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# NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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# WIND-TUNNEL INVESTIGATION OF THE OPENING CHARACTERISTICS, DRAG, AND STABILITY OF SEVERAL HEMISPHERICAL PARACHUTES


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# WIND-TUNNEL INVESTIGATION OF THE OPENING CHARACTERISTICS, DRAG, AND STABILITY OF SEVERAL HEMISPHERICAL PARACHUTES

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## SUMMARY

An investigation has been conducted to determine the opening characteristics of several hemispherical parachutes at airspeeds up to 200 miles per hour and to study the influence of the parachute design variables on these opening characteristics. The effects of design variables on the drag and stability characteristics of the parachutes were also evaluated.

Some of the parachutes "blossomed" fully when opened in the air stream. Beneficial effects on the parachute opening characteristics were obtained when longer shroud lines relative to parachute diameter were used, when the floating hem lines were tacked to prevent the hem-line loops from pulling out under load, or when a strip of low-porosity fabric was provided around the canopy in the area immediately above the hem line. The drag characteristics of the parachutes were not appreciably affected by these changes in design. The stability characteristics of the parachutes were affected somewhat adversely by the use of the low-porosity fabric just above the hem line. For a given parachute, increased airspeeds generally impaired opening characteristics, lowered drag coefficients, and improved stability.

## INTRODUCTION

Before some types of airplanes are accepted by the Armed Services, the contractor is required to assure by flight tests that the airplane will be satisfactory in recovery from a spin. During the spin demonstration flights, the airplane is usually equipped with a tail parachute for use as an emergency spin-recovery device. In the past, flat-type parachutes made of silk or nylon such as is conventionally used in personnel-type parachutes have been successfully used to effect spin recovery both in flight and with dynamically scaled-down airplane models in the Langley 20-foot free-spinning tunnel. The use of conventional parachutes has been objected to, however, on the grounds that, because of their inherent instability, they cause dangerous pitching and yawing gyrations of the airplane when opened during level-flight check runs prior to the spin demonstration flights. Unpublished results of a recent NACA investigation indicate that a stable rather than a conventional parachute would be desirable for use as an emergency spin-recovery device. In connection with the aforementioned investigation it was noted that although the stability of a parachute could be improved by increasing the porosity of the fabric in the canopy, the opening characteristics of the parachute might be affected adversely, that is, the parachute might not "blossom" fully immediately upon being opened and its maximum potential drag would therefore not be obtained to effect rapid spin recovery.

The present investigation was made in order to obtain more information regarding the principal design variables that influence parachute opening characteristics. A parachute manufacturer made available to the NACA seven types of hemispherical parachutes for this investigation. A feature of the design of some of the parachutes was a strip of low-porosity material in the canopy area just above the hem line which the previously mentioned investigation had indicated would be beneficial to opening characteristics. Each of the hemispherical parachutes differed somewhat in design and an attempt was made to evaluate generally the effects of shroud-line length, fabric porosity and weight, and hem-line construction upon opening characteristics. Tests were also made to determine the effects of some of these design variables on the drag and stability characteristics of the hemispherical parachutes.

Motion pictures of the opening characteristics of the parachutes were obtained during the tests and are available for loan upon request from NACA Headquarters, Washington, D. C.

## SYMBOLS

$L$ length of parachute shroud lines, feet

$D$ projected hemispherical diameter of parachute, feet

$q$ dynamic pressure, pounds per square foot $\left(\frac{1}{2}\rho V^2\right)$

$V$ airspeed, feet per second

$\rho$ density of air, slugs per cubic foot

$S$ projected area of parachute, square feet $\left(\frac{\pi D^2}{4}\right)$

$C_D$ drag coefficient of parachute $\left(\frac{\text{Drag}}{qS}\right)$

## APPARATUS

### Wind Tunnels

Tests to determine the opening characteristics of the various hemispherical parachutes were made in the Langley 300 MPH 7- by 10-foot tunnel, which is a horizontal atmospheric wind tunnel. Tests to determine the drag and stability characteristics of the parachutes were made both in the Langley 300 MPH 7- by 10-foot tunnel and in the Langley 20-foot free-spinning tunnel. The Langley 20-foot free-spinning tunnel is a vertical atmospheric wind tunnel with a vertically rising air stream.

### Parachutes

The parachutes used in this investigation had preformed hemispherical canopy shapes. The construction and dimensions of the parachutes as well as the porosity and weight of the canopy fabrics are shown in figures 1 to 7. The porosities given for the material in the parachutes were obtained from the manufacturer and are presented as the cubic feet of air that will pass through 1 square foot of the cloth per minute under a pressure of 1/2 inch of water. The weight of the nylon presented in the figures indicates the approximate weight of 1 square yard of the cloth. The parachutes were constructed with floating hem lines. (See fig. 8.) During many of the tests, the hem lines were tacked (fig. 9) to prevent the hem-line loops from pulling out and thus distorting the parachute shape during opening.

## METHODS AND TESTS

For testing the opening characteristics of the parachutes in the Langley 300 MPH 7- by 10-foot tunnel, the packed parachute with its towline was fastened to a cable which in turn was fastened to the tunnel balance scale. When an airspeed of about 200 miles per hour was attained, the pack was opened from outside the tunnel by pulling a chord attached to a pin which held a canvas restraining wrapper on the parachute pack. The ensuing action of the parachute was then observed and motion pictures were made of the tests. A pictorial sketch of an open parachute in the Langley 300 MPH 7- by 10-foot tunnel is presented in figure 10.

For the parachutes which blossomed fully when opened in the Langley 300 MPH 7- by 10-foot tunnel, drag-force measurements were made for an airspeed of 200 miles per hour. In the Langley 20-foot free-spinning tunnel, the drag of the parachute was determined from free tests during which the fully blossomed parachute supported a small spherical weight in the vertically rising air stream. The drag of the parachute was then taken to be equal to the sum of the weight of the parachute and the suspended weight. The drag coefficients calculated were based on the projected area of the hemispherical canopies. The tunnel airspeed during these tests was approximately 17 miles per hour.

The stability of each parachute which blossomed fully at 200 miles per hour in the Langley 300 MPH 7- by 10-foot tunnel was determined by observing its behavior at this speed. Also, the stability of each parachute was determined at a speed range of 30 to 46 miles per hour for the fully blossomed parachutes which were fastened to a horizontal bar in the Langley 20-foot free-spinning tunnel. At a given airspeed, parachutes which alined themselves with the air stream or which inclined no more than a few degrees ($3^{\circ}$ or $4^{\circ}$) from the air stream and did not oscillate were considered stable.

## RESULTS AND DISCUSSION

The results of the investigation to determine the opening and stability characteristics of the parachutes are presented in table I. All parachutes which blossomed fully or even opened to a pear shape withstood the force of the air at 200 miles per hour without tearing. The results of drag measurements are shown in figure 11.

### Parachute Opening Characteristics

Effect of shroud-line length.- Parachute 1 did not blossom to a hemispherical shape when the pack was opened at 208 miles per hour but rather opened to a pear shape. Parachutes 2 and 3 did not open so fully as did parachute 1 in spite of the fact that parachutes 2 and 3 were constructed with low-porosity fabric in the canopy area just above the hem line (figs. 2 and 3), which, according to previous experience (unpublished data), should be beneficial to opening characteristics. It appears that the poorer opening characteristics of parachutes 2 and 3 were caused by their lower ratio of shroud-line length to parachute diameter (1 as compared with 3 for parachute 1). This result is in agreement with unpublished British data which show that long shroud-line length relative to parachute diameter is desirable for good opening characteristics of parachutes. Film strips showing the opening of parachutes 1 and 2 are presented in figure 12.

Effect of hem-line tacking.- As previously indicated, the parachutes were constructed with a floating hem line, the operation of which is shown in figure 8; parachutes 1, 2, and 3 all had this type of hem line when tested. In an attempt to obtain satisfactory opening characteristics of parachutes 2 and 3 at 200 miles per hour, the hem lines of these parachutes were tacked in such a manner as to prevent the hem-line loops from pulling out appreciably. (See fig. 9.) With the hem lines tacked, the parachutes blossomed fully at 200 miles per hour except for a slight contraction caused by the shroud lines' pulling out small loops of the hem chord. Film strips showing the opening of parachute 2 with its hem line tacked are presented in figure 13. It is believed that had the hem line been tacked completely the slight contraction of the parachute would not have occurred. Because tacked hem lines had such a beneficial effect on the opening characteristics of parachutes 2 and 3, all the parachutes subsequently tested were tested only with tacked hem lines.

