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EFFECT OF GROUND PROXIMITY ON AERODYNAMIC CHARACTERISTICS OF TWO HORIZONTAL-ATTITUDE JET VERTICAL-TAKE-OFF-AND-LANDING AIRPLANE MODELS

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EFFECT OF GROUND PROXIMITY ON AERODYNAMIC CHARACTERISTICS OF TWO HORIZONTAL-ATTITUDE JET VERTICAL-TAKE-OFF-AND-LANDING AIRPLANE MODELS*

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SUMMARY

An investigation has been made to study the effect of ground proximity on the aerodynamic characteristics of two jet vertical-take-off-and-landing airplane models in which the fuselage remains in a horizontal attitude for the take-off and landing. The first model (called the tilt-wing model) had a tilting wing-engine assembly which was set at 90° incidence for the take-off and landing. The second model (called the deflected-jet model) had a cascade of retractable turning vanes to deflect the exhaust of the horizontally mounted jet engines downward for vertical take-off and landing while the entire model remained in a horizontal attitude. With the models at various heights above the ground in the take-off and landing configuration, the lift, drag, and pitching moment were measured and tuft surveys were made to determine the flow field caused by the jet exhaust. The tilt-wing model experienced a loss of lift of less than 3 percent near the ground. The deflected-jet model, however, suffered losses in lift as high as 45 percent near the ground because of a low pressure region under the model caused by the entrainment of air by the jet exhaust as it spread out along the ground. This loss in lift for the deflected-jet configuration could probably be reduced to less than 5 percent by the use of a longer landing gear and a high wing location.

INTRODUCTION

Flight tests of two types of jet vertical-take-off-and-landing airplane models have been made by the Langley Free-Flight-Tunnel Section. The first model, which will be referred to as the tilt-wing model, was designed so that the fuselage remained horizontal and the wing-engine assembly was set at 90° incidence for take-off and landing. The second model, which will be referred to as the deflected-jet model, has a cascade of retractable turning vanes to deflect the exhaust of the

*Supersedes recently declassified NACA RM L57G16 by William A. Newsom, Jr., 1957.

horizontally mounted jet engines downward for vertical take-off and landing while the entire model remained in a horizontal attitude. In the course of the flight tests, it was noticed that the deflected-jet model experienced a severe ground effect which required a substantially greater thrust for take-off than for hovering a few feet above the ground; whereas, the tilt-wing model experienced no noticeable ground effect. The present investigation was made to obtain a quantitative measure of the ground effect on the two models and to determine the cause of the ground effect.

The investigation consisted of force tests of the models at various heights and tuft studies to determine the flow fields induced by the jets. Force-test data and tuft studies for the deflected-jet model were obtained for the complete model and force-test data were obtained for the model with wing removed; force-test data and tuft studies for the tilt-wing model were obtained for both the complete model and the wing-engine assembly alone.

SYMBOLS

All forces and moments are referred to horizontal and vertical space axes which were also the body axes in most cases since most of the tests were made with the fuselage level. The symbols used in the paper are:

F_L lift, lb

$F_{L_{h=\infty}}$ value of lift for a height well above the ground (corresponds to highest test position)

F_D drag, lb

M_Y pitching moment, ft-lb

h_1 height of trailing edge of bottom vane of the deflected-jet model above ground, in.

c_1 mean aerodynamic chord of deflected-jet model, 16.61 in. or 1.38 ft

h_2 height of trailing edge of tilt-wing model wing above ground, in.

c_2 mean aerodynamic chord of tilt-wing model, 30 in. or 2.5 ft

d_1 diameter of one jet of deflected-jet model, in.

d_2 diameter of one jet of tilt-wing model, in.

θ pitch angle of model fuselage, deg

APPARATUS AND TESTS

Figure 1 shows three-view drawings of the two models. The tilt-wing model had six jet engines in the wing. For take-off, the wing was in a vertical position to direct the jet exhaust downward and for forward flight the wing was pivoted into a horizontal position. The deflected-jet model had three jet engines mounted in a nearly horizontal attitude in the lower forward part of the fuselage. The jet exhaust was deflected downward by a cascade of vanes which could be retracted into the fuselage for forward flight. The jet engines were represented on these models by small high pressure (about 85 lb/sq in. abs) compressed air nozzles exhausting into ejector tubes to give a jet of a proper size to represent afterburning turbojet engines.

The test setup is shown in figure 2. The model was suspended from a boom which projected from the wall, and the height of the model above the ground was changed by adjusting the length of the support strut.

The tuft studies of the flow field around the deflected-jet model were made only at ratio h_1/d_1 of 0.67 since that point was the approximate height of the model when sitting on its landing gear for take-off. For the systematic flow studies the model was sitting in the 7° nose-up attitude required for vertical take-off, but a check was made with the model level to make sure that the flow field was not appreciably affected by small changes in attitude. Flow studies of the tilt-wing model were made at a height of $h_2/d_2 = 0.63$ (which was the height of the model when sitting on its landing gear) and also at $h_2/d_2 = 5.63$.

Force tests of the deflected-jet model were made for a range of values of h_1/d_1 from 0.33 to 7.33 for the complete model and for the model with wing removed; and force tests of the tilt-wing model were made for a range of values of h_2/d_2 from 0.31 to 9.06 for the complete model and for the wing-engine assembly alone. At each test point, the lift, drag, and pitching moment on the model were measured with an electric strain-gage balance mounted as near the center of gravity as was practicable and the forces and moments were transferred to the center-of-gravity locations shown in figures 1(a) and 1(b). The center of gravity of the tilt-wing model was on the thrust line and even with the wing hinge at the top of the fuselage. The center of gravity of the deflected-jet model was on the upper surface of the wing at $0.25c_1$.

RESULTS AND DISCUSSION

Flow Surveys

Plots of the flow field about the deflected-jet model are presented in figure 3 as determined in a series of vertical planes passing through the center of the deflection vanes. The location of these planes is shown by the small plan-view sketches in the upper left-hand corner of each figure which also show a plan view of the flow immediately above the mixing region. It can be seen that the flow field about the model was divided into three regions. The primary flow from the jets which flowed downward out of the vanes struck the ground and spread outward in all directions as a very high velocity layer along the ground. This high velocity flow entrained some of the surrounding air and caused a low velocity inflow of air from above, which flowed down around the edges of the wing and sides of the fuselage toward the vanes. There was a very turbulent mixing region between the relatively smooth outward primary flow and low velocity inflow. As pointed out previously, the surveys for the deflected-jet model were made with the model sitting in the 7° nose-up attitude required for vertical take-off. A qualitative check of the flow with the fuselage level, however, showed that there was essentially no effect of the fuselage attitude on the general character of the flow.

