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DRAG COEFFICIENTS FOR PARTIALLY INFLATED FLAT CIRCULAR PARACHUTES

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16. Abstract

Free-body tests were made in the Langley spin tunnel to determine drag coefficients for 1.07-meter-diameter (3.5-foot) flat circular parachutes when restrained by wire frames in a series of shapes representing those that parachutes assume during the inflation process. Both high-porosity (stable) and low-porosity (unstable) parachutes were investigated. The results obtained should be applicable to inflation analyses for flat circular parachutes.

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DRAG COEFFICIENTS FOR PARTIALLY INFLATED FLAT CIRCULAR PARACHUTES

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SUMMARY

An experimental investigation has been conducted to determine the drag coefficients of parachutes in a series of shapes representing those assumed by a parachute during the inflation process. Such data are desirable in theoretical analyses of parachute inflation. The tests were made with 1.07-meter-diameter (3.5-foot) flat circular parachutes by means of free-body tests in the vertical airstream of the Langley spin tunnel. The parachutes were held by means of light wire frames in a series of shapes representative of those recorded during actual free-flight deployment and inflations. The tests were made for high-porosity (stable) and low-porosity (unstable) parachutes. The drag-coefficient results obtained are considered to be appropriate for use in analyses of the dynamic parachute-inflation process and, hence, should be of value in the prediction and/or evaluation of the performance of flat circular parachute systems.

INTRODUCTION

In a theoretical analysis of parachute inflation, it is necessary to know the drag of the parachute in various partially inflated conditions. The only such data available (ref. 1) were obtained using partially inflated conditions which a subsequent investigation (ref. 2) has shown to be unrealistic insofar as representing shapes which occur during an actual inflation. An investigation has, therefore, been conducted to determine the drag for parachutes held in a series of shapes representative of those shown in reference 2 for actual inflations.

Drag measurements were made in the Langley spin tunnel of two 1.07-meter-diameter (3.5-foot) flat circular parachutes held in the desired shapes by light wire frames. One of the parachutes used in the tests was constructed of relatively high-porosity fabric and was stable. The other parachute was made of low-porosity fabric and represented a typical unstable, or less stable, parachute. Each parachute was tested in a series of six different shapes representing partially inflated conditions, and each parachute was also tested fully inflated without a wire frame. The tests were free-body tests in which a configuration consisting of a partially (or a fully) inflated parachute, a wire frame to constrain the shape (when appropriate), and a payload were floated in the vertically rising airstream of the Langley spin tunnel.

SYMBOLS

Values are given in both SI and U.S. Customary Units. The measurements and calculations were made in U.S. Customary Units.

c	height of oblate hemispheroid segment shape used as part of wire frames (see table I and ref. 2), cm (inches)
C_D	drag coefficient based on surface area of parachute canopy, $\frac{\text{Drag}}{qS_o}$
d_x, d_i, l	large diameter, small diameter, and slant height of conical frustum shape used as part of wire frames, respectively (see table I and ref. 2), cm (inches)
D_p	projected diameter of parachute canopy when fully or partially inflated, meters (feet)
h	profile height of inflated parachute canopy, from bottom of skirt to top of crown, meters (feet)
q	dynamic pressure, N/m^2 (lb/ft^2)
S_o	surface area of parachute canopy, meters^2 (feet^2)
S_p	projected area of parachute canopy, meters^2 (feet^2)

MODELS

The 1.07-meter-diameter (3.5-foot) flat circular parachutes were constructed of nylon, and each had four solid-cloth gores and nylon shroud lines 1.43 meters (4.7 feet) in length. For most of the tests, eight such shroud lines were used, but for a few tests 16-line or 28-line configurations were used, as discussed subsequently. A sketch of the parachutes is shown as figure 1. The stable parachute was made of fabric which had a porosity of 119.5 $\frac{m^3/m^2}{min}$ $\left(392\ \frac{ft^3/ft^2}{min}\right)$ at an air pressure of 124.5 N/m^2 (the pressure of 1/2 inch of water), whereas the other parachute was made of fabric which had a porosity of 48.8 $\frac{m^3/m^2}{min}$ $\left(160\ \frac{ft^3/ft^2}{min}\right)$. The high- and low-porosity parachute canopies without shroud lines weighed 36 and 68 grams (1.27 and 2.40 ounces), respectively. Each shroud line weighed approximately 0.624 gram (0.022 ounce). For most of the tests, these parachutes had no vents; however, a 3.56-cm-diameter (1.4-inch) vent was included in the low-porosity parachute for a few tests to determine if the drag coefficient would be affected.

