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Measurements of the Effect of Windscreen  
Shapes on the Drag of Cockpit Canopies at  
Transonic and Low Supersonic Speeds Using  
the Free-Flight-Model Technique

*By*

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# Measurements of the Effect of Windscreen Shapes on the Drag of Cockpit Canopies at Transonic and Low Supersonic Speeds Using the Free-Flight-Model Technique

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*Summary.*—The effect of changes in the shape of the windscreen on the drag of a cockpit canopy has been measured on models in free flight. Canopies were attached to the models by means of a flexible mounting in such a way as to allow the canopy drag to be measured directly.

The drag of the canopy was measured over a range of Mach numbers between 0.85 and 1.55 and the results show the improvements to be obtained by variations in the sweep of a vee windscreen and changes in the angle of a sloping windscreen.

1. *Introduction.*—Some experiments to determine the drag of cockpit canopies at transonic and supersonic speeds have previously been reported by Alexander<sup>1</sup> (1948) and Welsh and Morrow<sup>2</sup> (1951) but little systematic work appears to have been done to determine the advantages to be gained or the penalties to be paid by changes in the shape of the pilot's windscreen. The present report describes a series of tests with this end in view. All the experiments were made using the ground-launched-rocket model technique and cover a Mach number range from 0.85 to 1.55. A general description of the rocket model technique has been given by Lawrence and others in Ref. 3 (1951).

2. *Experimental Technique.*—First attempts to determine the drag of a canopy were made by measuring the difference in drag between a model with canopies and one without. In this way the effects of interference of the body on the canopy and the canopy on the body were taken into account. There was, however, a serious objection to this method in that it necessitated the subtraction of two large quantities (total drags) from one another in order to determine the relatively small drag of the canopy. When looking for the small drag changes to be expected from small variations in windscreen shape the errors introduced in this way made the method almost useless.

To overcome this difficulty in the present investigation, the canopy itself was allowed freedom to move backwards relative to the main body of the model and this movement was restrained

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\* R.A.E. Report Aero. 2529, received 9th May, 1955.

by a spring system. The deflection of the spring system was measured during flight and was telemetered to a recording station at the launching site. In this way the drag of the canopy could be directly determined, although the method took no account of the interference effect of the canopy on the body nor of the mutual interference when two canopies were mounted on opposite sides of the body. It must nevertheless be remembered that the primary object of the experiments was to measure the effect of changes of windscreen shape, and although there exists the possibility of mutual interference between canopies this should be substantially constant for the different canopies, and the variations in interference owing to changes in windscreen angle should be small compared with the total canopy drag.

2.1. *Model Construction.*—It was expected that during flight large normal forces would be experienced by the canopies and this introduced some difficulties. Laboratory experiments had shown that normal loads on the spring mounting system would lead to large errors in the recording of drag and this difficulty could not be overcome in the simple system being used. A subsidiary problem was introduced when only one canopy was fitted, because the normal force associated with it made the prediction of the flight path of the model very difficult and this was unacceptable from the range safety point of view. Both these problems were overcome by fitting two canopies, one diametrically opposite the other and joined together mechanically so that their normal forces cancelled each other.

The forward part of the model, shown in Fig. 1, was formed from a cylindrical light alloy tube of 5-in. diameter with the ogival nose piece made of wood. In addition to the canopies and the drag balance, the forward part of the model contained the telemetering pick-up and transmitter. The twin spike aerials transmitting the telemetering signal were located behind the canopies in order to avoid any aerodynamic interference on the canopies. The rear part of the model, not shown in Fig. 1, consisted of a 5-in. L.A.P. rocket motor at the end of which four rectangular stabilizing fins were attached.

Between the forward part of the model and the rocket motor an explosive break-up charge was fitted with clocks set to detonate the charge 12 seconds after launching. The model was launched at an angle of 18 deg to the horizontal and reached a maximum height of about 2,000 ft and a Mach number of between 1.5 and 1.6. At 12 seconds the Mach number had fallen to about 0.85 and the height to 500 ft, and the explosive charge, operating at this time, blew the model in two. The forward part, being unstable by itself, tumbled and because of its consequent high drag, struck the ground relatively slowly causing no great damage. In this way component parts were recovered for use in later models.

2.2. *Canopy Drag Balance.*—The method of mounting the canopies so as to measure the drag is shown in Figs. 2 and 3. Both canopies were fitted to a light metal frame which was stiffened internally with balsa wood. The moving unit was made as light as possible in order to reduce its inertia and so minimise the corrections to be applied for longitudinal accelerations.