Figure 4 presents the results of the flow surveys about the tilt-wing model. It can be seen that for this model too there is a high velocity flow outward along the ground, from each group of three jets, but when the flow from the jets on one wing spreads out along the ground, it encounters an exactly opposite flow from the other wing at the plane of symmetry. The plane of symmetry then acts as a wall through which no flow can pass so that the air must go upward to escape. The flow under the fuselage, therefore, is directly upward in the plane of the wing and upward at progressively smaller angles ahead of and behind the wing plane. The flow plot also shows that the high velocity ground flow induces a downward flow over the top of the fuselage particularly near the wing-fuselage juncture. The velocity and direction of flow for the wing alone appeared to be essentially the same as that for the complete model.

Force Tests

The results of the force tests are presented in figure 5. The forces on the model have been made dimensionless by dividing them by the value of lift measured at the highest test position above the ground and the pitching moments have been divided by the product of the lift and the appropriate mean aerodynamic chord length. The height of the model above the ground has been related to the appropriate jet diameter. Figure 5(a) shows that the deflected-jet model began to experience a loss of lift at a value of h_1/d_1 of about 4.50. The lift continued to decrease as the model approached the ground until at $h_1/d_1 = 0.33$ about 45 percent of the original lift had been lost. When the wing was removed, however, the loss in lift was only about 12 percent. It is believed that the large loss in lift is caused by a low pressure area under the model which results from the entrainment of the relatively still air under the model in the high velocity jet exhaust as it spreads out along the ground. With the wing removed this effect is not nearly as great because there is less area subjected to the low pressure. A secondary reason could be that the pressure is not so low with the wing removed since the incoming air has easier access and less pressure differential is required to suck in air to replace that entrained by the jet. All of this systematic series of tests was run with the model in a level attitude ($\theta = 0^\circ$) since this was the hovering attitude (the attitude at which the drag was zero when the model was well away from the ground). The plot of drag shows that the vanes lost some of their turning effectiveness below $h_1/d_1 = 2.00$. A test was therefore made to determine whether the lift would be greatly changed with the model in the attitude to give zero drag for a vertical take-off at the height corresponding to the length of the landing gear $\left(h_1/d_1 = 0.67, \quad \theta = 7^\circ\right)$. It was found, as shown in figure 5, that the lift was almost exactly the same for both attitudes.

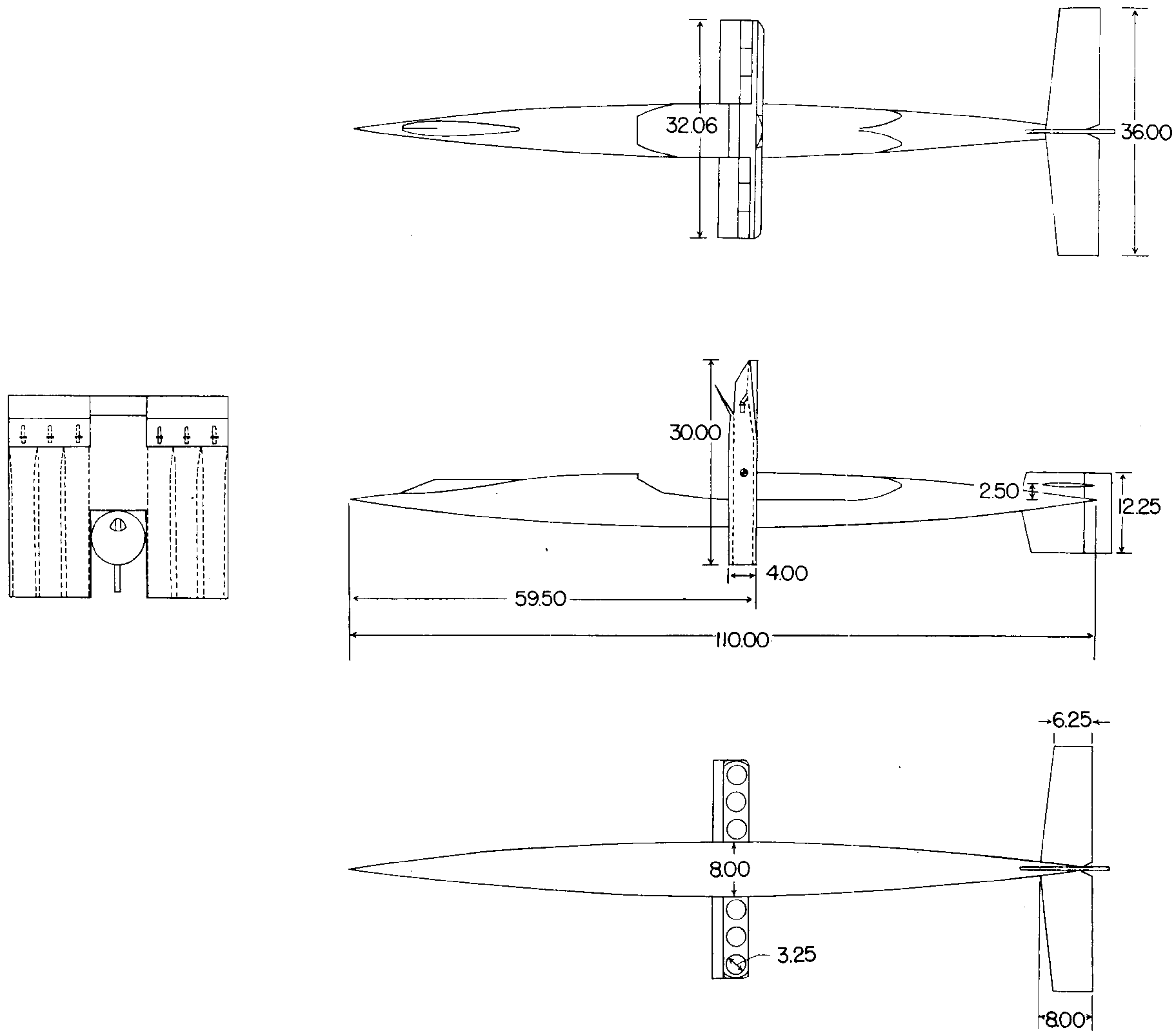
The loss in lift of the deflected jet model was 35 percent when sitting on the ground on its original landing gear $\left(h_1/d_1 = 0.67\right)$ which had been designed to be as short as was considered practicable to keep its weight down. The loss in lift could be reduced to less than 10 percent by the use of a longer but still reasonable length landing gear. Since removing the wing reduced the loss, it seems likely that a further reduction in the loss in lift near the ground could be effected by the use of a high wing location to get the wing as far as possible above the ground. By a combination of these two design features, long landing gear and high wing, the loss of lift of a deflected-jet airplane near the ground could probably be reduced to less than 5 percent.

