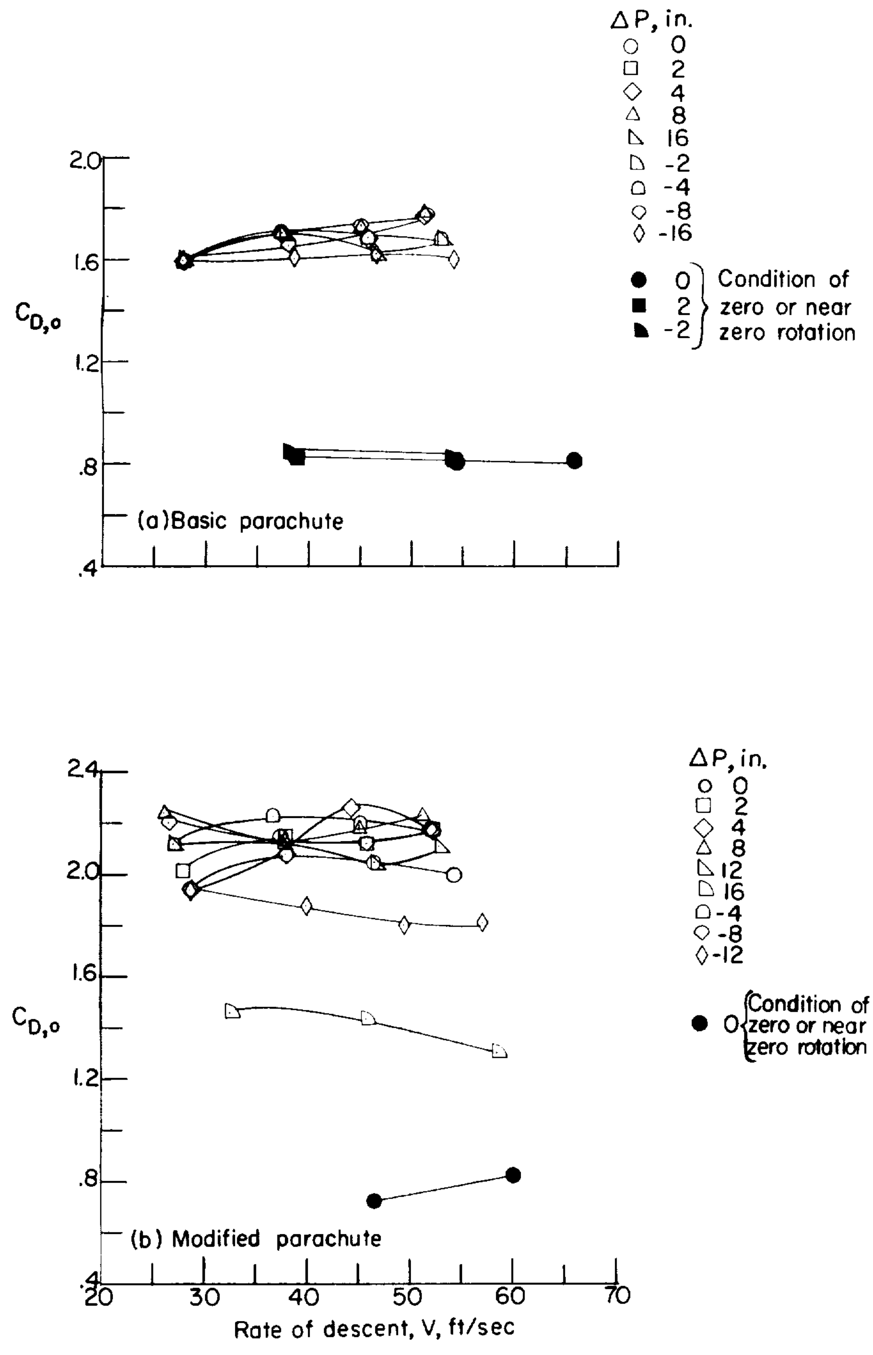


Figure 9.- Variation of $C_{D,o}$ with rate of descent for basic and modified rotary parachutes. Suspension-line and center-line lengths equal $63\frac{1}{8}$ inches.

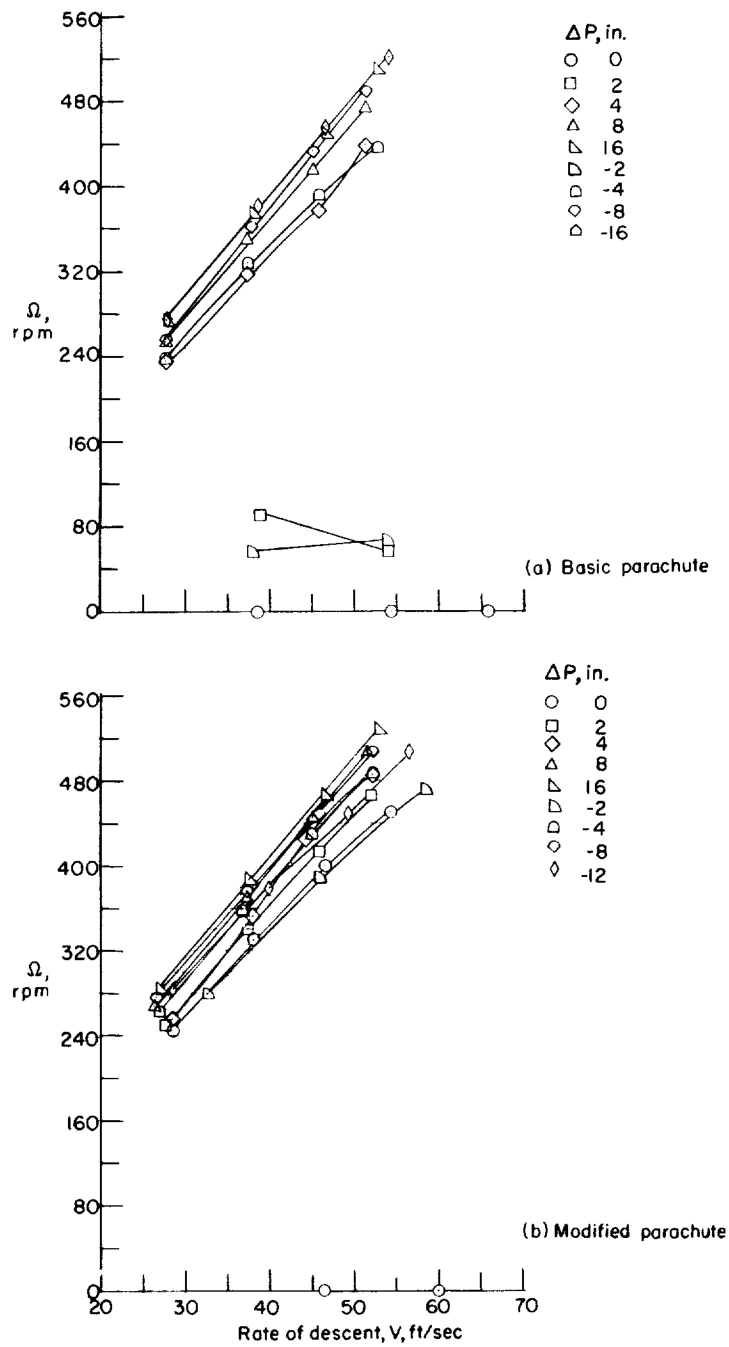


Figure 10.- Variation of rate of rotation with rate of descent for basic and modified parachutes. Suspension-line and center-line lengths equal $63\frac{1}{8}$ inches.