At the top and bottom of the front and rear bulkheads of the moving framework, flat plate-type springs were clamped. The centre sections of these springs were fixed to two cross-frames attached to the body. The frame containing the canopies was thus constrained to move in the longitudinal direction only. The spring stiffness was chosen so that a maximum longitudinal movement of the canopies of about 0.01 in. corresponded to the estimated maximum load expected on the system in flight. The amount of this deflection was measured by means of an inductance pick-up at the forward end of the framework. This pick-up consisted of a coil mounted rigidly on the fixed forward cross-frame and a small slug of high permeability material attached to the forward bulkhead of the moving frame. As the spring system deflected under load so the air gap between the slug and the coil changed and this altered the inductance of the pick-up. This pick-up formed part of a tuned circuit which reproduced the change of inductance as a change in frequency and this was then transmitted to the ground receiving station, where it was recorded. The small

slug forming part of the inductance pick-up was mounted in such a way that small adjustments could be made to vary the width of the initial air gap ; this starting gap was then set so that an optimum change of inductance occurred between zero and maximum deflection. At the rear bulkhead a stop was fitted which limited the travel of the moving frame during the boosting period when the high accelerations drove the frame over the full range of deflection.

2.3. *Calibrations.*—Experience showed that the drag balance needed ‘ bedding in ’ to prevent changes of calibration during the high acceleration boosting period and this was done by subjecting the model to longitudinal accelerations of the same order in the laboratory. The model was dropped on to a bed of Plasticine from a predetermined height such that it was subjected to axial accelerations of between 40 and 50g. This test was repeated two or three times on each model and the frequency corresponding to zero load was noted after each drop. Discrepancies of up to 10 per cent of full-scale deflection were experienced at the first drop but these discrepancies rapidly decreased with each subsequent drop until finally the variations in zero load deflection were small and random.

To calibrate the deflection system after the ‘ bedding in ’ process had been completed a metal bar was passed through a hole provided in the moving frame-work, so that with the model standing vertically the frame could be loaded by hanging weights symmetrically on to the bar. The telemetered frequencies corresponding to each load were then noted, allowance being made for the weight of the canopies and their mounting.

3. *Location and Shape of Canopies.*—The principal geometric parameters describing canopy shape are :

- (a) height
- (b) length
- (c) afterbody shape
- (d) windscreen shape. \*

The present programme was designed to combine values of these parameters which could be systematically varied and were yet not inconsistent with the operational requirements of a good canopy design. A canopy height to body diameter ratio of 0.25 was chosen based on an analysis of the canopy heights of existing and proposed fighter aircraft. A datum canopy was then stipulated which consisted of a body of revolution formed by two tangent ogives placed back to back with their axes of revolution coincident with the top of the fuselage body, and having a total length of 10 canopy heights (*see* Fig. 4). A canopy of this shape obviously would not satisfy the operational requirements for an actual aircraft. These requirements have been examined by Day<sup>4</sup> (1952) and a study of them led to the formulation of a series of shapes based on the datum canopy, but having more practical windscreens. The method of obtaining this series is illustrated in Fig. 4. Briefly, the afterbody was maintained identical with that of the datum canopy but from the maximum-height position was drawn a prolate spheroid of fineness ratio  $1\frac{1}{2} : 1$  with its major axis along the axis of the canopy. The forebody of the datum canopy was then intersected by a series of planes tangential to the prolate spheroid and subtending a systematic series of angles ; these cutting planes formed the windscreen, the junction between the planes and the curved afterbody of the canopy being radiused by 0.2 in. There was no radius at the intersection of the canopy and the body, nor at the intersection of the windscreen planes (*see* Fig. 2).

The angles of the intersecting planes were determined in the following manner :

If  $\theta_p$  is the angle between the plane and longitudinal canopy axis in the plan view, and  $\theta_s$  the corresponding angle in the side view, then we have  $\cot^2 \theta = \cot^2 \theta_s + \cot^2 \theta_p$ , where  $\theta_s$  is the angle of the windscreen plane to the axis (Fig. 4). Thus by choosing integral values of  $\cot^2 \theta_p$

and  $\cot^2 \theta_s$ , see Table 1 below, we obtain a programme of windscreen angles in which corresponding integral values of  $\cot^2 \theta$  may be obtained by various combinations of  $\theta_p$  and  $\theta_s$ .

