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An Experimental Study of the Drag of Rigid Models Representing Two Parachute Designs at M = 1.40 and 2.19

by

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AN EXPERIMENTAL STUDY OF THE DRAG OF RIGID MODELS REPRESENTING TWO PARACHUTE DESIGNS AT M = 1.40 AND 2.19

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B. G. Roberts, B.E.

SUMMARY

The flow about, and drag of, two types of parachute canopy have been examined at supersonic speeds at zero incidence, in isolation and in the presence of rigging lines, and behind bodies of revolution.

The investigation has shown that the presence of rigging lines reduces the canopy drag by an extent dependent upon the length of the lines. Several different flow regimes are encountered similar to those noted during investigations with spikes on bluff bodies, including an oscillatory condition when the lines are short. The presence of the body of revolution, either a cone-cylinder or a blunt cone, gives a low parachute drag when located close to the canopy.

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1 INTRODUCTION

About seven years ago, the Mechanical Engineering Department of this Establishment was approached by Guided Weapons Department regarding the use of parachutes to recover missiles travelling at supersonic speeds. Nothing was known of the behaviour of parachutes at such speeds and information was required on whether they would open, on their drag and on their stability. Information from a visit to the United States in 1955 indicated there a mixture of failure and success without any understanding of the cause of failure, or even of success.

In this country it was decided that full scale trials should be supported by some model work in a supersonic wind tunnel as the knowledge and understanding from such trials might accrue slowly and indefinitely. An account of the early full scale trials has, however, already been included in a report[1] on the development of a system for 'over-sea' recovery. Therefore, Aerodynamics Department was approached for their assistance with model experiments to which the present note relates.

Although a parachute is not a true body of revolution it was considered that solid bodies of revolution, parachute-like in shape, would make useful models for supersonic wind tunnel. Mechanical Engineering Department recommended that two shapes of model should be studied, one model to be made as a cup with a surface that conformed to Taylor's shape[2] and the other with a surface that conformed to Heinrich's guide surface[3] (Fig.1). This selection was made because the latter design is inherently stable at subsonic speeds whereas conventional shaped parachutes are not[4]. The tests have involved the examination of flow patterns and the measurement of drag at M = 1.40 and 2.19 of the two types of models.

Drag measurements on both shapes of parachute have been carried out at subsonic speeds and some information is available for a Taylor canopy in full scale trials at about M = 1.5 [1]. However, it has not yet been possible to analyse all the full scale work in these regions of speed so a comparison between model and full scale results has not been made. This may be difficult because it is known that parachutes do not necessarily inflate fully.

2 DETAILS OF PARACHUTE MODELS

2.1 Size of model

As a result of preliminary discussion regarding the size of model suitable for the small tunnel it was decided that two sizes of model should be made, 1½ in. and 2 in. overall diameter. The reason for the two sizes was a fear that the larger size of model could 'block' the tunnel at the lower Mach numbers and so spoil the flow pattern. Therefore, Mechanical Engineering Department designed and had made models to these two sizes for preliminary trials by Aerodynamics Department in a 9 in. × 9 in. tunnel[5]. As a result of these tests it was decided to transfer the main body of the investigation to a larger (18 in. × 18 in.) tunnel where the 2 in. model was quite satisfactory.

2.2 Canopies

Five rigid metal canopies were used for the wind tunnel tests. Of these, two were guide surface types with maximum diameters, D, of 1½ and 2 in., lip diameters of 0.6D and 45° guide surfaces. Similarly there were corresponding 1½ and 2 in. Taylor canopies with lip diameters of 0.95D. In addition a second 2 in. Taylor canopy, perforated so that approximately 30% of the canopy surface area was removed was tested to obtain information regarding the effect of porosity on parachute behaviour. Detailed drawings of the canopy shapes are given in Fig.2. All canopies were sting-mounted to a drag balance fitted with resistance strain gauges, and could be traversed axially along the tunnel working section.

2.3 Bodies of revolution

Two types of body of revolution were wire-mounted in turn upstream of the canopies for tests involving their influence on the canopy flow field and drag. The first was a cone cylinder with a 10° semi-angle, a diameter of 0.5D and a fineness ratio of 7.25 and the second a blunt-nose cone with a $12\frac{1}{2}^{\circ}$ semi-angle and a base diameter of 1D. Both these bodies of revolution are shown in Fig.3.

2.4 Rigging lines

Two rigging line configurations were used in conjunction with the canopies. The first type used with both canopy shapes, was composed of 12 lines 0.06 in. diameter emanating from the lip and meeting at an apex* on the canopy axis as generators of a cone. Three sets of solid rods representing rigging lines 1D, 2D and 3D in length were used in this configuration. For tests involving the 2 in. diameter canopies downstream of the cone-cylinder, a rod 0.1 in. diameter was fitted to the rigging line apex. This simulated a strop, and telescoped into the body for tests where the axial spacing of the body and the parachute was varied. The experimental arrangement is shown in Fig.4.

The second type of rigging line configuration was used with the 2 in. Taylor canopy only, when positioned downstream of the blunt nose cone. This arrangement is shown in Fig.5 and was composed of 8 lines 0.02 in. diameter emanating from a peripheral ring at the canopy lip as generators of a cylinder. The distance between the body and the canopy could be varied as before but, due to space limitations no significant telescoping of the wires into the blunt-nose cone was possible. It was therefore necessary to cut the rigging lines to length for each downstream canopy position required.

3 DETAILS OF TESTS

All tests were carried out in the 18 in. square test section of the Aerodynamics Department No.19 supersonic wind tunnel at R.A.E., Farnborough, during May and June, 1959. Drag measurements as well as flow visualisation were undertaken at zero incidence for $M = 1.40$ and 2.19 with Reynolds number per inch between 0.2×10^6 and 0.5×10^6. Tunnel stagnation pressures employed were between 0.67 and 1.34 atmospheres. The tests were divided into two major parts, the details of which are set out below.

3.1 Tests with parachute alone

The tests were divided as follows using both $1\frac{1}{2}$ and 2 in. Taylor and guide surface models.

(i) Canopies without rigging lines.

(ii) Canopies with conical rigging lines.

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* Throughout this note "apex" refers to the junction of the rigging lines, and not to the crown of the canopy as is sometimes the practice in parachute technology.

3.2 Tests with parachute behind a body of revolution

Although it was intended to test both $1\frac{1}{2}$ and 2 in. canopies, sufficient time was available to complete only the 2 in. canopy tests. These were divided as follows:-

(i) Canopies with conical rigging lines and strop behind the cone-cylinder.

(ii) Non-porous Taylor canopy with parallel rigging lines behind the blunt-nose cone.

Positions of the canopy to approximately 3.5D downstream of the bodies of revolution were investigated in these tests.

3.3 Method and accuracy of drag measurements

For the measurement of the total parachute drag, a balance consisting essentially of two strain-gauged flexure strips was employed. Under load the output signal from each of the strain gauges was fed to an automatic self-balancing Wheatstone bridge network. Base pressure was measured to 0.01 in. mercury by a Midwood automatic balance beam manometer from a pitot tube which could be located very close to the base of the canopy (see Fig.4). As previous tests by Earnshaw and Bateman[5] had shown the pressure to be essentially constant over the base of the non-porous canopies, one pressure measurement taken close to the canopy axis, was considered sufficient to determine the base pressure for these models. Drag coefficients were then corrected for the small error introduced by the difference between the balance and base pressures. Computed in this way, the inaccuracy in the drag coefficients (based on the maximum frontal area of the canopy) was no worse than 0.01.

4 PRESENTATION OF RESULTS

4.1 Parachute alone

The frontal drag coefficients have been determined from the present tests by subtracting the base drag from the measured total drag. Results for the isolated canopies and for the canopies with rigging lines are presented in Table 1 for M = 1.40 and 2.19 respectively. Also shown in brackets are the base drag coefficients C_{DB} for each parachute configuration. For the porous Taylor canopy, total drag coefficients $(C_D + C_{DB})$ are presented since no values of base drag were determined in this case. During testing flow oscillation was encountered in some cases involving canopies with 1D rigging lines (see section 5.1.2(a)), but was of a sufficiently high frequency as to be outside the response of the drag-recording equipment. In consequence the drag coefficients obtained in the presence of this type of flow are oscillatory mean values and have been indicated accordingly.

4.2 Parachute behind a body of revolution

The frontal drag coefficients obtained for the conically rigged parachute configurations in the presence of a strop as the downstream position behind the cone-cylinder is varied are given in Figs.6 to 8. Once again the coefficients presented for the porous Taylor parachutes are based on the total drag. Fig.9 presents similar information for the cylindrically-rigged Taylor canopy behind the blunt-nose cone.

5 DISCUSSION OF RESULTS

5.1 Parachute alone

5.1.1 Canopies without rigging lines

From Table 1 it can be seen that the frontal drag coefficient of the Taylor canopy at both Mach numbers is approximately 50% greater than that of the guide surface canopy although their associated base drag coefficients do not differ significantly. The drag coefficients of the canopies increase with free stream Mach number whereas their base drag coefficients decrease, so that the total drag is not greatly affected. Consequently the contribution of the base drag to the total drag of the canopy rapidly diminishes at high Mach numbers, and becomes less than 10% of the total drag at $M = 2.19$. Fig.10 illustrates the flow about the Taylor and guide surface canopies at this Mach number.

5.1.2 Canopies with rigging lines

The addition of conical rigging lines produces a marked change in the flow ahead of the canopy. This change gives rise to a substantial reduction in the total drag which is especially marked with the non-porous parachutes. In the latter case, however, the base drag is not affected to any large degree, and as a result becomes a more significant fraction of the total drag than it was in the absence of the rigging lines.

For a given set of free stream conditions, the reduction in the drag coefficient resulting from the addition of rigging lines is a function of their length. Generally the results of the investigation as presented in Table 1 indicate that the drag coefficient decreases with increasing rigging line length until a minimum value is reached. Further increase in length produces an increase in the drag coefficient. Furthermore the rigging line length for which the drag is a minimum appears to be significantly influenced by the porosity of the canopy and the free-stream Mach number.

The variation of the frontal drag coefficient with rigging line length is associated with the flow changes brought about by the interaction of the canopy and rigging line flow fields. Schlieren photographs show that with rigging lines present oscillatory and separated flows are induced ahead of the canopy similar in some respects to those observed by Mair[6] and Beastall and Turner[7] in spiked bluff body investigations. The flows as well as the changes in drag coefficient which are produced by the addition of rigging lines to the canopy are discussed in detail below.

(a) Canopies with 1D rigging lines

At $M = 1.40$ the addition of rigging lines 1D in length results in oscillatory flow ahead of the canopies. The oscillation is similar to that encountered in Refs. 6 and 7 with spike lengths a little greater than the detachment distance of the main shock. To illustrate this type of flow Fig.11 is presented for the guide surface parachute. The two limiting shock configurations of the oscillation are blurred but nevertheless can be seen. These appear as (i) a conical shock from the rigging line apex intersecting the detached canopy shock, and (ii) a curved shock passing slightly to the rear of the apex. Griggs and Goldsmith[8] have observed similar oscillations in investigations on centre-body diffusers and have shown that the oscillations may be of either small or large amplitude.

Sustained oscillations of the flow were experienced by all parachutes with 1D rigging lines at $M = 1.4$, and with the non-porous Taylor canopy at $M = 2.19$. The frequencies of the oscillation were not measured during the tests. Fig.12(b) illustrates the flow around the guide surface configuration at M = 2.19 which can be seen as a stable separation from some point in the vicinity of the rigging line apex with attachment occurring at the canopy maximum diameter. This flow is analogous to that experienced with spiked bodies, and centre-bodies, whose lengths are greater than that for which oscillation occurs.

(b) Canopies with 2D rigging lines

The addition of 2D rigging lines to both the Taylor and guide surface canopies at both speeds produces a conical separation of the type described above. The point of separation with these configurations, although still on the apex cone appears to be further back nearer to the base of the cone than to the tip. Fig.13 illustrates the type of separation obtained with these parachutes.

It is noteworthy that the frontal drag coefficients are substantially higher than would be obtained if the separated regions were replaced by solid cones. For the Taylor and guide surface canopies respectively the latter would give 0.27 and 0.22 at M = 1.4, and 0.21 and 0.16 at M = 2.19. The difference, may arise from local pressures on the canopies in the region of the maximum diameter where the flow reattaches, but the indications are that the frontal drag is a function only of the separation angle (viz. the angle between the boundary of the separated region and the free stream direction). For the same separation angle the effect of Mach number and canopy shape variation is very small.

In the case of the porous Taylor canopy also, the separation at M = 2.19 occurs from the rigging line apex, but at M = 1.4 it is located some distance downstream of this point, probably on the wake from the solid region formed by the junction of the rigging lines at the apex. This is shown in Fig.14 by the shock waves which emanate from a point within the lines. It is interesting to note that the initial shock wave angle is about 69° which corresponds to the limiting wave angle for attached flow on a cone at this Mach number.

It should be noted that the porosity in this canopy at this Mach number has increased the total drag (Table 1).

(c) Canopies with 3D rigging lines

With 3D rigging lines separation occurred consistently downstream of the rigging line junction at M = 1.4. At M = 2.19, however, the separation point fluctuated spasmodically between the rigging line apex and a point downstream, the drag in the former regime being only 30% - 50% of that in the latter (Table 1). This behaviour is analogous to that of the spiked bodies of Refs.5 and 9 in that at the higher Mach number the rigging line length is between the maxima at which separation from the apex is possible with a laminar and turbulent boundary layer respectively, whereas at the lower Mach number it exceeds both. The spasmodic behaviour at M = 2.19 is due to the change in the state of the boundary layer on the apex brought about by random variations of the turbulence level of the tunnel flow. It was found, as in Ref.9, that by ensuring that the boundary layer was turbulent (in the present tests by the use of a thin transition wire ring) the higher drag regime (i.e. separation from the wake) was obtained consistently. These results are indicated accordingly in Table 1. It will be seen from Table 1 that at M = 1.4* the frontal drag of the 2 in. diameter canopy with 3D rigging lines is noticeably greater than that of the $1\frac{1}{2}$ in. model. The models, however, are not exact scale replicas, the rigging line diameter and hence the size of the solid apex at their junction being the same for both, and therefore

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* Comparison is valid at this Mach number only since the flow is stable without artificial transition. With the transition ring present there is an additional drag contribution from the wire itself.

proportionately greater in the smaller model. It seems feasible (section 5.1.2(b)) that the greater the solidity of the structure ahead of the canopy the lower will be the drag, with the drag of the solid cone as the lower limit. This is consistent with the trends shown.

By analogy with the spiked body results it seems unlikely that, once the separation point has moved downstream of the rigging line junction, any further rise in drag will occur with further increase in rigging line length. On the other hand the greater the distance between the apex and the canopy the less well-defined will be the wake, and it might be that separation ahead of the canopy would not then occur. The argument is somewhat academic, however, since in practice the parachute will be operating behind a substantial body whose presence is likely to dominate the flow. Its behaviour in these conditions is described in the next section.

5.2 Parachutes behind a body of revolution

5.2.1 Conically rigged parachutes behind cone-cylinder of base diameter half that of the canopy

The drag coefficients of the various parachute configurations are presented in Figs.6 to 8 and are plotted against the non-dimensional parameter, y/D, where D is the canopy diameter, and y is the distance between the body base and the maximum diameter station of the canopy. This point on the canopy, rather than the face, for example, has been chosen since flow reattachment always appears to occur near to it irrespective of canopy shape, and it is thus a logical choice for the presentation and comparison of the test results with the two canopy shapes.

