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DETERMINATION OF TOWLINE TENSION AND STABILITY OF SPIN-RECOVERY PARACHUTES

By John H. Wood

Langley Memorial Aeronautical Laboratory
Langley Field, Va.

WASHINGTON

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ADVANCE RESTRICTED REPORT

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SUMMARY

Tests have been made of a number of spin-recovery parachutes from 1 foot to 8 feet in diameter in order to determine the force exerted by the parachutes on the towline and the stability of the parachutes. The magnitude of the shock load of a parachute during opening was also measured. In addition, the effects of various modifications to the parachutes on the towline tension and stability were investigated. For several of the parachute arrangements, a free drop was simulated and the drag of the parachute was determined.

The test results indicated that the average towline-tension coefficient, based on the surface area of the canopy, was approximately 0.76 for conventional silk spin-recovery parachutes and 0.56 for a nylon parachute. The shock loads obtained during parachute openings for restrained parachutes were as great as 2.29 times the average final loads. All the conventional parachutes tested were unstable and inclined away from the wind axis.

Various methods were tried to decrease the instability and increase the towline tension, such as varying shroud-line length, adding a central shroud line, varying the size of the canopy vent, and adding radial vanes to the canopy and shroud lines. These tests indicated that very little could be done to increase the towline-tension coefficient of the conventional silk parachute but that the stability could be increased by adding radial vanes to canopy and shroud lines although towline tension would be lowered.

Tests were also made of pyramidal and square pilot parachutes. These parachutes were generally more stable than conventional ones but gave lower values of towline-tension coefficients.

INTRODUCTION

Tests have been made of 1-foot to 8-foot spin-recovery parachutes. The towline tensions of parachutes were measured under steady conditions and during parachute openings. Observations were also made of the stability of the parachutes. Alterations were made to the conventional parachutes in order to study the general aerodynamic effects of shroud-line length, of a central shroud, of size of canopy vent, of decreasing the porosity of the canopies, and of attaching fabric vanes to the shroud lines. In addition, a pyramidal parachute was tested full length and truncated, and the characteristics of a square pilot parachute were determined. Most of the investigation was conducted in the Langley 20-foot free-spinning tunnel; however, some force tests were made of several of the conventional parachutes in the Langley full-scale tunnel and at higher speeds in the Langley 16-foot high-speed tunnel. The characteristics of some of the parachutes were also determined in simulated free drop.

APPARATUS

Wind Tunnels

The Langley 20-foot free-spinning tunnel, in which most of the data presented herein were obtained, is of the closed-throat type. The air flow in the test section is vertically upward. The Langley 16-foot high-speed tunnel is also of the closed-throat type but the air flow is horizontal. The Langley full-scale tunnel is of the open-throat type and the air flow is horizontal.

Parachutes

The Aircraft Laboratory of the Air Technical Service Command at Wright Field furnished the Langley Memorial Aeronautical Laboratory two 3-foot, two $3\frac{1}{2}$-foot, and two 5-foot silk tail parachutes, one 8-foot nylon tail parachute, two 7-foot towlines, one standard tail-parachute pack, and some spare canopy silk. The Langley Memorial Aeronautical Laboratory had a $2\frac{1}{2}$-foot-square pilot parachute similar in shape to the one shown in reference 1 and constructed a $1\frac{1}{2}$-foot octagonal parachute and a 1-foot-square pyramidal parachute from the silk supplied by the Aircraft Laboratory. The silk used in most of the canopies was believed to be of the type specified in reference 2.

Areas and descriptions of the parachutes tested are presented in table I. A sketch of a conventional spin-recovery parachute with a reinforced canopy is shown in figure 1. The pyramidal parachute is shown in figure 2 and the square parachute is shown in figure 3. In accordance with past practice (reference 3), the measurements of parachute dimensions were made with the canopies laid on a flat surface.

METHODS

The airspeed for the tests in the Langley 20-foot free-spinning tunnel was measured by the propeller tachometer (previously calibrated against a pitot tube). The values of the dynamic pressure q at the test section were computed by the use of the airspeed indicated by the propeller tachometer, the air temperature, and the barometric pressure.

Because the projected areas (as large as 25.68 sq ft) of some of the canopies were large relative to the area of the tunnel (319 sq ft), the data obtained were corrected by the factors given in figure 4 in order to represent corresponding data in free air. The correction curve of figure 4 was based on an average of values given by the theoretical treatment in reference 4 and the empirical data given in reference 5.

No corrections were applied to the angles measured between the parachute and the wind axes although some correction might be necessary in order to obtain the true attitudes of the large parachutes in free air.

The operation of a spin-recovery parachute on an airplane was simulated in the Langley 20-foot free-spinning tunnel by passing the lower end of the towline through fixed pulleys to weights outside of the test section (fig. 5), or by tying the lower end of the towline to a taut rope in the center of the test section (fig. 6). The towline tensions were measured by balancing the towline tension against known weights or by a deflectometer, a stiff coil spring equipped with an electrical device that enabled a time history of the tension to be recorded. The weight of the parachute was added to the measured towline tension in order to obtain the aerodynamic force exerted on the parachute. Each type of test in the Langley 20-foot free-spinning tunnel was photographed on movie film to augment observation of the stability and of the parachute openings.

For a few of the arrangements the descent of an unrestrained parachute was simulated by launching the parachute and an attached load in the rising air stream and by adjusting the airspeed until equilibrium was obtained between the drag of the parachute and load and the combined weight of the parachute and load. In computing the drag of the parachute, the aerodynamic drag of the suspended load (independently measured) was subtracted from the combined weight of the parachute and load.

In the determination of the forces on the parachutes tested in the Langley full-scale tunnel, the towline was attached to the balance struts by means of a bridle. The towline lengths were approximately 15 feet and the dynamic pressures used were approximately 3.2, 4.7, and 7.3 pounds per square foot. The forces were recorded by the balance system and were resolved into towline tensions. No corrections for tunnel interference were used because the test-section area was large compared with the parachute area.

In the determination of the forces on the parachutes tested in the Langley 16-foot high-speed tunnel, the towline was attached near the center of the test section to the apex of three cables that extended to the drag frame of the balance. Indicated airspeed in the tests ranged from 60 to 269 miles per hour. The drag component of the towline tensions was measured and the towline tension was estimated by dividing these drag measurements by the cosine of the angle between the parachute and wind axes. The angles between the parachute and wind axes were obtained for the particular parachutes from tests in the Langley 20-foot free-spinning tunnel.

Measurement of shock loads during the openings of the parachutes was obtained by means of the deflectometer. The parachute was in a standard tail-parchute pack mounted on a pole held in the air stream just above the deflectometer. When the pack was opened by pulling the release pins, the parachute billowed out and the pack was moved out of the way. A time history of the towline tension was recorded on a film. The deflectometer unit to which the parachute towline was attached weighed approximately 2.6 pounds.

RESULTS

In the following discussion and presentation of the test results, the towline tension of a parachute in a simulated tow is the aerodynamic force parallel to the towline and the drag in a simulated free drop is the aerodynamic force parallel to the wind direction. Although the towline tensions and drags are not directly comparable, it was observed during the investigation that a modification to a parachute indicated the same general effect when tested in simulated tow or free drop.

The forces were converted into coefficient form by dividing the corrected forces by the dynamic pressure and the canopy area.

The various test conditions are summarized in table II. Some of the tests were run on both of the duplicate parachutes. Inasmuch as the results were not appreciably different for the duplicate parachutes, data are presented for only one parachute in each pair. Figure 7 is a typical time-tension record of the parachute towline tension in a steady air stream as measured by the deflectometer. The average, the maximum, and the minimum values of several time-tension records of the towline tensions are given in table III. The towline tensions obtained by balancing the tension against weights are given in figure 8 for the $2\frac{1}{2}$-foot to 8-foot parachutes. The tensions are plotted against the dynamic pressure used in the tests, and in table IV these data are given in coefficient form. Figures 9 and 10 are typical time-tension records of the towline tensions of a parachute opening in a steady air stream; figure 11 is a copy of motion-picture film that shows a 3-foot parachute opening. Figure 12 is a plot of drag and towline-tension coefficients against the ratio of the shroud-line length to the parachute diameter for three parachutes. Figure 13 is a plot of the towline-tension coefficient against the central shroud-line length for a 3-foot octagonal parachute. The drag coefficient is plotted against vent area of a $1\frac{1}{2}$-foot octagonal parachute in figure 14. Table V contains data showing the effect of fabric vanes in different arrangements on towline tension, parachute drag, and angle between parachute and wind axes on a 3-foot octagonal parachute. In table VI comparable values of towline-tension coefficients are given for the different conventional parachutes tested in the Langley full-scale, 16-foot high-speed, and 20-foot free-spinning tunnels.

DISCUSSION

Conventional Parachutes

Parachute motions.- The parachutes generally showed instability in that the parachute axis tended to incline from the vertical, as indicated by the data in table III which are consistent with the results of other investigations. When the towline was fastened at the center of the tunnel, the parachute leaned over as much as 30° from the wind axis and rotated irregularly about its axis of symmetry and about the vertical axis of the tunnel. Both rotations were in the same sense. Table III shows that the angle between the parachute axis and the wind axis varied with tunnel airspeed, towline length, and type of parachute. Insufficient data are available to determine trends.

When a conventional parachute was attached to an unrestrained load, the parachute and load oscillated and wandered erratically about the test section.

Air forces on parachutes.- An appreciable fluctuation of the towline tension of the parachutes in a steady air stream is shown by the data presented in table III. A typical time-tension record of towline tension, presented as figure 7, illustrates the nature of the fluctuations and shows that fluctuations appreciably above and below the average towline tension occurred in approximately 1/4 second. The magnitude of the fluctuations averaged ±12.5 percent of the average towline tension. This effect is believed to be due to the erratic flow about the canopy.

The average towline-tension coefficients listed in table IV for the 3-foot, $3\frac{1}{2}$-foot, and 5-foot parachutes indicate a small increase in towline-tension coefficient with parachute diameter. The average of the towline-tension coefficients of these conventional silk parachutes tested was approximately 0.77 based on canopy surface areas. The towline-tension coefficient for the 8-foot nylon parachute was 0.58. This low value was probably due to the relatively higher porosity of the material and the relatively shorter shroud-line length.

The results of tests conducted on some of the conventional parachutes in the Langley full-scale and 16-foot high-speed tunnels at dynamic pressures used in the Langley 20-foot free-spinning tunnel afforded a check of the validity of the correction curve given in figure 4. Comparative data obtained in the three tunnels are given in table VI. The towline-tension coefficient obtained for the silk parachutes varied from 0.70 to 0.81 with an average value of 0.76 and for the 8-foot nylon parachute from 0.53 to 0.58 with an average value of 0.56.