Figure 5(b) shows the results of the force tests of the tilt-wing model. The scale of the lift curve has been expanded as compared with that used for the deflected-jet model to show more clearly the difference between the complete model and the wing-alone data. The wing-alone tests show no loss in lift until the model has descended to height corresponding to a value of h_2/d_2 of approximately 1.0 and show a maximum loss of only about 2.5 percent at a value of h_2/d_2 of about 0.5. The complete model began to lose lift at a greater height above the ground than the wing alone but had the same maximum loss of about 2.5 percent at height of about 0.5 to 1.0 jet diameters. Although the tests were run with the model wing vertical, the drag and pitching moment were not zero because of the unsymmetrical loads on the inlet and possibly a slightly out-of-trim jet-exhaust nozzle, but it can be seen that the drag and pitching moment were not significantly affected by proximity of the model to the ground.

CONCLUDING REMARKS

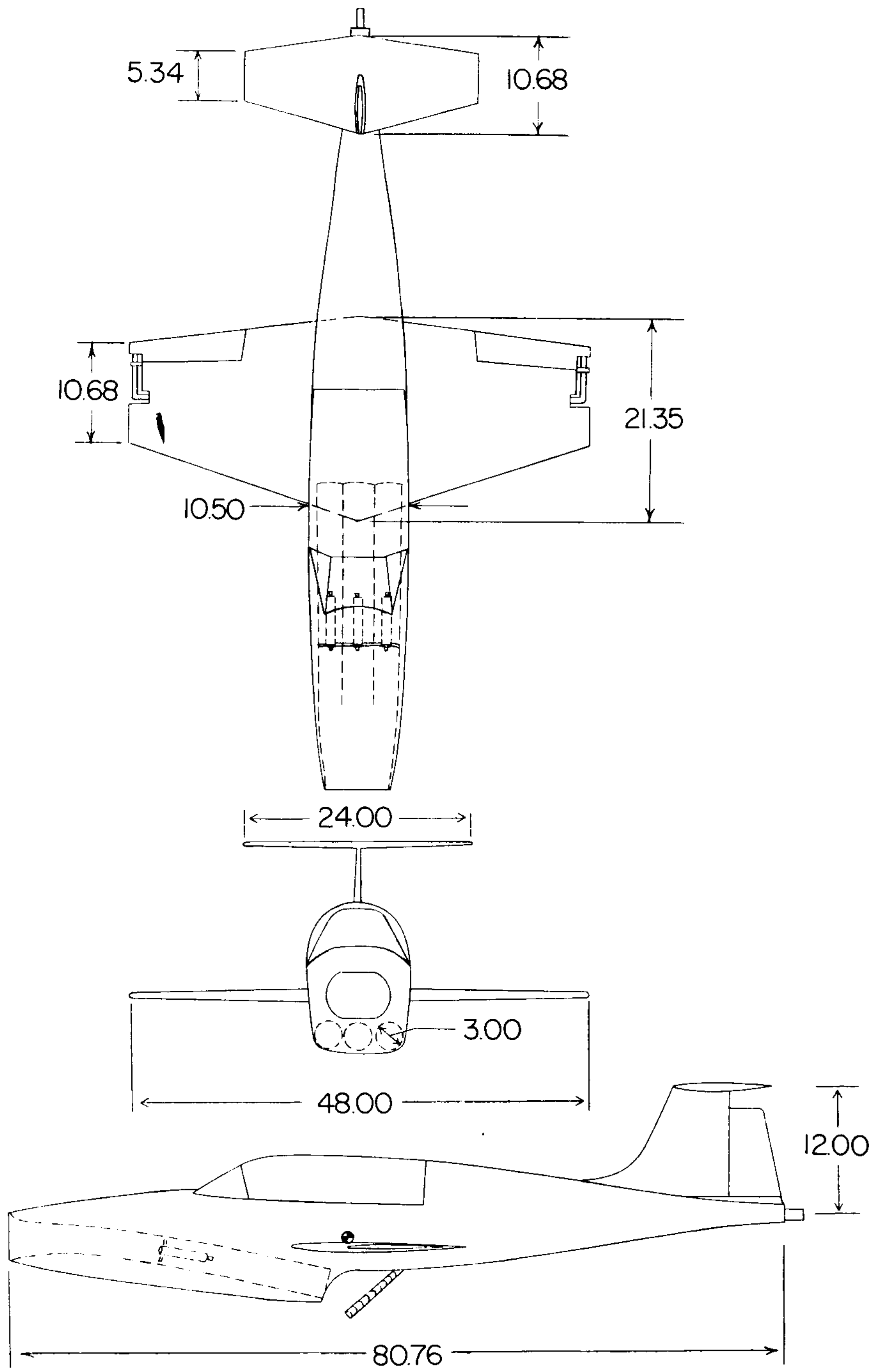
The results of the tests showed that the tilt-wing model experienced a loss of lift of less than 3 percent near the ground. The deflected-jet model however, suffered losses in lift as high as 45 percent near the ground because of a low pressure region under the model which resulted from entrainment of air under the model by the jet exhaust as it spread out along the ground. This loss in lift near the ground for the deflected-jet model was much less pronounced with the wing removed. These losses in lift for the deflected-jet configuration could probably be reduced to less than 5 percent by the use of a longer landing gear and a high wing location.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., June 25, 1957.



(a) Tilt-wing model.

Figure 1.- Three-view drawing of the models tested. All dimensions are in inches.



(b) Deflected-jet model.

Figure 1.- Concluded.