Effect of fabric porosity.- Parachute 5 (fig. 5) did not open in the air stream at an airspeed of 200 miles per hour. As the airspeed was reduced, the parachute tended to open a little but still did not open fully. The failure of this parachute to open was probably due to the fact that the entire canopy was constructed of high-porosity fabric (502), which result is in general agreement with previous experience. Parachute 6 (fig. 6) also did not open in the air stream at 200 miles per hour. Parachute 6 was generally similar in construction to parachutes 2, 3, and 4, but the fabric porosity in the region just above its hem line was higher (162 as compared with 96, 137, and 118, respectively). The failure of parachutes 5 and 6 to open in the air stream may be a further substantiation of the fact that a region of low-porosity fabric immediately above the tacked hem line of a parachute has a favorable effect on its opening characteristics.

Effect of fabric weight.- The weight of the fabric appeared to have little effect upon the opening characteristics of the parachutes.

Effect of crown vent.- Parachute 7 differed from the other parachutes tested primarily in that it had a single-thickness low-porosity crown with a high-porosity vent. The parachute opened to a pear shape at 200 miles per hour in a manner similar to parachute 1. As the speed was lowered, it opened more than at high speeds but it still did not open fully. Comparison of the construction of parachute 7 (fig. 7) with that of parachute 1 (fig. 1) indicates that in addition to differences in crown construction, parachute 7 differed from parachute 1 in that it had lower porosity in the main body of its canopy, had a tacked hem line, and had a lower ratio of shroud-line length to parachute diameter. The first two differences should have been beneficial to opening characteristics of parachute 7, whereas the third should have impaired its opening characteristics. Inasmuch as the quantitative effects of the aforementioned design differences were not known, an evaluation was not possible of the effect of the differences in the crown nor the effect of the vent. A comparison of parachute 7 with parachute 2 indicates that, in addition to differences in crown construction, parachute 2 had a region of low-porosity fabric immediately above the hem line. The results indicate that alteration of the crown construction, including the addition of the vent, did not tend to improve opening characteristics as much as the installation of the low-porosity fabric immediately above the hem line.

## Effect of Design Variables on Parachute Drag Characteristics

The drag coefficients obtained for each parachute tested in the Langley 20-foot free-spinning tunnel (at approx. 17 mph) are plotted as a function of the porosity of the fabric of the large middle panel of the parachute canopy. (See fig. 11.) Included in figure 11 for comparison is a curve from a previous investigation showing the variation of parachute drag coefficient with parachute porosity. For the previous tests, each hemispherical parachute had its entire canopy made of material of a given porosity. The test points for the present investigation fall along the previously established curve and the results indicate that the parachute design variables investigated did not appreciably affect the drag characteristics of the hemispherical parachutes.

Drag coefficients obtained for the parachutes in the Langley 300 MPH 7- by 10-foot tunnel (at approx. 200 mph) are also plotted in figure 11. All these drag coefficients are appreciably lower than those obtained at low speeds in the free-spinning tunnel. The decrease in drag coefficients may have been due in part to distortion or changes in the parachute fabric with the increase in airspeed which may have resulted in greater porosity. This result is in general agreement with previous NACA data which indicated that when a hemispherical parachute was opened at low speed, the drag coefficients decreased as the speed was increased to 200 miles per hour even though the parachute remained fully blossomed. In addition to fabric distortion, the slight contraction of the parachutes when opened at 200 miles per hour (table I) may have been a factor contributing toward the decrease in drag coefficients.

## Effect of Design Variables on Parachute Stability Characteristics

The results of the investigations made to determine the stability of the parachutes are presented, as mentioned previously, in table I. Only parachutes 1 (porosity 400) and 5 (porosity 502) were stable at all airspeeds tested. The results obtained with these two parachutes indicate that the stability of a parachute improves as the porosity increases and that for porosities over 400 the angle a parachute makes with the air stream approaches zero. These results are in agreement with previous NACA experience.

The effect of shroud-line length on the stability of a parachute has not been specifically determined during the present investigation but previous experience has indicated it to be small. Since parachutes 2, 3, 4, 6, and 7 were not stable at 30 to 46 miles per hour, it appears that the use of low-porosity fabric near the hem line impaired the stability characteristics of the parachutes somewhat for these speeds. At 200 miles per hour no appreciable adverse effect of low-porosity fabric near the hem line was indicated. A general comparison of the stability indicated for the parachutes at 200 miles per hour and at 30 to 46 miles per hour indicated greater stability for a given parachute at the higher airspeed. As previously discussed, possible distortion in the parachute fabric at high speed may have effectively increased the porosity. This possible increase in porosity may explain the increase in stability.

As shown in table I, parachute 4 was somewhat less stable at all airspeeds tested than were parachutes 2 and 3. This difference in stability may be a result of the appreciably greater weight of the fabric in parachute 4 as compared with the fabric used in the other two parachutes. This single test result indicates that fabric weight may be a secondary factor contributing to parachute stability.

It should be possible to develop a hemispherical or other type of parachute that will blossom fully and quickly and yet be stable, such as is desirable for spin-recovery parachutes, by application of the principles and results discussed herein. These results indicate that as airspeed is increased, the opening and drag characteristics of a given parachute are affected adversely, whereas the stability characteristics are improved. Proposed parachute designs should be checked by testing the full-scale parachutes at the desired airspeeds before being selected for a specific use.

## CONCLUSIONS AND RECOMMENDATIONS

On the basis of the results of investigations of several hemispherical parachutes to study their opening characteristics and to evaluate the effects of the parachute design variables on the opening, drag, and stability characteristics of the parachutes, the following conclusions and recommendations are made:

1. Some of the parachutes blossomed fully in the air stream if their hem lines were tacked.

2. In general, beneficial effects on hemispherical-parachute opening characteristics were obtained when greater shroud-line length as compared with parachute diameter was used, when the floating hem lines were tacked to prevent the hem-line loops from pulling out under load, or when a strip of low-porosity fabric was provided around the canopy in the area immediately above the hem line.

3. The drag characteristics of the parachutes were not appreciably affected by changes in shroud-line length, by tacking of hem lines, or by use of a low-porosity-fabric strip above the hem line.

4. The stability characteristics of the parachutes were affected somewhat adversely by the use of the low-porosity fabric just above the hem line.

5. For a given parachute, increased airspeeds generally impaired opening characteristics, decreased the drag coefficient, and improved the stability.

6. Proposed parachute designs should be checked by testing of full-scale parachutes at the desired airspeeds before being selected for a specific use.

Langley Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Air Force Base, Va., February 17, 1949

TABLE I

OPENING AND STABILITY CHARACTERISTICS OF VARIOUS HEMISPHERICAL PARACHUTES DETERMINED FROM TESTS IN

THE LANGLEY 300 MPH 7- BY 10-FOOT TUNNEL AND THE LANGLEY 20-FOOT FREE-SPINNING TUNNEL

[Unless otherwise indicated all parachutes were 30 in. in diam., had 16 shroud lines, had ratio of shroud-line length to parachute diam. of 1, had tacked hem lines, and had double-thickness crown]

| Parachute | Porosity (cu ft/sq ft/min at 1/2 in. of water) | | Weight of nylon (oz/sq yd) | | Opening characteristics | | Stability characteristics | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | At 200 mph | At 30 to 46 mph | |
| | Fabric immediately above hem line | Fabric in main panel and in crown | Fabric immediately above hem line | Fabric in main panel and in crown | Description of test | Behavior of parachute | | Maximum angle parachute made with air stream (deg) | Comments |
| a,b,c1 | 400 | 400 | d1.5 to 2.0 | d1.5 to 2.0 | Parachute pack opened at tunnel airspeed of 208 mph | Parachute opened and assumed pear shape | ---------- | 4 | Parachute was very steady in air stream |
| | | | | | Tunnel airspeed reduced from 208 mph to 0 mph | Parachute retained pear shape as speed was reduced | ---------- | ------------- | ------------- |
| c2 | 96 | 362 | 1.38 | 1.49 | Parachute pack opened at tunnel airspeed of 200 mph | Parachute opened only partially; whipping action caused parachute to start tearing | ---------- | ------------- | ------------- |
| | | | | | Airspeed reduced | Parachute tended to open a little | ---------- | ------------- | ------------- |
| | | | | | Parachute forced open by hand at low airspeed, then airspeed increased gradually to 200 mph | Parachute remained open as airspeed was increased until at 200 mph parachute suddenly collapsed again to partially open condition | ---------- | ------------- | ------------- |
| c3 | 137 | 404 | 2.18 | 4.81 | Parachute pack opened at tunnel airspeed of 200 mph | Results similar to those for parachute 2 | ---------- | ------------- | ------------- |
| 2 | 96 | 362 | 1.38 | 1.49 | Parachute pack opened at tunnel airspeed of 200 mph | Parachutes blossomed fully except for slight reduction in diameter caused by shroud lines' pulling out small loops of the hem chord | Parachutes were fairly steady with slight tendency to rotate | 10 | Parachute 2 tended to circle around slowly and occasionally made angle of 0° with air stream |
| 3 | 137 | 404 | 2.18 | 4.81 | | | | 8 | |

[a]Parachute 11.84 in. in diameter.
[b]Ratio of shroud-line length to parachute diameter, 3.
[c]Hem line not tacked.
[d]Estimated.