In the Langley 16-foot high-speed tunnel an attempt was made to burst the $3\frac{1}{2}$-foot silk parachute, but the tests were terminated at an indicated airspeed of 269 miles per hour because of the vibration imparted to the side-force component of the balance system. The towline-tension coefficient of the parachute varied from 0.73 to 0.81 as the airspeed was increased from 60 to 269 miles per hour. This variation may have been caused by a change in canopy shape or mouth area, or both.

Comparison with data obtained from towed parachutes.- The force coefficients obtained in the wind-tunnel tests appeared to be lower than values previously determined in a flight investigation (reference 3). On the basis of the flight tests in which drag measurements were made while parachutes were towed behind airplanes, the drag coefficient based on surface area of the parachutes was 1.02, approximately equal to a towline-tension coefficient of 1.16. Inasmuch as the parachute in the flight tests was attached to a short towline and towed at full throttle in the slipstream behind the airplane, the drag coefficient based on the airplane speed would be expected to be higher than the values obtained in the tunnel.

An investigation (reference 6) in which large parachutes were towed behind a truck at speeds up to 50 miles per hour yielded results that were in better agreement with the wind-tunnel tests reported herein. Based on surface areas, drag-coefficient values between 0.38 and 0.57 for a special 60-foot parachute and values between 0.75 and 1.00 for a 24-foot standard service parachute were obtained. The parachutes were attached to 70-foot and 22-foot towlines, respectively, and are reported to have oscillated either vertically or horizontally with an amplitude of approximately the diameter of the canopy.

Shock loads.- The time history of the tension in the towline during an opening of a parachute in a steady air stream in simulated tow indicated that an instantaneous tension in excess of the final average tension was obtained. The ratio of the maximum tension to the final average tension is termed the "shock-load factor."

A maximum value of shock-load factor of 2.29 was obtained in a series of 21 measurements on both a 3-foot and a 5-foot parachute. The values ranged from 1.50 to 2.29 but could not be correlated with airspeed or parachute size although the shock load built up in less time with the smaller parachute. These shock loads were of the same order of magnitude as the shock loads subsequently obtained when the parachutes were opened by snapping a thread that held the canopy closed while the towline and shroud lines were fully extended. This result indicates that the inertia of the parachute had only little effect on the total shock load measured. Typical time-tension records obtained are shown in figures 9 and 10 for both methods.

Figure 11 is a motion-picture record of a typical opening of a 3-foot tail parachute from a standard parachute pack. The air-stream velocity was 39.5 feet per second. The figure shows that the unfolding of the canopy required approximately 15/32 second (the first 15 frames), the inflation of the canopy took approximately 6/32 second (the next 6 frames), and a "pumping" cycle followed during which the projected area of the canopy varied (area increased in frames 21, 26, and 30 and decreased in frames 24, 28, and 32). As these results indicate shock-load factors as high as 2.29, it is recommended that the designer of the restraining system for airplane parachutes consider a possible shock-load factor of approximately 2.3 and also allow for additional overloading of the parachute if it is in the propeller slipstream.

Modifications to Conventional Parachutes

Shroud-line length.- The effect of shroud-line length upon the parachute towline tension and stability was investigated by shortening the shroud lines of the 3-foot octagonal and 5-foot circular parachutes and by equipping the $1\frac{1}{2}$-foot canopy with various alternate sets of shroud lines. In all these tests the towline length was increased by the amount the shroud lines were shortened. The results of these tests (fig. 12) indicated that the shroud-line length should be at least 1.25 times the diameter of the flattened-out canopy in order to obtain nearly maximum towline-tension coefficient. A decrease in the angle between the parachute and the wind axes was noted when the shroud lines were the shortest.

Central shroud line.- The effect of a central shroud line upon the towline tension and stability of the 3-foot parachute was studied by pulling the center of the inflated canopy down in five steps through a distance of 0.67 foot from its normal position. The towline tension initially increased and then decreased to approximately its original value as the central shroud was shortened (fig. 13). A maximum increase in the towline-tension coefficient of approximately 11 percent was obtained by the addition of a central shroud line 0.28 foot shorter than the normal distance of 3.83 feet from the junction of the shroud lines to the center of the canopy. The original poor stability of the parachute was not appreciably affected by the central shroud.

Canopy vent.- When the vents of the canopies were closed by a paper insert on the 3-foot and 5-foot parachutes, no effect on the stability of the parachutes in simulated tow was observed. A slight decrease in the towline tension caused by the closing of the vents was noted.

The vent of the $1\frac{1}{2}$-foot octagonal canopy in a simulated free drop was successively increased in size until the vent diameter was one-half that of the canopy diameter. At a given airspeed, the drag of the parachute generally decreased as the size of the vent increased although the drag coefficient generally increased when based on the remaining canopy area. (See fig. 14.) With the largest vent, the parachute occasionally would collapse under load. The stability of the parachute was not greatly affected by the size of the vent; however, the angle between the parachute and wind axes tended to decrease as the vent area was increased.

Porosity.- Decreasing the porosity of a $3\frac{1}{2}$-foot parachute by superimposing two and four canopies did not change the towline-tension coefficients from those obtained with a single canopy. The effects of increased porosity were not investigated; however, as mentioned previously, the nylon parachute was observed to have relatively higher porosity and a lower towline-tension coefficient than the silk parachutes.

Fabric vanes.- An attempt was made simultaneously to increase the drag and stability of a parachute by attaching four mutually perpendicular fabric vanes to the shroud lines and to the inner surface on the canopy of the 3-foot parachute, as described in table V. For these arrangements data were obtained in both simulated tow and free-drop conditions. A typical arrangement is shown in figure 15. The average angle between the parachute and wind axes was decreased as much as 16°, but the corresponding towline-tension coefficient was decreased 0.14 (table V). The frequency of the oscillation of the canopy increased as the angle between the parachute and wind axes decreased.

The fabric vanes appeared to divert the approaching air flow to the low side of the canopy and blanket the high side that could be seen occasionally to collapse and inflate. The cause of the oscillation of the canopy was attributed to the action of the vanes.

Special Parachutes

Pyramidal.- Tests of a pyramidal silk parachute 1 foot square and approximately 37 inches high (fig. 2) in a simulated free drop indicated that the drag coefficient based on projected area was 1.48 but based on surface area was only 0.24. The parachute was more stable than the conventional canopies in that its axis was more nearly vertical in the tunnel. The inflated parachute assumed the shape of a cone. With a 1-foot-square wire frame at the skirt, a smaller drag coefficient (1.35) was obtained. Without the square wire frame but with the upper two-thirds of the pyramid removed and an 8-inch-square cap sewn over the top, the drag coefficient of the truncated parachute was 1.36, a decrease of 7 percent based on projected area, but was 0.36 based on surface area, an increase of 50 percent. With the cap removed the parachute would not inflate. This truncated pyramidal parachute is uneconomical because of the amount of material used. Tests of the full pyramidal shape with various shroud-line lengths indicated that the minimum shroud-line length required in order to keep the canopy from collapsing under load was approximately 1.7 times the width of the base of the pyramid.

Square pilot.- The towline-tension coefficient of the $2\frac{1}{2}$-foot-square pilot parachute sketched in figure 3 based on projected area was 0.69 and based on surface area was 0.29. Because of the amount of material used, this parachute is also uneconomical. This parachute was the most stable of the parachutes tested in that it did not wander about the test section during simulated free drop and did not tilt from the vertical more than 2° for either test condition. The fabric vanes and the canopy did vibrate, however, and occasionally a corner of the canopy would momentarily collapse. The fluctuation of the towline tension, shown in table III, for this parachute was appreciably more than for the conventional parachutes.

CONCLUDING REMARKS

Tests of the 1-foot to 8-foot parachutes to determine towline tension and stability indicated the following:

1. Characteristics of conventional parachutes:

(a) The average towline-tension coefficient, based on surface area of the canopy, of the silk parachutes was 0.76 and of the 8-foot nylon parachute was 0.56.

(b) The parachutes attached to towlines were unstable in that the axis of symmetry of the parachutes inclined as much as 30° from the wind axis and rotated irregularly about the wind axis.

(c) The shock loads obtained during the openings of a 3-foot and a 5-foot parachute ranged from 1.50 to 2.29 times the average final loads but could not be correlated with airspeed or parachute size.

(d) The $3\frac{1}{2}$-foot silk parachute tested in the Langley 16-foot high-speed tunnel did not fail at an indicated airspeed of 269 miles per hour.

2. Effect of modifications to conventional parachutes:

(a) A shroud-line length of at least 1.25 times the diameter of the flattened-out canopy is desirable in order to obtain nearly maximum towline-tension coefficient.

(b) The average angle between the parachute and wind axes was decreased as much as 16° by the addition of radial fabric vanes to the shroud lines and to the inner surface of the inflated canopy of the 3-foot parachute. These vanes decreased the towline-tension coefficient 0.14.

(c) Adding a central shroud line, varying the canopy vents, or decreasing the porosity of the canopies did not appreciably affect the towline-tension coefficient or the stability.

3. The pyramidal and square pilot parachutes were stable in that they assumed an approximately vertical attitude in the tunnel but, if the amount of material used for a given drag is considered, these parachutes are uneconomical.

Langley Memorial Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Va.

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TABLE I.- AREAS AND DESCRIPTIONS OF PARACHUTES TESTED

Parachute designation	Minimum diameter of canopy (ft)	Normal vent diameter (ft)	Surface area of canopy (sq ft) (a)	Projected area of inflated canopy (sq ft)	Material of canopy	Normal length of shroud line (ft)
1-ft pyramidal (37 in. high)	1.00	--------	6.17	1.00	Silk	1.7
$1\frac{1}{2}$-ft octagonal	1.46	0.12	1.78	.98	---do---	1.7
$2\frac{1}{2}$-ft square pilot	2.68	--------	17.20	7.19	---do---	[b]1.9
3-ft octagonal	2.93	.25	7.06	3.88	---do---	3.2
$3\frac{1}{2}$-ft octagonal	3.51	.25	10.22	5.62	---do---	4.0
5-ft circular	4.85	.29	18.51	10.18	---do---	5.3
8-ft 16-sided	7.67	.88	46.70	25.68	Nylon	7.2

[a]Including vent.

[b]Shroud lines replaced by fabric vanes extending 1.9 feet below the canopy (see fig. 3).