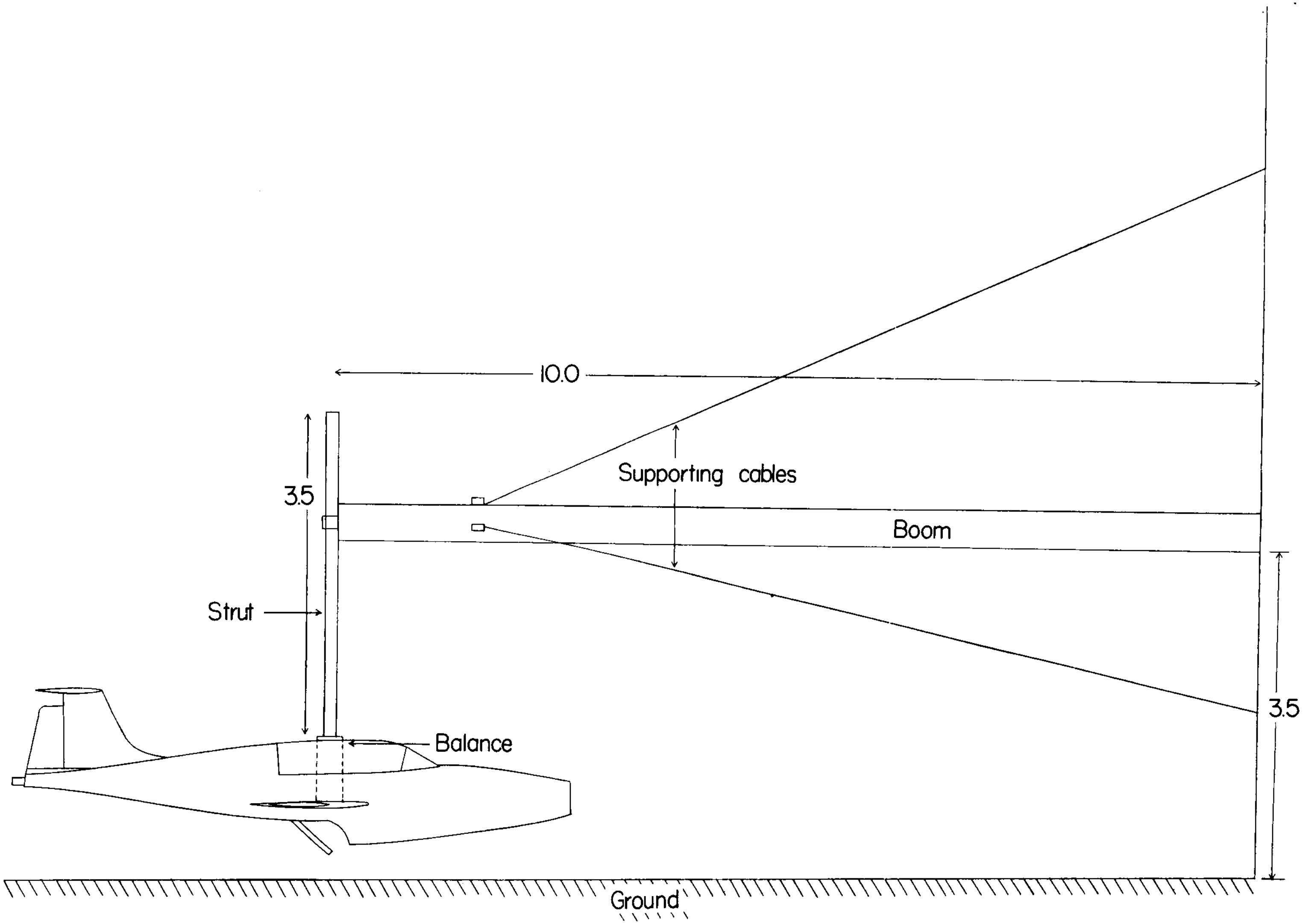
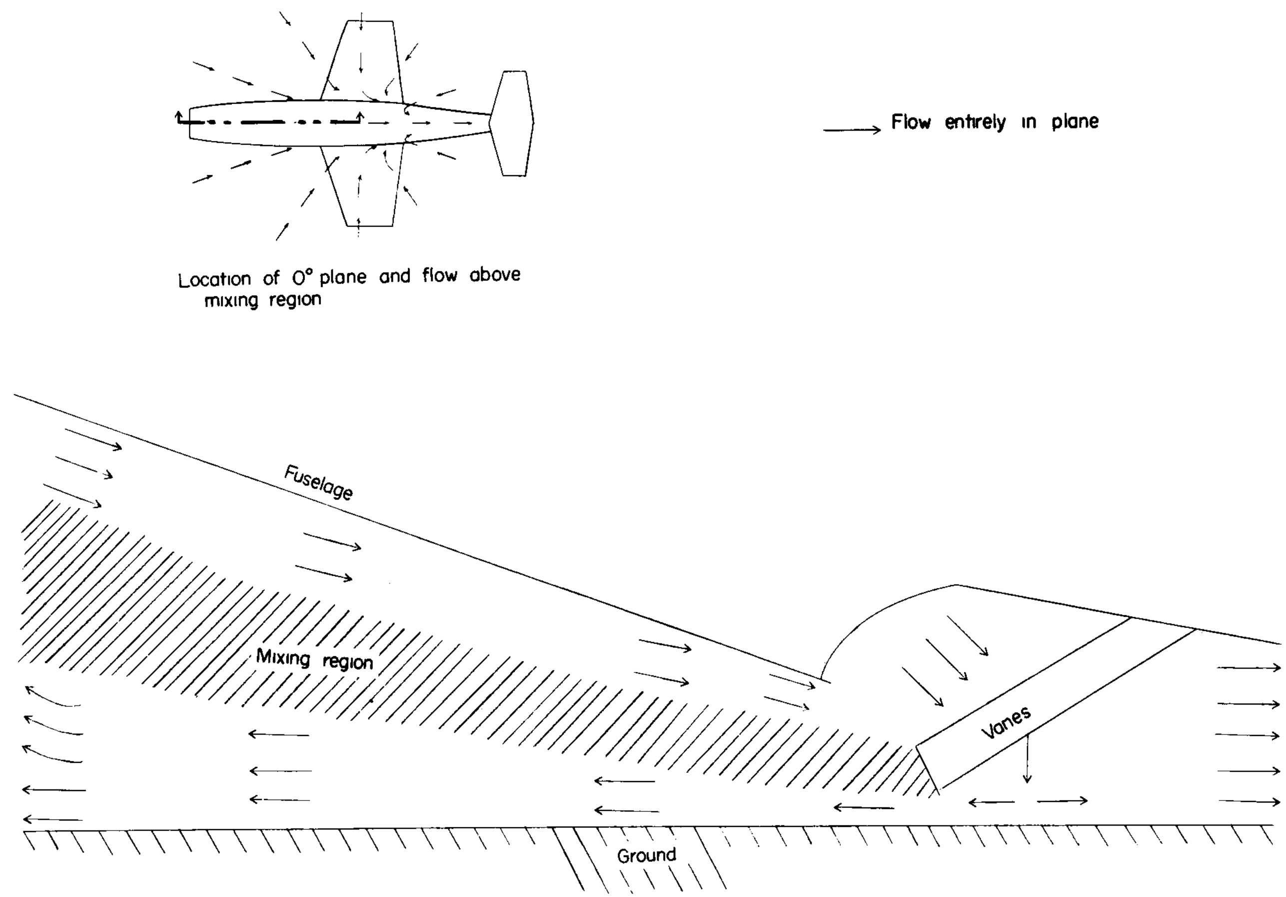
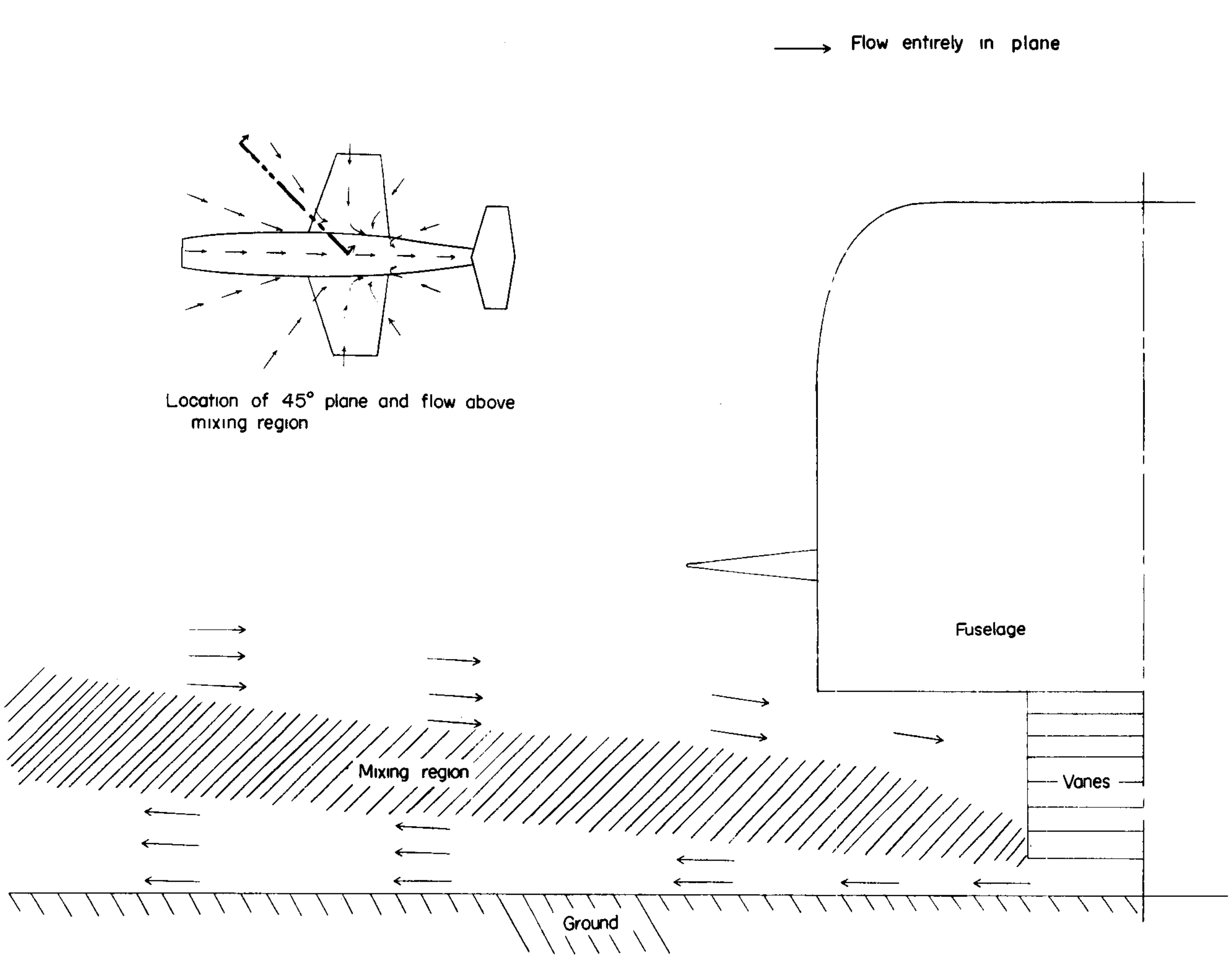