Generally it can be said that for all positions of the canopy behind the cone cylinder, the parachute is subjected to a separated flow field with a point of separation which is a function of the downstream location of the canopy and the length of the rigging lines. For y/D less than about 2.5 the flow separates from the base of the cone-cylinder, and either reattaches on to the canopy directly (Fig.16), or produces a wake which wholly envelops the canopy i.e. there is no conical separation from the apex, etc., as with the body absent. In this condition the frontal drag is usually low, and decreases as the separation angle is reduced, i.e. by increasing the distance between the body and the canopy (Figs.6 and 7). Ultimately, however, when this distance is too great, the pattern changes, reattachment of the cylinder base separation now occurring on the strop, and a fresh separation occurring ahead of the canopy akin to that with the body absent (Fig.17). This is accompanied by a rise in frontal drag to a level which is little influenced by further increase of the spacing between the body and the canopy (Figs.6 and 7).

For the canopies with 3D rigging lines the geometry is such that although the lines are too long for the first flow regime to occur (i.e. base separation combined with reattachment to the canopy), the lines prevent the base separation developing as for the second. Fig.18 shows the resulting hybrid pattern which obtains with the rigging line apex close to the body base. The drag in this condition is considerably lower than that with the body absent.

With the porous Taylor canopy the change to the conical separation occurs, as would be expected, with a smaller body canopy spacing. The drag characteristics are similar in form to those of the non-porous version (Figs.6 to 8), although the drag level after the rise is, if anything, slightly higher.

From a practical point of view it would seem desirable to operate with the parachute in the second regime in which the drag is higher, i.e. to ensure that the distance between the canopy and the body is adequate to prevent the separation from the base reattaching directly to the canopy. It should be remembered that in the first regime there will be an upstream influence of the canopy onto the body, which will reduce the body base drag, and consequently further reduce the drag of the body-parachute combination. It should be emphasised that the minimum spacings determined here are probably peculiar to the ratio of the canopy-body diameter tested, viz. 2, and the type of rigging used.

5.2.2 Cylindrically-rigged Taylor parachute behind a blunted cone of same base diameter as the canopy maximum

The results shown in Fig.19 illustrate the last point. The body is a blunt cone of semi-angle $12\frac{1}{2}^{\circ}$, a typical re-entry capsule shape, to which the canopy, originally the capsule base, is attached by parallel rigging lines. In this case separation from the base to the canopy persisted up to the limit of the spacing possible in the test, viz. 3.3 canopy diameters (Fig.19(b)), and the extent to which this must be increased to obtain the second type of flow is not known.

The frontal drag is consequently very low (Fig.9), and for $y/D < 1.5$ is negative. For y/D very small, the total drag of the canopy happens to be zero.

6 CONCLUSIONS

The flow and drag behaviour of both the Taylor and guide surface types of parachute have been studied at $M = 1.4$ and 2.19 at zero incidence with and without rigging lines, and also when located downstream of two bodies of revolution. As a result of this investigation, the following conclusions can be drawn:-

6.1 Canopies without rigging lines

(1) The frontal drag coefficient of the Taylor canopy at both Mach numbers is approximately 50% greater than that of the guide surface canopy, but their associated base drag coefficients do not differ significantly.

(2) The frontal drag coefficients of the canopies are increased by an increase in the free stream Mach number whereas their base drag coefficients are decreased, so that the total drag is not greatly affected. Consequently the contribution of the base drag to the total drag of the canopy rapidly diminishes at high Mach numbers.

6.2 Canopies with rigging lines

(1) The addition of rigging lines produced a substantial reduction in the frontal drag, but does not affect the base drag significantly.

(2) The variation of the drag with rigging line length is associated with flow changes brought about by the interaction of the canopy and rigging line flow fields. As a result oscillatory and separated flows are induced ahead of the canopy similar in many respects to those observed in spiked bluff body investigations[5,6,9].

(3) The drag decreases with increase of rigging line length until a minimum value is reached. The length of line at which this occurs does not appear to be influenced to any great extent by canopy shape, but is a function of the porosity of the canopy and the free stream Mach number.

(4) The rigging line length for minimum drag occurs when the location of the canopy downstream of the apex is the maximum for which the point of separation can be maintained on the rigging line junction. Boundary layer transition or any further increase in rigging line length, causes the point of separation to move downstream and yields an increase in drag.

6.3 Parachutes behind bodies of revolution

(1) Behind a cone-cylinder of base diameter half that of the canopy the frontal drag of the canopy is low when the spacing is small. In this condition the flow that separates from the body base either reattaches directly onto the canopy or envelops the canopy. For larger body-to-canopy spacings, depending upon rigging line length, the flow pattern changes to give a conical separation ahead of the canopy, accompanied by a sudden increase in the drag, which is unaffected by further increase in the body to canopy spacing.

(2) In the former (small spacing) condition the base drag of the cone-cylinder will be influenced by the presence of the canopy, and the overall drag of the body-parachute combination should therefore be calculated with due regard to this fact.

(3) The downstream position of the canopy at which the flow field and drag of the parachute approach those obtained in the absence of the body is again a function of rigging line length.

(4) A blunt cone upstream of the Taylor canopy of the same diameter at $M = 2.19$ caused a flow separation of the small spacing type, viz. direct from the base to the canopy, which persisted for all the body-to-canopy spacings investigated, i.e. up to 3.3 canopy diameters. The canopy drag is less than 10% of that of the isolated canopy. For very small spacing (less than 1.5 diameters) the frontal drag is negative.

7 POSSIBLE FURTHER WORK

The results of the tests reported in this note suggest that the work could be extended in several directions, viz.

(1) To define more clearly the boundaries of the different flow regimes, in particular that of the oscillatory flow, and their dependence upon the canopy and body geometry, canopy porosity, Mach number and Reynolds number.

(2) To study in more detail the similarity with a spike ahead of a bluff body. A review of the information on the latter is currently in preparation by the author.

(3) To examine the local pressure distribution, particularly in the regions of the canopy where reattachment occurs, in order to determine conditions in which a non-rigid canopy would collapse, or possibly not inflate.

LIST OF SYMBOLS

C_D	Frontal drag coefficient of parachute referred to maximum frontal area of canopy
C_{DB}	Base drag coefficient of parachute
d	Diameter of body of revolution upstream of the parachute
D	Maximum diameter of parachute canopy
M	Mach number of free stream
R_D	Reynolds number referred to maximum diameter of parachute canopy
$R_{e/\ell}$	Reynolds number per inch
y	Distance from the maximum diameter station on the canopy to the base of the body of revolution upstream

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TABLE 1

Drag coefficients for parachute alone

M = 1.40

Configuration	Rig line length	Taylor		Taylor (30% porous)	Guide surface	
		1½"	2"	2"	1½"	2"
No rig lines $R_{e/\ell} = 0.51\times10^6$	0	1.20 (0.32) ‡	1.20	1.11*	0.85 (0.30)‡	0.85
"Conical" rig lines $R_{e/\ell} = 0.51\times10^6$	1D	0.83 ↕ (0.30) ‡	0.83 ↕ ↕	0.83*	0.71 ↕ (0.27)‡	0.73 ↕ ↕
	2D	0.41 (0.28) ‡	0.43	0.93*	0.44 (0.29)‡	0.47
	3D	0.78 (0.32) ‡	0.85	0.99*	0.73 (0.31)‡	0.82

M = 2.19

Configuration	Rig line length	Taylor		Taylor (30% porous)	Guide surface	
		1½"	2"	2"	1½"	2"
No rig lines $R_{e/\ell} = 0.29\times10^6$	0	- (0.11) ‡	1.51	1.10*	1.04 (0.11) ‡	1.04
"Conical" rig lines $R_{e/\ell} = 0.29\times10^6$	1D	1.00 ↕ (0.13) ‡	1.00 ↕	0.73*	0.73 (0.16) ‡	0.74
	2D	0.40 (0.13) ‡	0.41	0.77*	0.46 (0.17)‡	0.47
	3D	0.33 0.85 (0.17) ‡	0.34 0.93T	0.86*	0.36 0.70 (0.19)‡	0.38 0.95T

*	Total drag coeff.
T	With transition ring
↕	Oscillatory
( ) ‡	Base drag coeffs.

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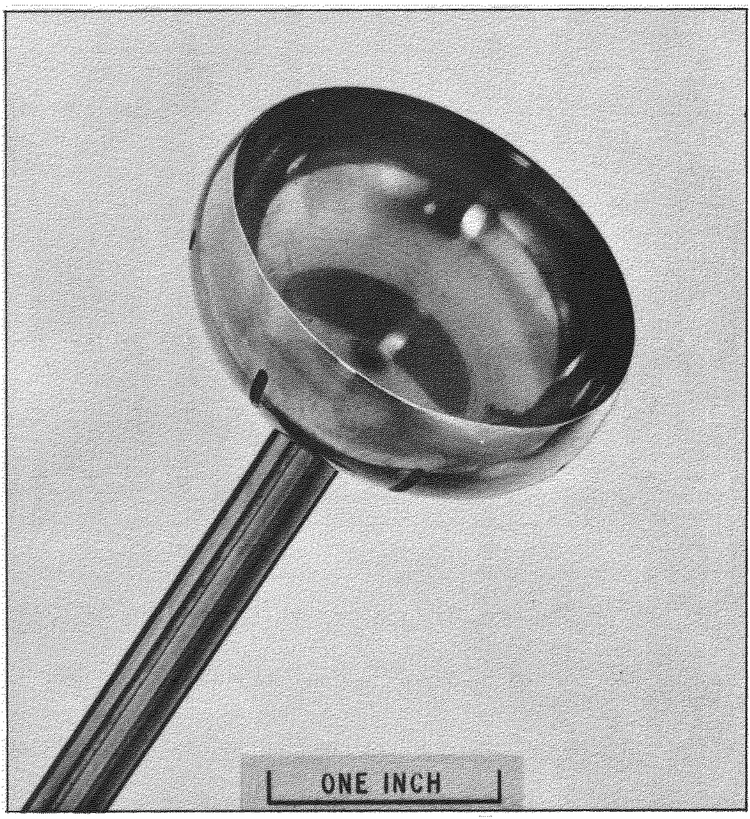
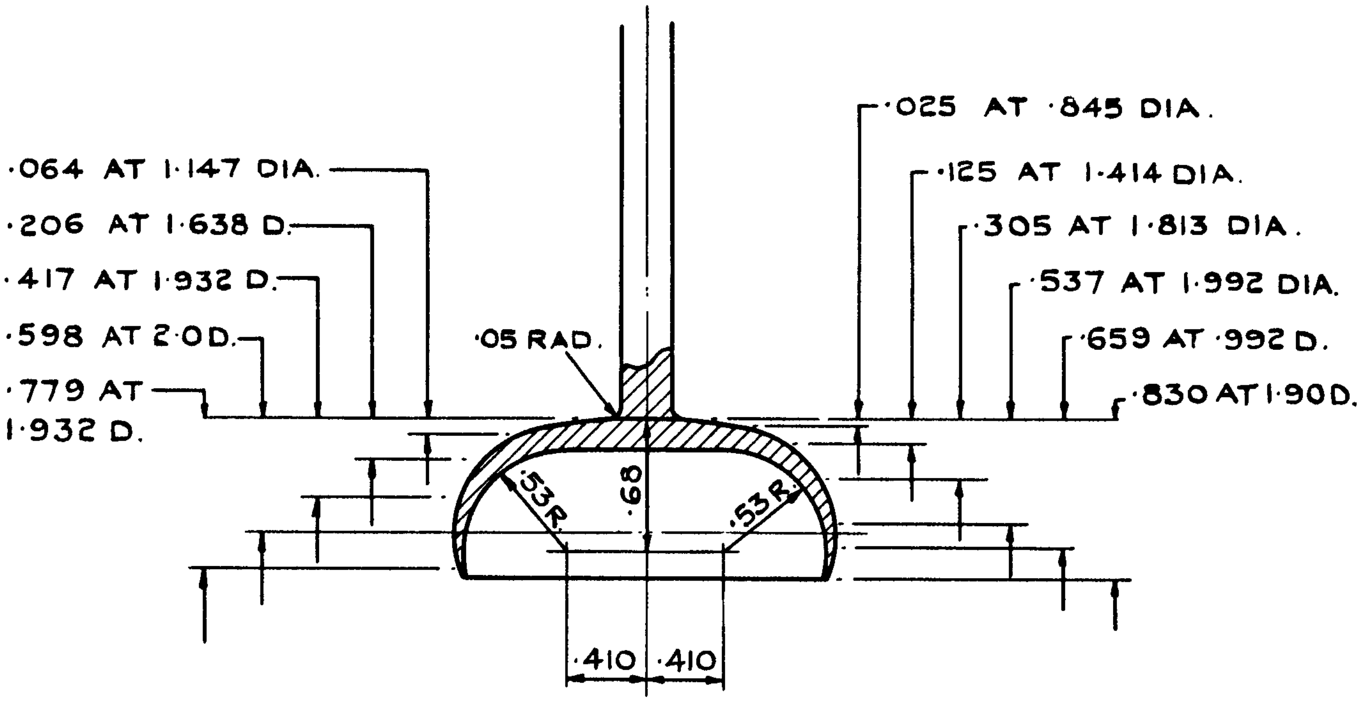


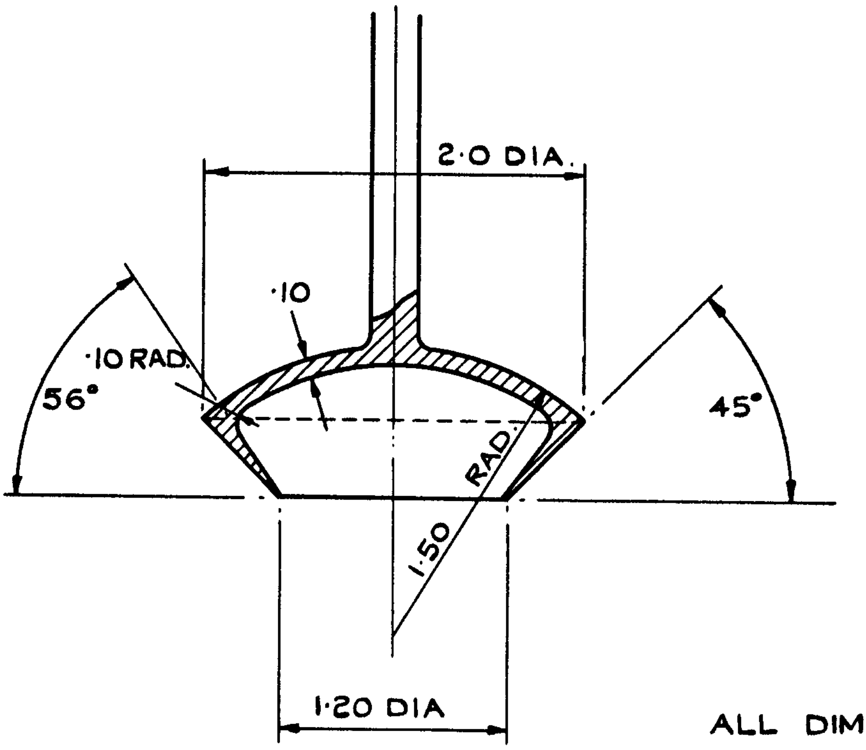
a. TAYLOR CANOPY

b. GUIDE SURFACE CANOPY

FIG. [illegible] CANOPY MODELS



(a) TAYLOR CANOPY.



ALL DIMENSIONS
IN INCHES.