TABLE 1

$\phi$	$\cot^2 \phi$
90	0
35.3	2
26.6	4
22.2	6
19.5	8

The programme of windscreen angles tested is given below in Table 2. In this table the canopies have been identified by writing two figures, the first being the value of  $\cot^2 \theta_p$  and the second  $\cot^2 \theta_s$ ; this method of notation has been followed in the presentation of the results.

TABLE 2

Canopy	$\theta_p$ (deg)	$\theta_s$ (deg)	$\theta$ (deg)
00	90	90	90
02	90	35.3	35.3
04	90	26.6	26.6
06	90	22.2	22.2
20	35.3	90	35.3
40	26.6	90	26.6
60	22.2	90	22.2
22	35.3	35.3	26.6
24	35.3	26.6	22.2
42	26.6	35.3	22.2
44	26.6	26.6	19.5
26	35.3	22.2	19.5
62	22.2	35.3	19.5

From this table we see that canopies 00, 02, 04 and 06 are windscreens which slope progressively backward and 00, 20, 40 and 60 are vee windscreens with the apex progressively sharpening. The canopies 22, 24, 42, 44, 26 and 62 consist of both slope and vee combined.

4. *Analysis of Results.*—For the determination of drag coefficient  $C_D$  a knowledge was required of the drag of the canopy, Mach number and ambient air pressure. In all cases  $C_D$  was based on the total frontal area of the canopies (0.0378 sq ft). The methods used for obtaining Mach number and ambient air pressure from radio-doppler, kine-theodolites and meteorological data has been described fully by Lawrence<sup>3</sup> (1951).

The forces on the canopy during the decelerating part of the flight when the measurements were made were: the drag force acting backwards, a force due to the inertia of the moving parts consisting of the canopies and their mounting acting forwards, and a component of the weight of the moving parts due to the angle of the model to the horizontal.

Thus  $D = r + w(f - \sin \phi)$ , where  $D$  is the total canopy drag;  $r$  is the net load deflecting the spring system obtained from the telemetered information;  $w$  is the weight of the moving parts (obtained before assembly of the model);  $f$  is the deceleration of the model, in  $g$  units, obtained

from the differentiation of the velocity-time data, which in turn was obtained by means of radio-doppler;  $\phi$  is the angle of the model to the horizontal, obtained from the analysis of kine-theodolite records (nose-up is positive).

In Fig. 5a the drag coefficients of canopies 00, 02, 04 and 06 are plotted against Mach number and the curves indicate the gains to be obtained by progressively decreasing the angle of slope of the windscreen to the horizontal. The measurement of the drag of canopy 00, windscreen 90 deg to the horizontal, proved to be rather difficult because the record showed that there was considerable buffeting which induced a severe fluctuation in the undamped flexible mounting. Fig. 8 shows sections from the telemetering record obtained from three models; these were for canopies 00, 40 and 60. These records illustrate the difference in the fluctuations and show just how bad canopy 00 was in this respect. Because of the nature of the record the experiment on this particular canopy was repeated and the curve shown in Fig. 5a is the mean of the two results.

The values of  $C_D$  for the two results were plus or minus 5 per cent on either side of this mean curve at  $M = 0.85$  and  $1.0$  and the difference decreased to zero at  $M = 1.6$ .

There was also some suspicion attached to the result of canopy 0.2, so this test was also repeated and as before the curve plotted is the mean of the two results. In this case the dispersion was somewhat less, plus or minus 4 per cent of  $C_D$  in the region of the drag rise and at  $M = 1.0$  and less than half this figure at the higher Mach numbers.

Also plotted in Fig. 5a is the drag of the datum canopy and we may consider its 'windscreen' shape to be aerodynamically the best that could be achieved for this lay-out of canopy.

Canopies 20, 40, and 60 had vee windscreens and the drag of these is plotted in Fig. 5b. Both 40 and 60 had less drag than their counterparts 04 and 06 which had the same angle of windscreen. On the other hand canopy 20 had a higher drag than its counterpart 02. One might feel that there was some error in the results of canopy 02, since between  $M = 0.85$  and  $1.25$  there is no difference in the drag of this canopy and canopy 04, which had a smaller angle  $\theta_s$ . But it has been pointed out earlier that the experiment with canopy 02 was repeated and the second results confirmed the first.

Canopies 24 and 42 and canopies 26 and 62 are pairs in that they interchange  $\theta_p$  and  $\theta_s$  to give the same value of  $\theta$ , the true angle relative to the axis. The results from these canopies are plotted in Fig. 5c and show that supersonically canopy 24 is better than 42 and canopy 26 is better than 62. From this we might conclude that for this particular combination of angles we achieve a better result by making  $\theta_p$  greater than  $\theta_s$ . However the differences in drag are small and an examination of Figs. 5a and 5b shows that this result is not generally true.