TABLE I – Concluded

OPENING AND STABILITY CHARACTERISTICS OF VARIOUS HEMISPHERICAL PARACHUTES DETERMINED FROM TESTS IN THE LANGLEY 300 MPH 7- BY 10-FOOT TUNNEL AND THE LANGLEY 20-FOOT FREE-SPINNING TUNNEL – Concluded

| Parachute | Porosity (cu ft/sq ft/min at 1/2 in. of water) | | Weight of nylon (oz/sq yd) | | Opening characteristics | | Stability characteristics | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | At 30 to 46 mph | |
| | Fabric immediately above hem line | Fabric in main panel and in crown | Fabric immediately above hem line | Fabric in main panel and in crown | Description of test | Behavior of parachute | At 200 mph | Maximum angle parachute made with air stream (deg) | Comments |
| 3 | 137 | 404 | 2.18 | 4.81 | Hem line of parachute forced completely open, airspeed increased to 200 mph | Parachute contracted slightly as shroud lines pulled out small loops of the hem chord | ---------- | --------------- | ------- |
| 4 | 118 | 438 | 7.94 | 6.15 | Parachute pack opened at tunnel airspeed of 200 mph | Parachute blossomed same as 2 and 3 with tacked hem line | Parachute floated at small angle with air stream and was not as steady as parachutes 2 and 3 with tacked hem lines | 11 | Parachute tended to move back and forth and occasionally made angle of 0° with air stream |
| 5 | 502 | 502 | 4.5 | 4.5 | Parachute pack opened at tunnel airspeed of 200 mph | Parachute did not open; whipping action caused parachute to start tearing | ----------- | 0 | Parachute was very steady in air stream |
| | | | | | Airspeed reduced | Parachute tended to open a little | ----------- | ------------- | -------- |
| 6 | 162 | 407 | 2.24 | 2.14 | Parachute pack opened at tunnel airspeed of 200 mph | Parachute did not open | ----------- | 8 | -------- |
| | | | | | Airspeed reduced | Parachute tended to open in a pear shape | ----------- | ------------- | -------- |
| [a]7 | 318 | Main panel, 318 Crown, 137 | 1.38 | Main panel, 1.38 Crown, 2.3 | Parachute pack opened at tunnel airspeed of 200 mph | Parachute opened and assumed pear shape | ----------- | 6 | Parachute moved continuously back and forth in air stream |
| | | | | | Airspeed reduced | Parachute opened more fully but was not fully open even at low airspeeds | ----------- | ------------- | -------- |
| | | | | | Airspeed increased | Parachute again became pear shaped | ----------- | ------------- | -------- |

[a]Single-thickness crown with crown vent of 4.50 oz/sq yd nylon, porosity 502.

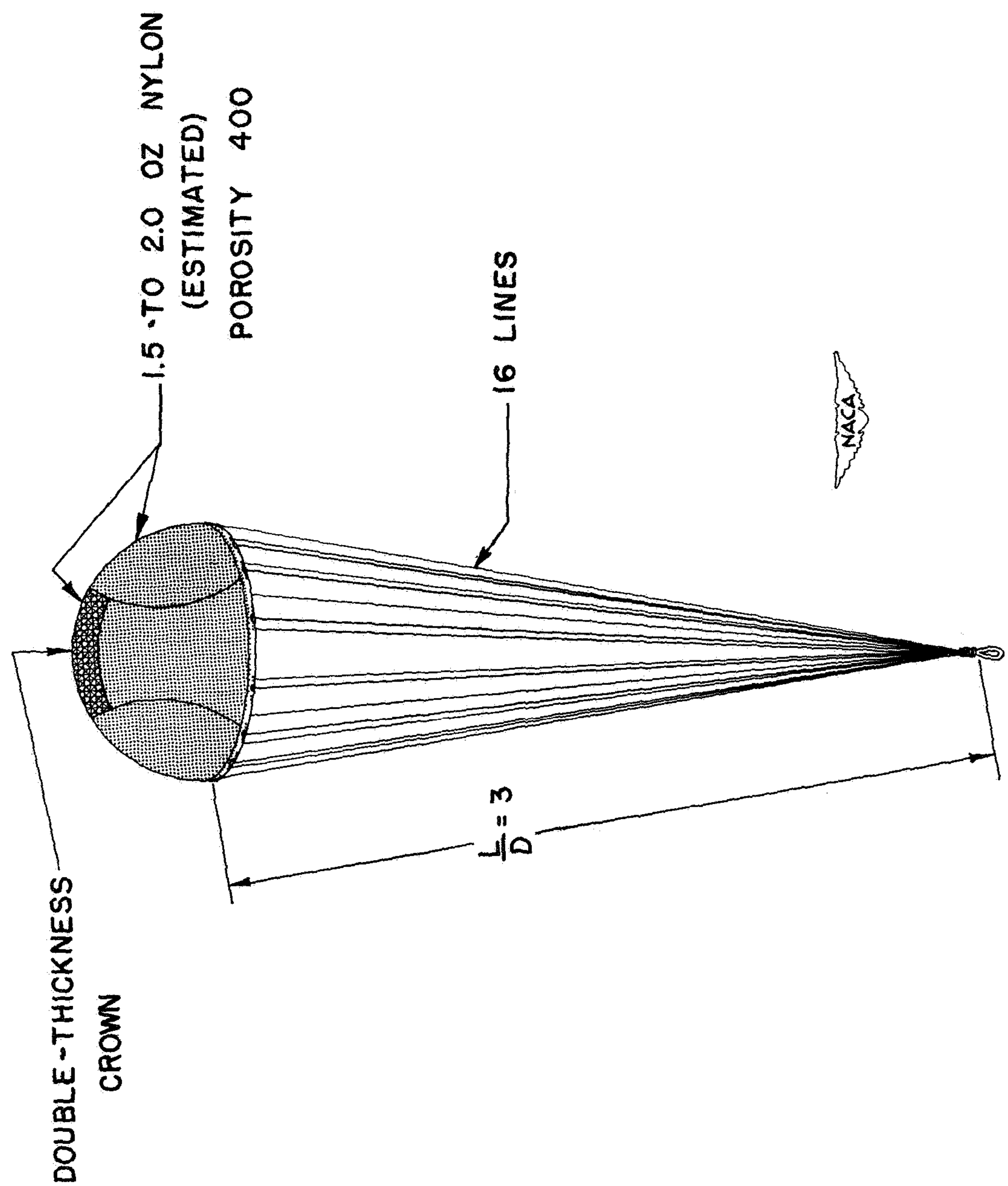


Figure 1.- Parachute 1; 11.84-inch diameter.