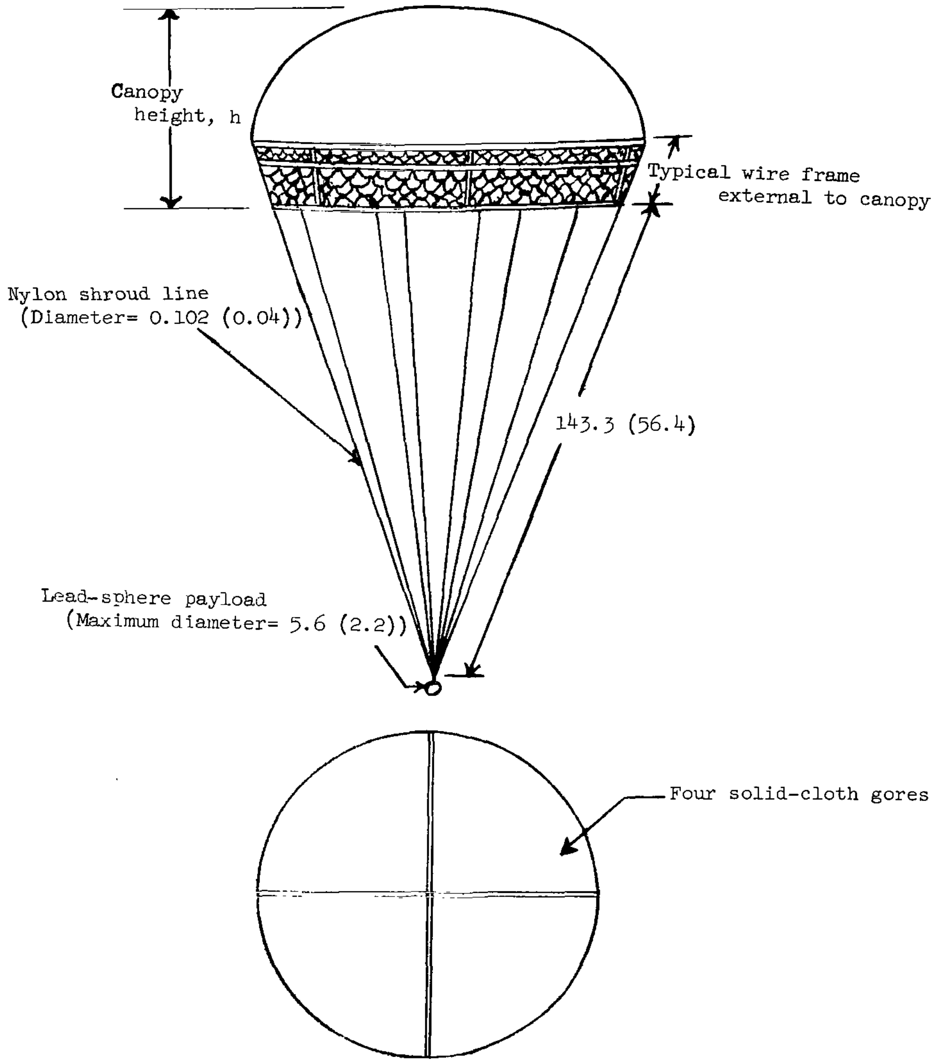
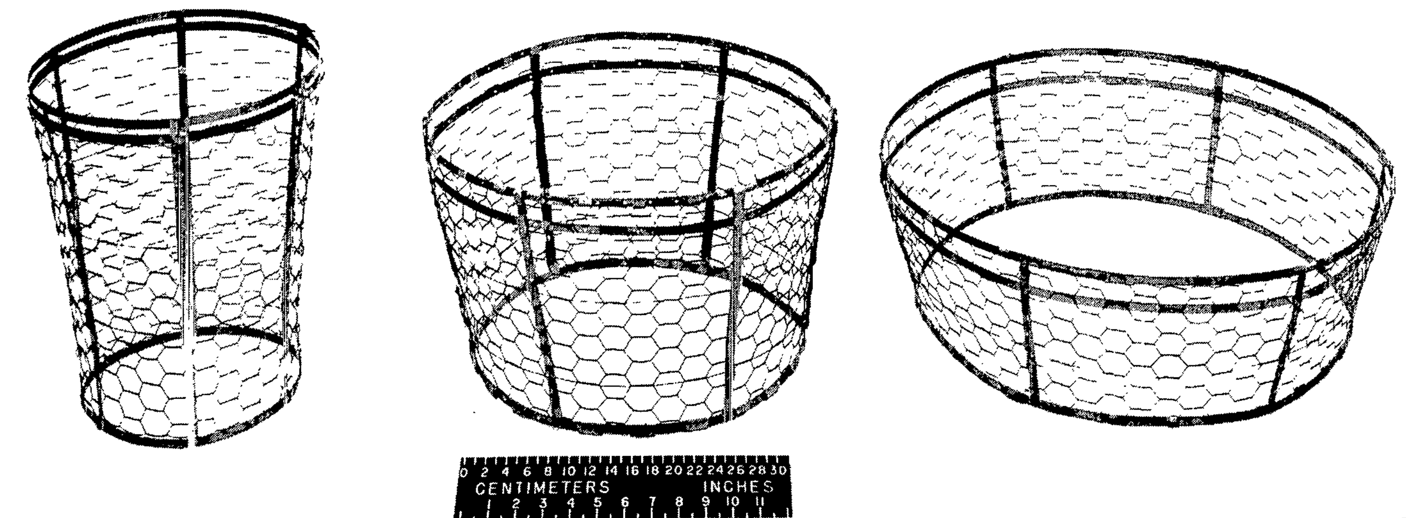