(b) GUIDE SURFACE CANOPY.

FIG. 2. DETAILS OF CANOPIES.

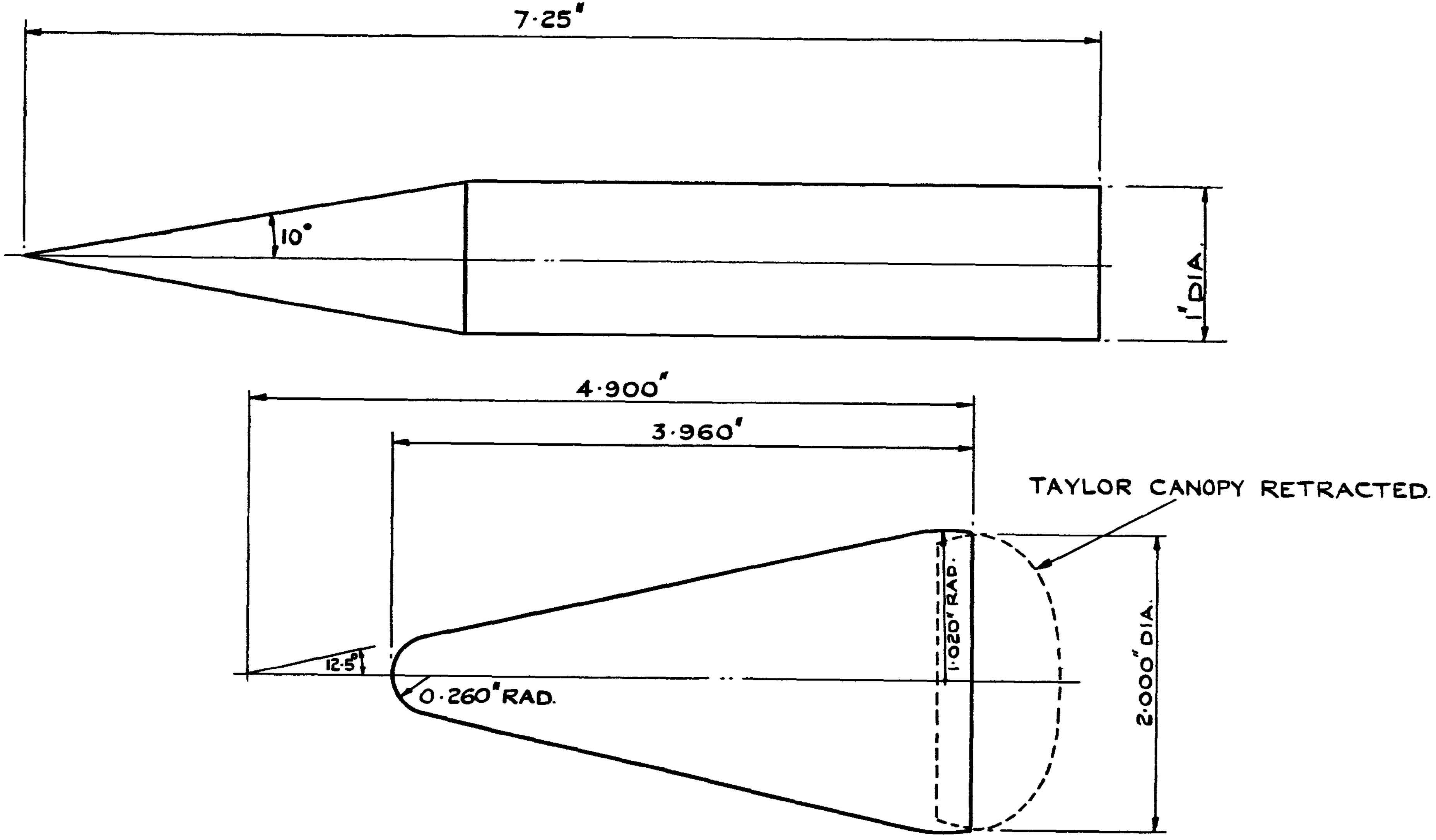


FIG. 3. DETAILS OF BODIES OF REVOLUTION.

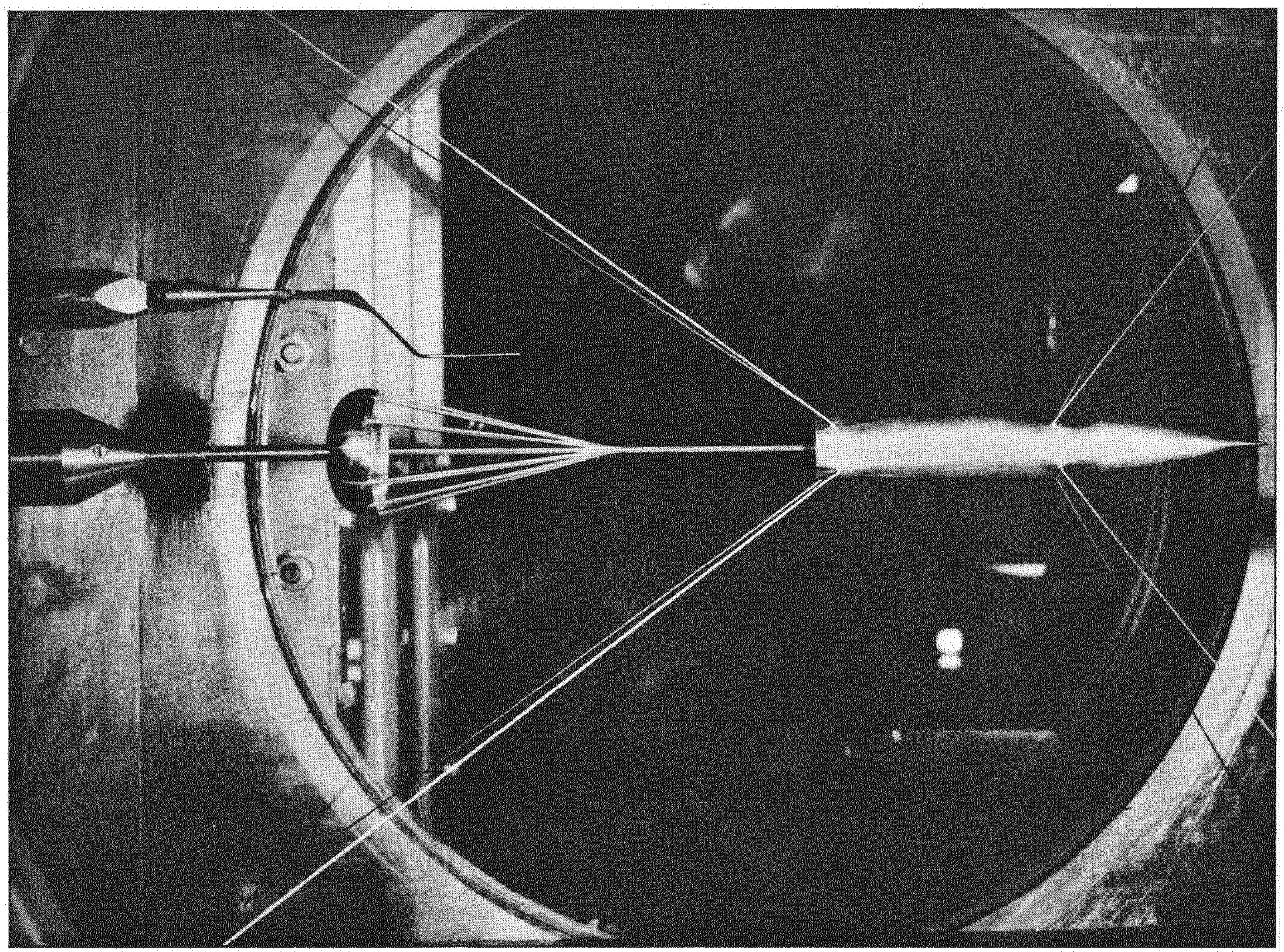


FIG. 4. ARRANGEMENT FOR TESTS BEHIND CONE-CYLINDER

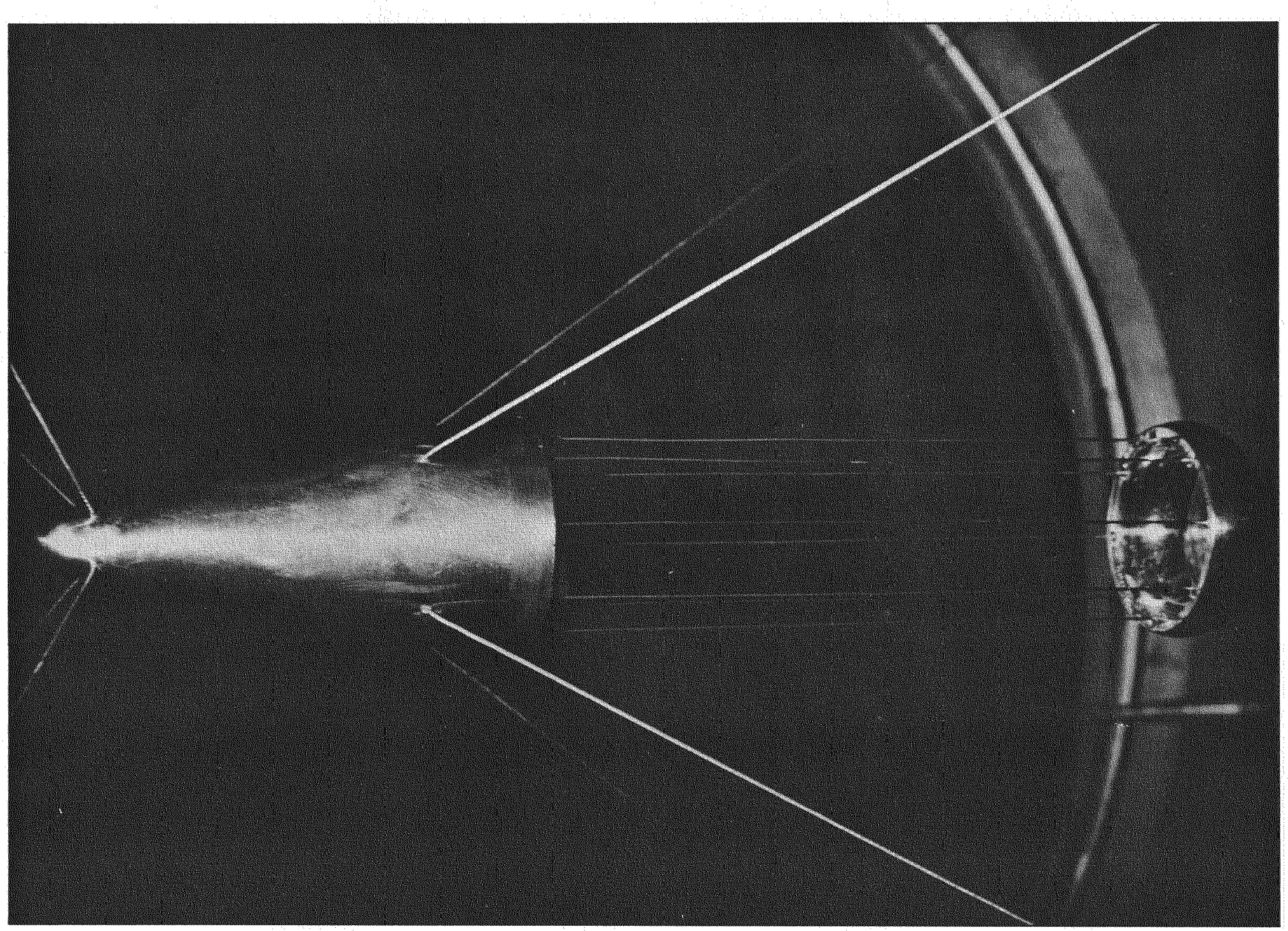
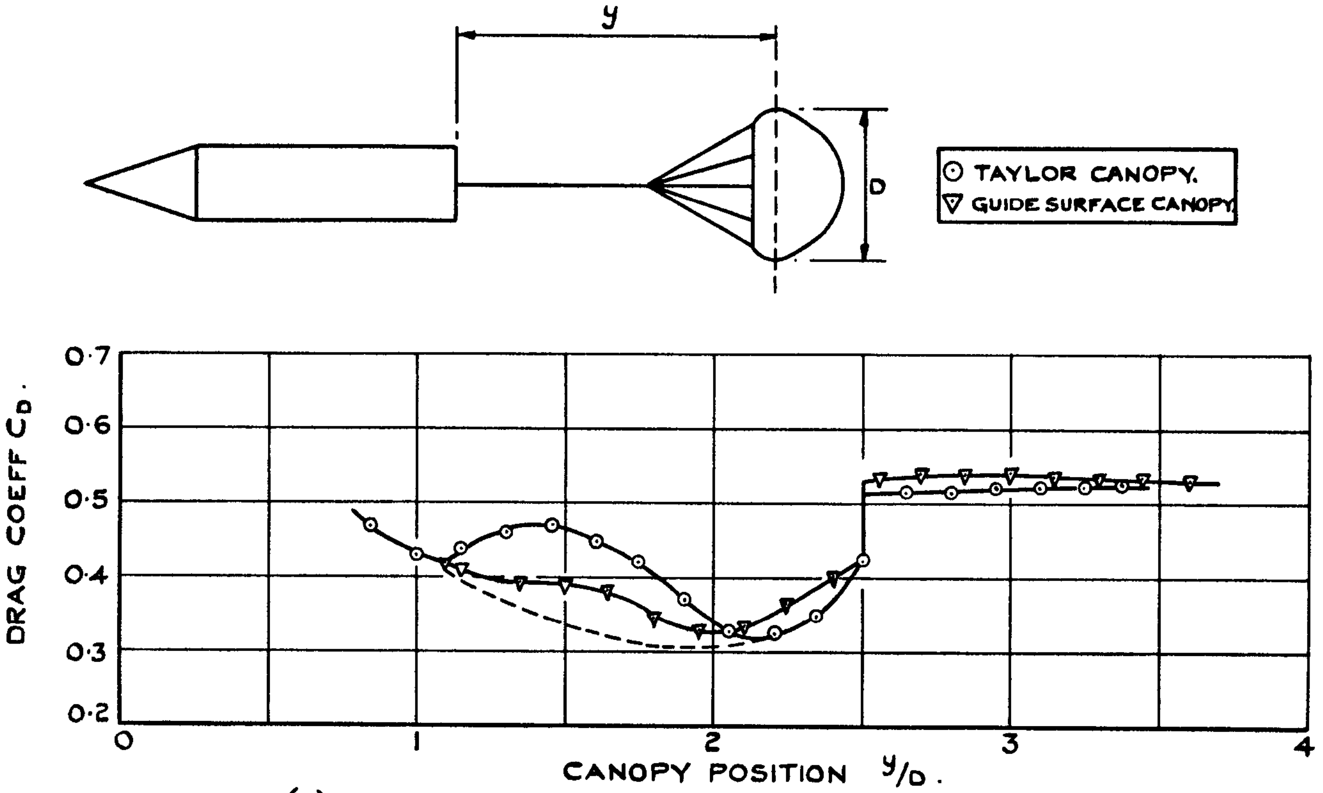
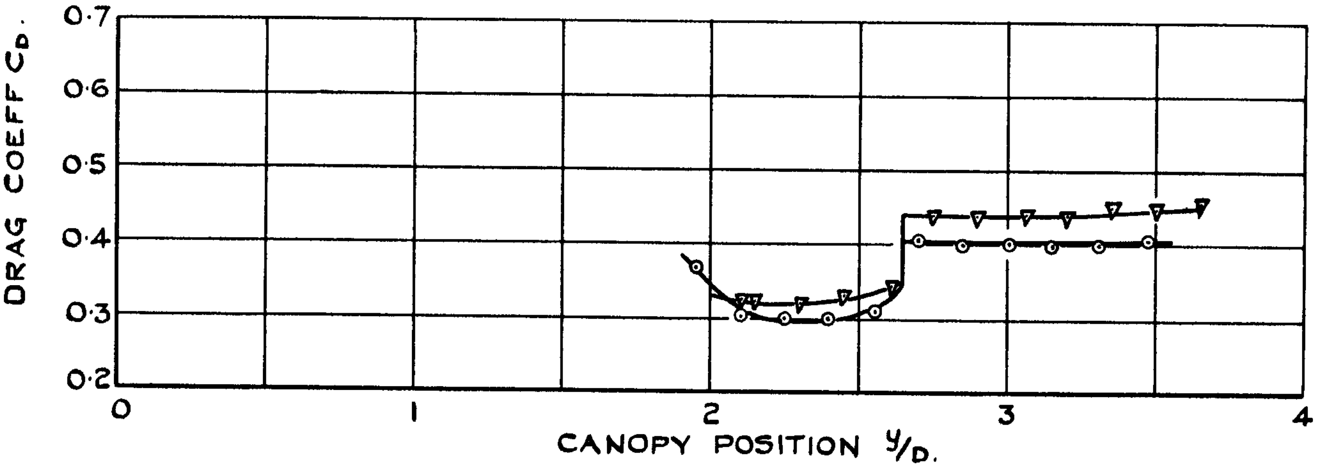


