R. & M. No. 2543
(8,388, 10,762)
A.R.C. Technical Report

MINISTRY OF SUPPLY

AERONAUTICAL RESEARCH COUNCIL
REPORTS AND MEMORANDA

Wing Parachutes for Recovery from the Spin

By

G. E. PRINGLE, Ph.D., and T. V. SOMERVILLE, B.Sc.

LONDON: HER MAJESTY'S STATIONERY OFFICE
1954
THREE SHILLINGS NET

Wing Parachutes for Recovery from the Spin

PART I

General Design Requirements

By

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COMMUNICATED BY THE PRINCIPAL DIRECTOR OF SCIENTIFIC RESEARCH (AIR),
MINISTRY OF SUPPLY

Reports and Memoranda No. 2543*
March, 1947

Summary.—The design data presented include:—

(i) Recommended diameter of parachutes, $D = (0{\cdot}14s/\varrho)\sqrt{S}$.

(ii) Rates of descent in the spin ($C_D = 1$ at 60 deg, $0{\cdot}5$ at 30 deg).

(iii) Rates of rotation $\Omega = 18\sqrt{\bar{w}}/s$.

(iv) Directions of the pull of the tow cables. Large fore-and-aft angles are assumed for the spin and large sideways angles during recovery with sideslip.

Advice is also given on the precautions to be taken during the installation and on the strength requirements. A table of stressing cases is given in section 9.1.

1. *Introduction.*—The suggestion to use parachutes attached near the wing tips for recovery from bad spins is not news, but was considered before tail parachutes were introduced[1]. With the increasing interest in tailless types it has become necessary to reconsider the wing parachute as a safety device, and wind-tunnel tests have shown that it can be of powerful assistance.

2. *Wind-tunnel Tests.*—The design data of this note are based on some measurements in the vertical wind tunnel on the General Aircraft Company's glider with 29·4 deg sweepback, with model parachutes having approximately correct scaled weight. The tests showed that ten more units of pro-spin yawing moment were required to prevent recovery when a parachute was streamed from the outer wing than without it, and the simultaneous release of two parachutes on opposite wings was correspondingly more powerful. This solution is favoured because in the recovery phase the assymetric moment of a single parachute would be troublesome. The equivalent full-scale diameter of parachute in these tests was $2\frac{1}{2}$ ft for a gross wing area of 350 sq ft. It is suggested that the parachute area should be proportional to wing area. For different

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* R.A.E. T.N. ~~report~~s Aero. 1559 and 1881, received 31st January, 1945, and 28th July, 1947.

points of attachment (*e.g.*, inner end of the elevons) it seems from a further test that the parachute diameter should vary inversely as the distance of attachment from the centre line. The formula for the diameter then becomes

$$D \quad 0{\cdot}14\,\frac{s}{\varrho}\sqrt{S}$$

where D parachute diameter
S gross wing area
s semi-span
ϱ spanwise distance from centre-line to attachment.

3. *General Remarks on the Formula for Diameter.*—It is noted that the formula is different in form from that for tail parachutes. Tail parachutes act partly by pitching moment and partly by introducing a damping in yaw. The relative importance of these terms has not been fully ascertained, but from the fact that the recovery still seems good even when the parachute rides down the spinning axis it seems that the pitching moment dominates if the cable is reasonably long. In any case our design formulae for that type of installation are so framed that with certain simplifying assumptions the pitching-moment coefficient has always the same value, of the order of 0·020 (20 units) in spins at 45 deg incidence.

For wing-tip parachutes the case is quite different. Here it seems certain that what dominates is the moment about the spinning axis (rolling moment in wind axes).

To a first approximation this anti-spin moment will be determined by the cable pull, assumed to equal the parachute drag in an airstream of speed V, where V = rate of descent of aircraft, acting at an angle ϕ to the vertical in a plane containing the chord (Fig. 1),

where $\tan\phi = \dfrac{\Omega\varrho}{V}$

and Ω = rate of rotation of aircraft.

With the suggested diameter this moment becomes

$$\tfrac{1}{2}\rho V^2 \frac{\pi}{4} D^2 C_p \frac{\Omega\varrho}{V}\, 2\varrho = \tfrac{1}{2}\rho V^2 \frac{\pi}{4}(0{\cdot}14)^2 S\, C_p\left(\frac{\Omega s}{V}\right)2s,$$

where C_p = drag coefficient of the parachutes.