Figure 2.- Test setup showing deflected-jet model in position. All dimensions are in feet.



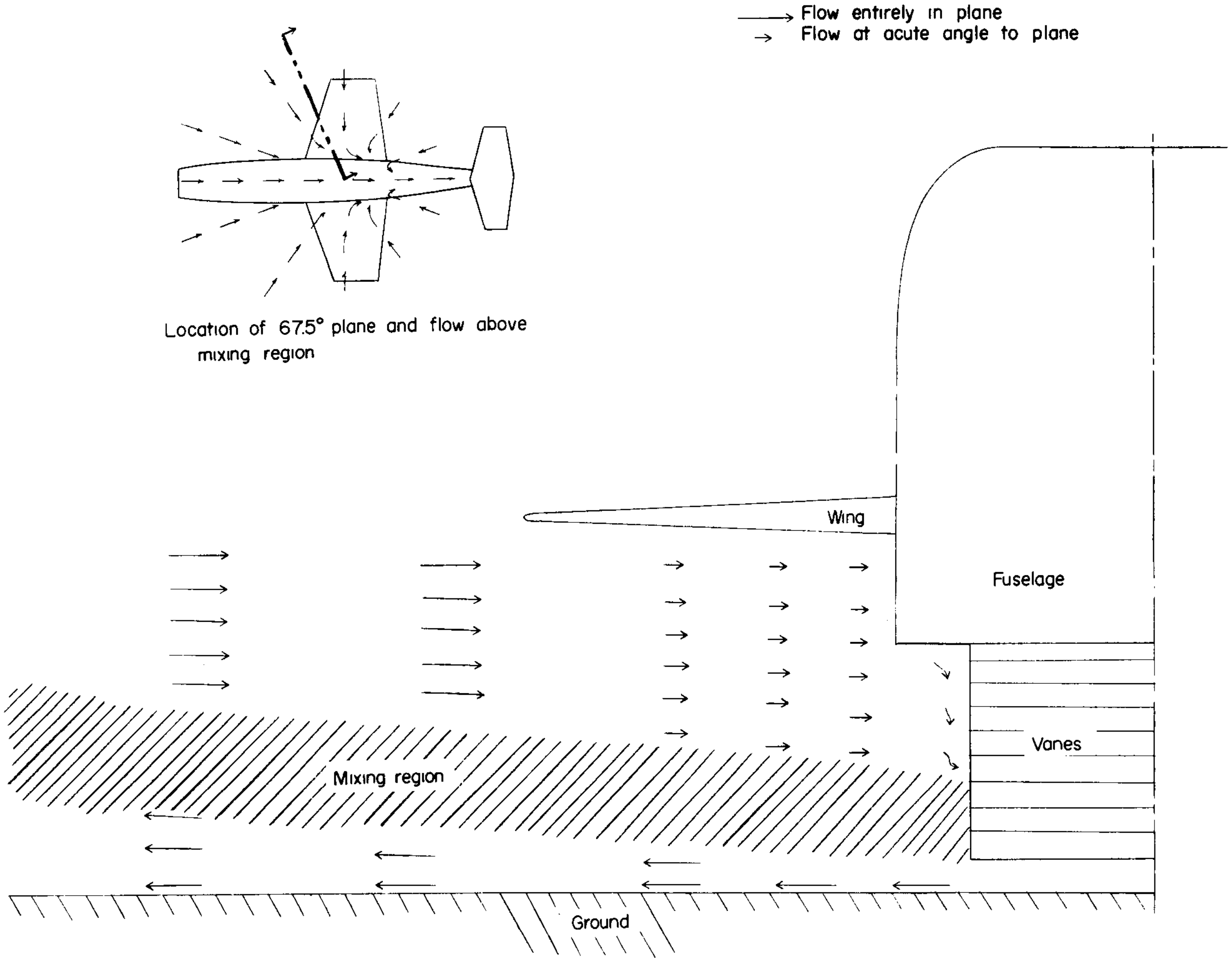
(a) 0° plane.