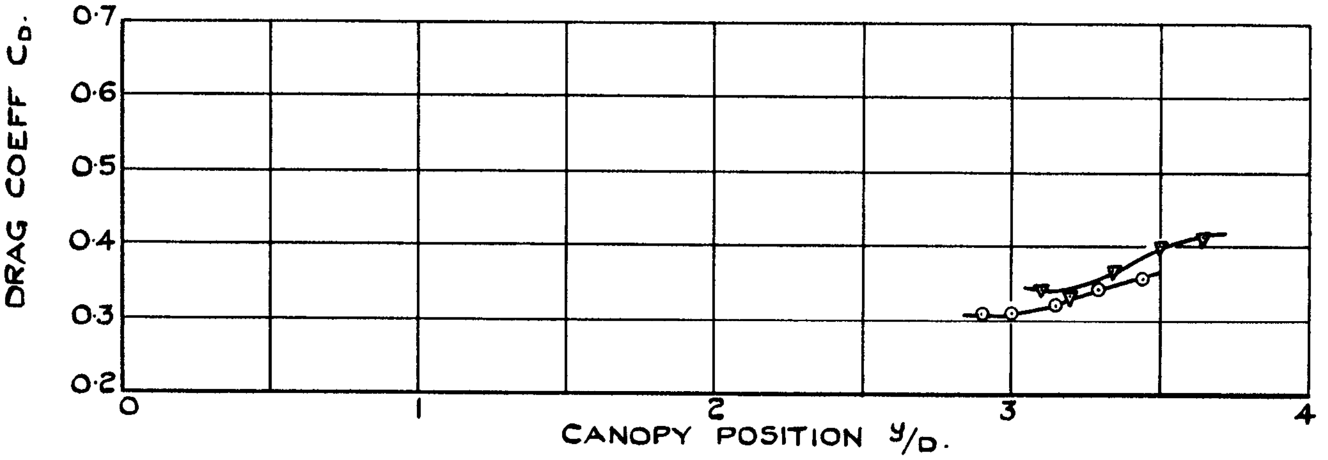
FIG. 5. ARRANGEMENT FOR TESTS BEHIND BLUNT NOSE CONE



(a) PARACHUTES WITH 1D RIG LINES.

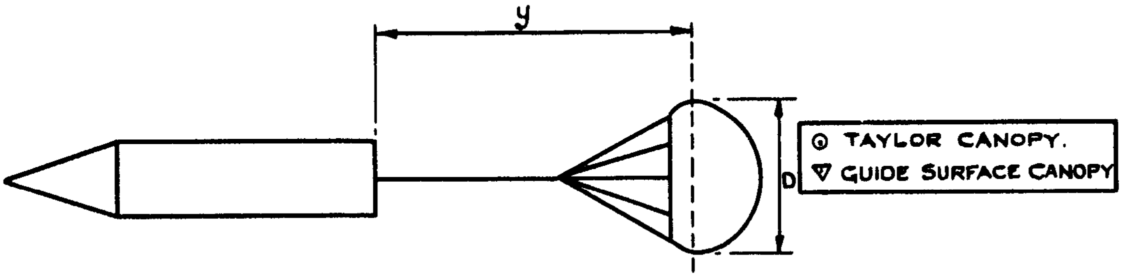


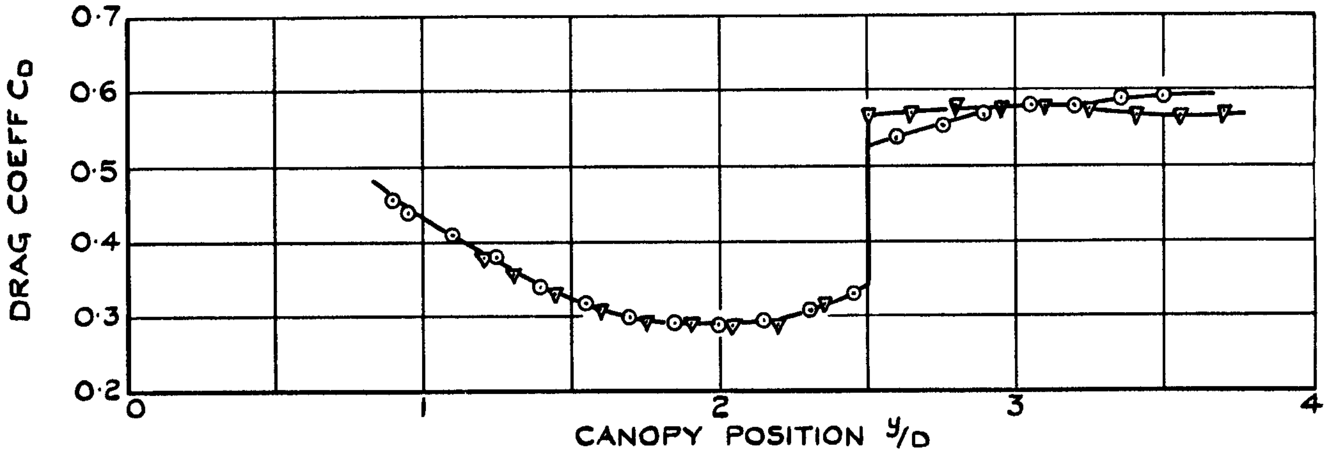
(b) PARACHUTES WITH 2D RIG LINES.



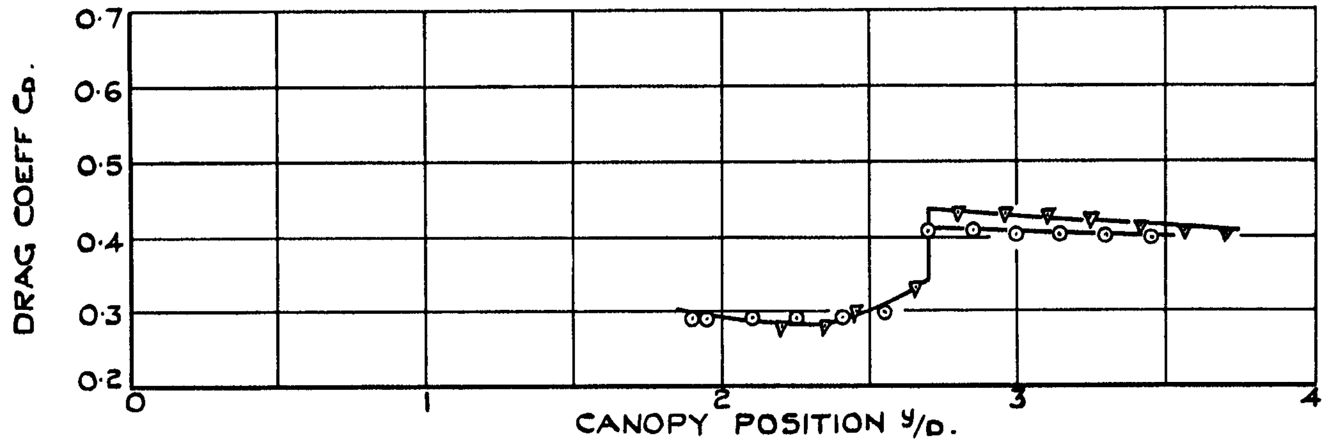
(c) PARACHUTES WITH 3D RIG LINES.

FIG. 6. DRAG OF PARACHUTES BEHIND CONE-CYLINDER AT $M=1{\cdot}40$ $\left(R_D=0{\cdot}78\times10^6, \frac{d}{D}=0{\cdot}5\right)$

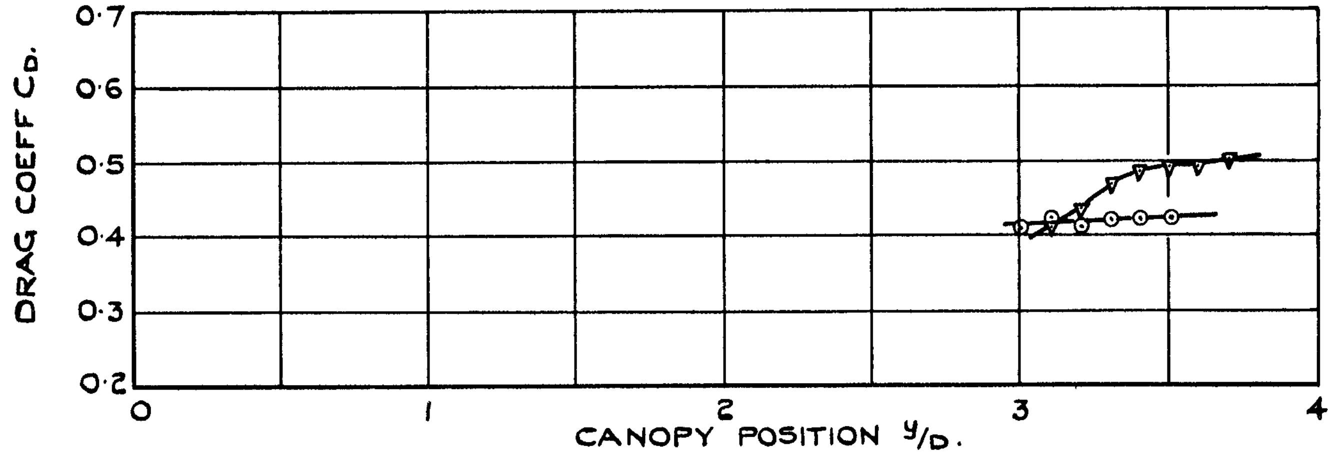




(a) PARACHUTES WITH 1D RIG LINES.

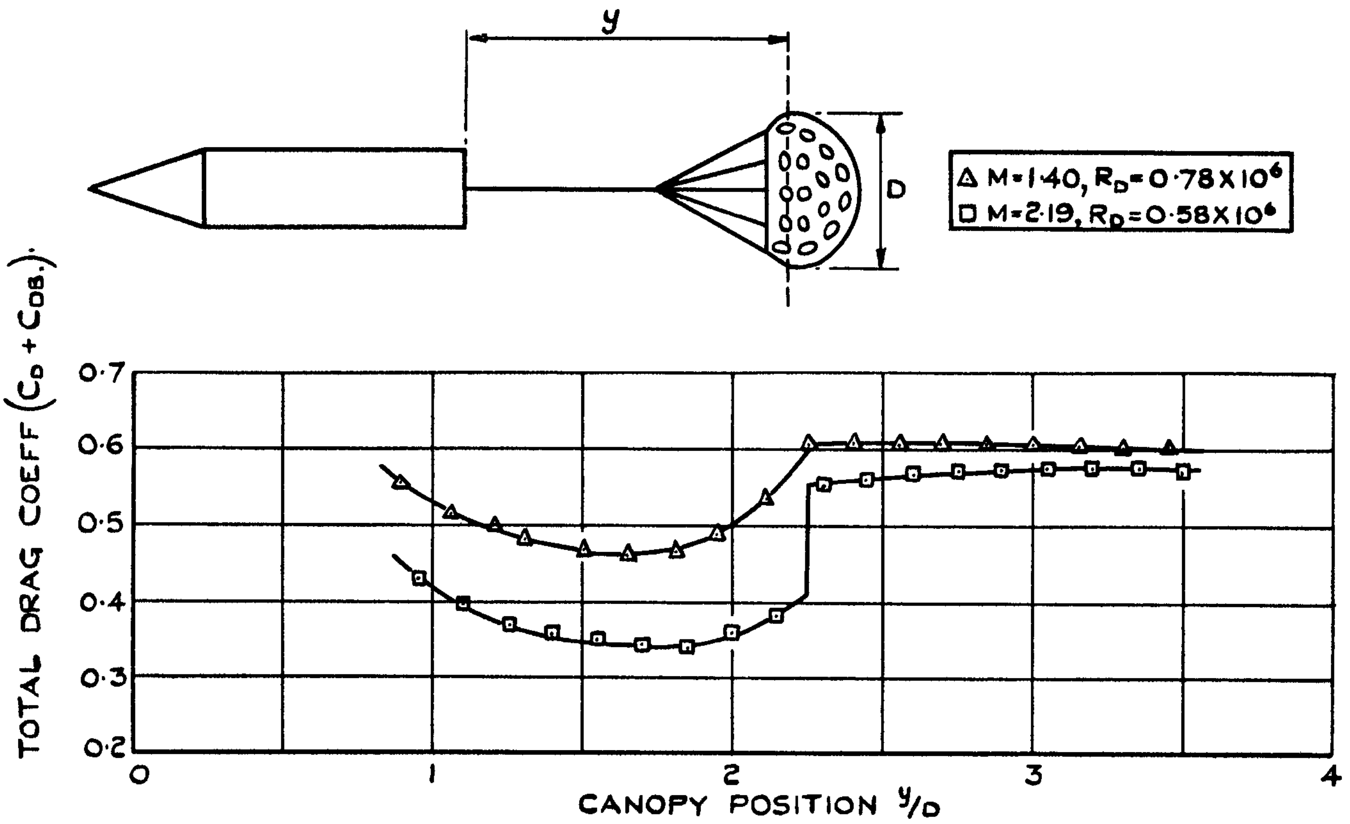


(b) PARACHUTES WITH 2D RIG LINES.