Hence the moment coefficient C_ϱ is given by the formula

$$C_\varrho = 0{\cdot}015 C_p\lambda \text{ where } \lambda = \frac{\Omega s}{V},$$

$$= 0{\cdot}0075 \text{ (7·5 units) if } \lambda = 0{\cdot}45 \text{ and } C_p = 1{\cdot}07.$$

The theoretical aim is, therefore, that of providing an approximately constant anti-spin moment irrespective of the points of attachment, on the assumption of a given spin parameter. Faster spins will generate larger damping moments.

4. *Attachment to Wing.*—In the tests referred to, the attachments to the wings were at the tips, but the model had then no fins and rudders. However, the major problems occur in avoidance of fouling the controls by the parachute cables, bearing in mind the possibility of awkward angles taken up by the cables, especially during recovery with large sideslip. Two principal solutions seem to be possible—either to have the attachments built out behind the rudders, or else sufficiently far inboard to allow considerable lateral freedom (say the inner end of the elevon) (but see Part II).

As a result of photography of the model, the following cable angles have been adopted for stressing in the spin and for consideration of possible fouling:—

Angle to chord	0 to 110 deg upwards
Angle to plane of symmetry	± 60 deg.

The large sideways angles appear to be possible during recovery just as the rotation stops.

The usual type of parachute release-slip can be used, and it is a useful preliminary to instal either mechanical cable controls or electrical cables during construction of the wing, to operate the streaming and jettison mechanisms. The standard slip will not allow for the large range of angles specified, but this may be overcome by using a guide ring large enough to pass the end loop of the cable.

5. *Cable Length.*—It was thought at first that the wake of the wing would be avoided if the length of the cable was made equal to the spanwise distance from the point of attachment to the plane of symmetry. Later work reported in Part II, however, shows that the cables should be made as long as possible up to one and a half spans in length to avoid the wake of the wing.

6. *Jettison.*—Attention is drawn to the paramount need for ensuring simultaneous breakaway of wing parachutes, to avoid large unbalanced yawing moments after recovery. This can be done either

(*a*) by the pilot using his control,

(*b*) by failure of the weak link of one parachute being arranged to operate the jettison mechanism of the other,

(*b*) can be arranged either electrically or mechanically. If the operation is mechanical it can be arranged, for example, by so joining the parachute cables that the double tension comes on the second weak link as soon as the first has been broken. Electrical operation can be in the form of a relay actuating the opposite jettison slip mechanically or electrically.

7. *Speeds of Descent.*—The speeds are approximately as for spinning of conventional types, but in the case of wing parachute attachment we distinguish the local airspeed from the aircraft speed.

The steeper spins are assumed to result in a rate of descent $V = \sqrt{1680w}$ ft/sec indicated where w = wing loading in lb/sq ft which is equal to the aircraft speed for this purpose. To allow for a possible rate of rotation of

$$\Omega = \frac{18\sqrt{w},}{s}$$

where s is the semi-span, the resultant opening speed for the parachute, assumed to ride at radius ϱ, is

$$V_1 = \sqrt{\left\{\left(1680 + 320\,\frac{\varrho^2\partial}{s^2}\right)w\right\}}\ \text{ft/sec},$$

and for this purpose we may take $\sigma \bumpeq 1$ (low altitude).

8. *Safety Link.*—As with tail parachutes, a safety link must be provided, the purpose of which is two-fold:—

(*a*) To guard against damage to the structure in the event of any unforseen high parachute loads combined with the aerodynamic loads.

(*b*) To ensure that the parachutes are jettisoned in the dive after recovery before the combined loads become excessive, in case the pilot delays the operation of his jettison control or forgets it.

Generally the safety link, consisting of a copper pin in double shear, is designed to break at 1·1 to 1·2 times the opening pull of the parachute.