Figure 3.- Results of flow survey on the deflected-jet model. $\frac{h_1}{d_1} = 0.67$.



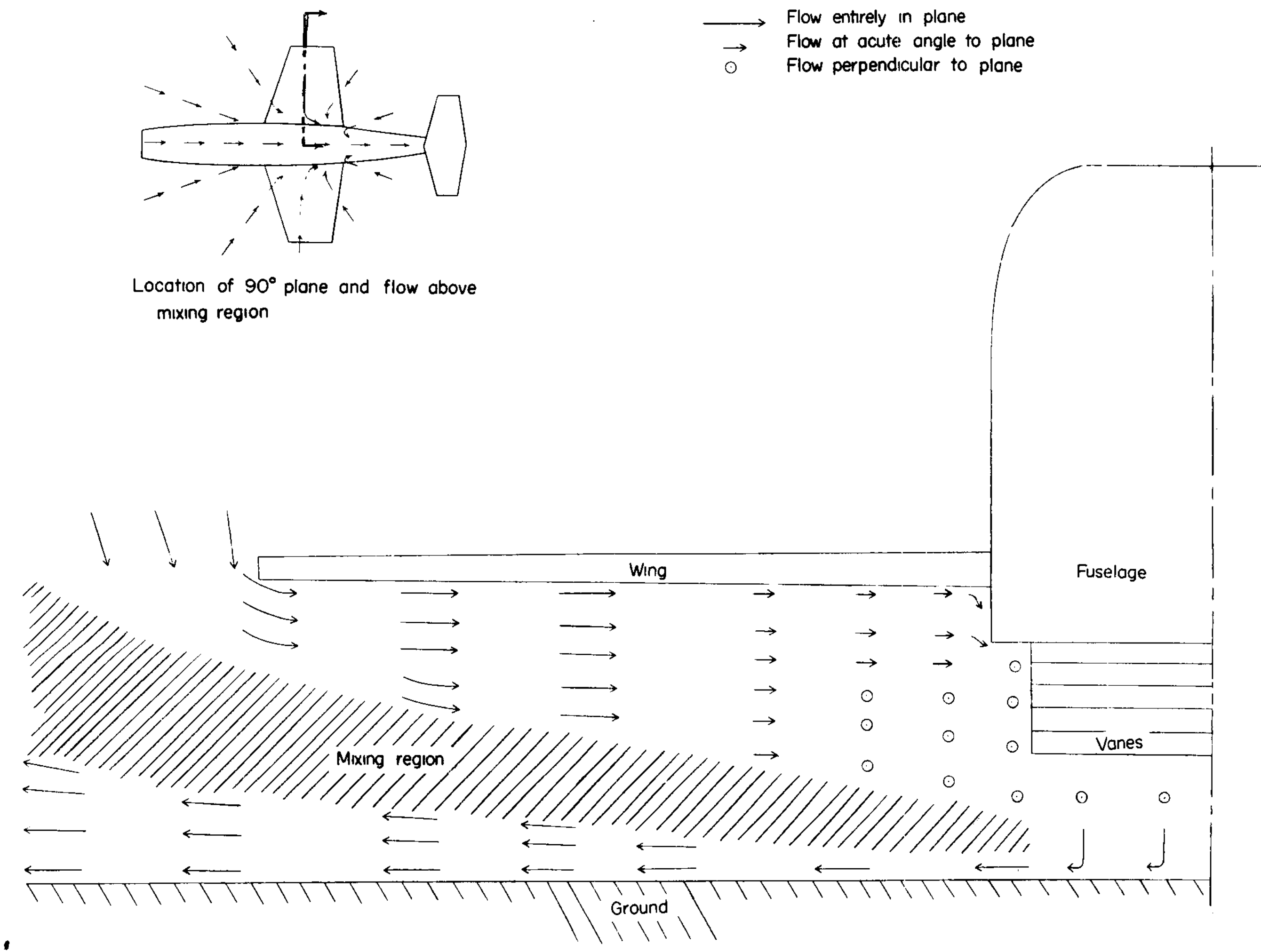
(b) 45° plane.

Figure 3.- Continued.



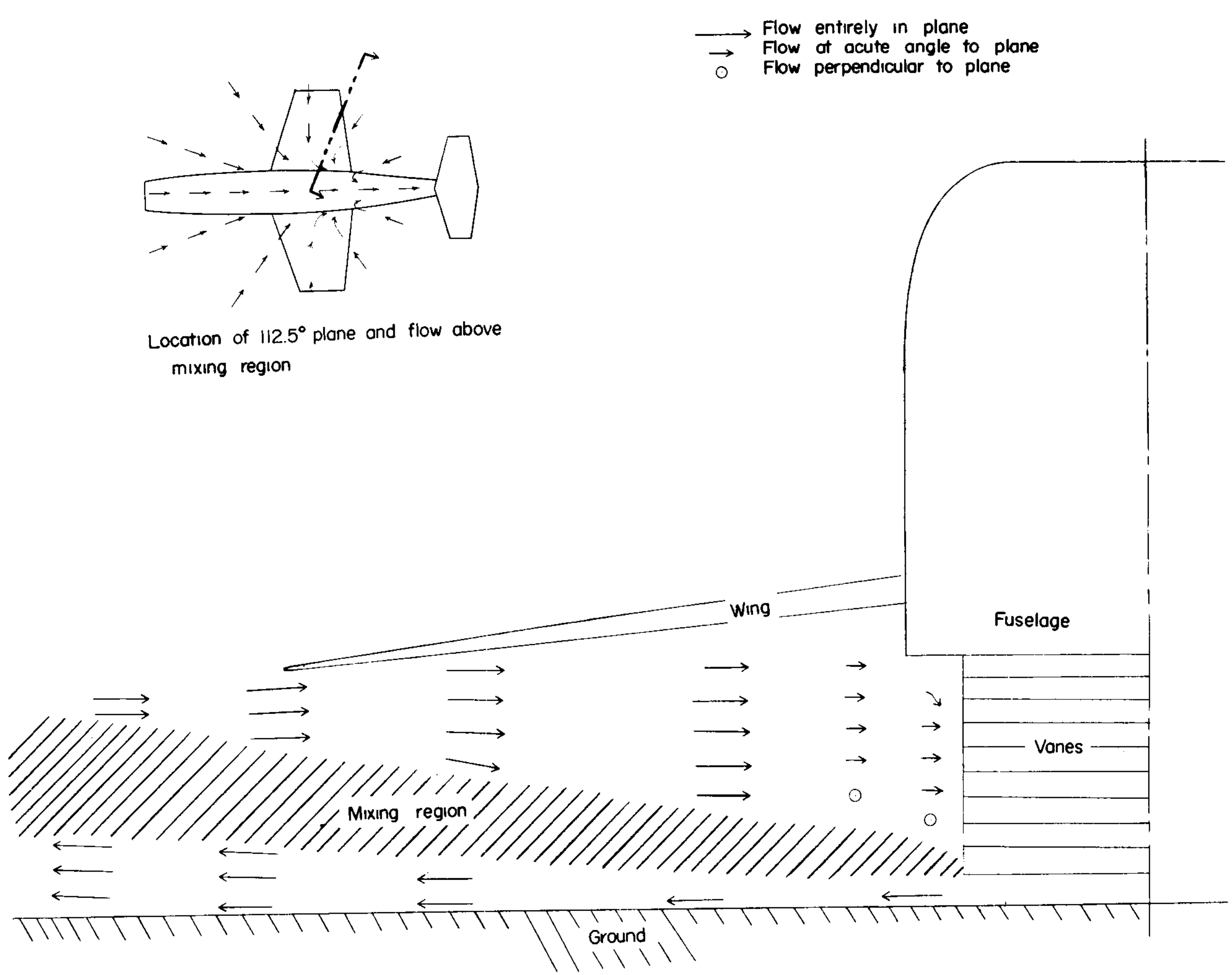
(c) 67.5° plane.