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TABLE II.- CONDITIONS TESTED ON PARACHUTES

[Data obtained indicated by *]

Parachute designation	Approx. towline length (ft)	Towline tension: Measured with deflectometer	Towline tension: Balanced against known weights	Shock load in towline during openings	Drag of free parachute with load attached	Angle between parachute and wind axes	Data
Tested in Langley 20-foot free-spinning tunnel							
[a]1-ft pyramidal	0.2				*		Text
[b]1-ft pyramidal	0.2				*		Text
[a]$1\frac{1}{2}$-ft octagonal	0.2				*		Fig. 12
[c]$1\frac{1}{2}$-ft octagonal	0.2				*		Fig. 14
$2\frac{1}{2}$-ft square pilot	4		*		*		Table IV, fig. 8
$2\frac{1}{2}$-ft square pilot	2.2	*				*	Table III
3-ft octagonal	2.2	*				*	Table III, fig. 7
3-ft octagonal	4		*				Table IV, fig. 8
3-ft octagonal	4			*			Figs. 9, 11
[a]3-ft octagonal	4 to 6		*				Fig. 12
[d]3-ft octagonal	4		*				Fig. 13
[e]3-ft octagonal	4		*		*	*	Table V
[f]3-ft octagonal	4		*				Text
[g]$3\frac{1}{2}$-ft octagonal	4		*				Text
$3\frac{1}{2}$-ft octagonal	2.2	*				*	Table III
$3\frac{1}{2}$-ft octagonal	17.5	*				*	Table III
$3\frac{1}{2}$-ft octagonal	4		*				Table IV, fig. 8
5-ft circular	2.2	*				*	Table III
5-ft circular	17.5	*				*	Table III
5-ft circular	4		*				Table IV, fig. 8
5-ft circular	4			*			Fig. 10
[a]5-ft circular	4 to 7		*				Fig. 12
[f]5-ft circular	4		*				Text
8-ft 16-sided	1		*				Table IV, fig. 8
8-ft 16-sided	2.2	*				*	Table III
8-ft 16-sided	15	*				*	Table III
Tested in Langley full-scale tunnel							
5-ft circular	15	Towline tension measured on balance system of tunnel					Table VI
8-ft 16-sided	15						Table VI
Tested in Langley 16-foot high-speed tunnel							
3-ft octagonal	0.2	Drag component of towline tension measured on balance system of tunnel					Table VI
$3\frac{1}{2}$-ft octagonal	0.2						Table VI
5-ft circular	0.2						Table VI
8-ft 16-sided	0.2						Table VI

[a]Shroud-line length varied.
[b]Upper two-thirds of canopy removed, 0.67-foot-square cap sewn on.
[c]Vent diameter was varied.
[d]Central shroud line added between apex of canopy and junction of shroud lines.
[e]Four fabric vanes added to parachute.
[f]Parachute with vent closed.
[g]Parachute with double and quadruple canopy.

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TABLE III.- MAXIMUM ANGLES OF PARACHUTE AXIS FROM WIND AXIS AND TOWLINE TENSIONS TAKEN FROM TIME-TENSION RECORDS OF PARACHUTE TENSION IN LANGLEY 20-FOOT FREE-SPINNING TUNNEL

Parachute designation	Towline length (ft)	Tunnel airspeed (ft/sec)	Maximum angle of parachute axis from wind axis (deg)	Towline tension (lb) (a)		
				Av.	Min.	Max.
$2\frac{1}{2}$-ft square pilot	2.2	44.40	2	11.0	6.0	15.0
Do----------	2.2	60.40	2	21.0	12.0	25.5
Do----------	2.2	77.75	2	34.0	14.0	41.5
Do----------	2.2	92.35	2	46.0	21.0	63.0
3-ft octagonal	2.2	44.25	23	11.5	10.0	12.5
Do----------	2.2	60.20	22	21.5	20.0	24.5
$3\frac{1}{2}$-ft octagonal	2.2	44.35	27	16.5	15.0	18.5
Do----------	2.2	53.60	25	27.0	23.5	31.5
Do----------	17.5	60.30	--------	34.0	30.5	40.0
Do----------	17.5	77.60	--------	58.0	50.0	65.0
Do----------	17.5	92.20	16	84.5	74.5	94.5
5-ft circular	2.2	44.55	28	30.5	29.0	35.5
Do----------	2.2	60.60	28	67.0	64.0	75.0
Do----------	2.2	78.00	26	112.5	95.0	124.0
Do----------	2.2	92.60	24	156.0	133.0	173.5
Do----------	17.5	78.00	14	126.5	117.0	144.0
Do----------	17.5	92.60	14	140.5	123.0	155.5
8-ft 16-sided	2.2	26.90	29	28.0	28.0	28.0
Do----------	2.2	46.80	15	82.5	80.5	85.5
Do----------	2.2	62.85	8	149.5	141.5	156.0
Do----------	2.2	78.70	11	235.0	229.5	239.0
Do----------	2.2	95.60	8	322.0	308.5	331.5
Do----------	15.0	26.90	11	23.0	23.0	23.0
Do----------	15.0	49.75	11	87.0	85.0	92.0
Do----------	15.0	62.85	11	138.5	131.5	141.0
Do----------	15.0	78.70	10	205.5	196.0	209.0
Do----------	15.0	95.60	15	288.5	282.5	296.0

[a]Weight of parachute and towline added to measured tension to give total air load along axis of parachute.

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TABLE IV.- TOWLINE-TENSION COEFFICIENTS BASED ON DIRECT FORCE MEASUREMENTS OF PARACHUTES IN THE LANGLEY 20-FOOT FREE-SPINNING TUNNEL

Parachute description			Towline-tension coefficient	
Parachute designation	Material of canopy	Towline length (ft)	Based on surface area given in table I	Based on projected area given in table I
$2\frac{1}{2}$-ft square pilot	Silk	4	0.29	0.69
3-ft octagonal	---do---	4	.73	1.33
$3\frac{1}{2}$-ft octagonal	---do---	4	.78	1.42
5-ft circular	---do---	4	.81	1.47
8-ft 16-sided	Nylon	1	.58	1.04

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TABLE V.- EFFECT OF FABRIC VANES ON TOWLINE TENSION, DRAG, AND ANGLE BETWEEN PARACHUTE AND WIND AXES ON 3-FOOT OCTAGONAL PARACHUTE

[Data obtained in Langley 20-foot free-spinning tunnel]

Location of fabric vanes (four radial vanes intersecting perpendicular at axis of symmetry)	Towline-tension coef-ficient (a)	Drag coef-ficient (b)	Angle between parachute and wind axes (deg)			
			In simulated tow		In simulated free drop	
			Av.	Max.	Av.	Max.
Without fabric vanes	0.73	0.79	26	29	---	34
Extending from apex of canopy to periphery of canopy	.68	.66	---	25	---	30
In cavity of canopy extending downward one-fifth of shroud-line length	.65	.65	---	12	---	22
In cavity of canopy extending downward one-half of shroud-line length[c]	.60	.70	---	9	---	20
Extending from towline attachment to periphery of canopy	.59	.62	10	14	15	24
Extending from periphery of canopy downward one-half of shroud-line length	.61	.63	10	15	17	27
Extending from towline attachment upward one-half shroud-line length	.71	.70	23	24	31	40

[a]Values given are averages of several tests.

[b]Values given are for single test with load of approximately 10 pounds.

[c]Figure 15.

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TABLE VI.- COMPARISON OF TOWLINE-TENSION COEFFICIENTS OBTAINED FOR PARACHUTES IN LANGLEY 20-FOOT FREE-SPINNING, FULL-SCALE, AND 16-FOOT HIGH-SPEED TUNNELS

[Coefficients are based on surface area of canopy]

Parachute designation	Towline-tension coefficients		
	Langley 20-foot free-spinning tunnel	Langley full-scale tunnel	Langley 16-foot high-speed tunnel (a)
3-ft octagonal	0.73	----------	[b]0.75
$3\frac{1}{2}$-ft octagonal	.78	----------	.73
5-ft circular	.81	0.70	.79
8-ft 16-sided	.58	.57	[c].53

[a]Values obtained at approximately 60 miles per hour indicated airspeed.

[b]Estimated value assuming an average angle of 27° between the parachute and wind axes.

[c]Estimated value assuming an average angle of 10° between the parachute and wind axes.

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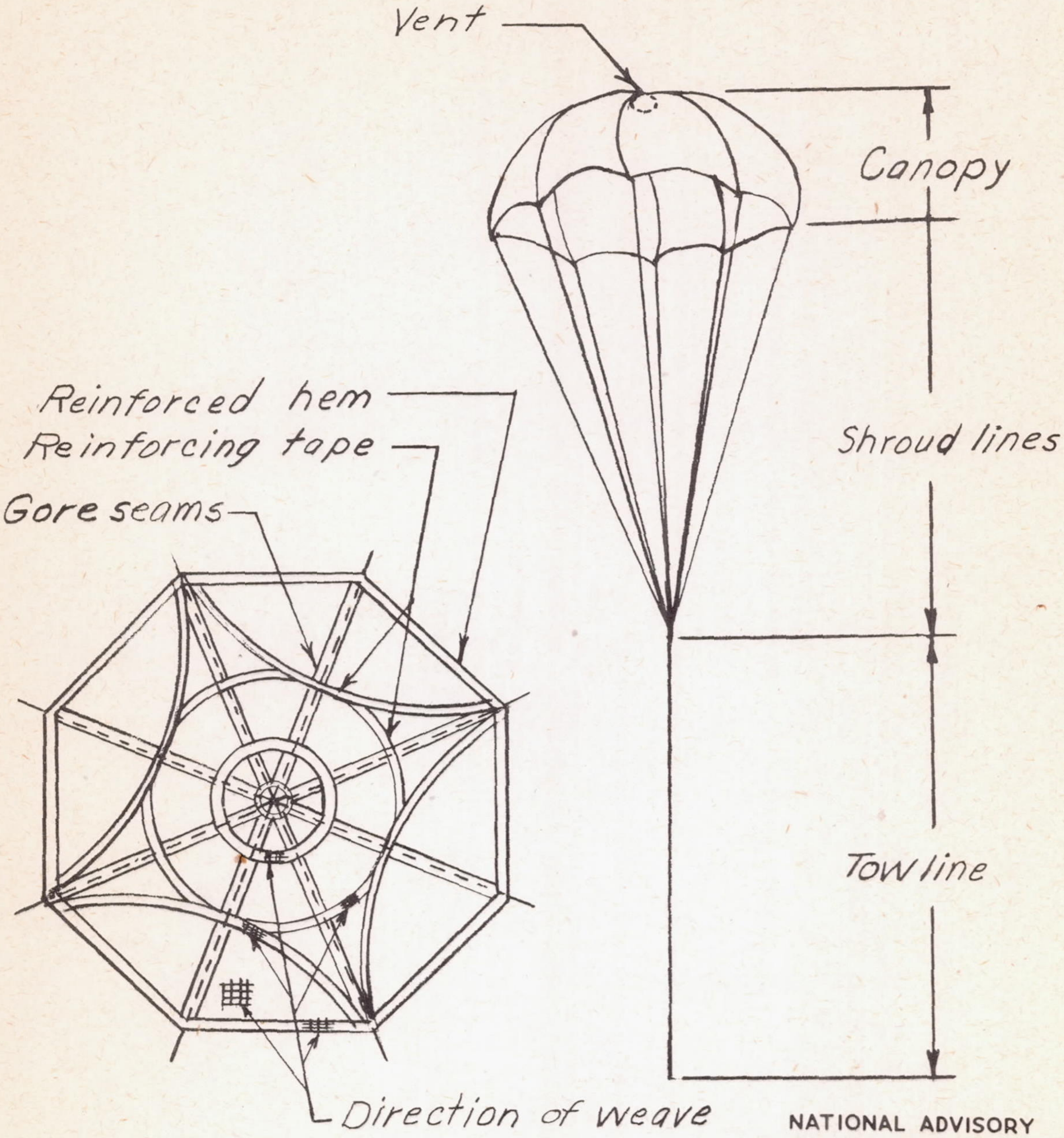

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Figure 1.- Spin-recovery parachute with reinforced canopy.