The opening pull is taken to be

$P_1 = 0\cdot0015V_1^2D^2$ (equivalent to parachute $C_p = 1\cdot07$ and shock factor 1·5)

and the steady load in the dive to be

$P_2 = 0\cdot001V_2^2D^2$ (equivalent to parachute $C_p = 1\cdot07$)

Hence V_2 must generally be $V_1\sqrt{(1\cdot5 \times 1\cdot15)} = 1\cdot3V_1$

The strength of the weak link quoted above should be regarded as the minimum requirement for safety. Where an adequate margin of structural strength is provided by compliance with other stressing cases it may be desired to increase the strength of the weak link above this value. It is convenient to regard the strength of the weak link as being equal to 1·1 to 1·2 times P_3, where P_3 is decided by the strength of the structure but is not in any case less than P_1. The opening load for which the aircraft and installation should be stressed then becomes P_3, and V_2 is given by

$$0{\cdot}001\, V_2^2 D^2 = 1{\cdot}15 P_3, \text{ or } V_2 = \sqrt{\left(\frac{1150 P_3}{D}\right)}.$$

9. *Strength of the Installation.*—9.1. *Spinning Cases.*—

(i) The aircraft should be assumed in a steady spin with rate of rotation

$$\frac{18\sqrt{w}}{s} \text{ radn/sec},$$

and the attitude as given in the following table.

Table of Spin and Dive Data

Note: Parachute diameter D is not less than $0{\cdot}14\,\frac{s}{\varrho}\sqrt{S}$.

Case	Attitude	Aircraft speed	Local speed at parachute	Parachute load	Cable angles
I Flat Spin	60° to vertical	$V=\sqrt{(840w)}$	$V_1=\sqrt{\left\{\left(840+320\frac{\varrho^2}{s^2}\right)w\right\}}$	$P_1 = 0{\cdot}0015 V_1^2 D^2$	0 to 110° upwards 0 to ± 60° to plane of symmetry
II Steep Spin	30° to vertical	$V=\sqrt{(1680w)}$	$V_1=\sqrt{\left\{\left(1680+320\frac{\varrho^2}{s^2}\right)w\right\}}$	$P_1 = 0{\cdot}0015 V_1^2 D^2$ or P_3	
III Dive	—	$V_2 = 1{\cdot}3\, V_1$ or $V_2 = \frac{\sqrt{(1150 P_3)}}{D}$		$P_2 = 0{\cdot}001 V_2^2 D^2$	0 upwards 0 to 20° sideways

(ii) The attachment of the cable to the wing and the adjacent structure, including the jettison hook and guide ring (if any) should have an ultimate factor of at least 2·0 under the loads in (iii) (*c*) below.

(iii) The rest of the fuselage should have a factor of at least 1·5 under the following combined loads:—

(*a*) wing and elevon loads assuming a normal force coefficient $C_Z = 1{\cdot}0$,

(*b*) fin and rudder load assuming a normal force coefficient $C_Y = 1{\cdot}0$ (Cases I and II only),

(*c*) parachute cable load P_1 or P_3 acting in the direction stated in the table.

9.2. *Dive Case.*—The aircraft should be assumed in a steady glide at a speed V_2 after recovery from the spin. A factor of at least 1·5 on the structure and cable attachments, including the jettison hook, is required under the balancing aerodynamic loads with a cable load P_2 or P_3 acting backwards either parallel to flight path or at the angles stated in the above table, section 9.1. The yawing moment exerted by the cables, which may be assumed parallel, is taken to be balanced by the application of the rudders.

9.3. *Parachute Strength.*—All parts of the parachute, including the rigging lines and tow cables, should have a factor of at least 1·5 on the cable load P.

9.4. *Ground Test.*—Ground streaming and jettison tests of the complete installation are made under conditions similar to those of A.P. 970, Chap. 716.

10. *Symbols in This Note.*

S	gross wing area
s	semi-span
V	aircraft rate of descent
V_1	local speed at parachute
V_2	aircraft dive speed
Ω	rate of rotation
σ	relative density
w	wing loading
D	parachute diameter
ϱ	distance from plane of symmetry to parachute attachment
C_p	parachute drag coefficient based on flying area
C_ϱ	rolling-moment coefficient in wind axis
P_1	parachute opening load
P_2	parachute diving load
P_3	a load depending on weak link strength

REFERENCE

No.	*Author*	*Title, etc.*
1	Alston	Note on Use of a Wing-tip Parachute in Recovery from Spins. R.A.E. Report B.A. 1014. March 1933.