Figure 3.- Continued.



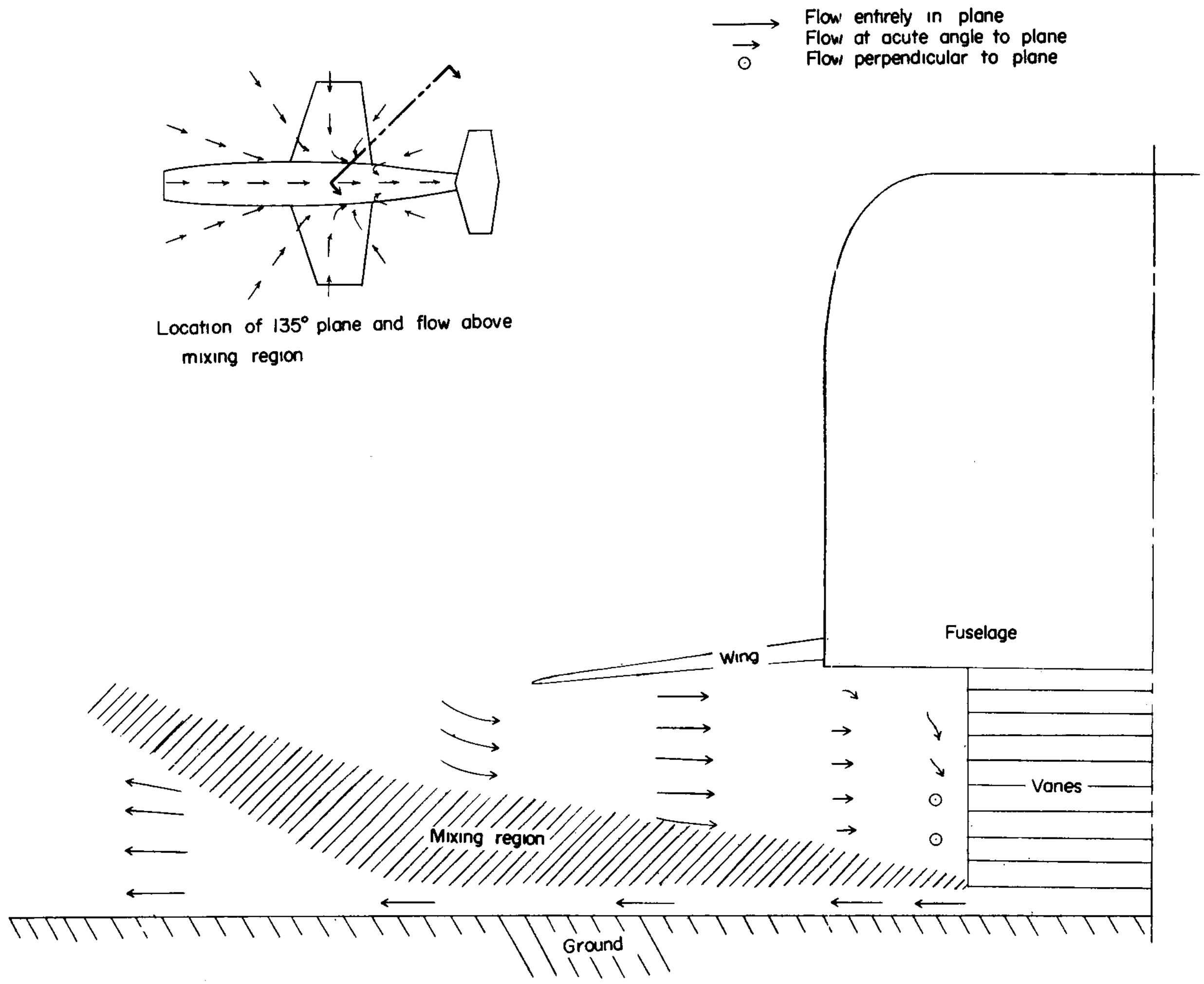
(d) 90° plane.

Figure 3.- Continued.



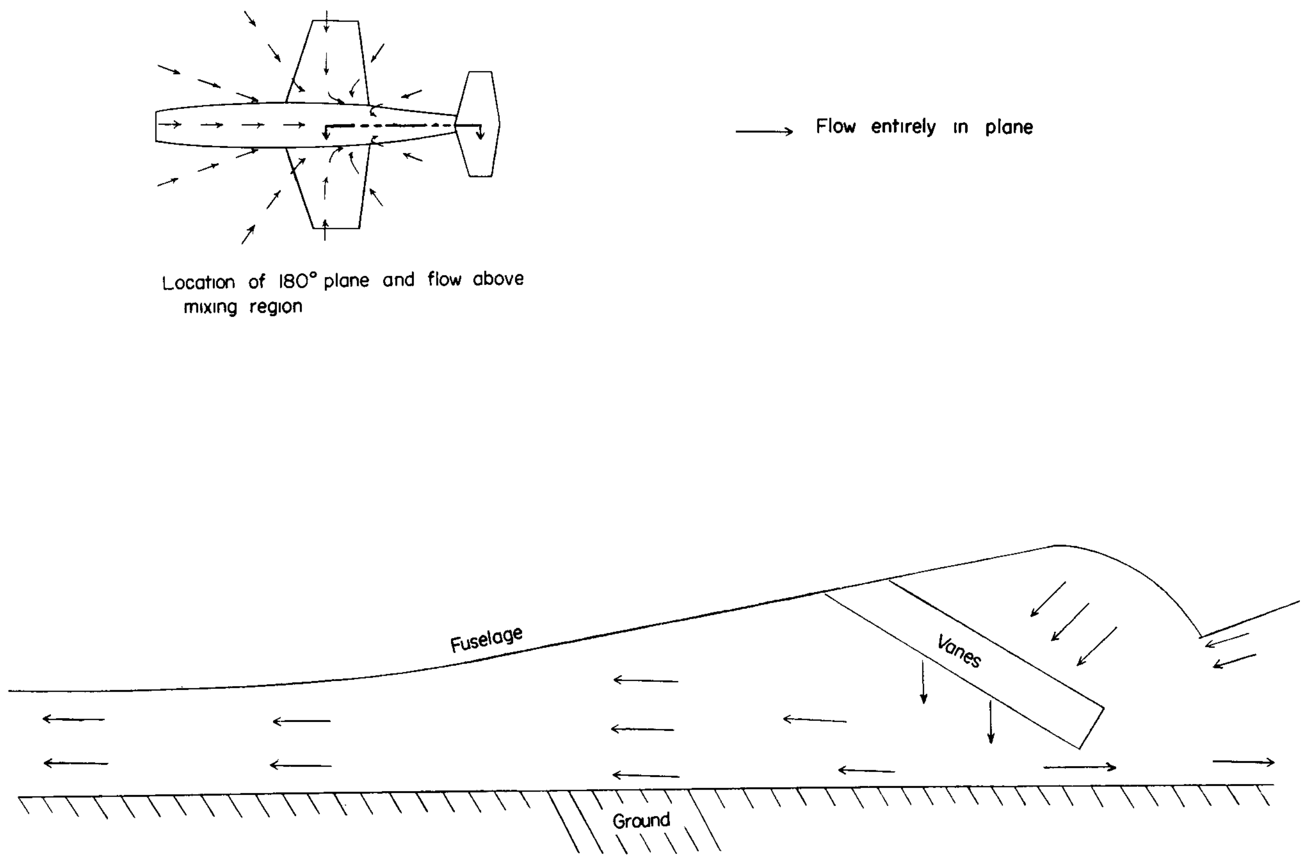
(e) 112.5° plane.