Figure 1.- Sketch of 1.07-meter-diameter (3.5-foot) parachutes tested in the Langley spin tunnel. A typical partially inflated condition is shown. Dimensions are given in centimeters and parenthetically in inches.

The lightweight wire frames used to restrain the parachutes in the partially inflated conditions were made of light hexagonal-mesh wire netting and stainless steel bands. Photographs of the frames are shown in figure 2. A parachute canopy was put inside a wire frame with the skirt of the parachute at the bottom of the frame. The frame then



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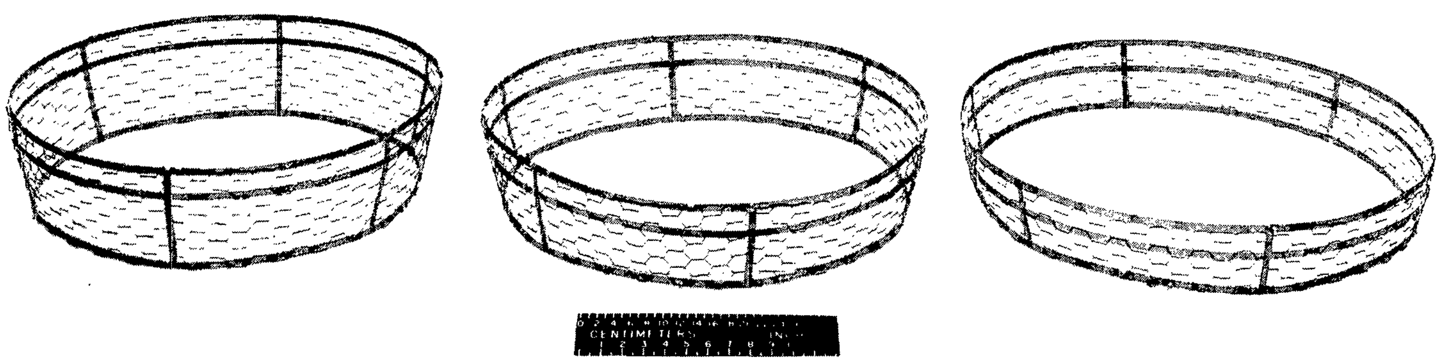
Frame 1
$S_p/S_o = 0.071$

Frame 2
$S_p/S_o = 0.166$

Frame 3
$S_p/S_o = 0.261$



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Frame 4
$S_p/S_o = 0.300$

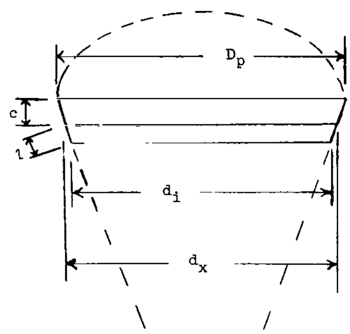
Frame 5
$S_p/S_o = 0.336$

Frame 6
$S_p/S_o = 0.377$

Figure 2.- Wire frames used to restrain parachutes in partially inflated conditions.

restrained the parachute from ballooning out into a more rounded shape. The frames varied from 295 to 365 grams (10.4 to 12.9 ounces) in weight, and dimensions used in constructing them are shown in table I. The formulas used in calculating these dimensions and the symbols used were taken from reference 2. The partially inflated parachute shapes which resulted from the use of the frames are among the shapes which are considered to be assumed by flat circular parachutes during the parachute-inflation process, according to the information presented in reference 2.