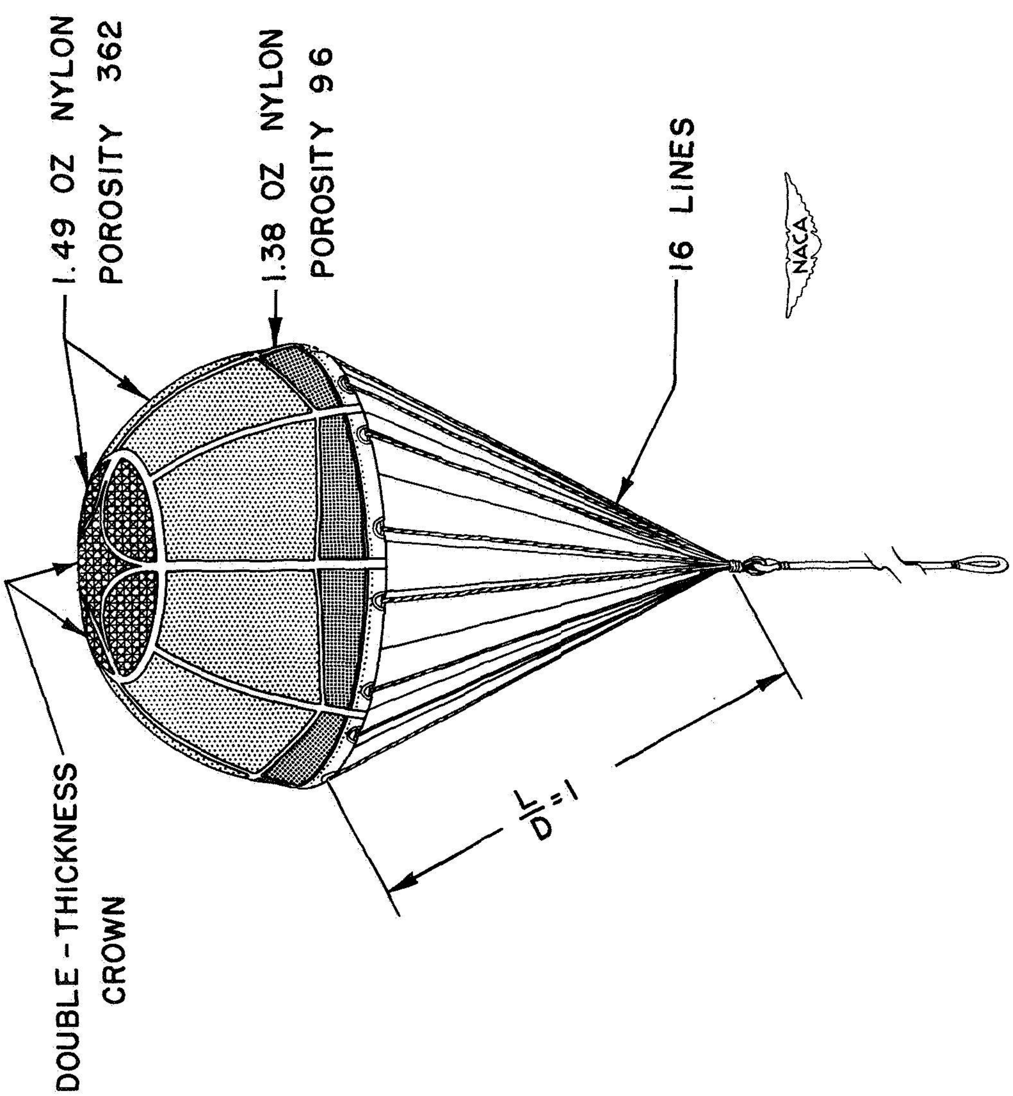


Figure 2.- Parachute 2; 30-inch diameter.

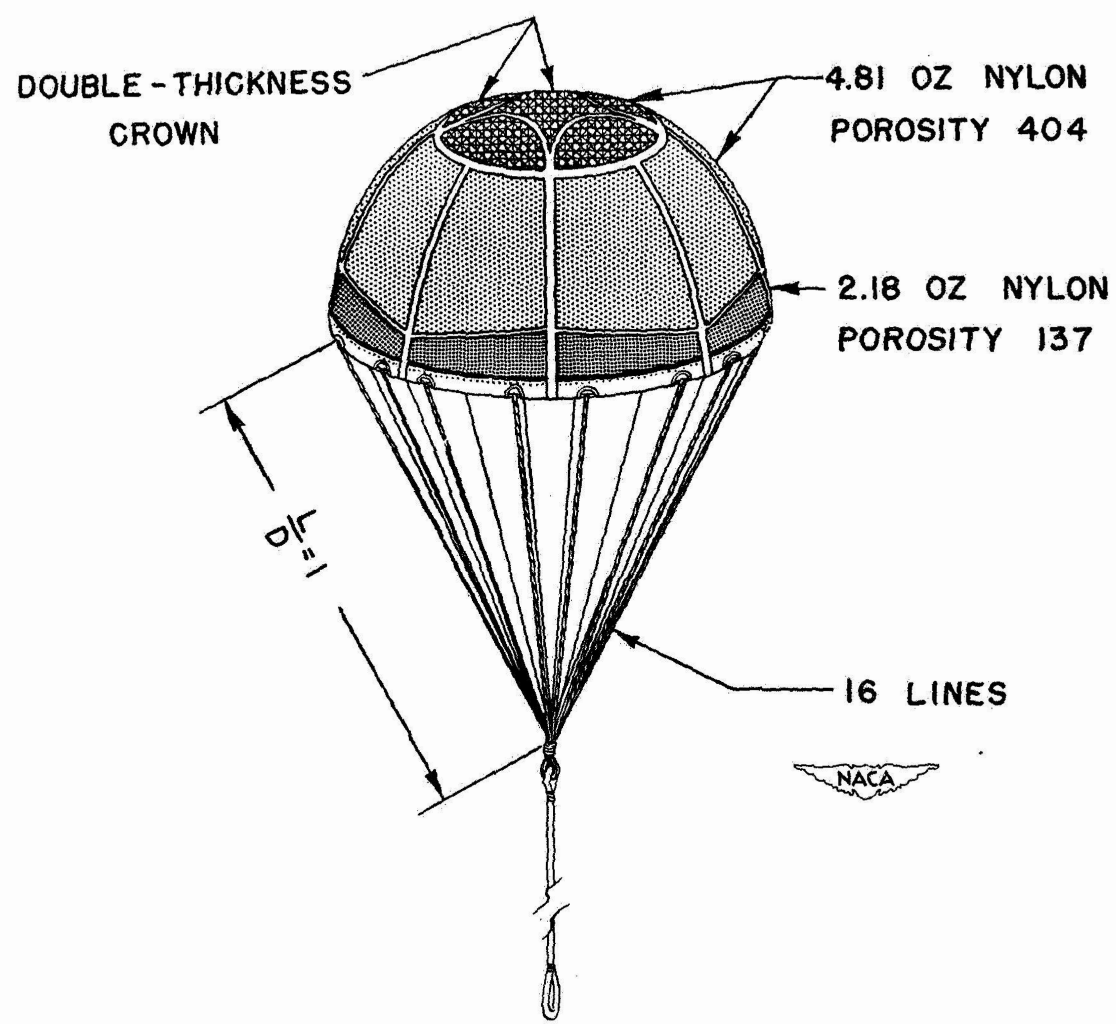


Figure 3.– Parachute 3; 30-inch diameter.

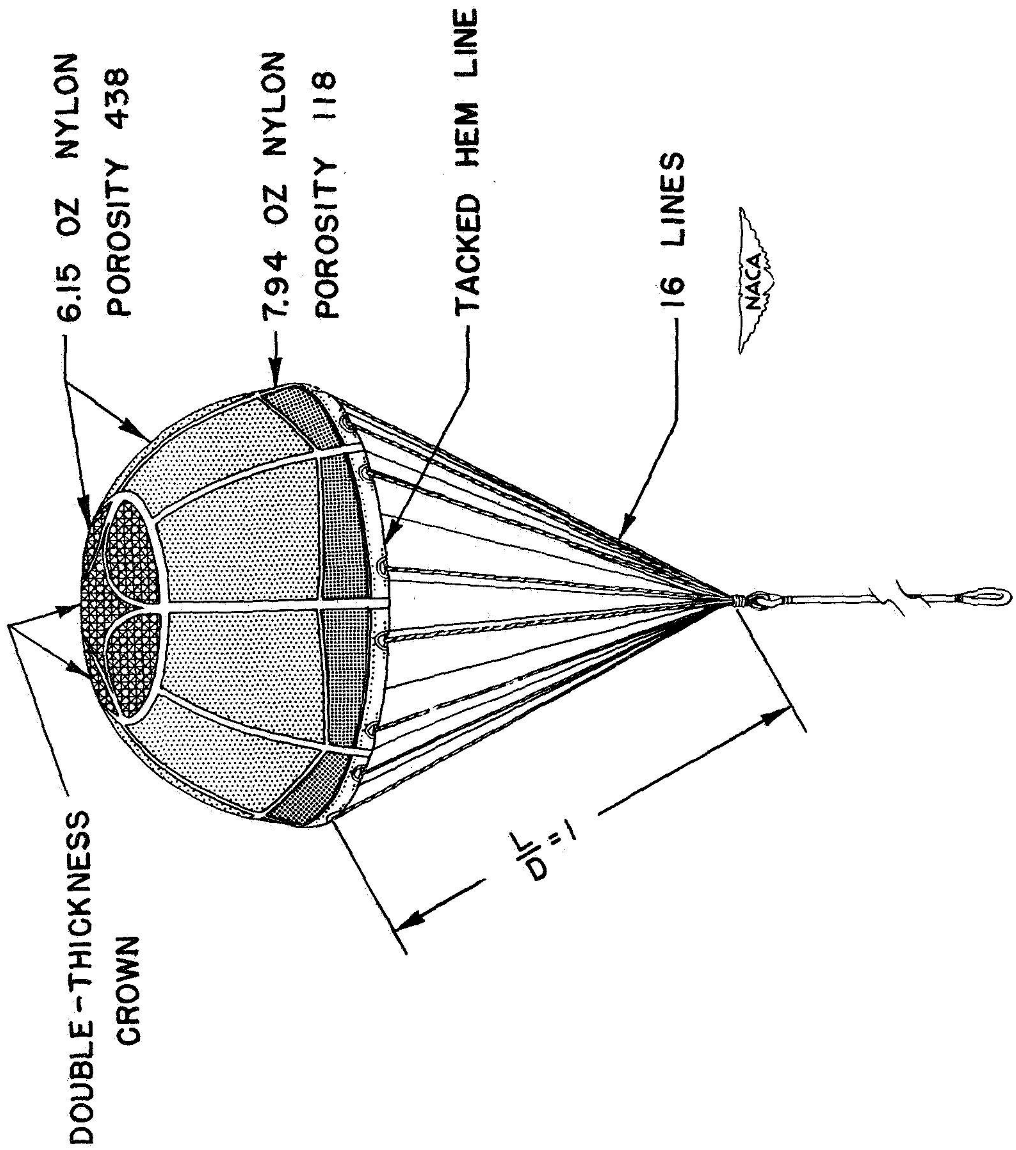


Figure 4.- Parachute 4; 30-inch diameter.