In Fig. 6 the drags of the canopies are plotted in groups, each group having the same value of  $\theta$ . Canopies 04, 40 and 22 ( $\theta = 26.6$  deg) are shown plotted in Fig. 6b and in the range of Mach numbers covered, canopy 40 (pure vee windscreen) is substantially better than 04 and 22. The canopies in which  $\theta$  is  $22.2$  deg are shown plotted in Fig. 6c, and again the pure vee windscreen (canopy 60) is better except in the subsonic region. However owing to the low drag loads at  $M < 1$  the percentage errors in  $C_D$  are about four times those at  $M > 1$  so that the changeover shown in Fig. 6c, is most probably merely a reflection of the reduced telemetering accuracy. Canopies 44, 26 and 62 ( $\theta = 19.5$  deg) are plotted in Fig. 6a; in this group no canopy with a pure vee windscreen was tested.

The general effect of sweeping and sloping the windscreen is shown in Fig. 7 where the drag coefficients of all the canopies tested have been plotted against  $\cot^2 \theta$  at three different values of Mach number.

5. *Conclusions.*—The experimental results show that the measurements in free flight, of the drag of small excrescences, in this case cockpit canopies, can be done most satisfactorily by

means of a simple drag-balance system. The lack of any damping in the balance has led to difficulties in only one case, *i.e.*, when the canopy windscreen was as 90 deg to the free-stream direction. There were, in fact, certain advantages in this, since it revealed more clearly that a canopy of this type would be subjected to severe buffeting.

The results give a consistent variation of canopy drag with variation in windscreen slope over the range  $M = 0.85$  to  $M = 1.55$ .

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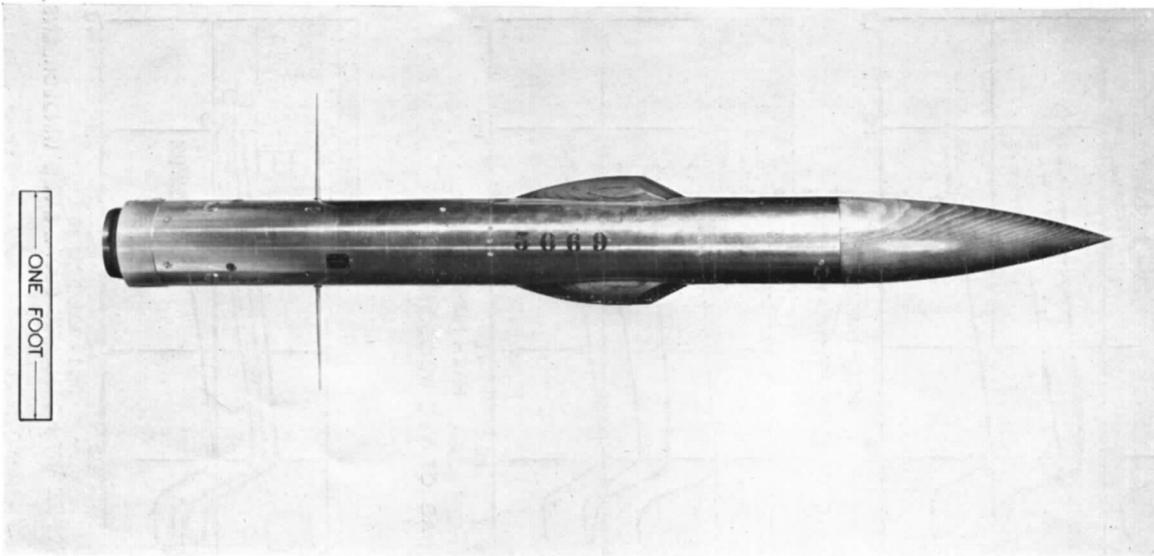


Fig. 1. Forward part of model containing telemetering equipment.