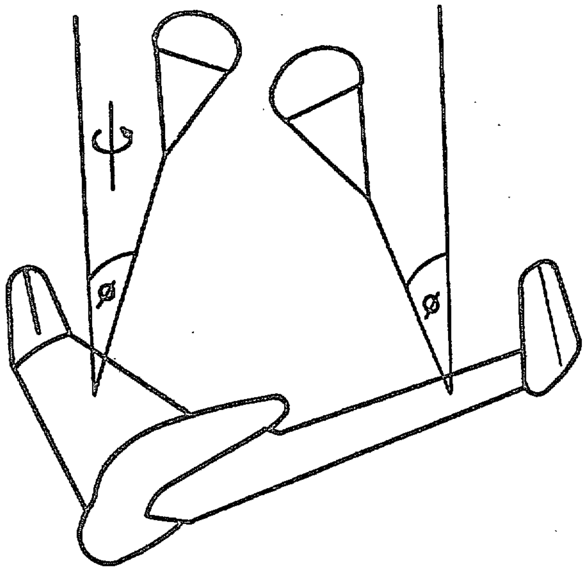

FIG. 1. Tailless craft with wing parachutes streamed.

PART II

Wake Phenomena

By

D. J. HARPER, J. R. MITCHELL,
J. PICKEN and G. E. PRINGLE

Summary.—The wing parachutes of a tailless aircraft prototype failed to open when streamed in an accidental spin. This gave a clue to the existence of a marked wake effect when a parachute is deployed on a tow cable behind a stalled wing. This wake effect is such as greatly to reduce the critical closing speed of the parachute. The effect measured in a wind tunnel diminishes as the cable is lengthened. It is recommended that the cables should be made as long as possible up to one and a half spans in length; here the danger of entanglement becomes real. The centrifugal forces in spinning may also be turned to good account in making the parachutes ride outside the wing wake; for the same reason, attachment at the extreme tip is preferred to attachment inboard.

1. *Introduction.*—1.1. *General.*—Anti-spin parachutes are safety devices for use in emergency only, and flight experience is not obtained by deliberate testing. In an incident involving a tailless aircraft prototype valuable information was obtained as a result of an accidental inverted spin. The aircraft recovered in response to controls but the pilot had meanwhile streamed the wing-tip parachutes. He observed that they were deployed at the ends of their cables, with a slight coning instability, but that the canopies remained closed, until one of them opened at about 310 ft/sec A.S.T., as the aircraft dived away. At this juncture he jettisoned both parachutes satisfactorily. Details of the parachutes used are given in section 2.1 below.

1.2. *Deductions from the Flight Evidence.*—The pilot's observations showed that the gear operated satisfactorily up to the point when the canopies were expected to open. They do not point, however, to a straightforward speed effect as the cause of failure to open, since an opening brought about by increasing speed is contrary to the usual trend of behaviour. Hypotheses advanced to explain the failure to open were as follows:—

(*a*) The parachute cables had untwisted during ejection causing the rigging lines of the parachutes to twist. This would reduce their effective length and reduce the opening speed of the parachutes.

(*b*) A similar twisting effect had been caused by vortices shed from the wing.

(*c*) The distorted flow behind the wing had materially altered the critical opening and closing speeds of the parachute. Such an effect has been measured by Picken (unpublished results) for a cylindrical obstacle with its axis along the direction of flow.

To test the explanations above a series of experiments was made in the Royal Aircraft Establishment 24-ft Wind Tunnel, during December, 1946.

2. *Tunnel and Flight Tests.*—2.1. *Details of Flight Parachutes.*—The parachutes were constructed to the Exeter type 12 design, and had a nominal flying diameter of 2 ft 6 in. The canopies and vent patches were in cotton fabric to specification D.T.D. 583 and were rigged with eight nylon lines 5 ft long and with a breaking strength of 225 lb each. Each parachute was attached to a wing-tip by means of a flexible steel cable of length 20 ft, or approximately half the aircraft span, the parachute and cable being stowed in a special container with appropriate streaming and jettison gear. Because of the small bulk of the parachute when packed in its snatch-bag, it was thought doubtful whether the drag would be sufficient to rip the bag with normal arrangements, and accordingly an additional ' pilot parachute ' was fitted to tear away the bag. This was in the form of a gathered parasheet of 1 ft diameter.