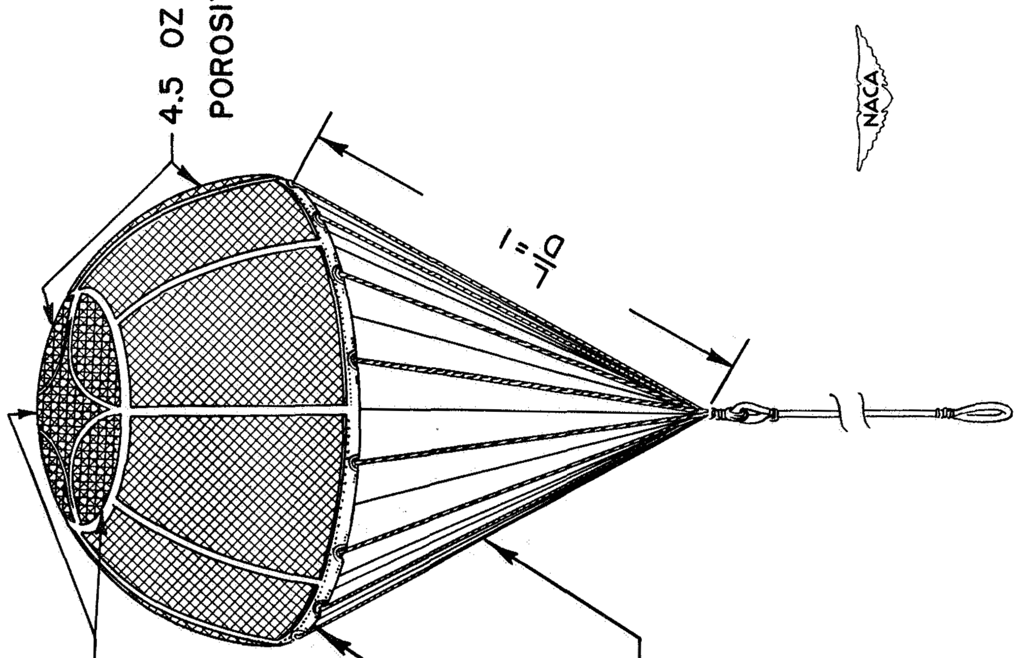


Figure 5.— Parachute 5; 30-inch diameter.

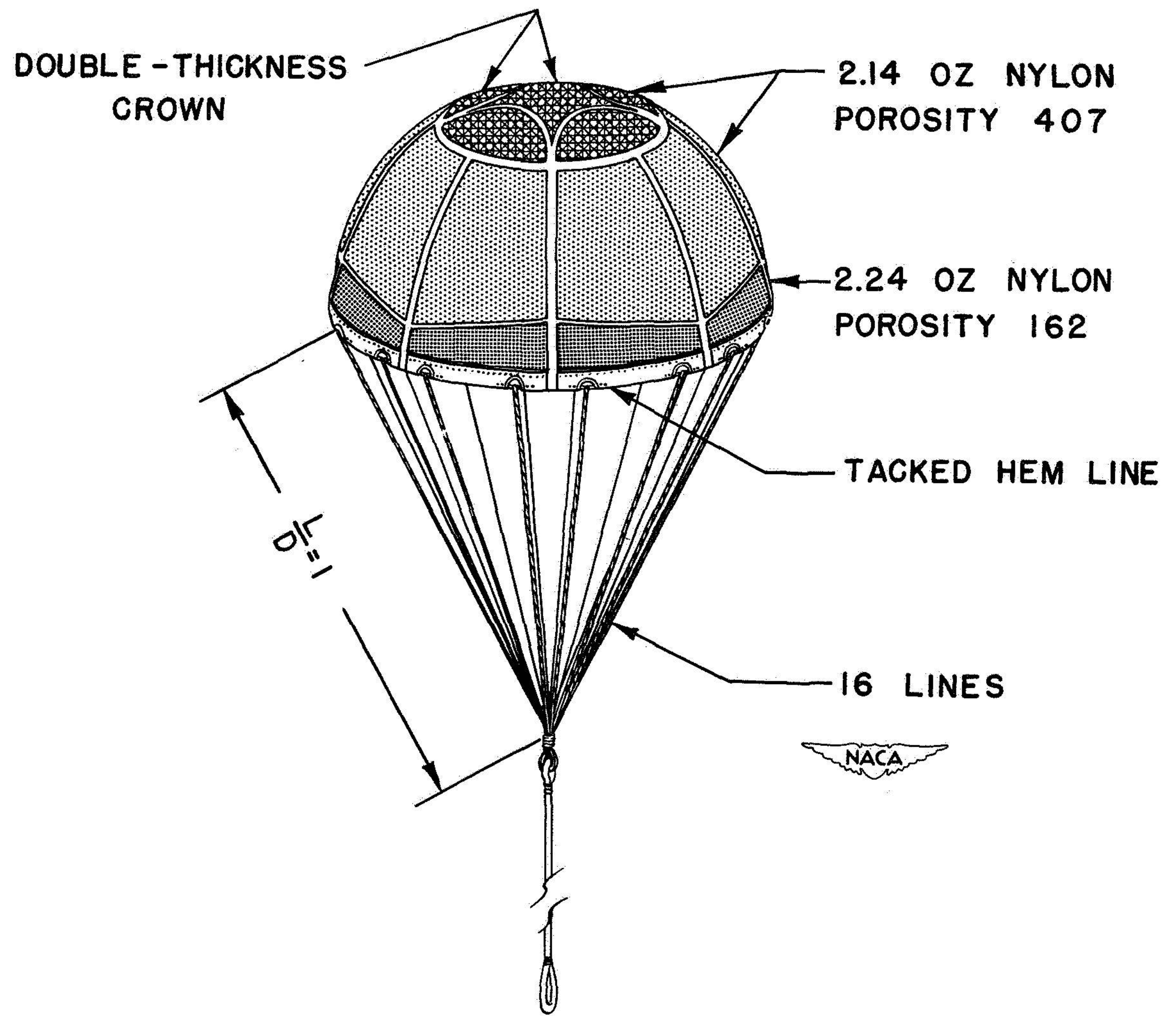


Figure 6.– Parachute 6; 30-inch diameter.