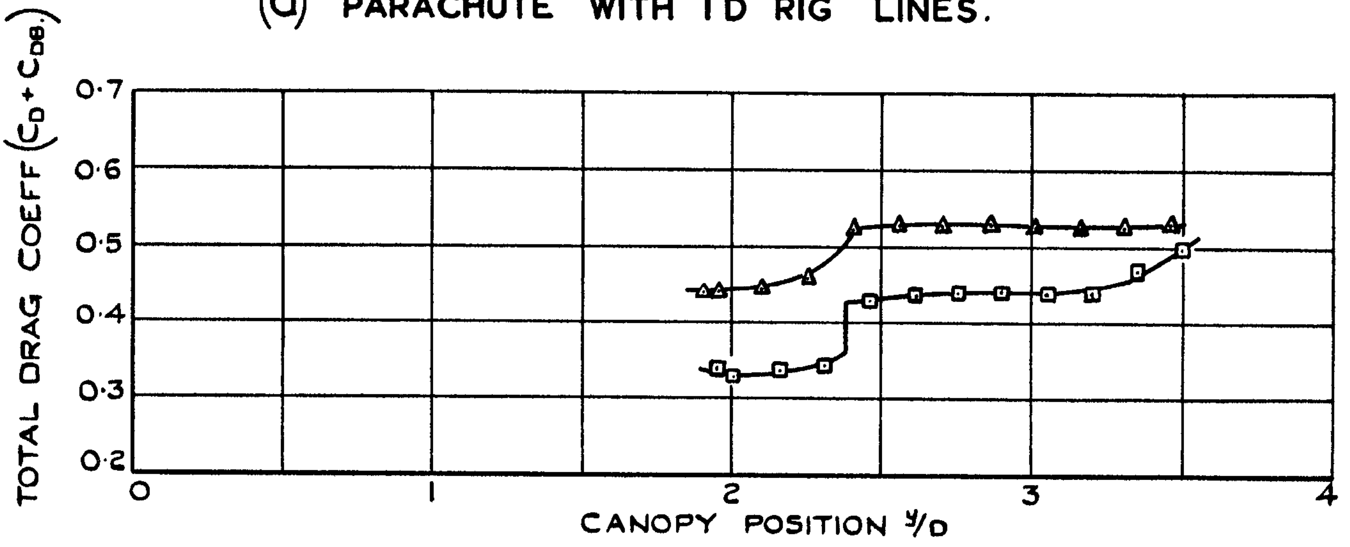


(C) PARACHUTES WITH 3D RIG LINES.

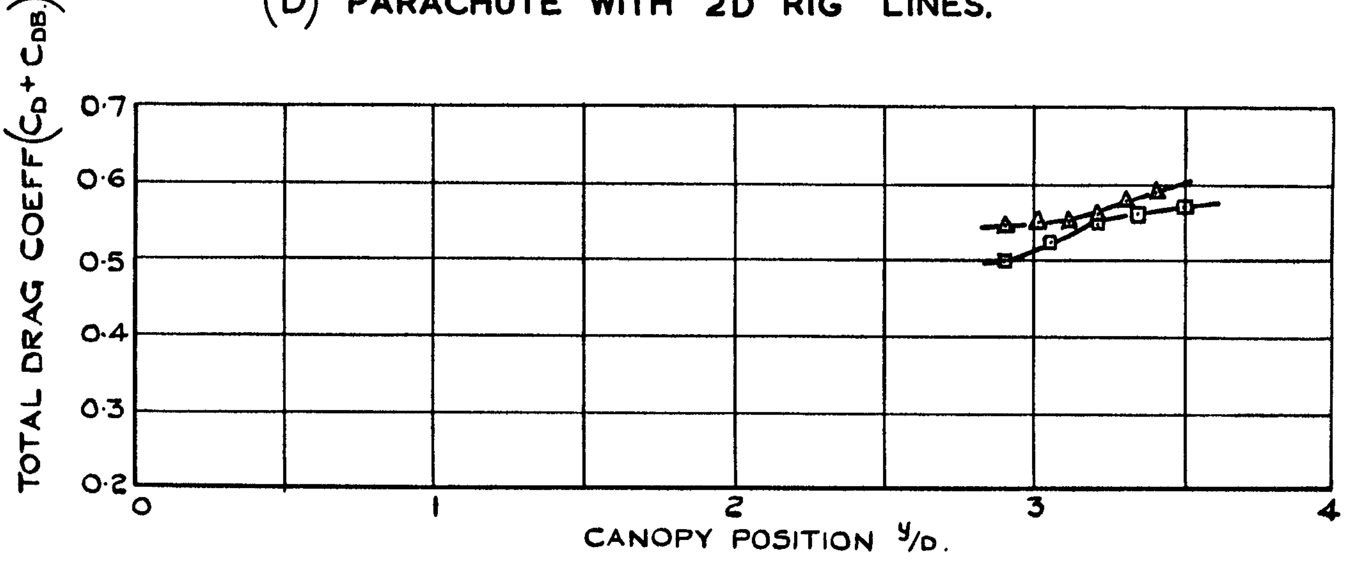
FIG. 7. DRAG OF PARACHUTES BEHIND CONE-CYLINDER AT $M = 2{\cdot}19$ ($R_D = 0{\cdot}58 \times 10^6$, $\frac{d}{D} = 0{\cdot}5$.)



(a) PARACHUTE WITH 1D RIG LINES.



(b) PARACHUTE WITH 2D RIG LINES.



(c) PARACHUTE WITH 3D RIG LINES.

FIG. 8. DRAG OF POROUS TAYLOR PARACHUTE BEHIND CONE-CYLINDER ($\frac{d}{D}$ = 0·5.)

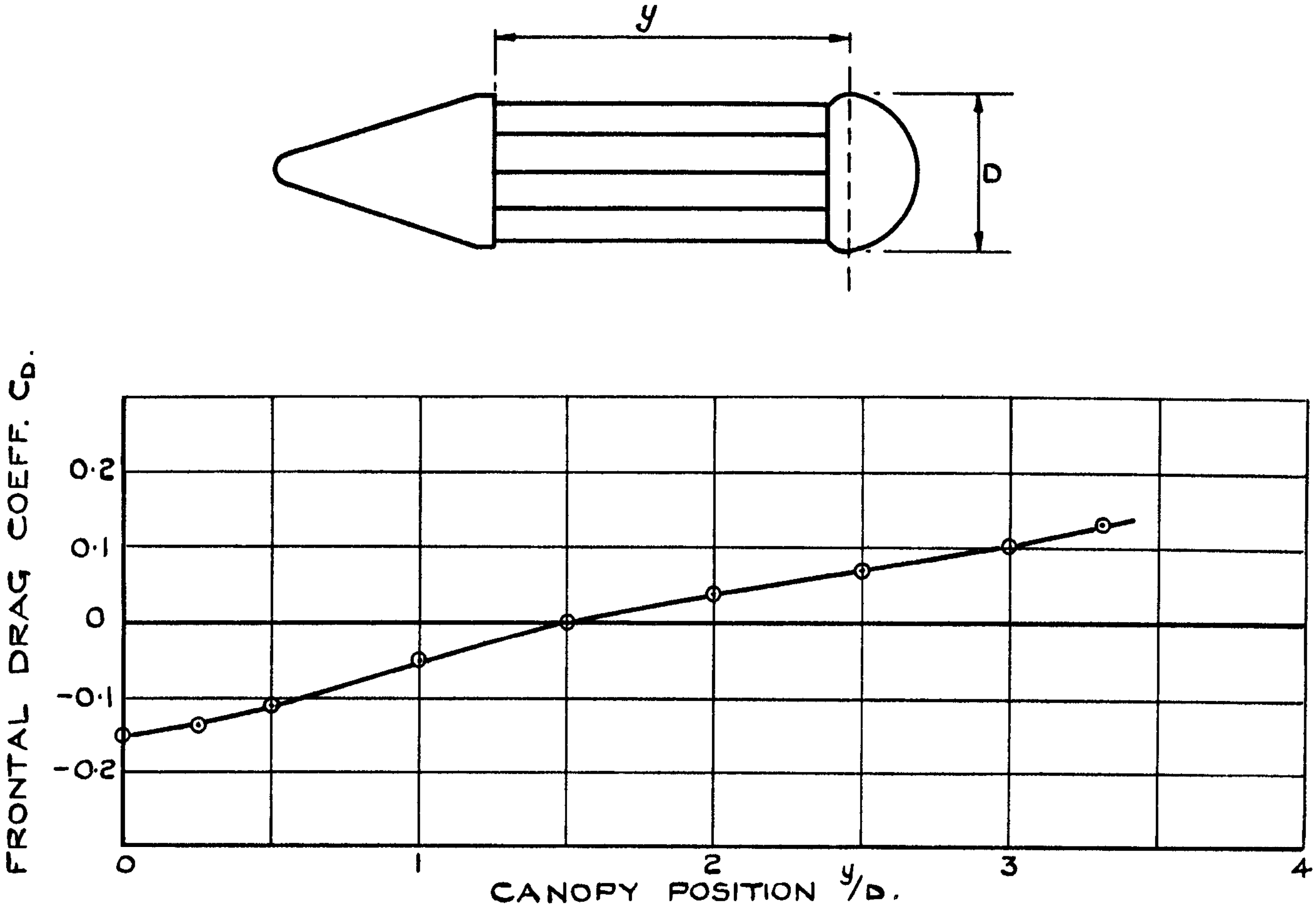
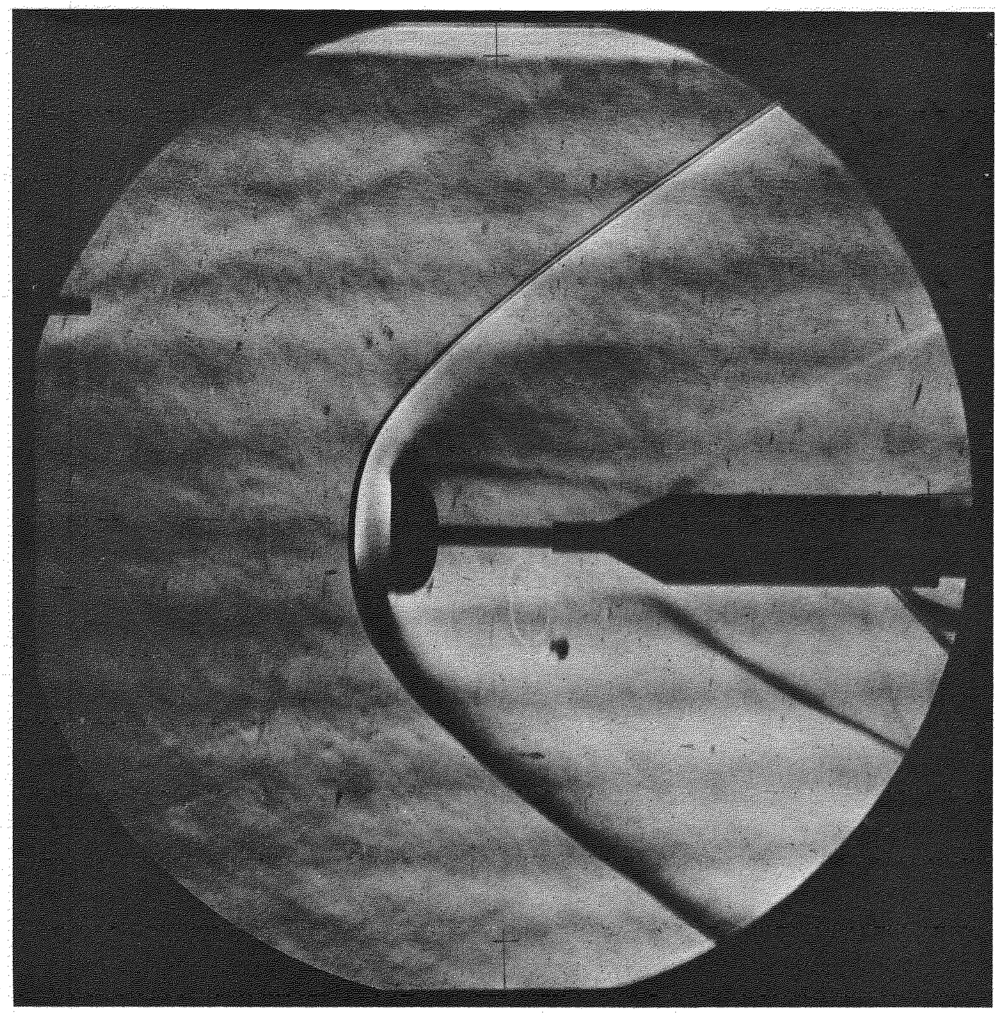
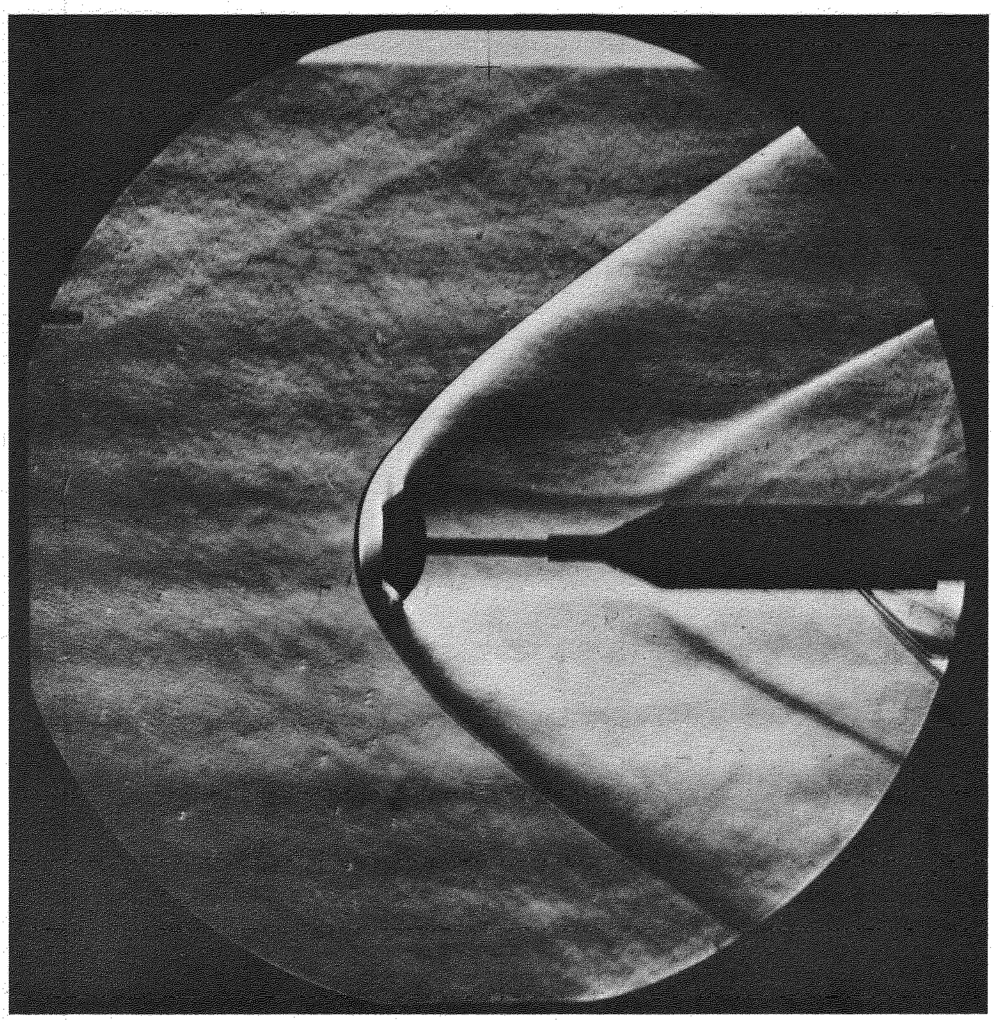