TABLE I.- DIMENSIONS OF WIRE FRAMES



Frame	S_p/S_o	D_p		d_x		d_i		l		c	
		cm	in.	cm	in.	cm	in.	cm	in.	cm	in.
1	0.071	28.430	11.193	27.821	10.953	21.298	8.385	32.669	12.862	1.923	0.757
2	.166	43.457	17.109	42.527	16.743	35.326	13.908	21.745	8.561	2.941	1.158
3	.261	54.435	21.431	53.269	20.972	47.181	18.575	13.764	5.419	3.683	1.450
4	.300	58.316	22.959	57.069	22.468	51.760	20.378	10.940	4.307	3.945	1.553
5	.336	61.714	24.297	60.394	23.777	55.954	22.029	8.471	3.335	4.176	1.644
6	.377	65.425	25.758	64.026	25.207	60.744	23.915	5.773	2.273	4.427	1.743

With regard to the number of shroud lines to be used with the partially inflated parachutes, some exploratory tests were made by using alternately eight or 16 such lines, and within the accuracy of the free-body tests, no measurable consistent effect of number of shroud lines on drag coefficient was found. Accordingly, as a matter of testing convenience, only eight shroud lines were used during most of the tests of the partially inflated configurations. The number of lines used in these tests, of course, had no effect on the shape of the restrained, partially inflated parachutes.

The fully inflated parachutes had no wire frames to restrain them and were free to assume their natural fully inflated shapes. Previous parachute-inflation technology indicates that the inflated shape can be affected by (among other things) design features such as number of shroud lines, number of gores in the canopy, assembly details, and so forth. (See ref. 3.) Obviously, when the parachute shape is affected, the magnitude of S_p/S_o and the magnitude of the drag coefficient can also be affected; therefore, some selection had to be made as to how many shroud lines to use on the fully inflated parachutes. It was decided that 28 lines would be used in order to obtain some similarity to the inflated shapes of large flat circular parachutes, such as were used in the investigation described in reference 2 and such as are described in reference 3 as being used for numerous purposes.

The fully inflated parachutes in the current investigation indicated an S_p/S_o of approximately 0.48 and a value of h/D_p of approximately 0.38.

Payloads used in the tests consisted of various lead spheres which ranged in weight from 485 to 1072 grams (17.1 to 37.8 ounces) and ranged in diameter from 4.45 cm (1.75 inches) to 5.59 cm (2.2 inches). One or two of these weights were used for each test. Total configuration weights used during the tests ranged from 821 grams (29.03 ounces) (for the high-porosity parachute with frame 1 plus a one-sphere payload) to 2428 grams (85.4 ounces) (for the low-porosity parachute with frame 5 plus a two-sphere payload).

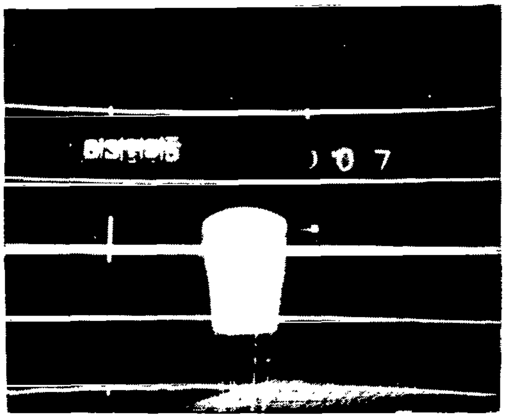
TESTS

Each parachute configuration was launched into the vertically rising airstream of the Langley spin tunnel, which has a diameter of 6.1 meters (20 feet), airspeeds up to about 27.4 m/sec (90 ft/sec), and appropriate nets for recovering the models. The tunnel and its operation are described in reference 4. For each configuration, two different weighted conditions were used to obtain two data points. For one test, one lead sphere was used as a payload, and for the second test, two lead spheres were used. The spheres were so small relative to the size of the parachutes that they were considered to have negligible aerodynamic effects on the drag coefficients. Motion pictures were made of the model tests, and a careful observation was made of the tunnel velocity required to hold the configuration at a constant test level in the tunnel. Atmospheric temperature and pressure in the tunnel at the time of each test were also recorded for use in the determination of the drag coefficient. In addition, an observation of the stability of each configuration was made. The three photographic views in figure 3 are typical of the test configurations as seen in the tunnel.