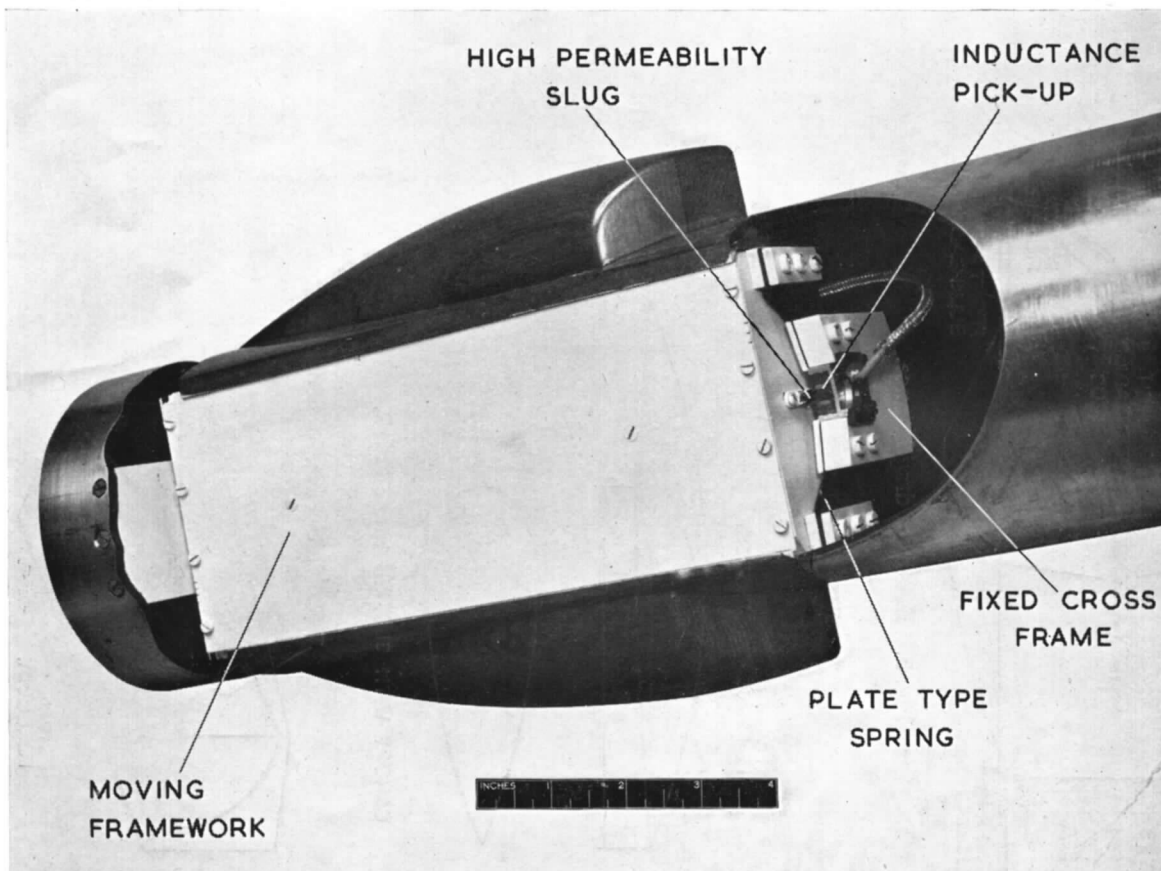


Fig. 2. Cut-away view of drag balance.



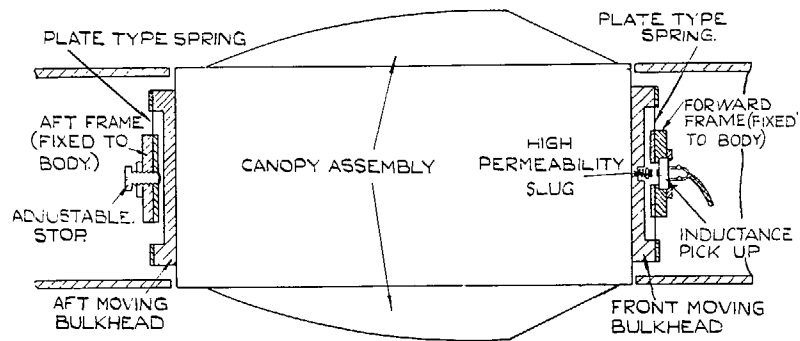


Fig. 3. Details of drag balance.