FIG.9. DRAG OF TAYLOR PARACHUTE BEHIND BLUNT-NOSE CONE AT $M = 2{\cdot}19$ ($R_D = 0{\cdot}58 \times 10^6$, $\frac{d}{D} = 1$)



a. TAYLOR CANOPY



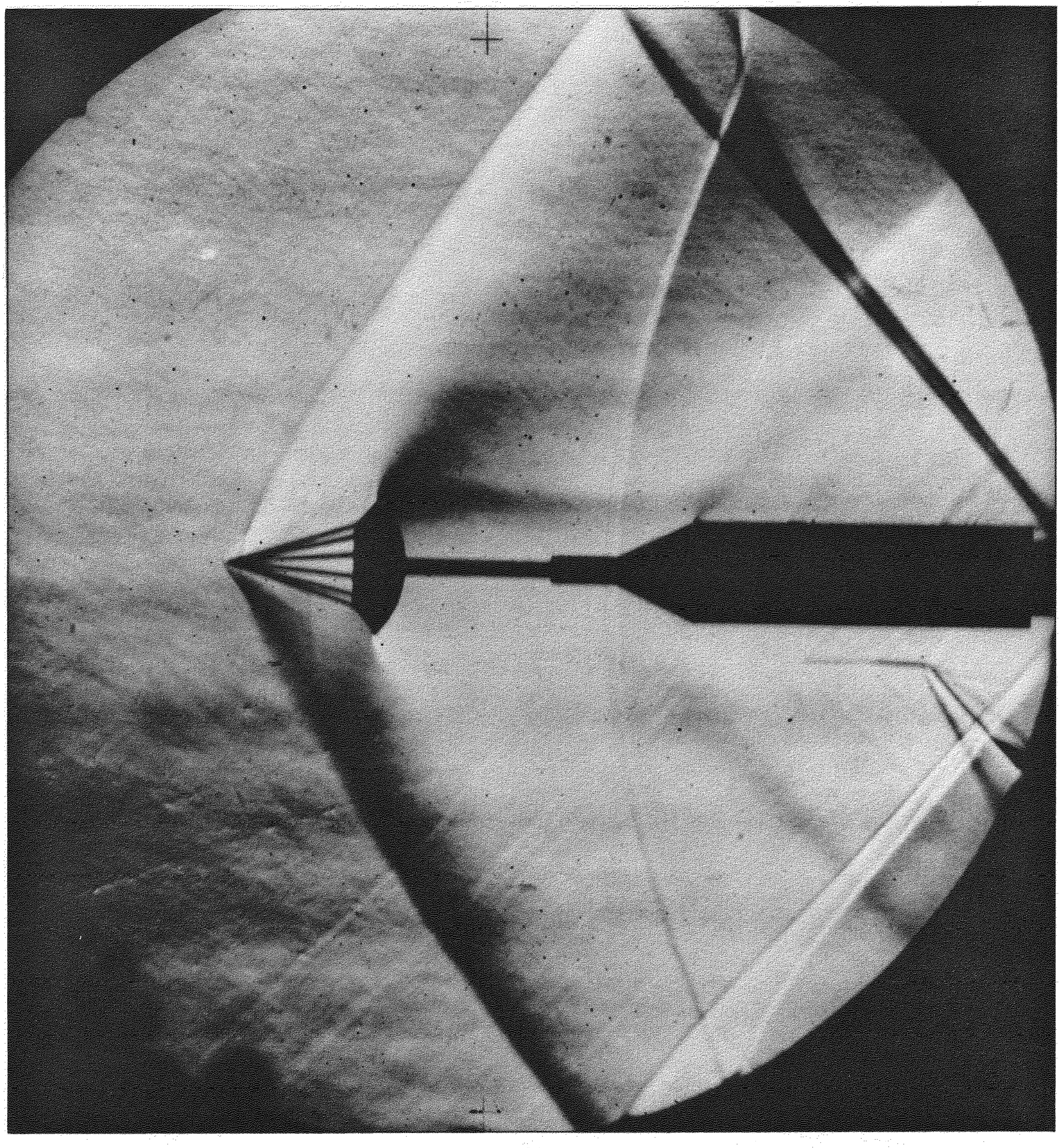
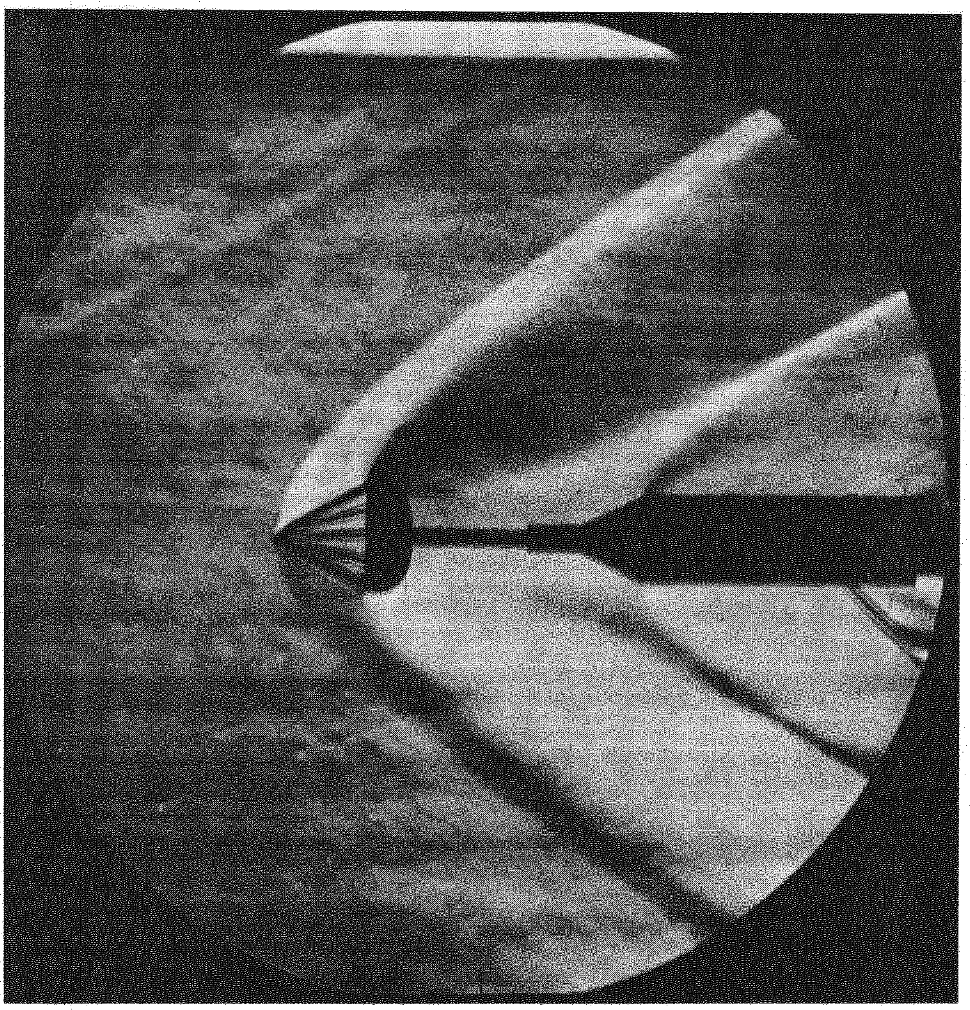
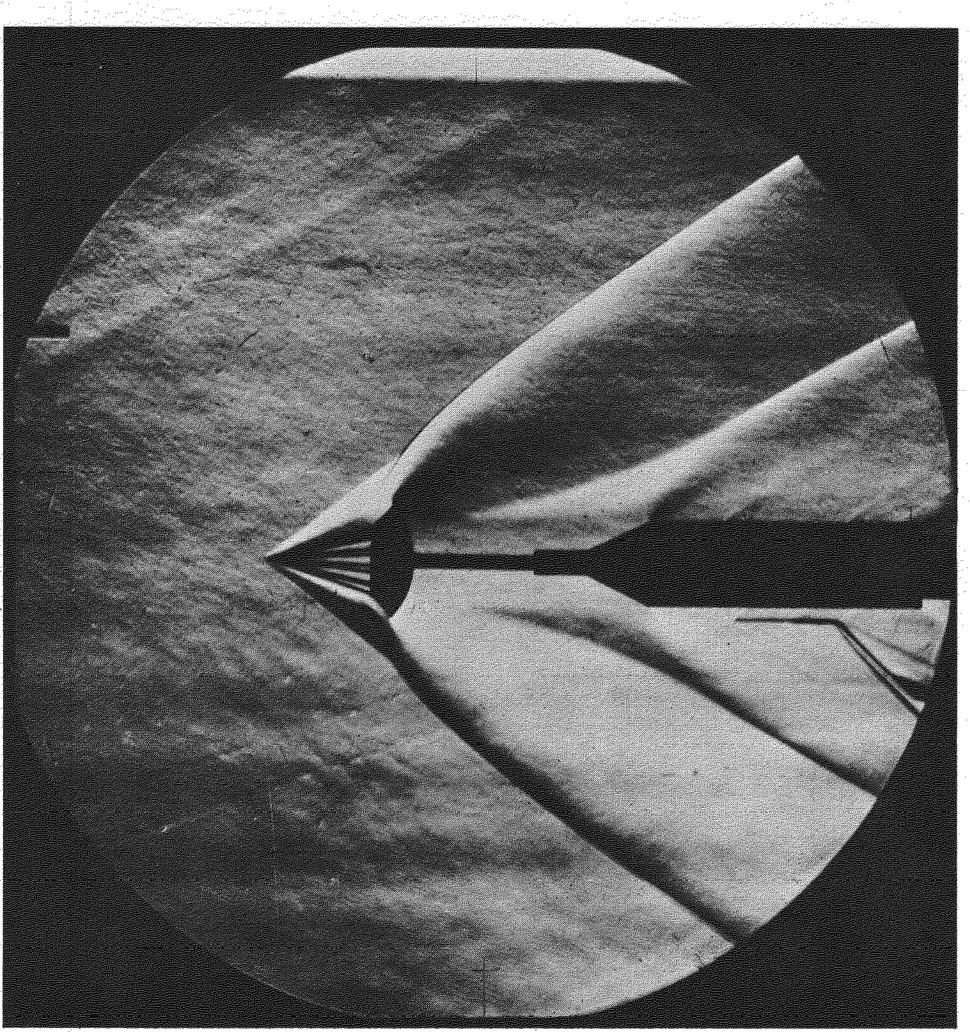
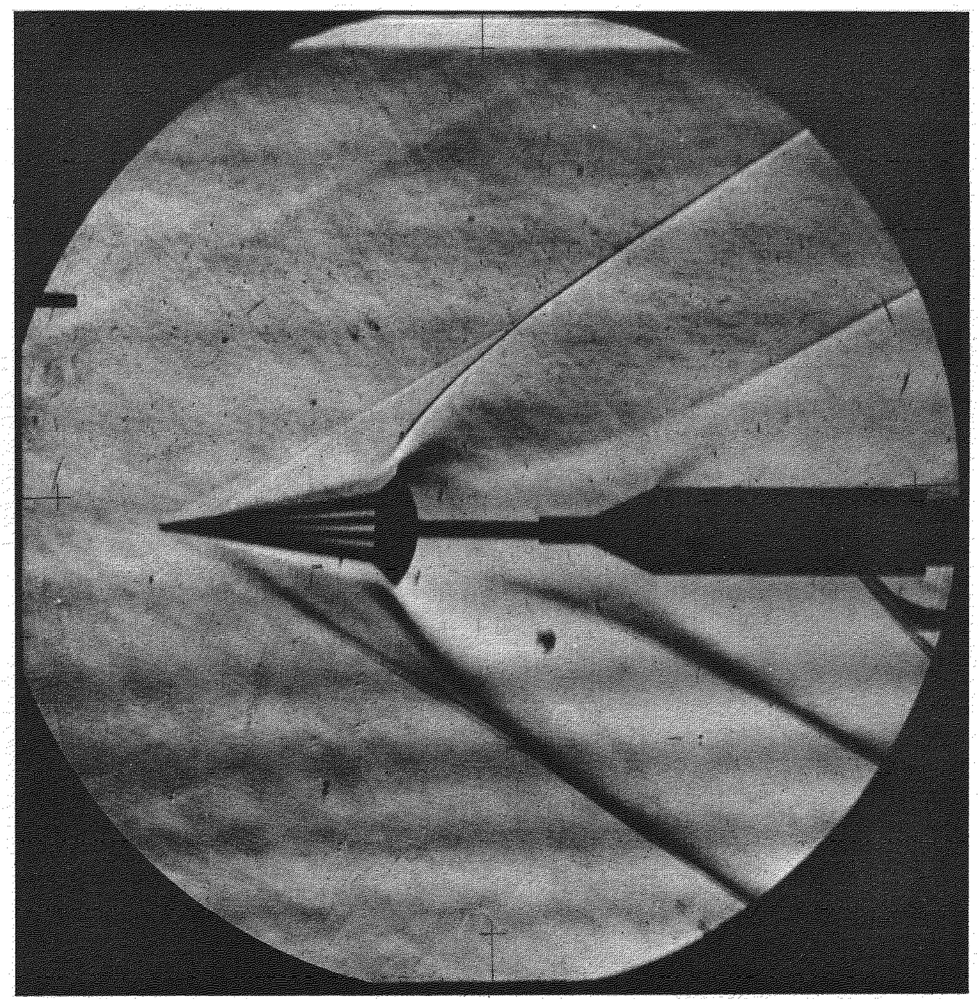