Reynolds numbers, based on the parachute diameter of 1.07 meters (3.5 feet), ranged from about 0.536×10^6 for the fully inflated configurations to about 1.512×10^6 for the minimum-diameter configurations (frame 1).

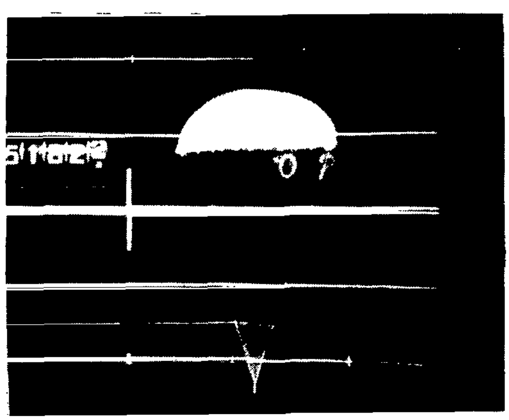
RESULTS AND DISCUSSION

The results of the drag tests are presented in figure 4, which is a plot of drag coefficient as a function of the nondimensionalized projected area S_p/S_o of the parachutes. As may be noted from the figure, the drag coefficients obtained up to $S_p/S_o = 0.38$ were about the same for the high- and low-porosity parachutes. For the tests simulating the fully inflated condition, the drag coefficient for the low-porosity parachute averaged about 0.81 and was about 4 percent higher than the 0.78 average value obtained for the high-porosity parachute. Both of these values were within the drag-coefficient range of 0.65



Low-porosity parachute partially inflated to shape of frame 1, $S_p/S_o = 0.071$.

Low-porosity parachute partially inflated to shape of frame 6, $S_p/S_o = 0.377$.



High-porosity parachute fully inflated.

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Figure 3.- Photographs of typical test configurations consisting of 1.07-meter-diameter (3.5-foot) parachutes and wire frames being tested in the Langley spin tunnel.