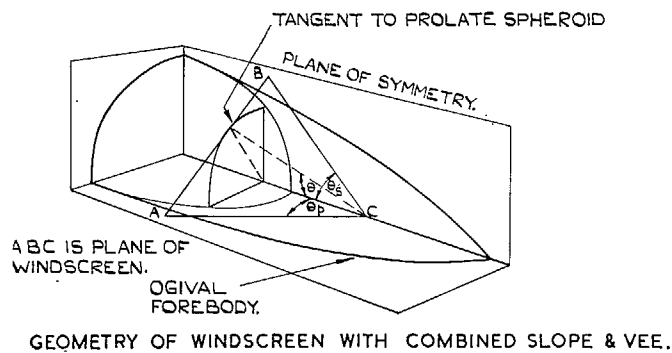
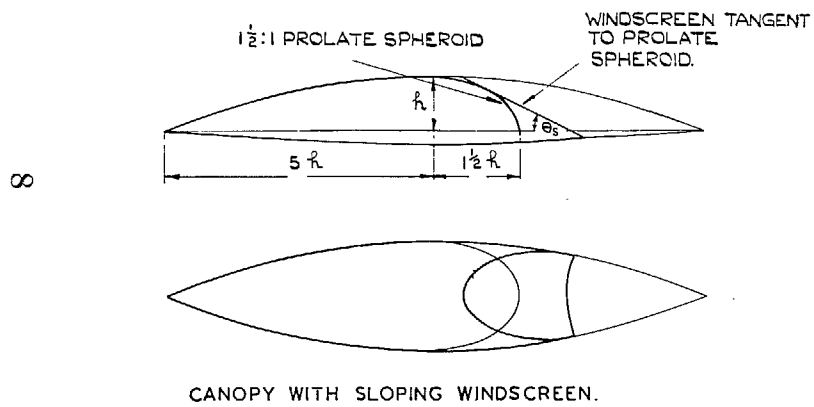
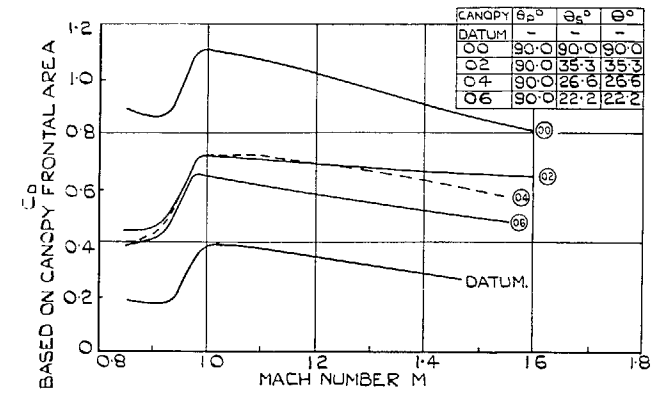
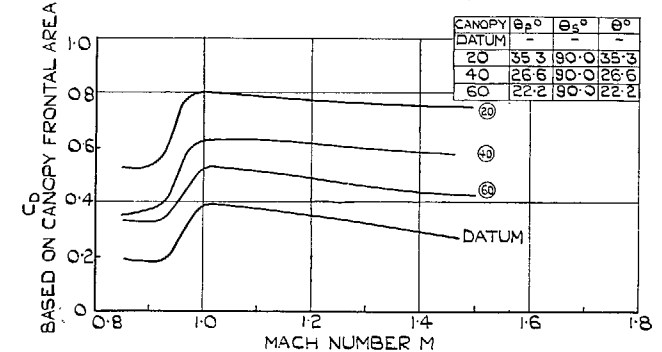


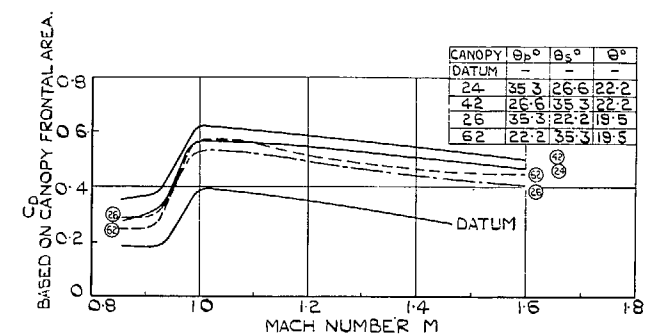
Fig. 4. Canopy basic-design data.



(a) DRAG OF SLOPING WINDSCREENS.

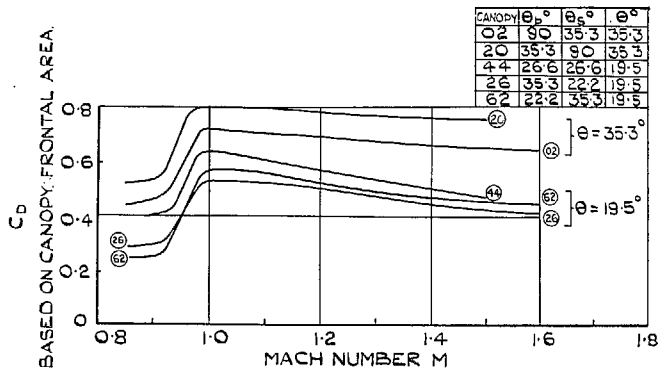


(b) DRAG OF VEE WINDSCREENS.