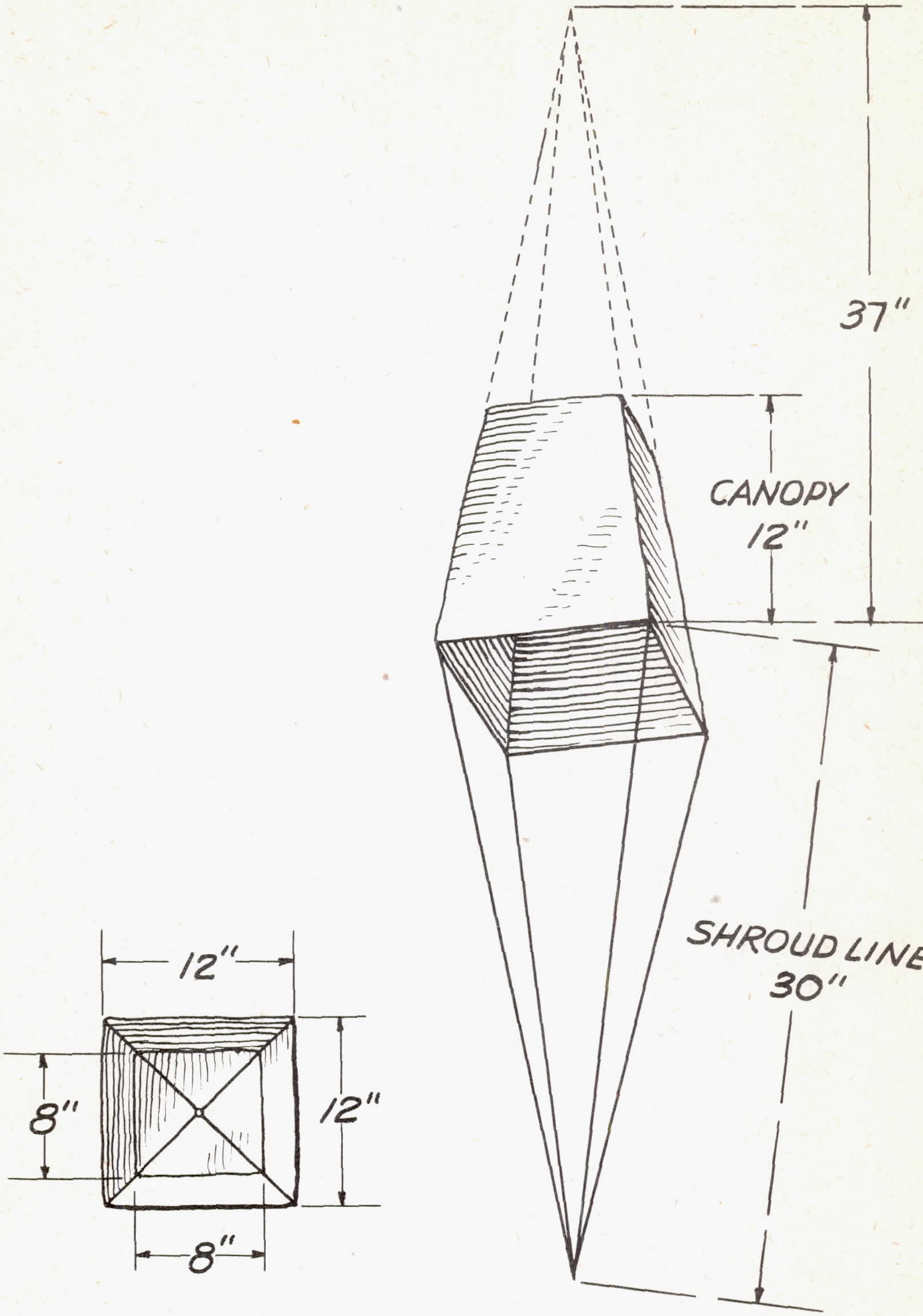

Figure 2.- Pyramidal parachute.

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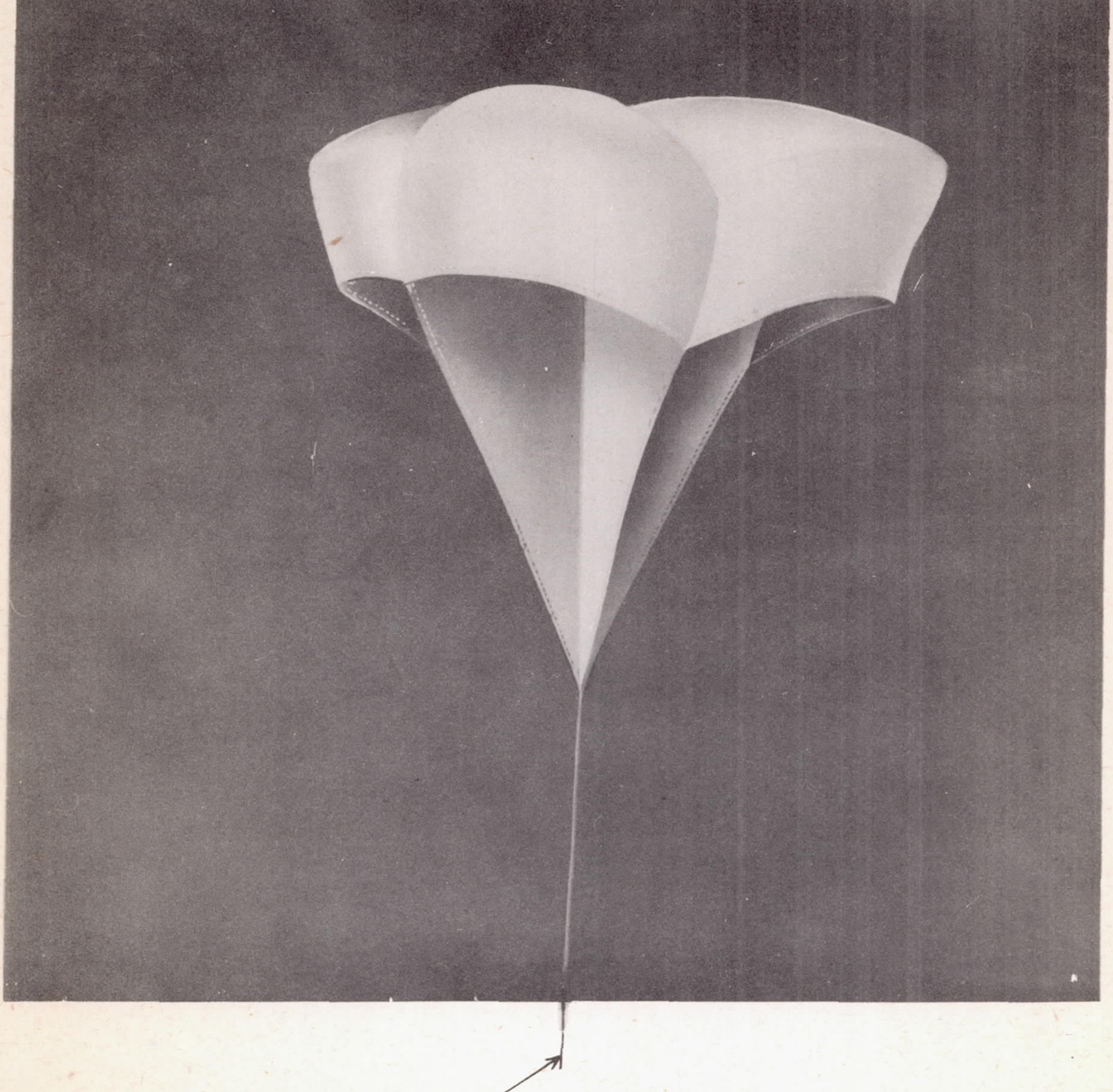

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Figure 3.- Perspective view of the $2\frac{1}{2}$-foot square pilot parachute.

