high altitudes during his flight and permitted Ivans a small view of the world outside at least. (See SOARING, Jan.-Feb., 1951).

A short synopsis of the flow situation may explain the aerodynamic foundations for mounting bubbles. The total drag of an aircraft increases by every additional protuberance added to the original surface. This increase is composed of the form drag of the protuberance and the induced parasitic drag which the protuberance causes over the remaining surface of the aircraft. The amount of the induced drag depends on the position of the protuberance on the airplane. With unfavorable locations the induced drag may be a multiple of the form of drag of the protuberance. Unfortunately many canopies are located unfavorably (see Fig. 8). In Figure 8 the bubble has been replaced for this measurement by two disturbance plates which represent the protuberance.

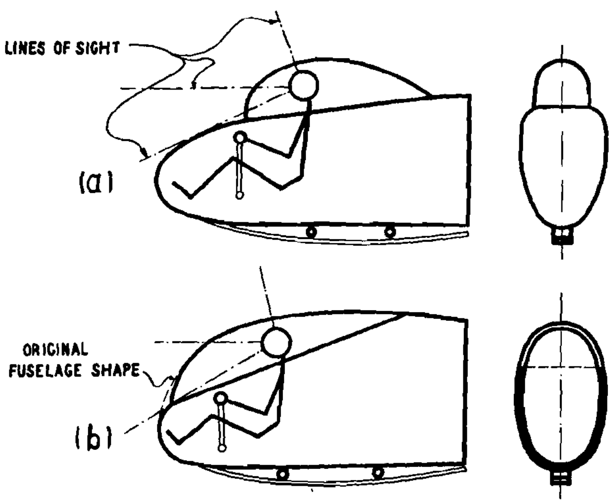

Fig. 7

Types of mounting for a blown canopy.
(a) Super Body Contour. (b) Fuller Contour Canopy.

If the flow is not in any way disturbed the transition point from laminar to turbulent boundary layer is located at about 33% of the length of the body. When the disturbance plates are in the region of the laminar boundary layer, however, the transition point moves forward on the fuselage. The reason for this change in the transition point is a basic aerodynamic fact: when there is a sudden pressure rise the transition from a laminar to a turbulent boundary layer occurs at the position of the pressure rise. A sudden pressure rise is produced by the disturbance plates. The effect described causes an additional drag, which is shown in Figure 8 by the shaded area. As soon as the disturbance plates are placed beyond the 33% mark there is no longer any additional drag. The boundary layer is already turbulent.

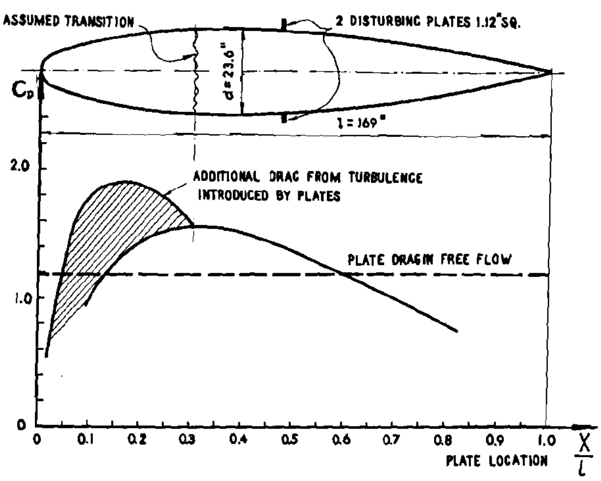

Fig. 8

Drag increase of a streamline body caused by adding two small disturbance plates. (Ref. 1) Body: length = 4-29 meters, cross-sectional area = 0.282 square meters, C_d = 0.06 RN = 15 million; Dia/length = 14%.

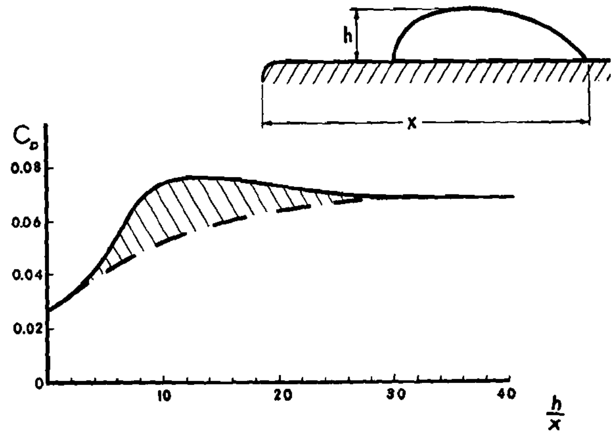

Fig. 9

Drag of a streamline half body as a function of height. The best position of the bubble on the fuselage can be found from the diagram.

The largest drag coefficient is obtained when the plates are at about 15%, and has a value approximately twice as high as the form drag of the disturbance plates. If wider plates had been used, the percentage increase in drag would have been no larger. The above results can be applied to bubbles, as shown in Figure 7a. The reader may visualize the disturbance plates represented by the bubble. Unfortunately, the authors were unable to find any measurements to show the drag of a bubble at various positions on the fueslage. There are, however, some measurements made on a flat plate, and these should prove satisfactory for our purpose. The turbulence effect (shaded area) in Figure 8 can also be seen in Figure 9. The lower curve shows a slight difference from that of Figure 8, because the drag coefficient refers to both the bubble and the wall and the drag of the wall is not negligible. The reader may observe that in Figure 8, C_d is plotted versus x/1 and in Figure 9 versus x/h. Supposing both values (h,1) to be constant, it is easy to show that $C_d = K. f(x)$. In other words, h and l are only reference lengths.

From the above results for the practical application of the bubble to a sailplane the following conclusions may be drawn:

1. The optimal position and the drag coefficient for bubbles (Ref. 3 and 7) can be derived from Figure 9.
2. The interference wing—bubble was not taken into consideration, since no direct measurements were available. As far as experience goes the lowest drag is obtained for high wings.
3. Not only blunt intersections but also sharp breaks in the fuselage contour cause a sudden rise in pressure. In order to avoid sudden pressure rises and their consequences it is advisable