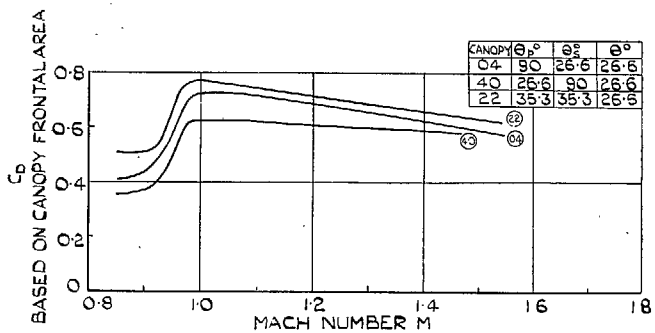


(c) DRAG OF CANOPIES WITH COMBINED SLOPE & VEE WINDSCREENS.

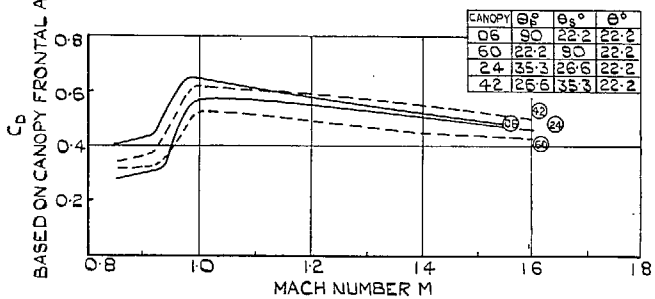
Figs. 5a to 5c. Variation of canopy drag with Mach number.



(a) DRAG OF CANOPIES WITH  $\theta = 35.3^\circ$  &  $19.5^\circ$



(b) DRAG OF CANOPIES WITH  $\theta = 26.6^\circ$



(c) DRAG OF CANOPIES WITH  $\theta = 22.2^\circ$

Figs. 6a to 6c. Drag of canopies with similar values of  $\theta$ .

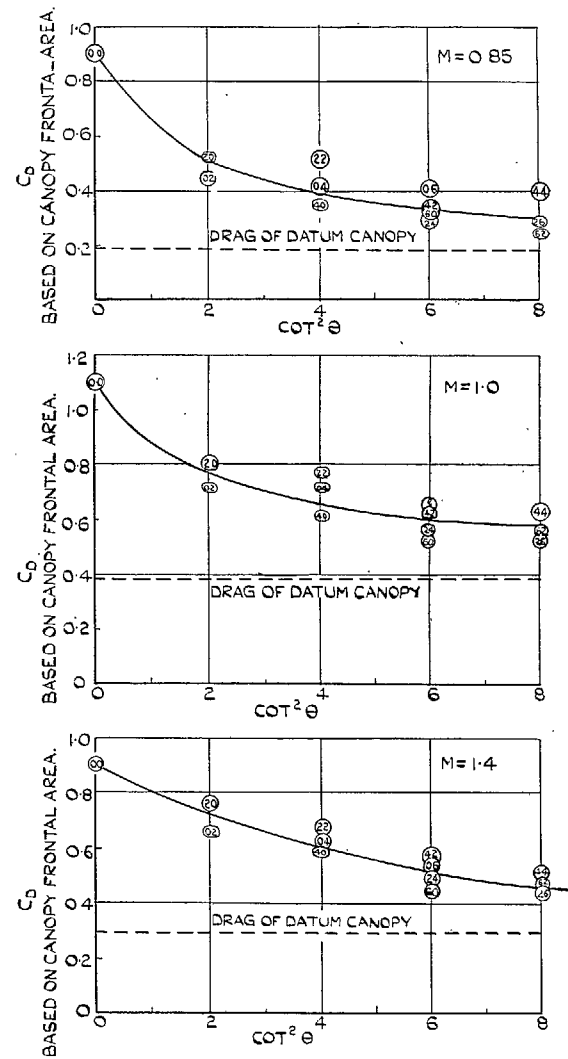


Fig. 7. Effect of windscreen angle on drag.