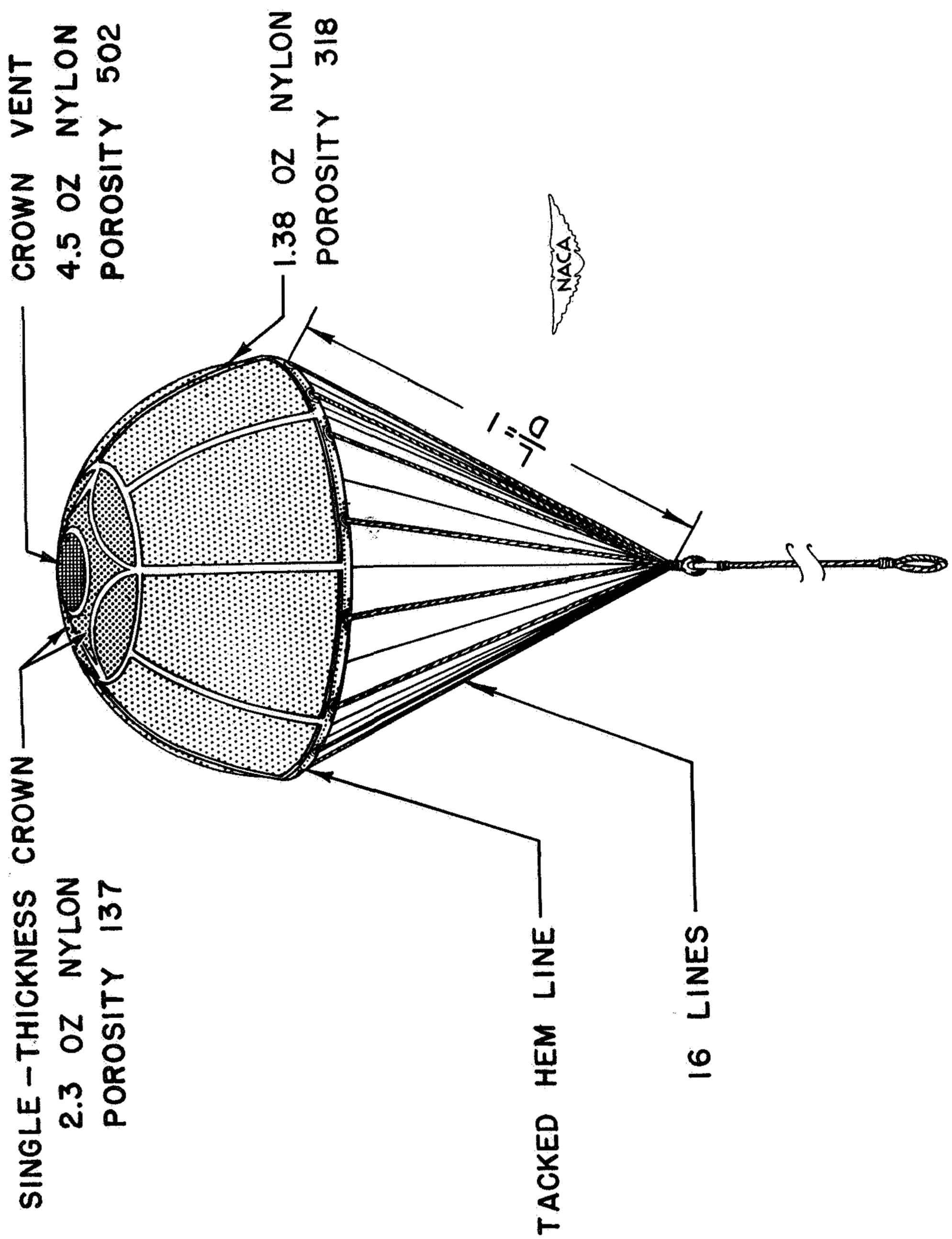


Figure 7.- Parachute 7; 30-inch diameter.

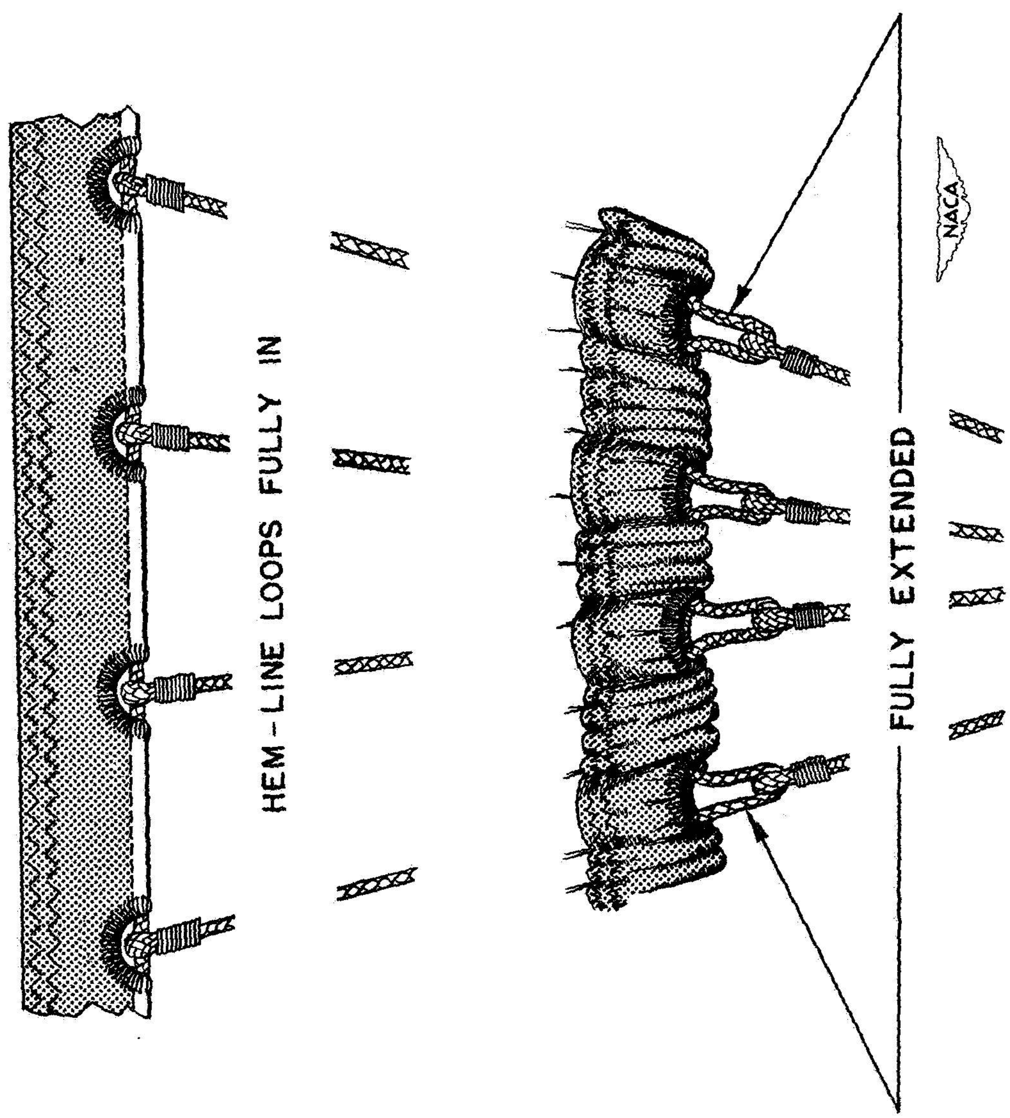


Figure 8.- Floating hem line.