2.2. *Model Details.*—A half-wing, of constant chord $3 \cdot 5$ ft, span 12 ft, and 45 deg sweepback was mounted at an angle of incidence of 45 deg in the centre of the 24-ft Tunnel. The parachutes were attached to the wing tip by a flexible cable, the length of which was variable. Wind speeds up to 150 ft/sec were used.

2.3. *Tunnel Tests.*—A first test was made to simulate the full-scale conditions by using a similar parachute. However, as the linear dimensions of the model wing were approximately half-scale, and also the maximum tunnel speed of 150 ft/sec was only about half the full-scale value referred to in section 1.1, this test gave no positive result, the parachute opening satisfactorily even when only 5 ft from the wing. Attempts to influence the opening by introducing twists into the rigging lines also gave negative results.

To explore wake effects more carefully, it was necessary to design and make a parachute having its critical opening speed within the tunnel speed range. This parachute had a diameter of 1 ft 3 in., thus making the ratio of diameter to mean wing chord approximately the same as for full-scale. The parachute was of similar type to the full-scale one, but its 2 ft 6 in. rigging lines were shortened, as required, to vary the critical speeds. Opening was tested by throwing the parachute pack into the wing wake, or by reducing tunnel speeds; closing, by increasing tunnel speed.

2.4. *Results Using a 1 ft 3 in. Diameter Parachute.*—With the wing at zero incidence, the critical opening speed was not appreciably affected by varying the distance from canopy to wing-tip between 12 ft and 22 ft. In most of the tests the critical closing speed was still above the tunnel maximum in this arrangement.

When the wing incidence was changed to 45 deg, the critical closing speed became lower, and it diminished rapidly as the cable length was reduced. The critical opening speed at first was not very much affected, until decreases of cable length reduced the value of the closing speed to near that of the opening speed. The distance between canopy and wing-tip at which this occurred is shown diagrammatically in Fig. 2 and is referred to as the critical distance. As the cable length was still further reduced, the opening speed fell in the same way as the closing speed. The experimental points for three lengths of rigging lines are shown in Fig. 3.

From Fig. 3 it appears that the critical opening speed for 45 deg incidence, at long distances from the wing tip, is above the corresponding value for zero incidence, but the speeds plotted are tunnel speeds and ignore the effect of the wake on local air velocity.

2.5. *Remarks on Higher Incidences.*—A small-scale model of the aircraft held fixed in the vertical tunnel with small paper discs representing parachutes showed satisfactory streaming with cotton tow-lines of length equal to the aircraft span and at the same distance as in the half-scale tests. These parachutes were also effective in stopping the spin of the model; not less so than with half-span lines. Held fixed at higher incidences the model gave a more intense wake, and above about 55 deg this was sufficient to cause the discs to become unstable, and eventually to bring them to the wing surface owing to their loss of drag, and the reversed flow near the wing. In the free spin at similar incidences this did not occur, and it was observed that the discs rode outwards evidently under the action of centrifrugal forces. This suggested further tests with the parachutes dynamically represented on the model. Although this condition could not be satisfied completely, the tests indicated that the operation of the parachutes could be improved by augmenting the centrifrugal forces. The fact that they ride outwards would extend the effectiveness of parachutes to higher incidences.

2.6. *Flight Test on Full-scale Parachute.*—A flight trial was carried out to assess approximately the free-air values of the critical opening and closing speeds of the flight parachute. The parachute under test was ejected from the rear turret of a *Halifax* aircraft in level flight at a speed of 310 ft/sec A.S.I. It was attached to the rear of the fuselage by means of a 10 cwt flexible steel cable 40 ft long, and opened as soon as the deployment of the cable was completed. The air speed was then increased to 420 ft/sec when the parachute closed and broke up. Allowing for some effect of aircraft wake, these tests indicate that the critical opening speed of the parachute was greater than 310 ft/sec and that the closing speed in free air was greater than 420 ft/sec.

3. *Interpretation of Results.*—It is apparent from the model tests (Fig. 3) that, when a parachute is streamed behind a wing at a high incidence, the critical closing speed is reduced from the free-air value. If the distance of the canopy from the wing is less than the critical distance, then the opening speed may also be reduced since the closing speed clearly fixes its upper limit.