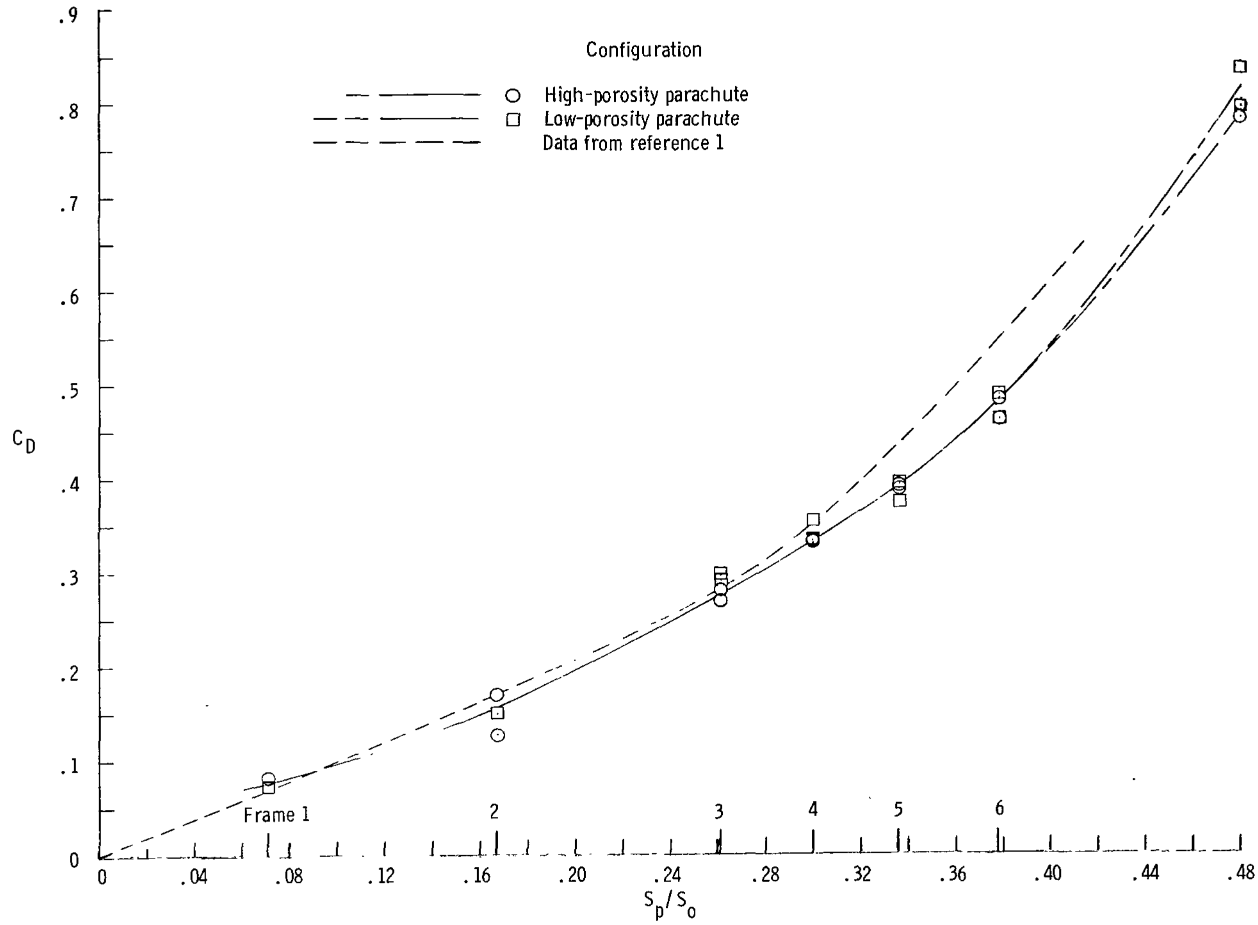

Figure 4.- Parachute drag coefficients as a function of S_p/S_o. Frames described in table I.

to 0.90 reported in reference 3 as being applicable for fully inflated flat parachutes. When a small vent was cut into one of the parachutes for a few tests, as described earlier, no effect on drag coefficient resulted.

With respect to the stability of the parachutes, the high-porosity parachute was stable in all test conditions in that little or no oscillations occurred, and the configurations remained essentially at a given lateral location in the tunnel. Similar results occurred for configurations using the low-porosity parachute partially inflated to the shapes of frames 1 to 4. However, when frame 5 was used for the low-porosity parachute, gentle oscillations of $\pm 10^{\circ}$ to $\pm 15^{\circ}$ from the vertical occurred, and when either frame 6 or the fully inflated parachute was used, the oscillations were $\pm 25^{\circ}$ to $\pm 30^{\circ}$ from the vertical. For the fully inflated parachute, considerable lateral travel of the parachute also occurred.

The curve shown in figure 4 is believed to be representative of steady-state aerodynamic drag coefficients which would exist on a flat circular parachute if it were frozen at appropriate instants during the dynamic-inflation process. As shown in the figure, the curve is reasonably similar to a curve derived from information presented in reference 1 for values of S_p/S_o up to 0.30. The referenced data had been based primarily on tests of a 40.6-cm-diameter (16-inch) parachute in partially inflated conditions which differed from the more appropriate shapes used in the present investigation and based on the more recent information in reference 2. In analyses of the inflation of flat circular parachutes, the curve in figure 4 should be applicable with perhaps some adjustment to the upper end of the curve if the value of S_p/S_o and/or the magnitude of the drag coefficient for the specific fully inflated parachutes are known to differ appreciably from the values obtained on the specific parachutes used in this investigation. A different drag coefficient would be expected for fully inflated flat circular parachutes having canopy shapes or porosities different from those tested in this study.

The results obtained in this investigation should be of value in the prediction and/or evaluation of the performance of flat circular parachute systems.

CONCLUSIONS

Free-body tests were made in the Langley spin tunnel to determine drag coefficients for flat circular parachutes in a series of shapes representing those that parachutes assume during the inflation process. The tests were made with 1.07-meter-diameter (3.5-foot) parachutes, and lightweight wire frames were used to restrain these parachutes in suitable shapes to represent partial inflation. Both high-porosity (stable) and low-porosity (unstable) parachutes were investigated.

The drag-coefficient results obtained are considered to be appropriate for use in analyses of the dynamic parachute-inflation process and, hence, should be of value in the prediction and/or evaluation of the performance of flat circular parachute systems.

Langley Research Center,
National Aeronautics and Space Administration,
Hampton, Va., July 20, 1971.

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