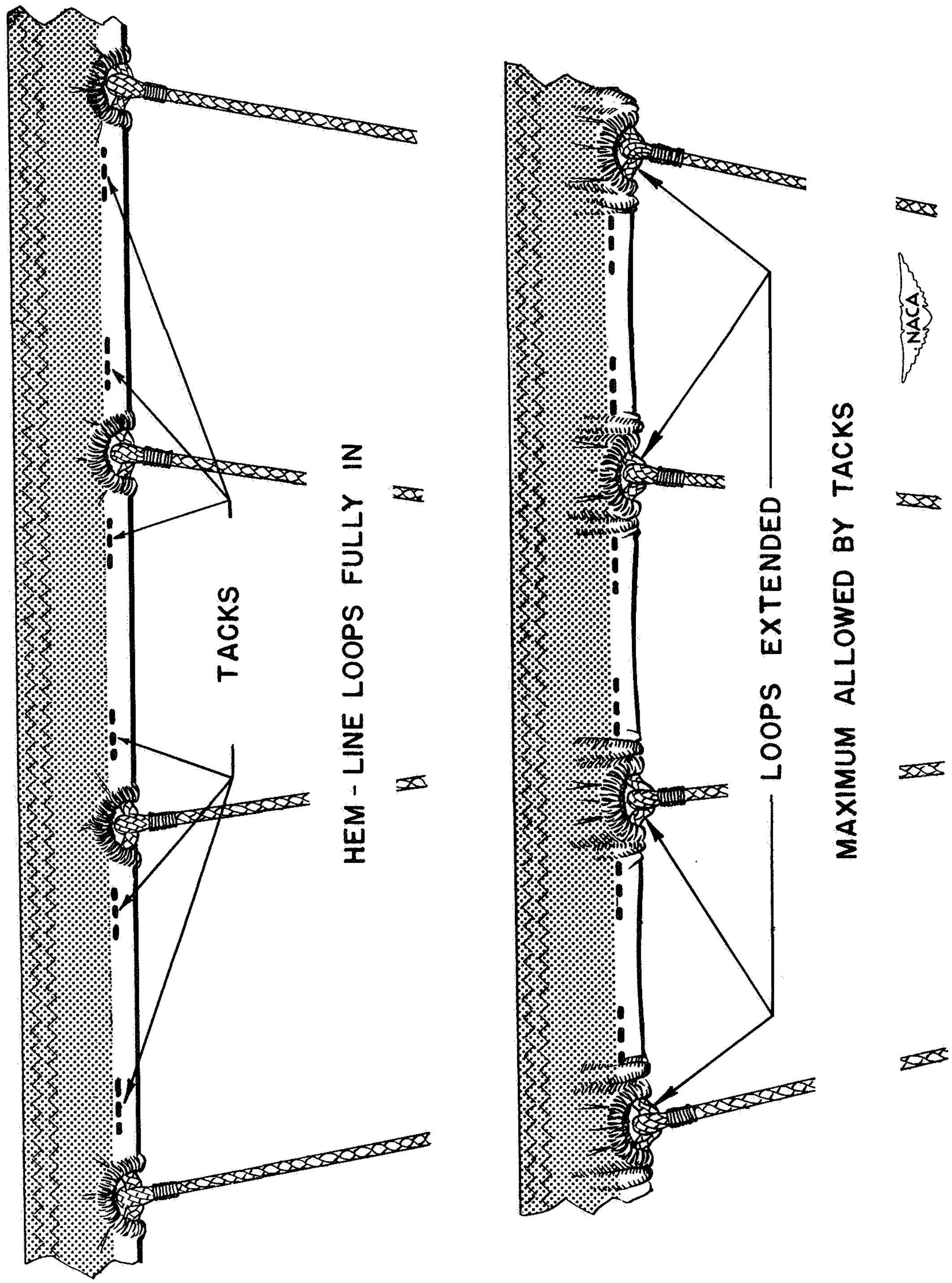


Figure 9.– Tacked hem line.

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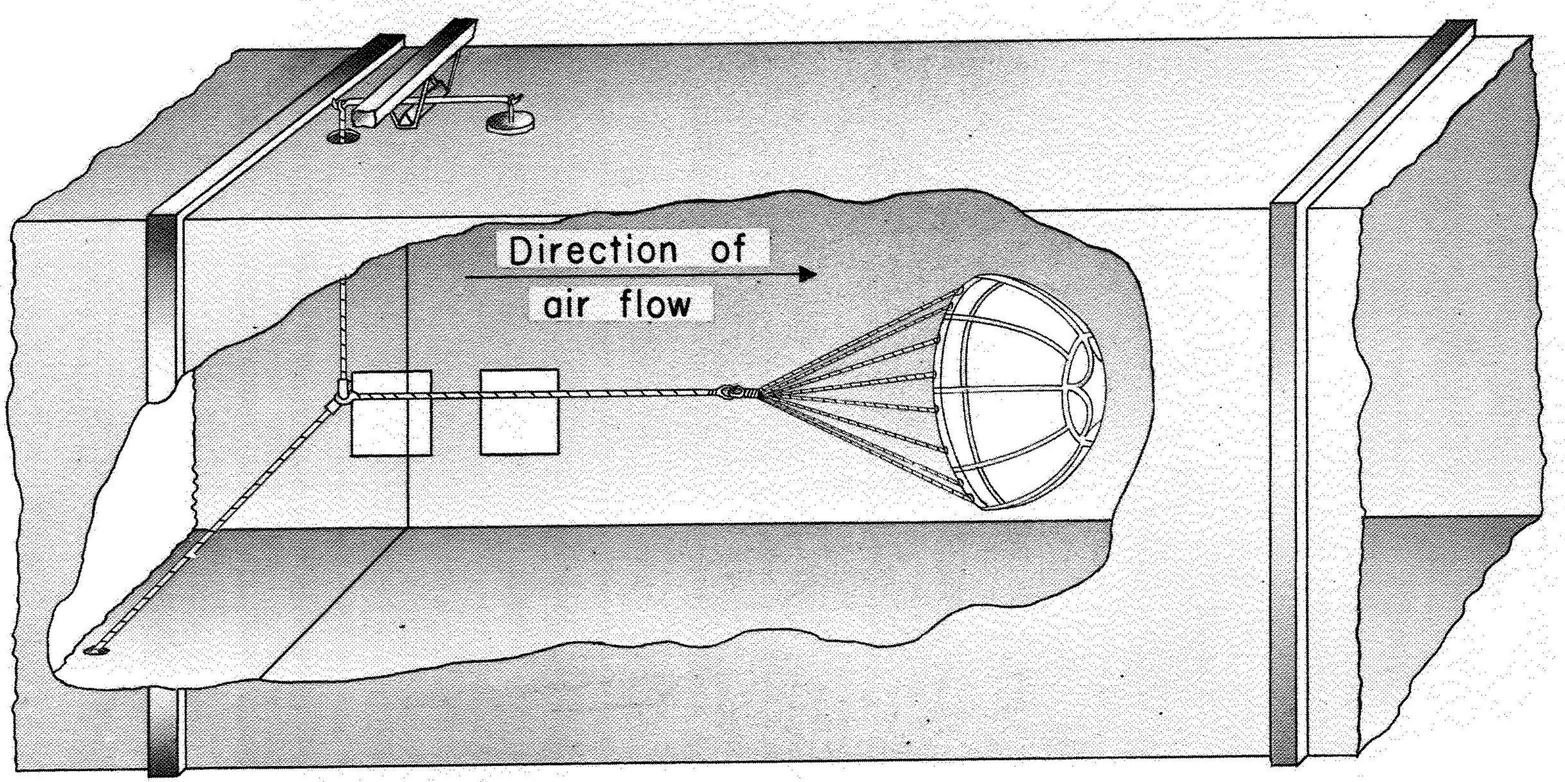


Figure 10.– Pictorial sketch of open hemispherical-type parachute in Langley 300 MPH 7- by 10-foot tunnel.