FIG. 11. GUIDE SURFACE PARACHUTE WITH ID LINES AT M = 1·40

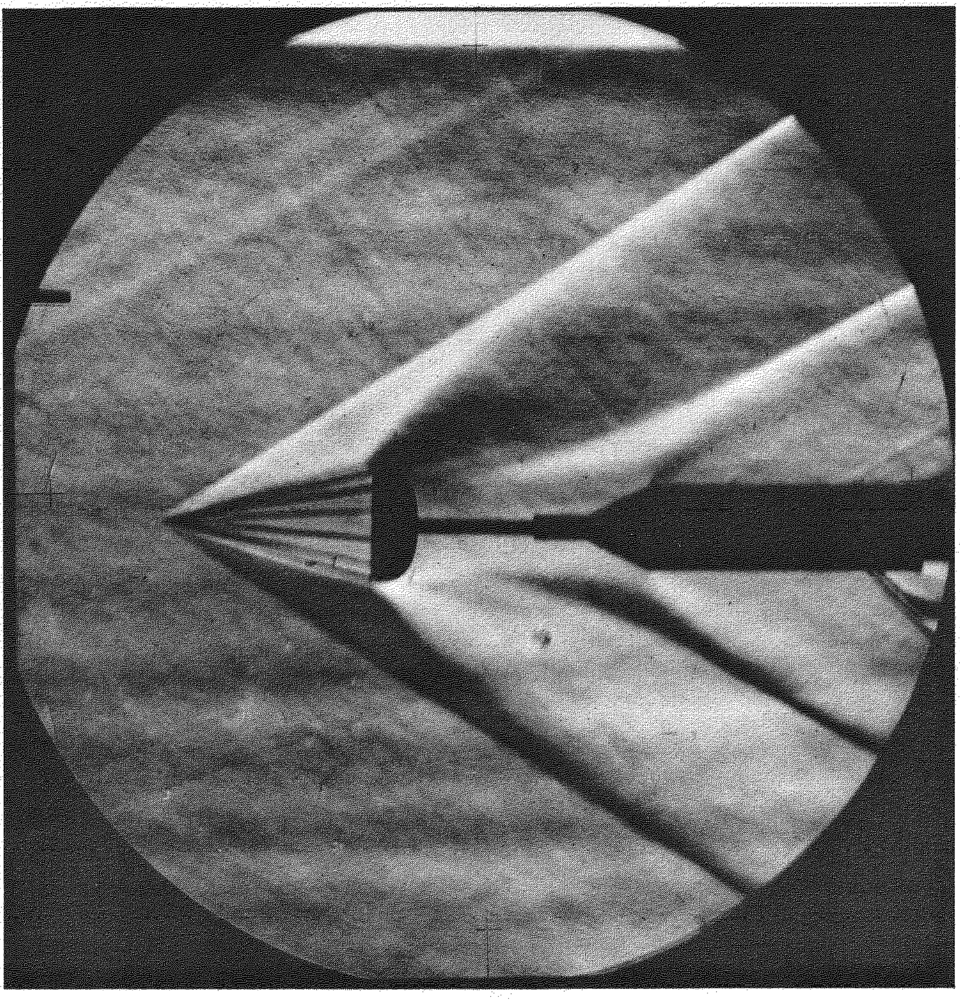


a. TAYLOR CANOPY





a. GUIDE SURFACE CANOPY



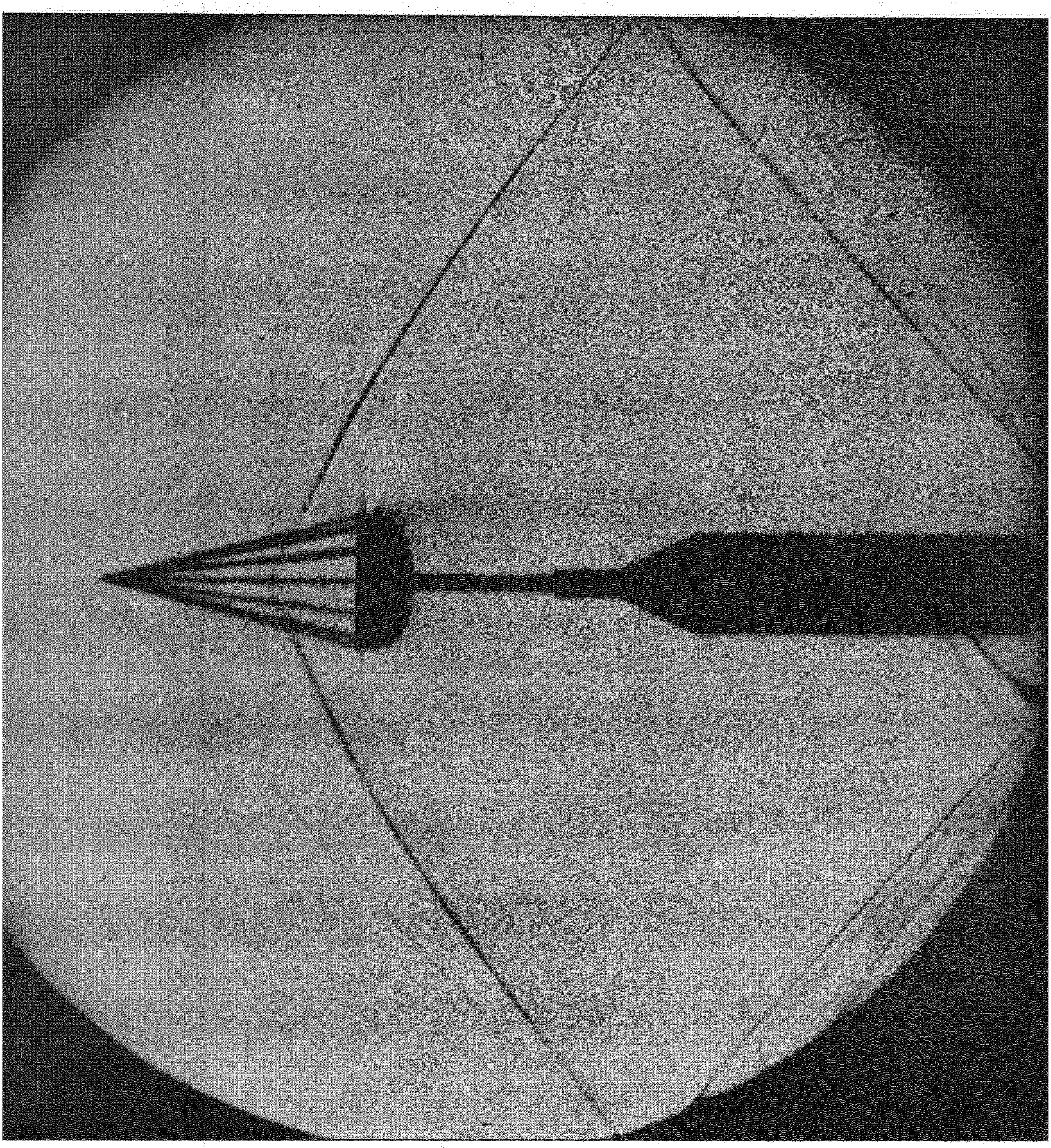
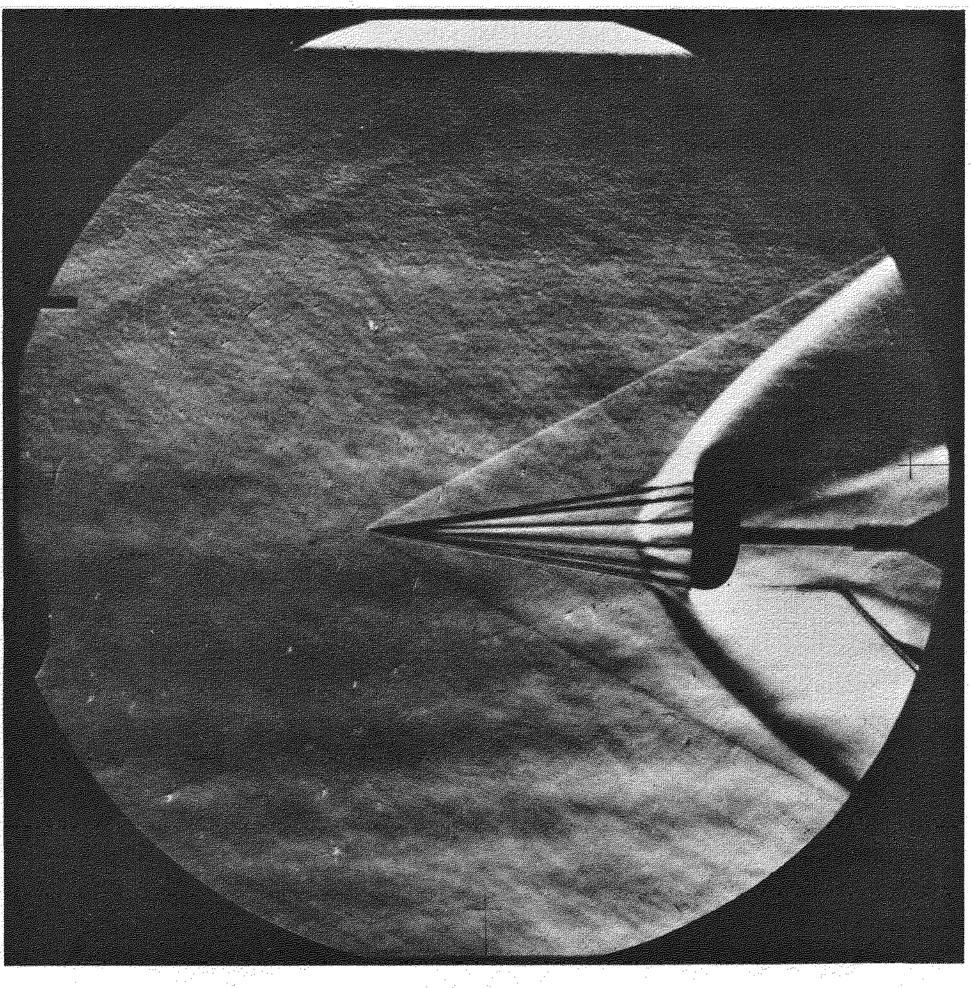
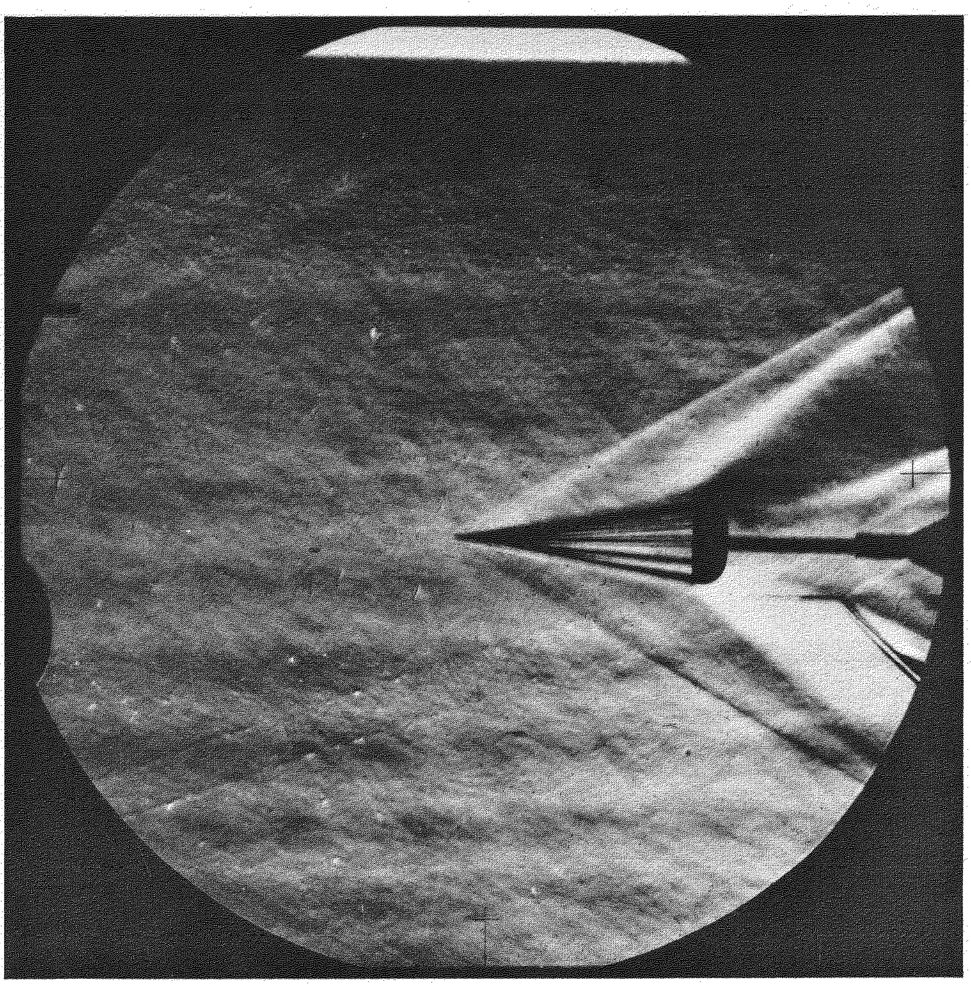
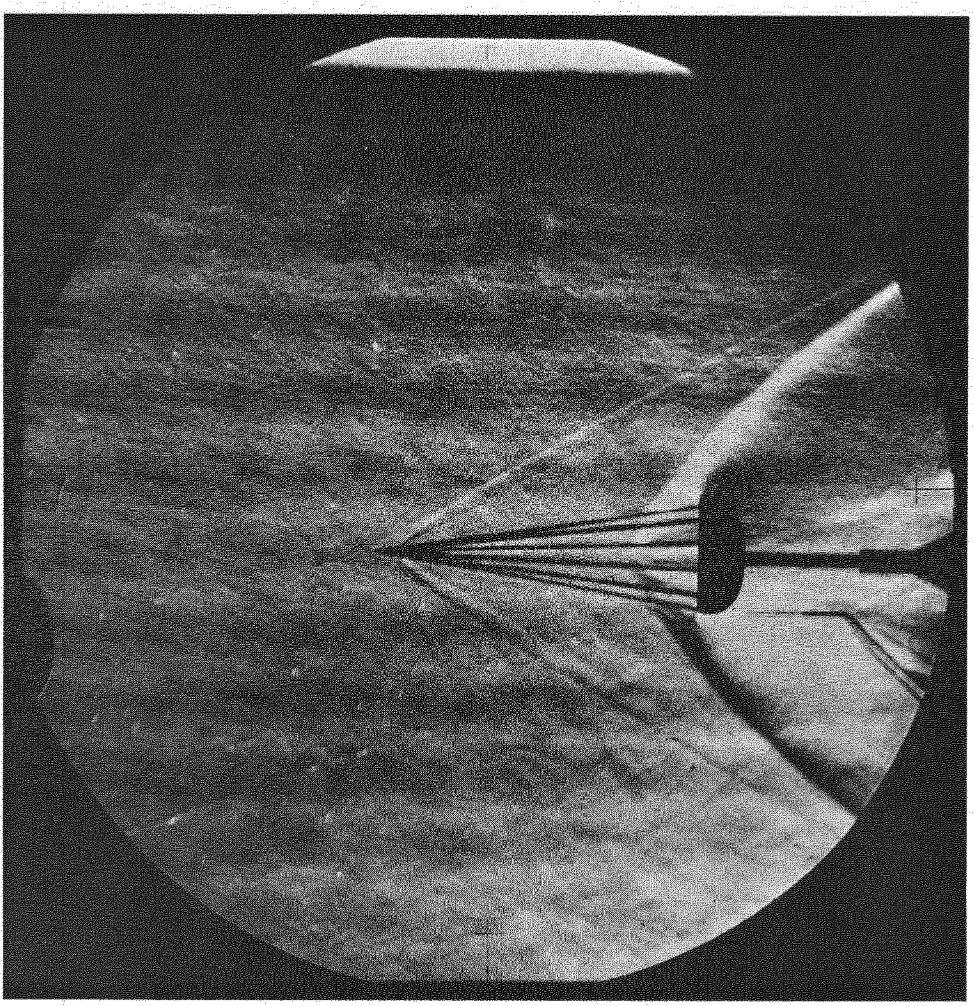