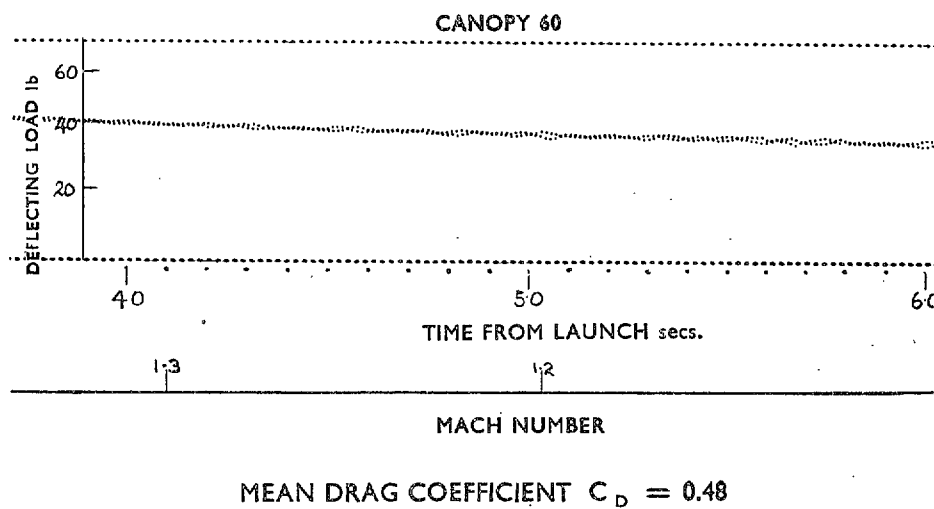
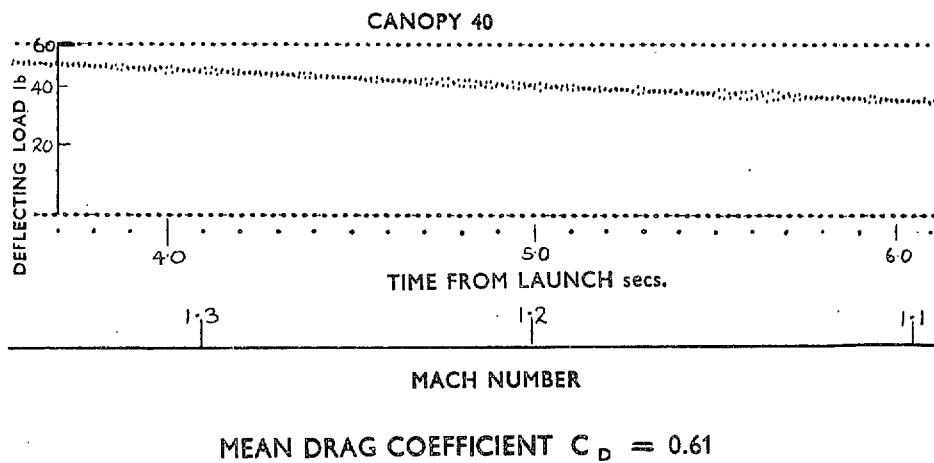
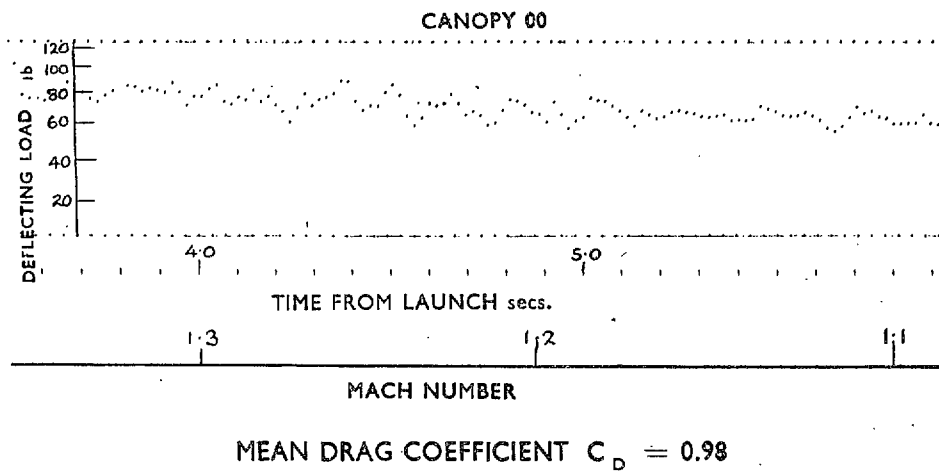


Fig. 8. Specimen telemetering records showing the relative effect of buffeting.

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