The results of the model tests provide an explanation of the incident described in section 1.1. These show that by reducing the length of the cable attaching the model parachute to the wing or increasing the incidence of the wing the critical closing speed of the parachute can be substantially reduced below its free-air value. In the full-scale case this effect may have resulted in the closing speed of the parachute being reduced below the rate of descent of the aircraft in the spin. When the aircraft came out of the spin the wing incidence would be reduced. Thus the critical closing speed would be increased and consequently result in an increase in the opening speed to a value greater than the velocity of the aircraft.

4. *Conclusions and Recommendations.*—It is concluded that anti-spin parachutes require to be equipped with longer tow cables than those previously recommended if reduction of their critical speeds by wake phenomena is to be avoided. Further tunnel tests are required to investigate the effect on critical closing speed of variation of the characteristics of parachutes and of the source of wake phenomena. Such tests are not likely to be completed for a long time even were wind tunnels available. In the interim it is considered advisable to make the cables as long as possible up to one and a half spans in length, when the danger of entanglement may become real, and that the opening *and* closing speeds be made as high as possible consistent with a reasonable shock load on opening.

To ensure that the parachutes ride as far from the wake as possible, attachment of the cables at the extreme wing tips is recommended if this is at all possible. Advantage should also be taken of centrifrugal effects, for example by weighting the cables.

As a precaution against possible twisting of the rigging lines, a swivel may be fitted, although this is not considered essential.