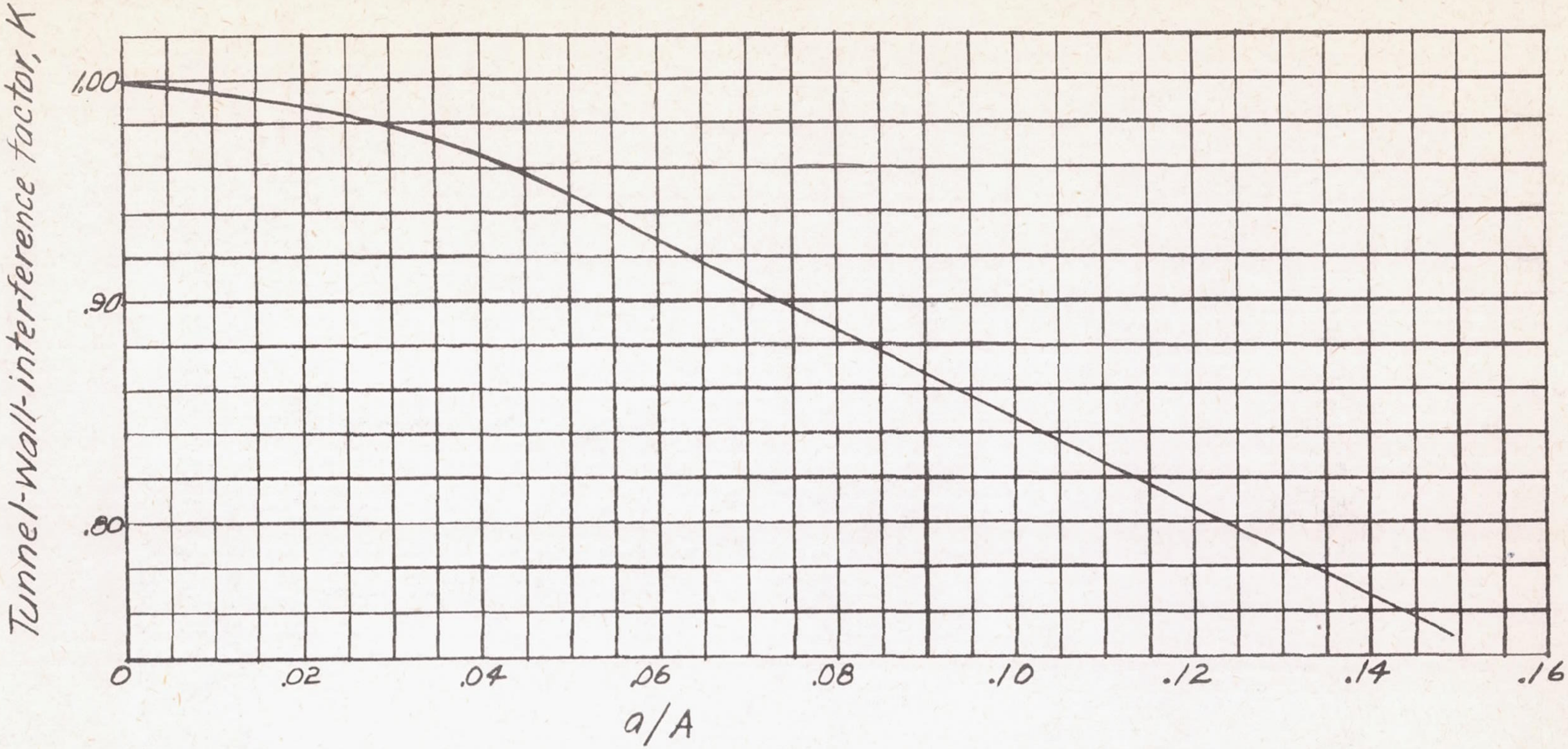

Figure 4.- Tunnel-wall-interference factor K against ratio of projected area a of object normal to air stream to cross-sectional area A of air stream. Drag or towline-tension coefficient in free air equals K times coefficient obtained in tunnel.

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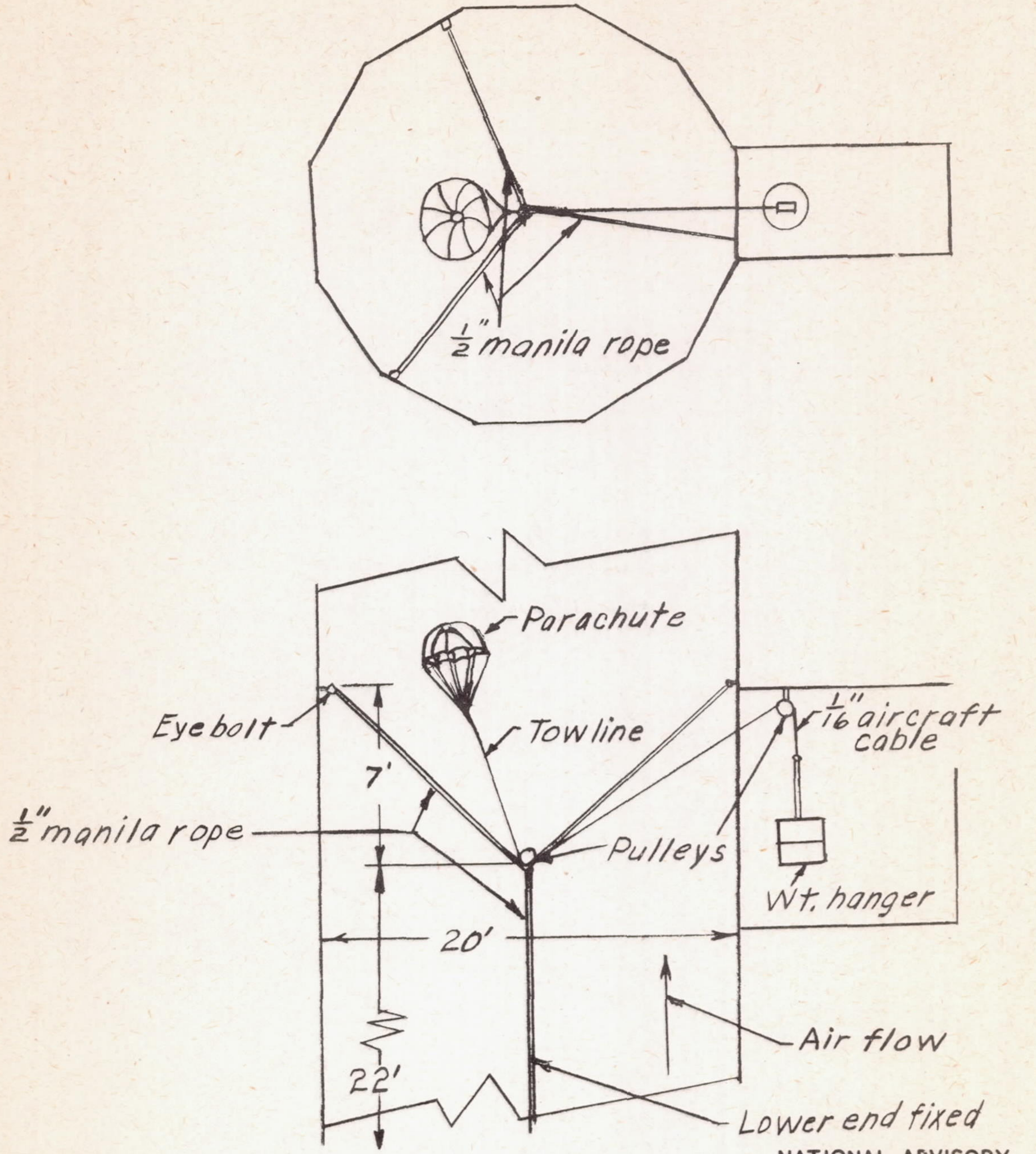

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Figure 5.- Installation in Langley 20-foot free-spinning tunnel for measuring force in towline of a parachute.

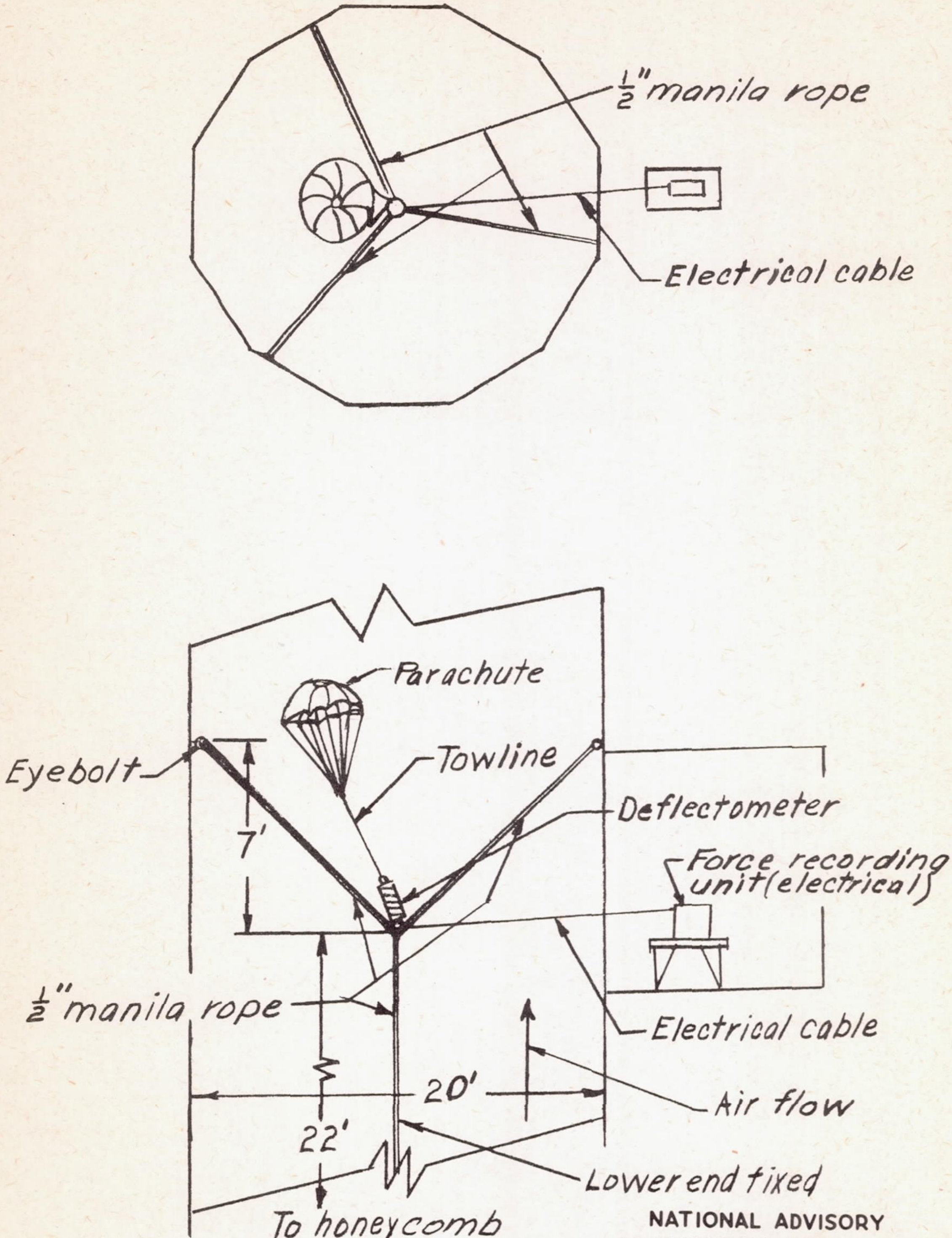

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Figure 6.- Installation in Langley 20-foot free-spinning tunnel for measuring force in towline of a parachute.