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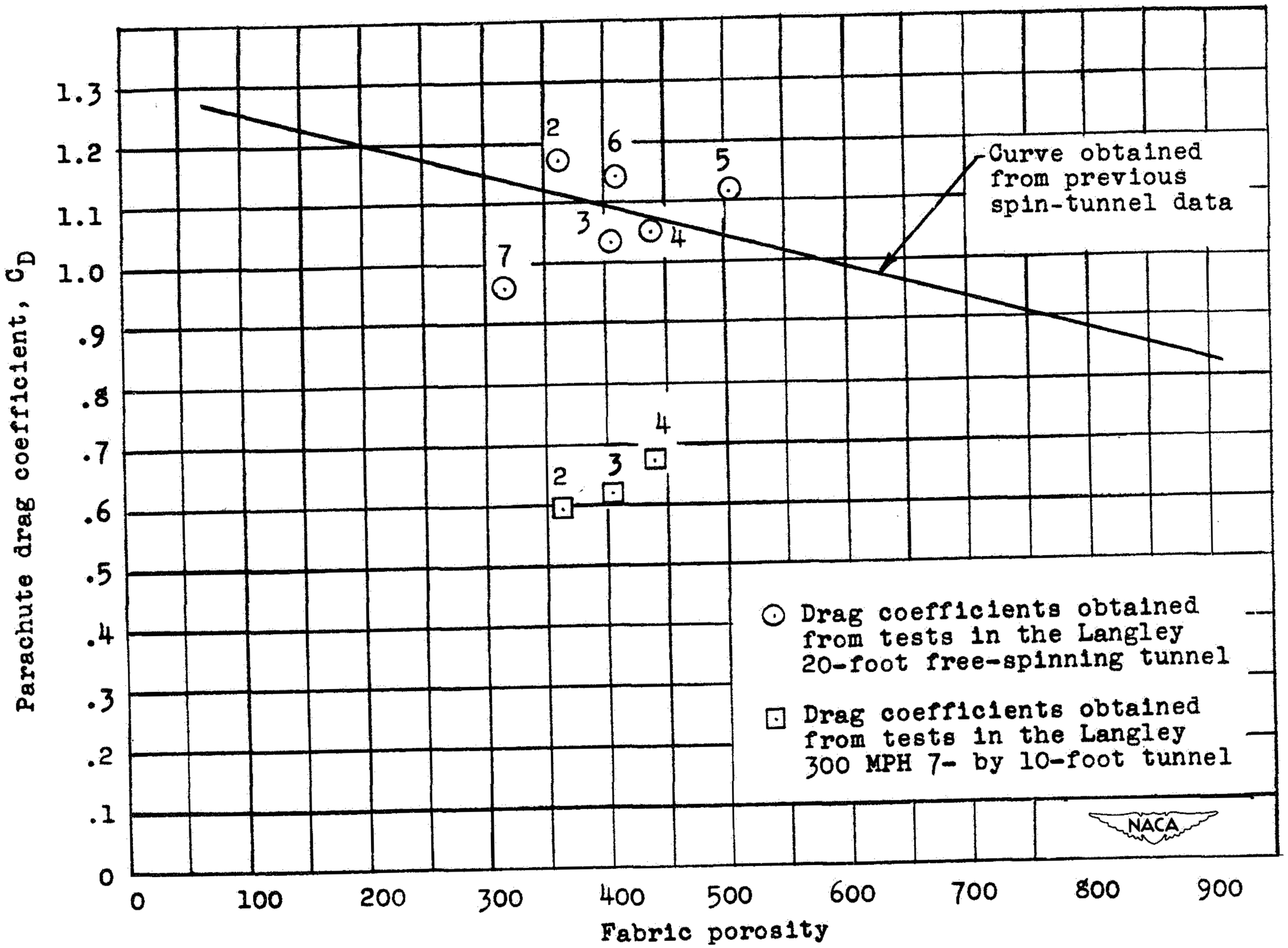
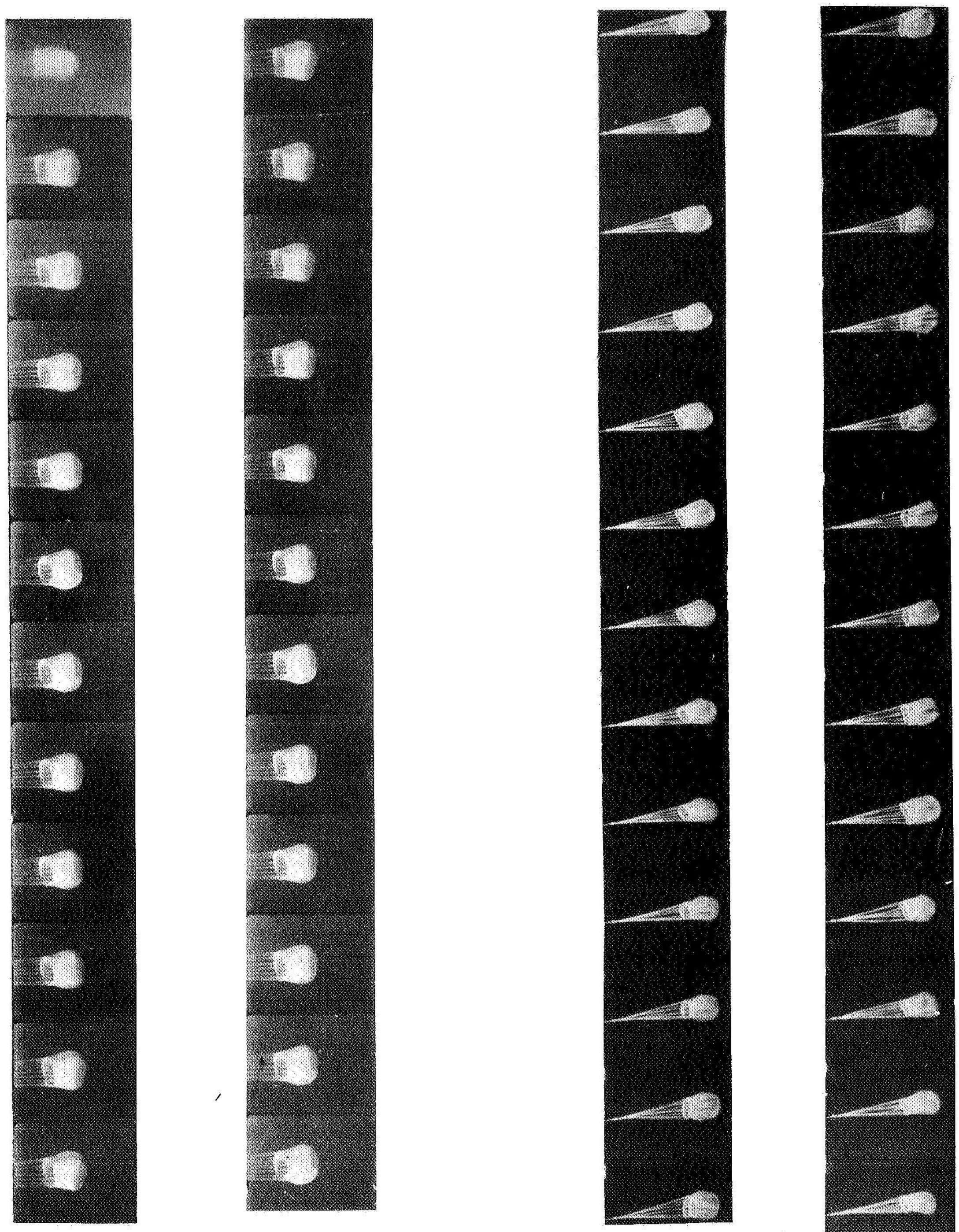



Figure 11.– Variation of parachute drag coefficient with porosity for hemispherical-type parachutes tested in the Langley 20-foot free-spinning tunnel and in the Langley 300 MPH 7- by 10-foot tunnel.



(a) Parachute 1. Tunnel airspeed, 208 miles per hour.

(b) Parachute 2. Tunnel airspeed, 200 miles per hour.

Figure 12.- Film strips showing the opening of parachutes 1 and 2 in the Langley 300 MPH 7- by 10-foot tunnel. Pictures were made at camera speed of 64 frames per second.

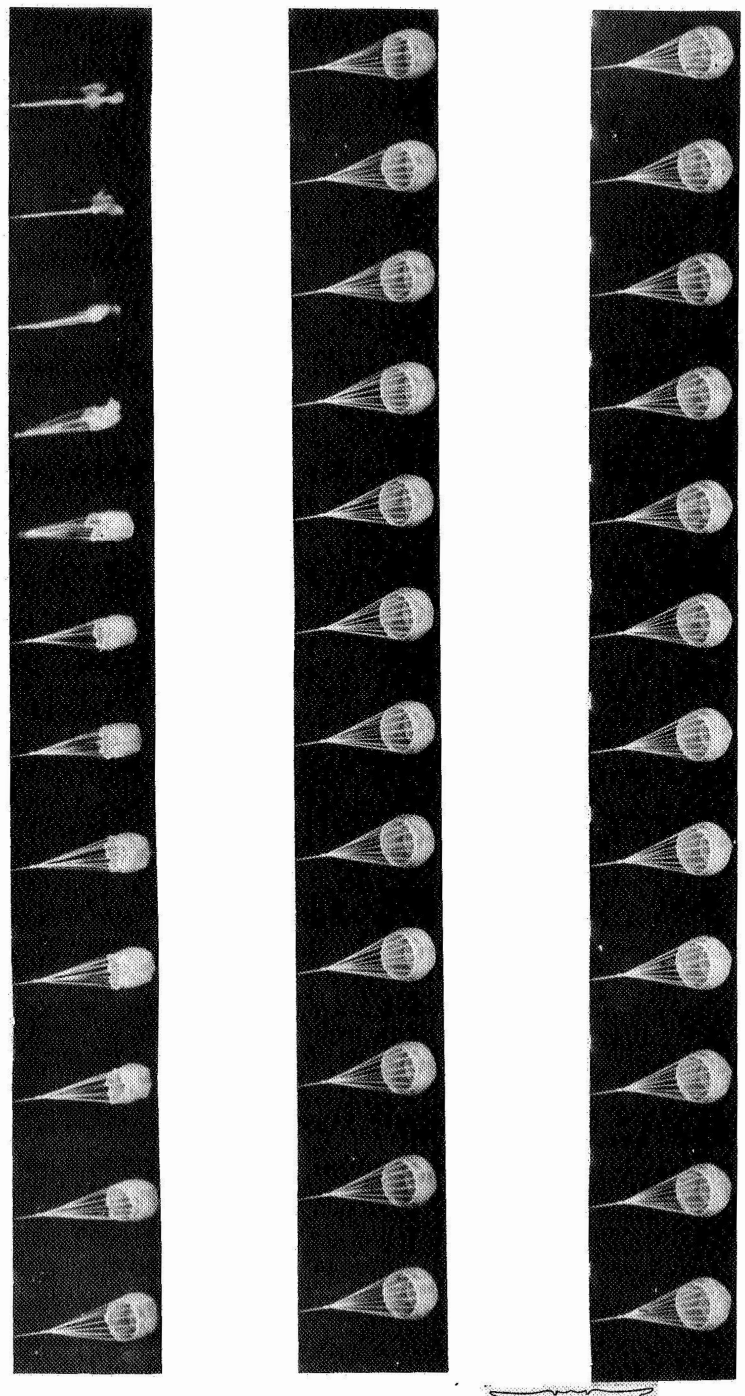


Figure 13.- Film strips showing the opening of parachute 2 with tacked hem line in the Langley 300 MPH 7- by 10-foot tunnel. Tunnel airspeed, 200 miles per hour. Pictures were made at camera speed of 64 frames per second.