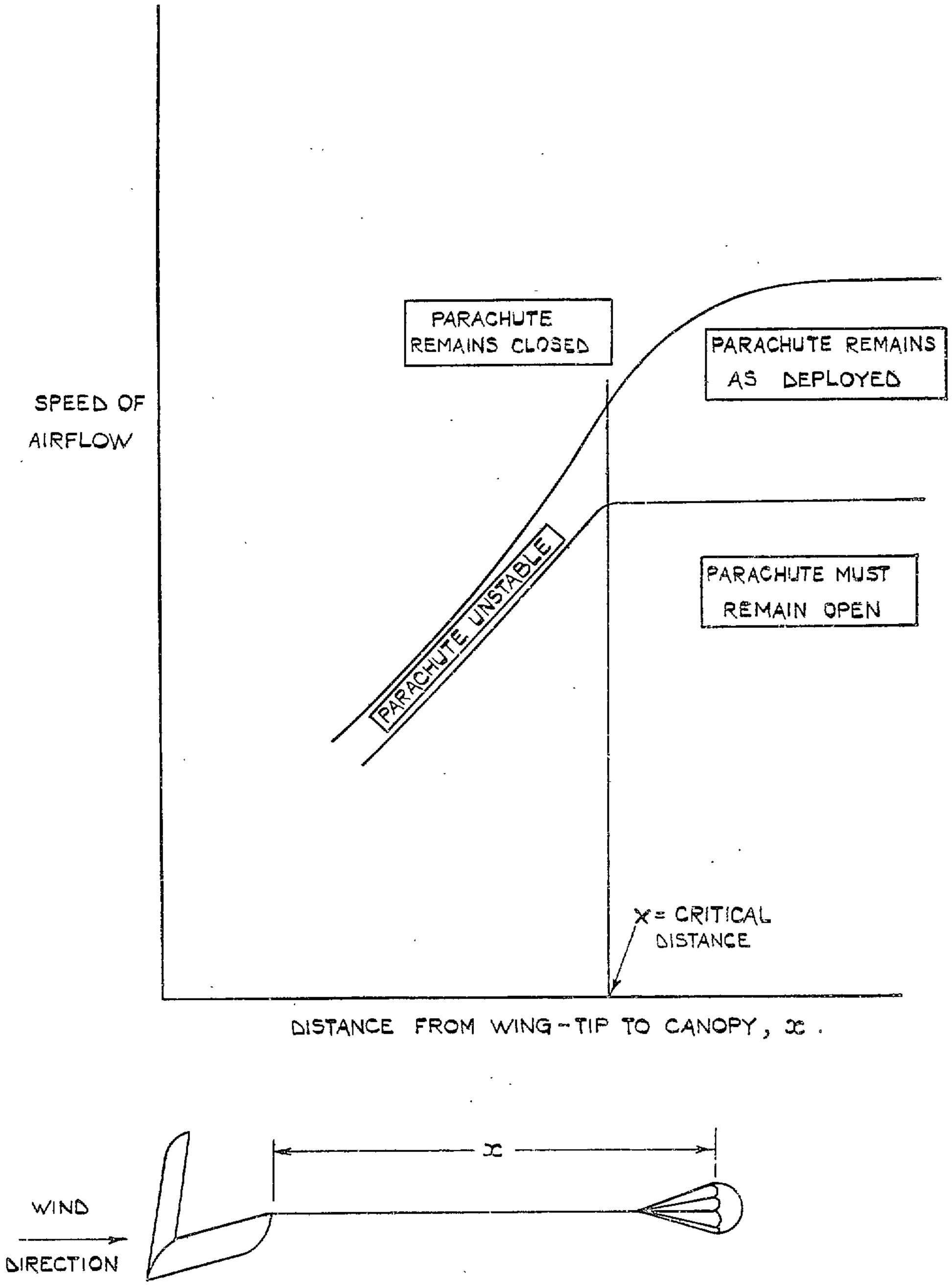

FIG. 2. Diagram showing effect of wake on critical opening and closing speeds of parachutes deployed from wing tips.

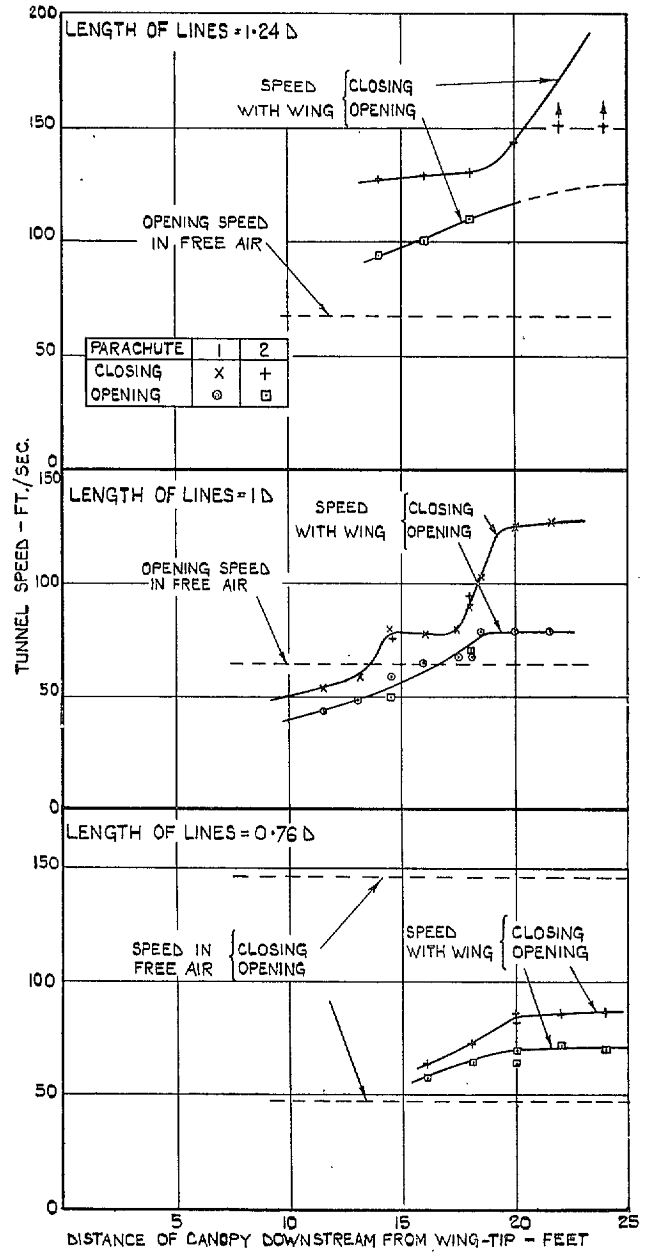

FIG. 3. Effect on parachute critical speeds of distance from wing. D = parachute diameter, = 0·375 × wing mean chord = 15 in. Span of half-wing = 12 ft, sweepback = 45 deg, incidence = 45 deg.

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