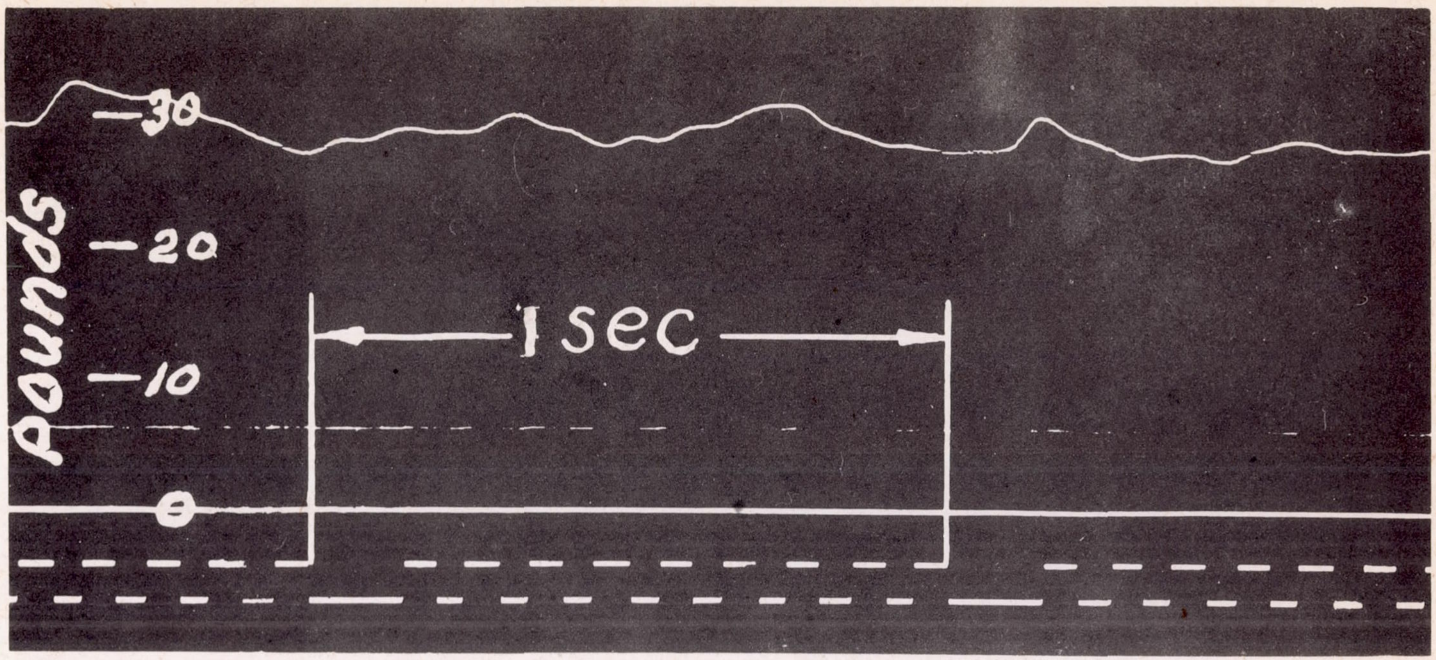

Figure 7.- Typical time-tension record of parachute towline tension in steady air stream. Record is for 3-foot octagonal silk tail parachute tested in Langley 20-foot free-spinning tunnel at 60.2 feet per second; towline length, 2.2 feet.

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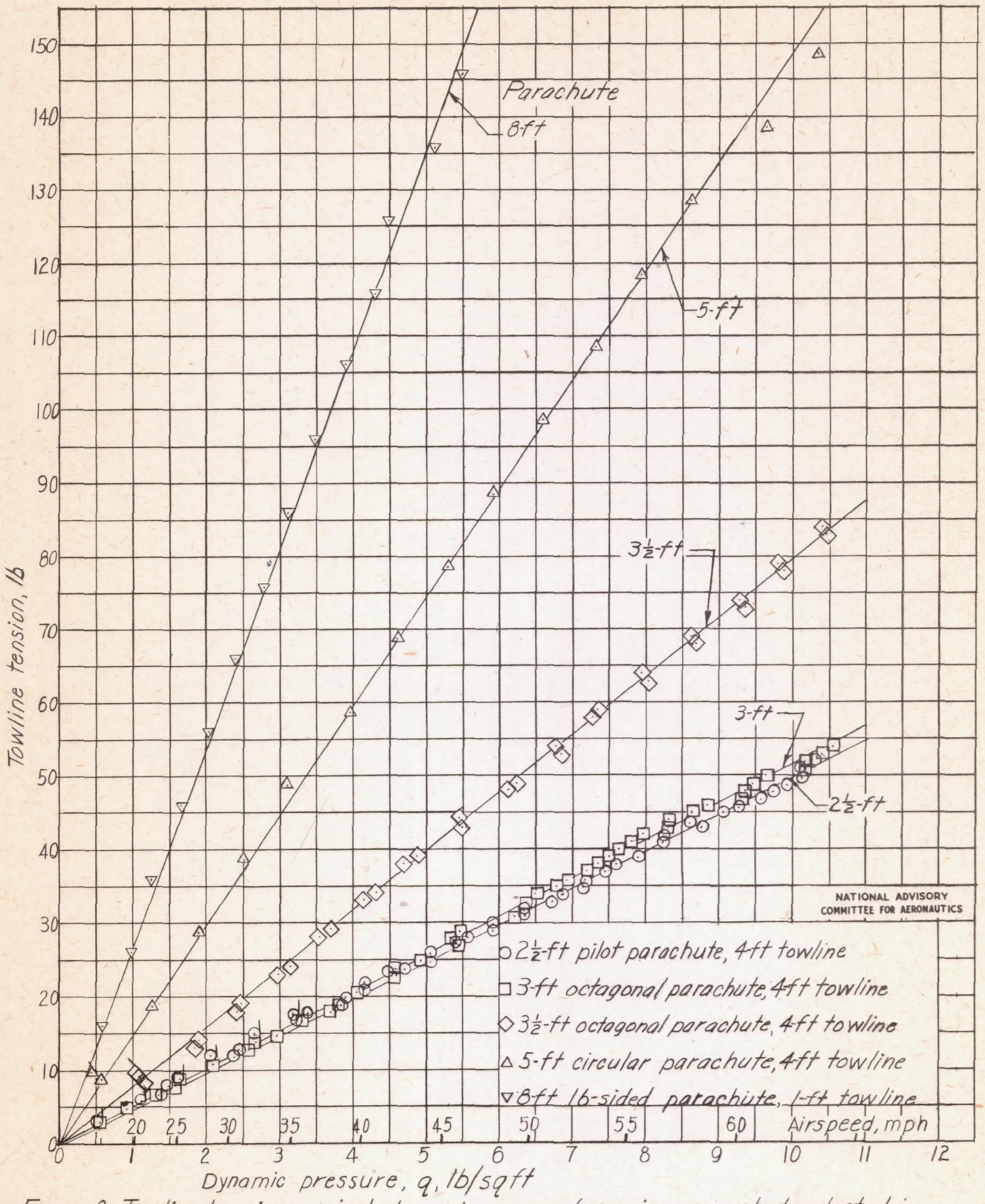

Figure 8.- Towline tension against dynamic pressure for various parachutes tested in Langley 20-foot free-spinning tunnel. Symbols with flag indicate drag in pounds for parachute in simulated free drop.

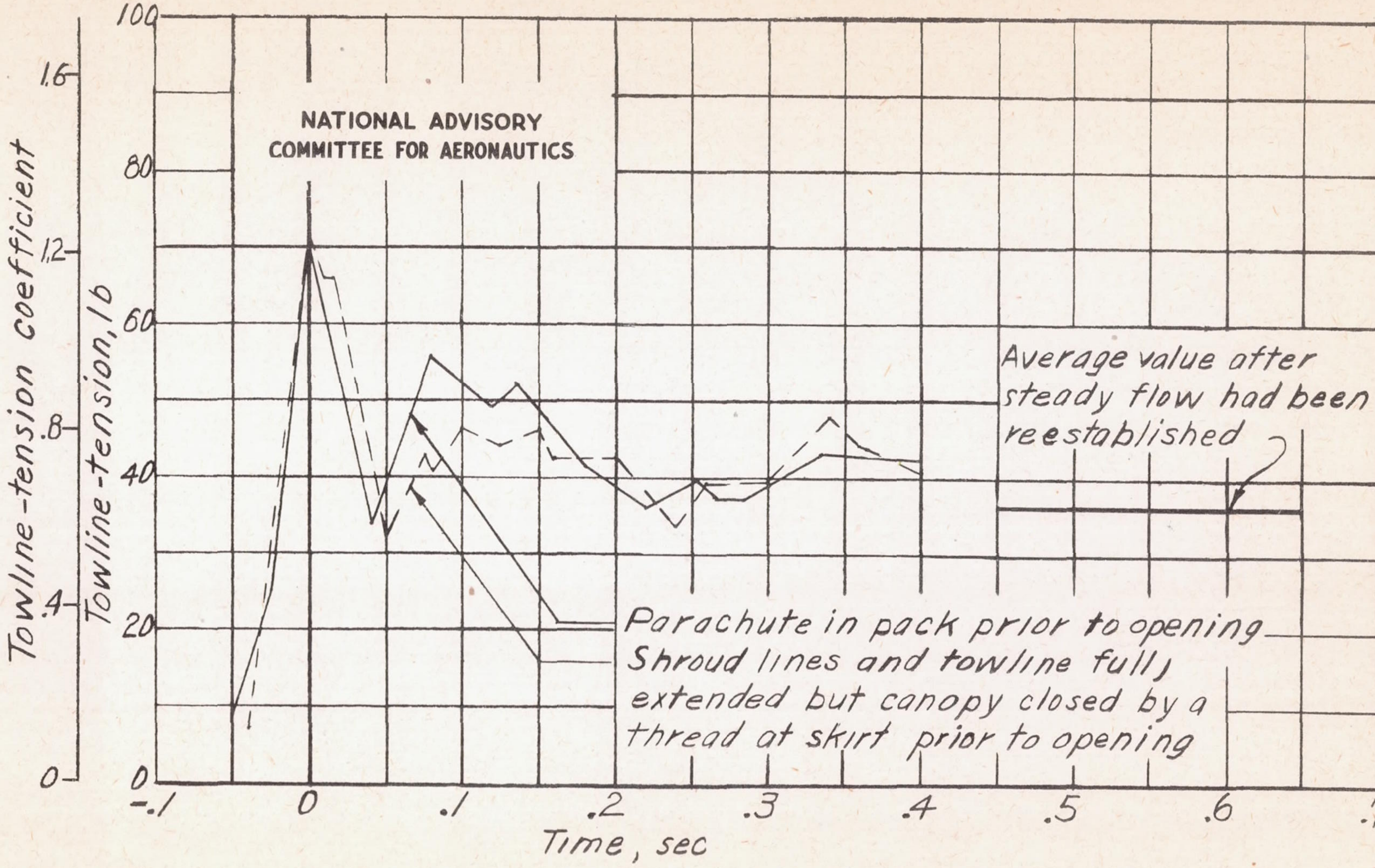

Figure 9.- Time-tension record of 3-foot parachute opening in steady air stream. (q = 8.30 lb/sq ft; tested in Langley 20-ft free-spinning tunnel.)