FIG. 14. POROUS TAYLOR PARACHUTE WITH 2D LINES AT M = 1·40



a. SEPARATION FROM APEX WAKE





c. TRANSITION RING ON APEX

FIG. 15c. TAYLOR PARACHUTE WITH 3D LINES AT M = 2·19

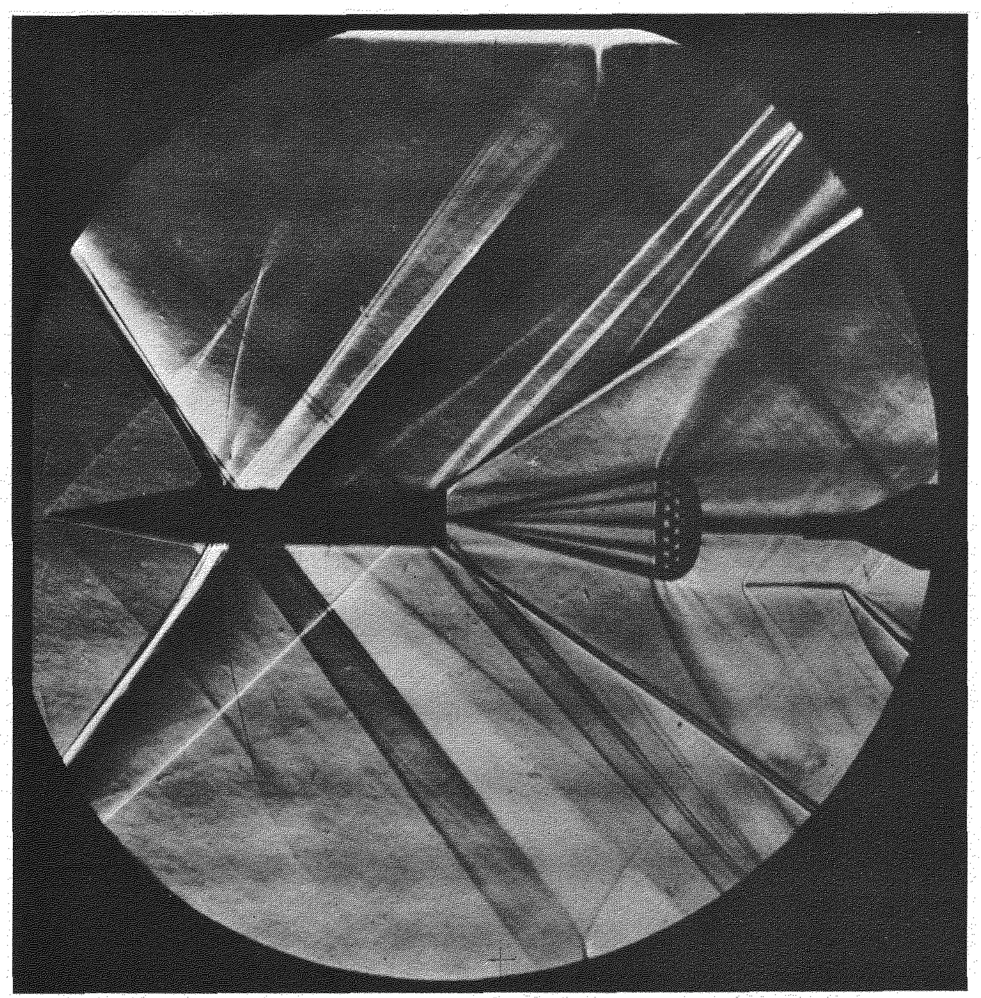
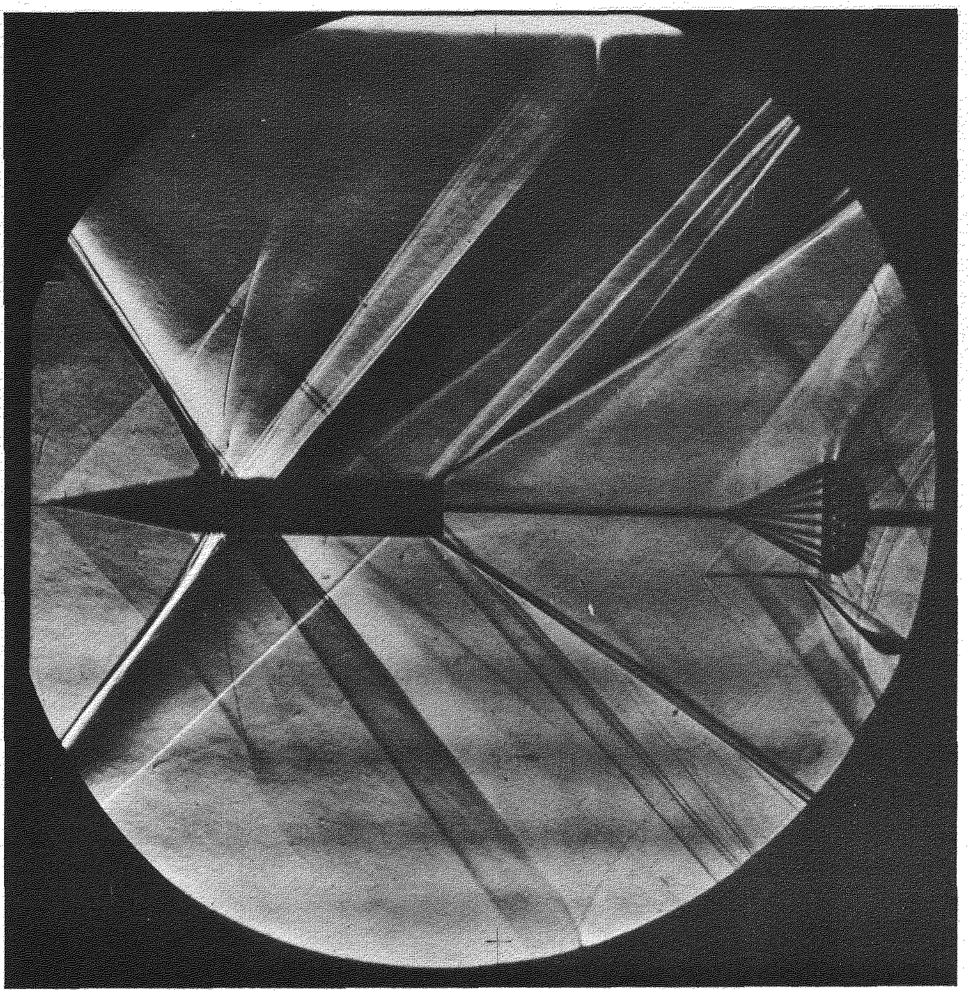


FIG. 16. POROUS TAYLOR PARACHUTE WITH 2D LINES BEHIND CONE-CYLINDER AT M = 1·40



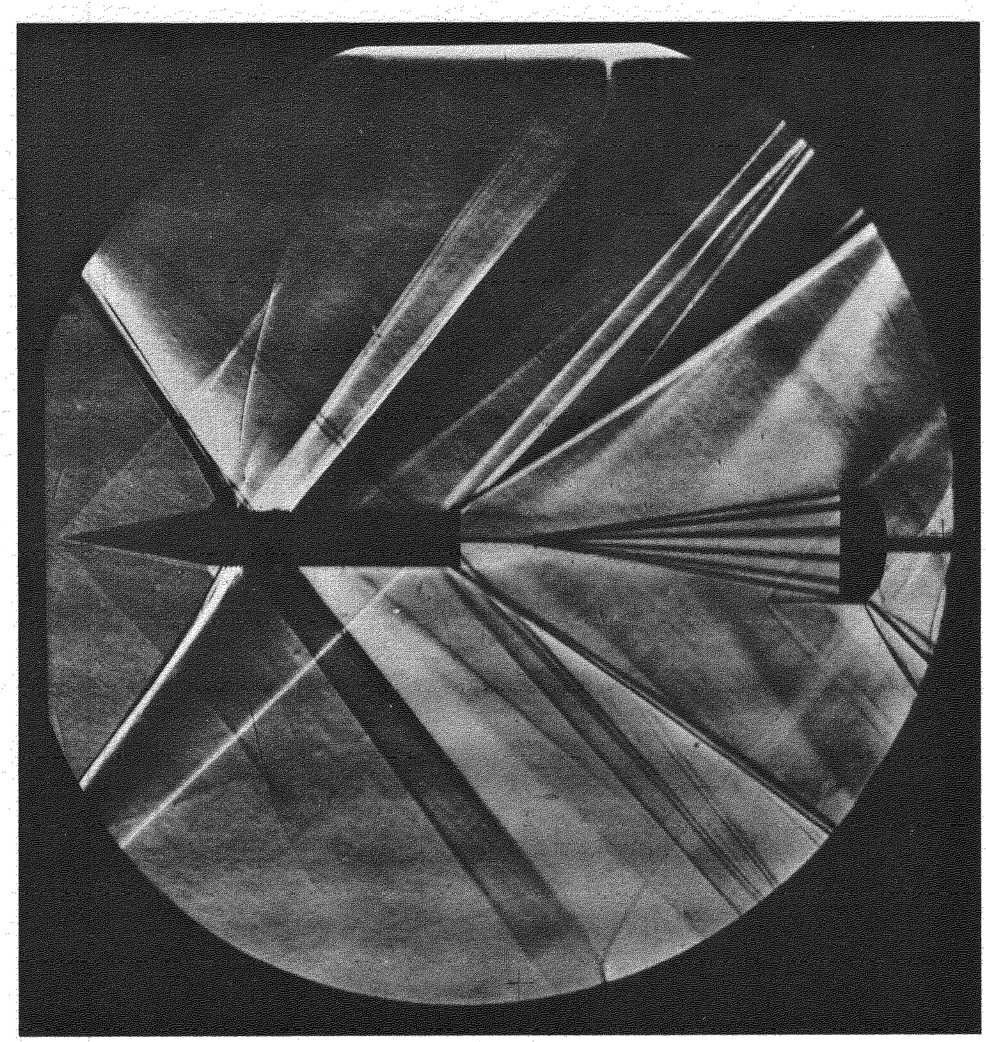
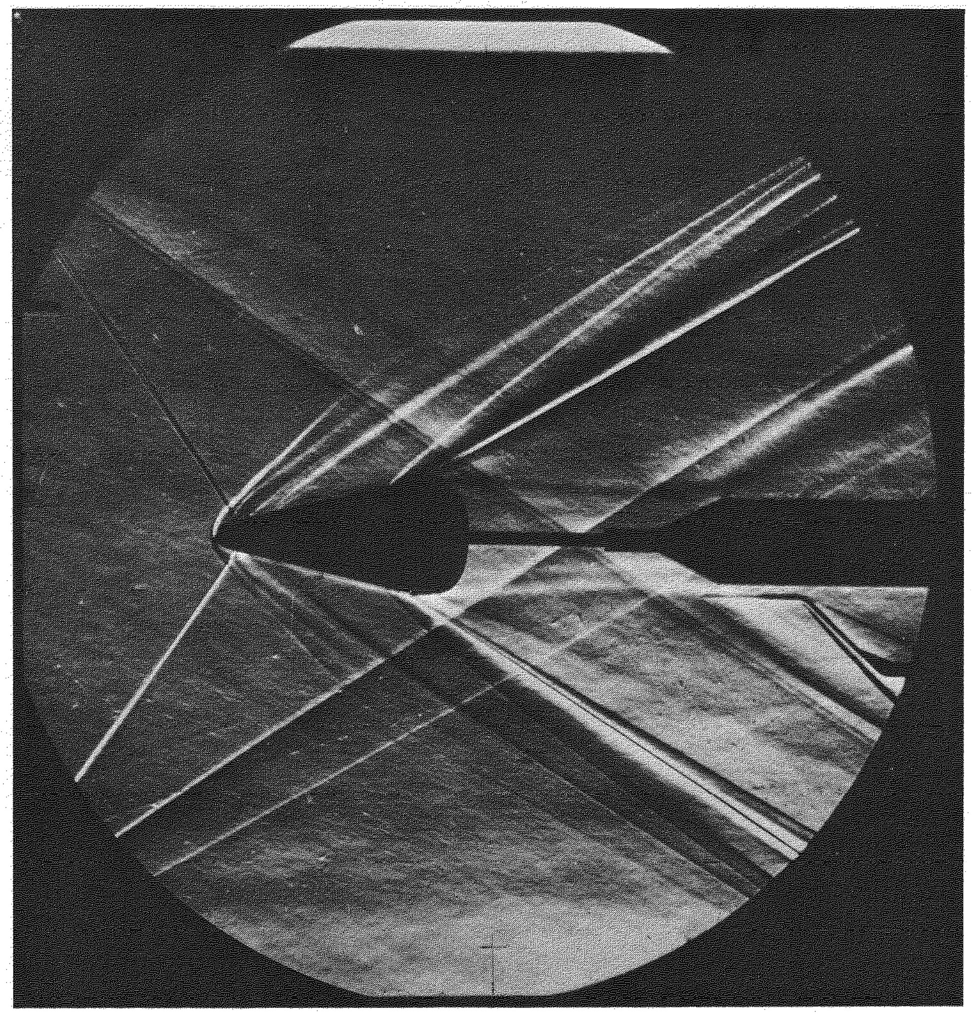
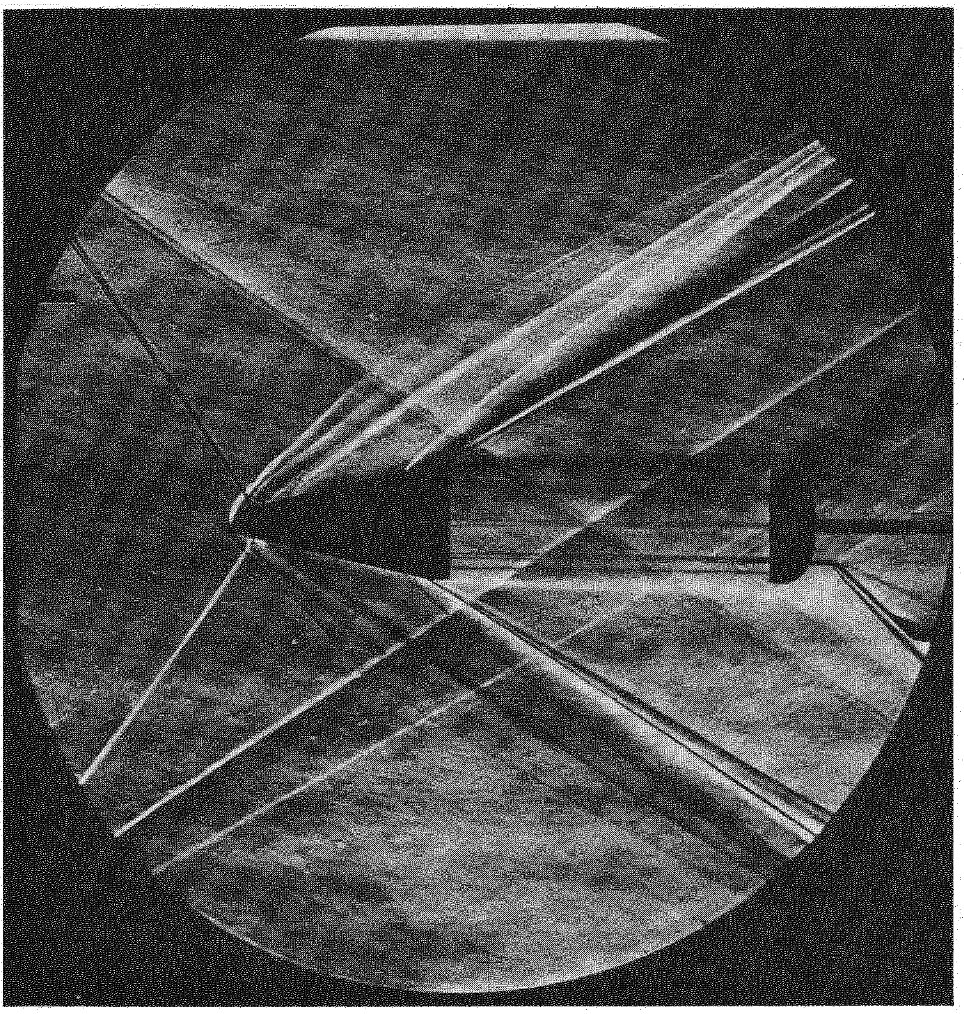


FIG. 18. TAYLOR PARACHUTE WITH 3D LINES BEHIND CONE-CYLINDER AT M = 1·40



a. MINIMUM SPACING



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REPRESENTING TWO PARACHUTE DESIGNS AT M = 1.40 AND
2.19. Roberts, B.G. December, 1960.

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The investigation has shown that the presence of rigging lines reduces the canopy drag by an extent dependent upon the length of the lines. Several different flow regimes are encountered similar to those noted during investigations with spikes on bluff bodies, including an oscillatory condition when the lines are short. The presence of the body of revolution, either a cone-cylinder or a blunt cone, gives a low parachute drag when located close to the canopy.

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