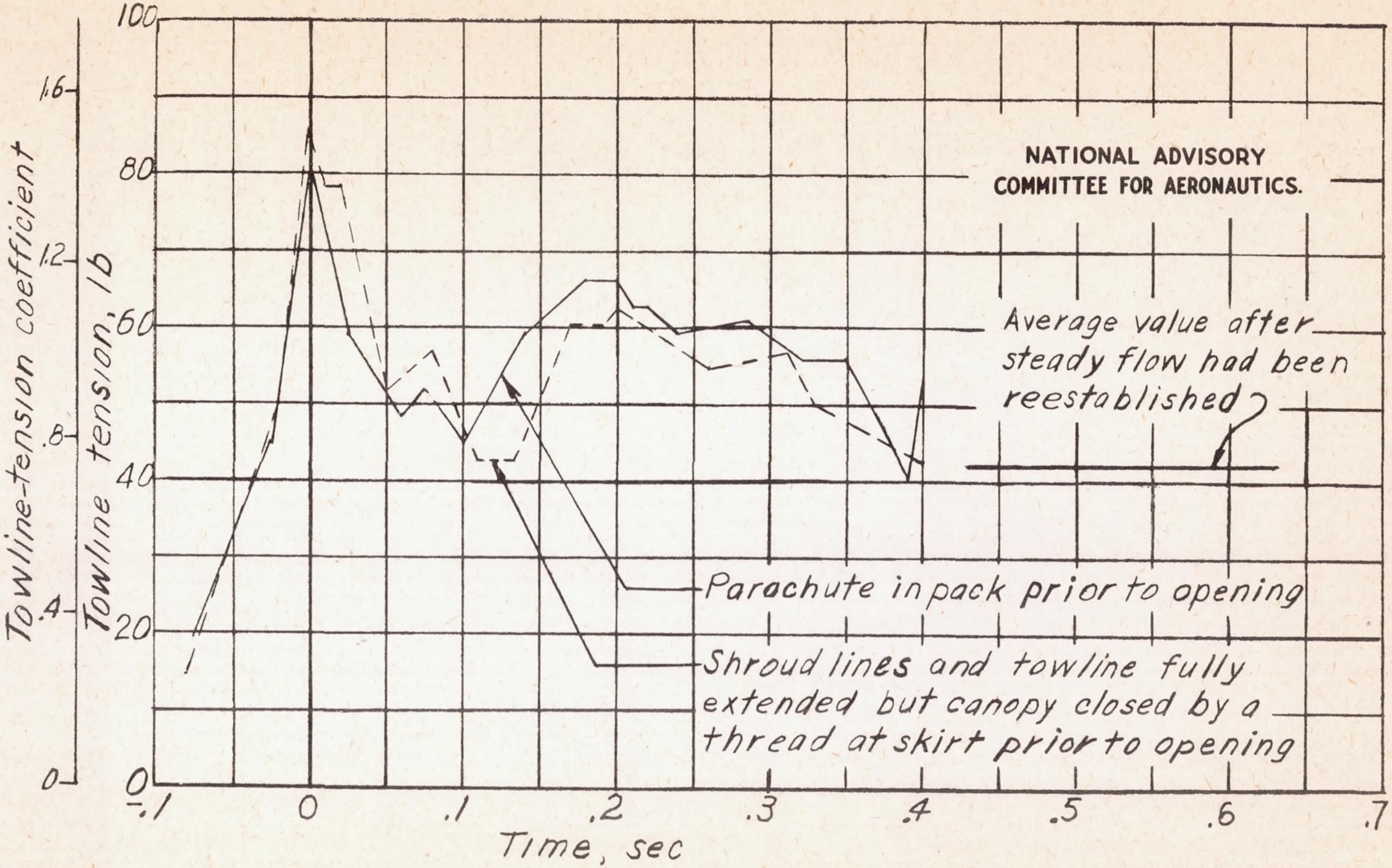

Figure 10.- Time-tension record of 5-foot parachute opening in steady air stream. (q=3.10 lb/sq ft; tested in Langley 20-ft free-spinning tunnel.)

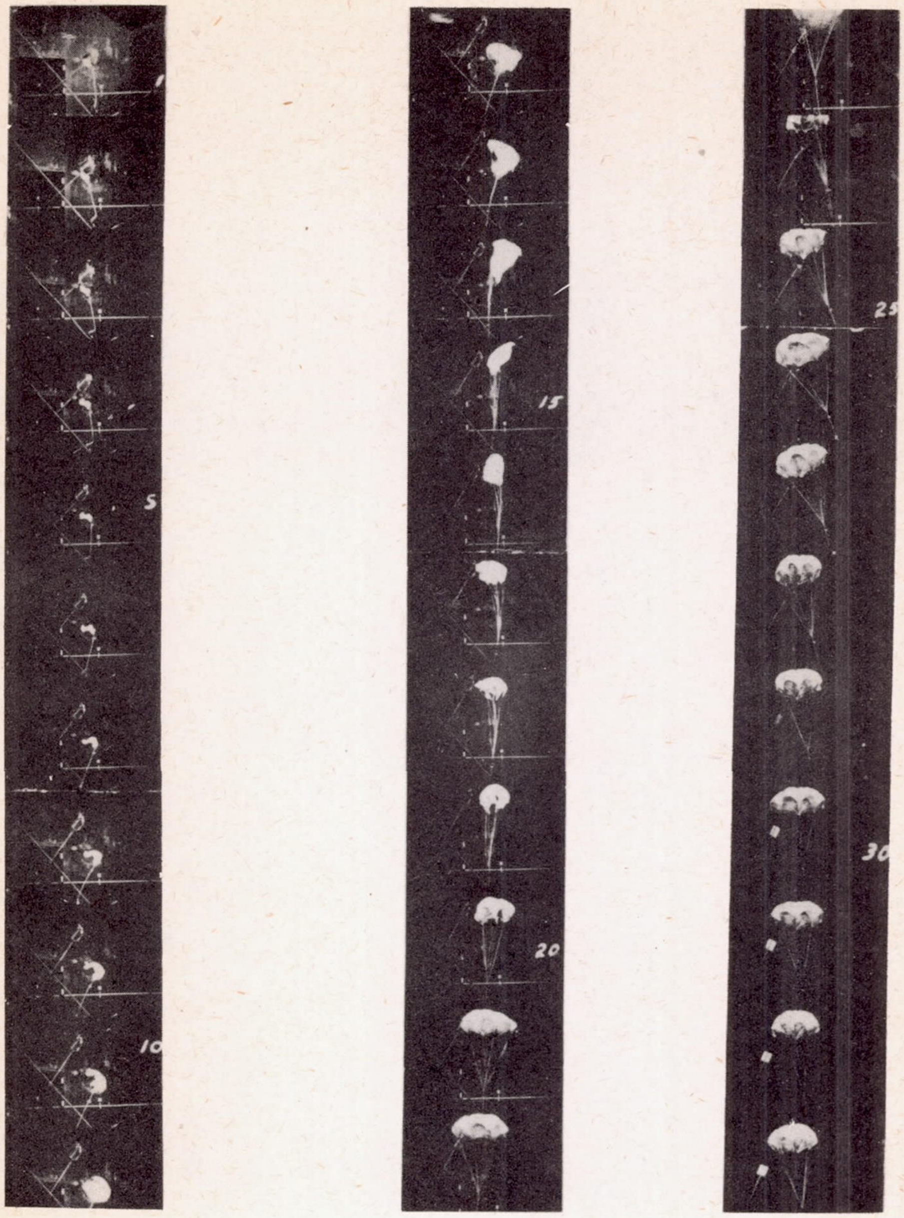

Figure 11.- Typical opening of 3-foot parachute from standard parachute pack tested in Langley 20-foot free-spinning tunnel. Air-stream velocity, 39.5 feet per second; time interval between each frame approximately 1/32 second.

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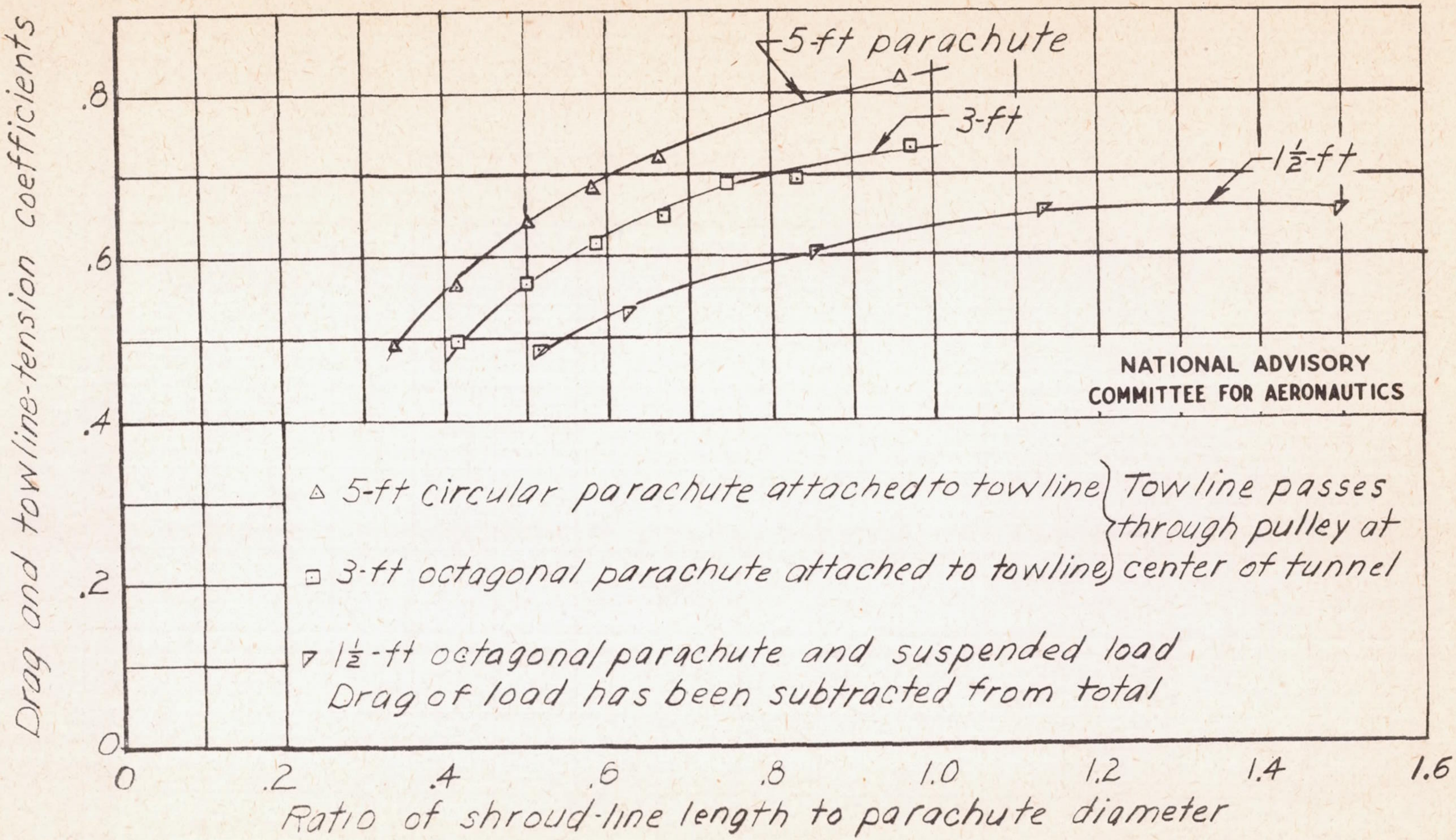

Figure 12.- Effect of shroud-line length on drag and towline-tension coefficients for three parachutes tested in Langley 20-foot free-spinning tunnel.

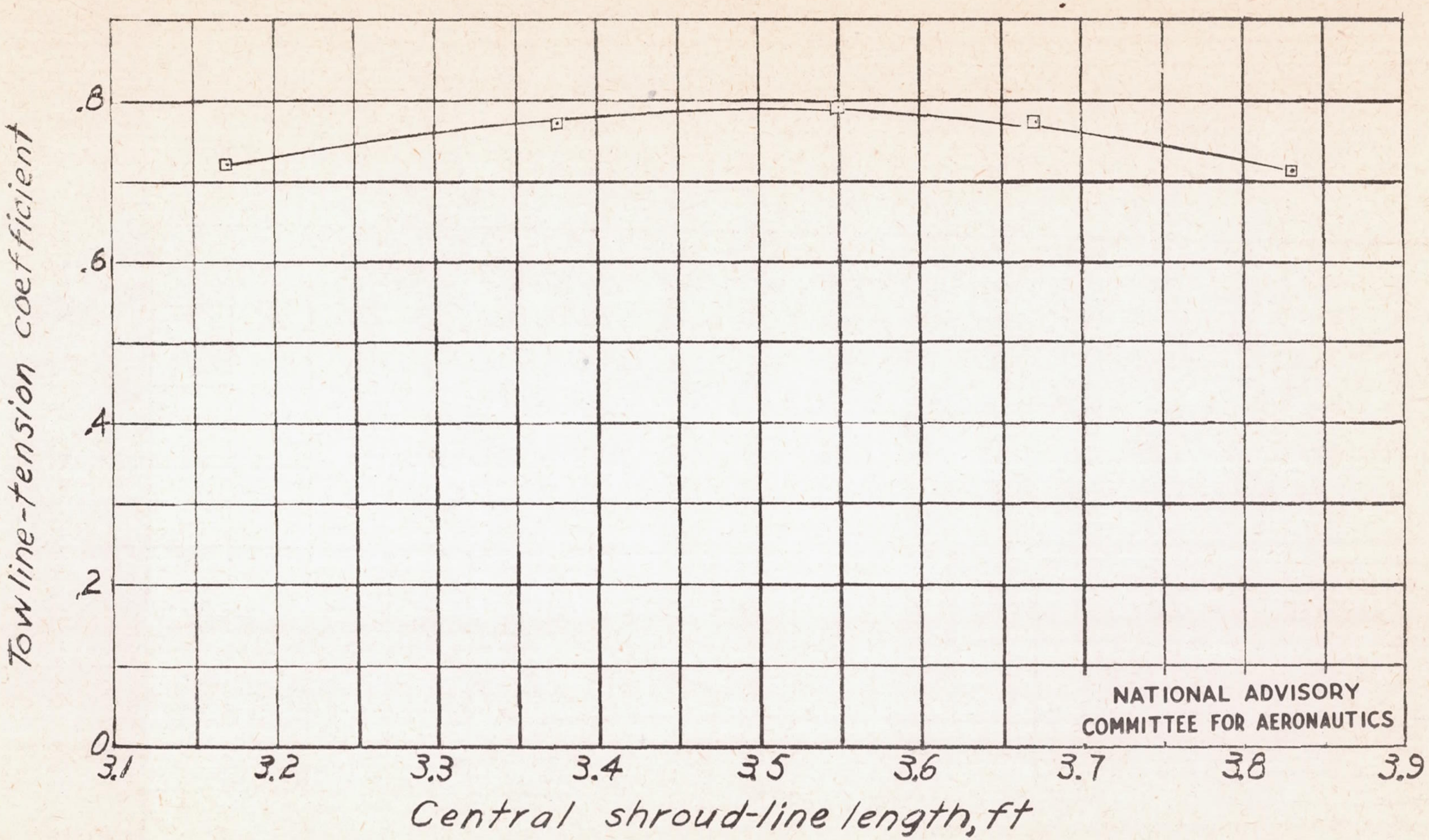

Figure 13.- Effect of central shroud-line length on towline-tension coefficient for 3-foot octagonal parachute. Normal length from towline attachment to apex of inflated canopy, 3.83 feet; tested in Langley 20-foot free-spinning tunnel.

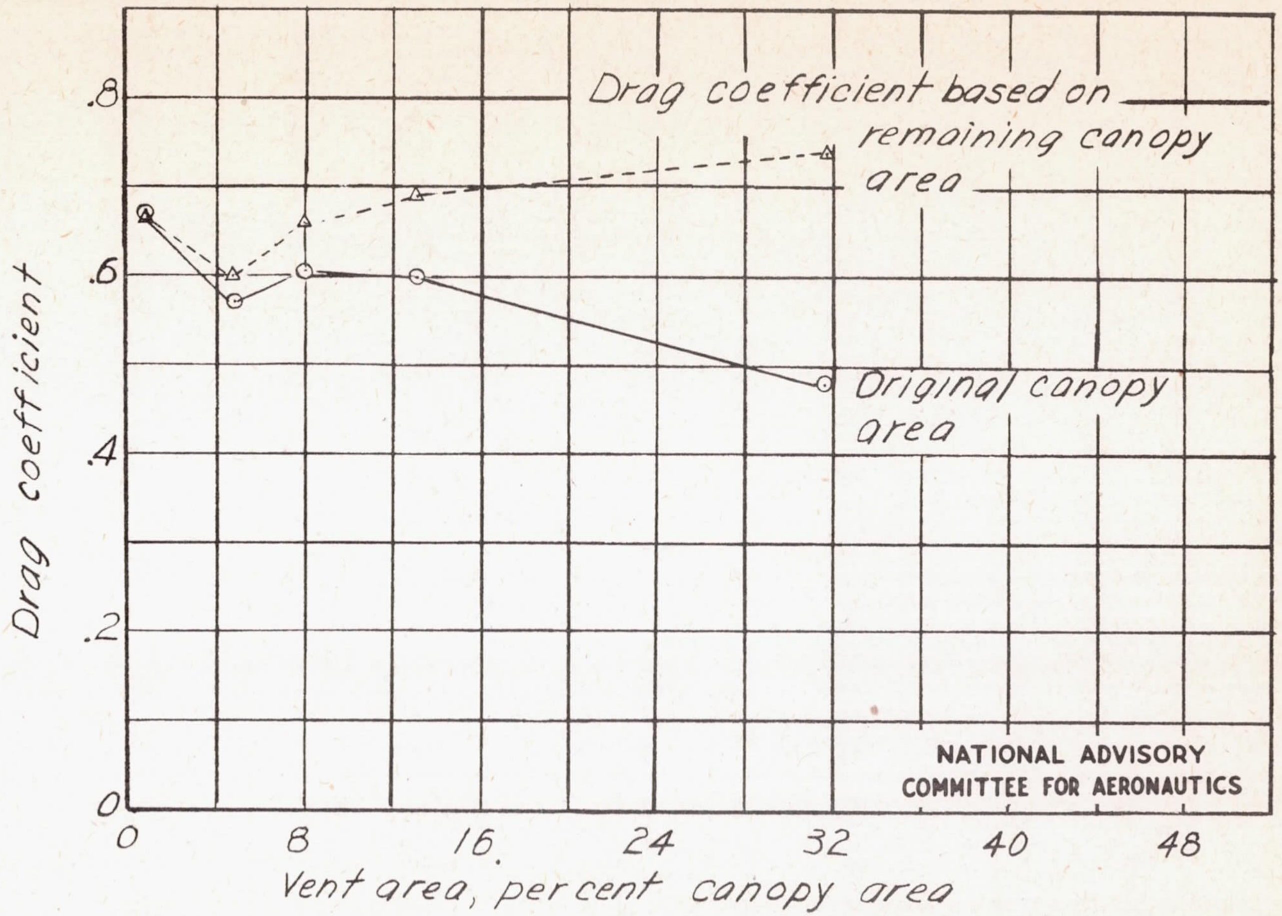

Figure 14.- Effect of vent size on drag coefficient for $1\frac{1}{2}$-foot octagonal silk parachute. Each coefficient represents an average of five values obtained with loads of 1, 2, 3, 4, and 5 pounds; tested in Langley 20-foot free-spinning tunnel.

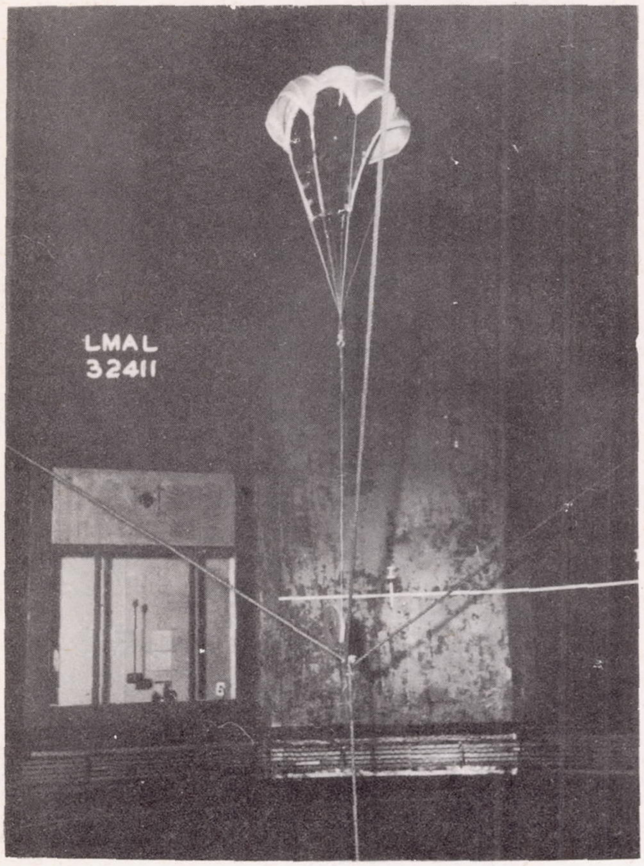

Figure 15.- The 3-foot parachute equipped with fabric vanes tested in Langley 20-foot free-spinning tunnel.