Figure 3.- Continued.



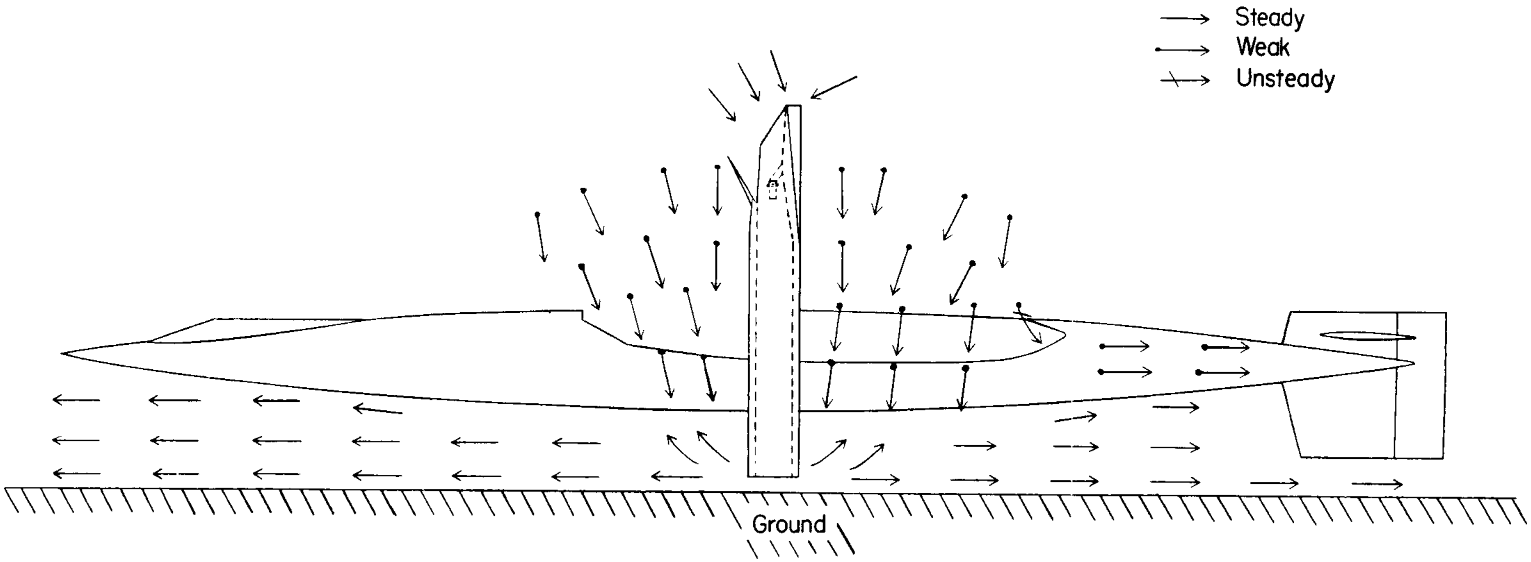
(f) 135° plane.

Figure 3.- Continued.



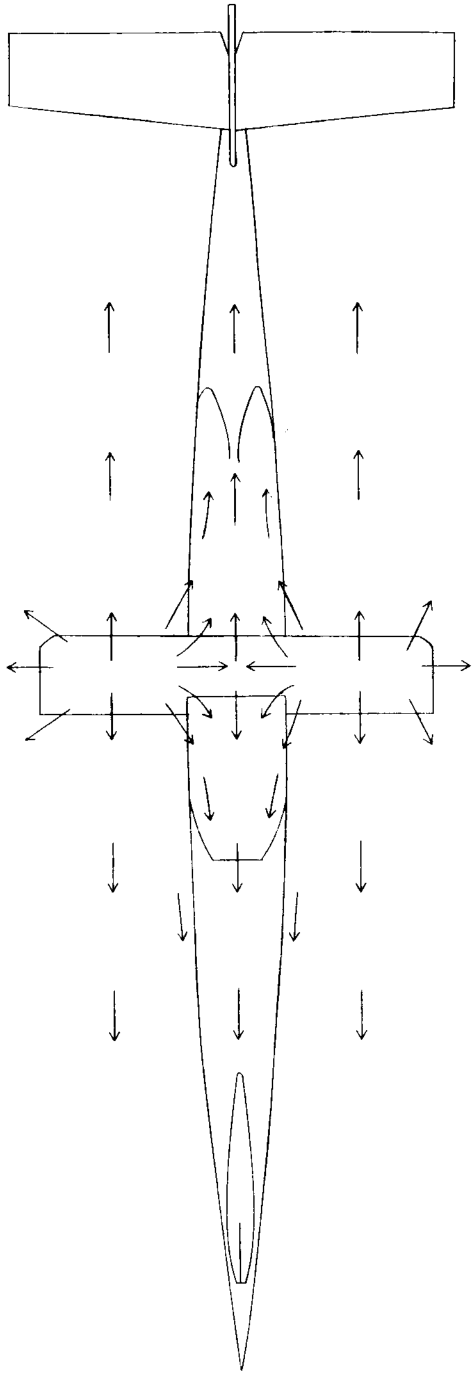
(g) 180° plane.

Figure 3.- Concluded.



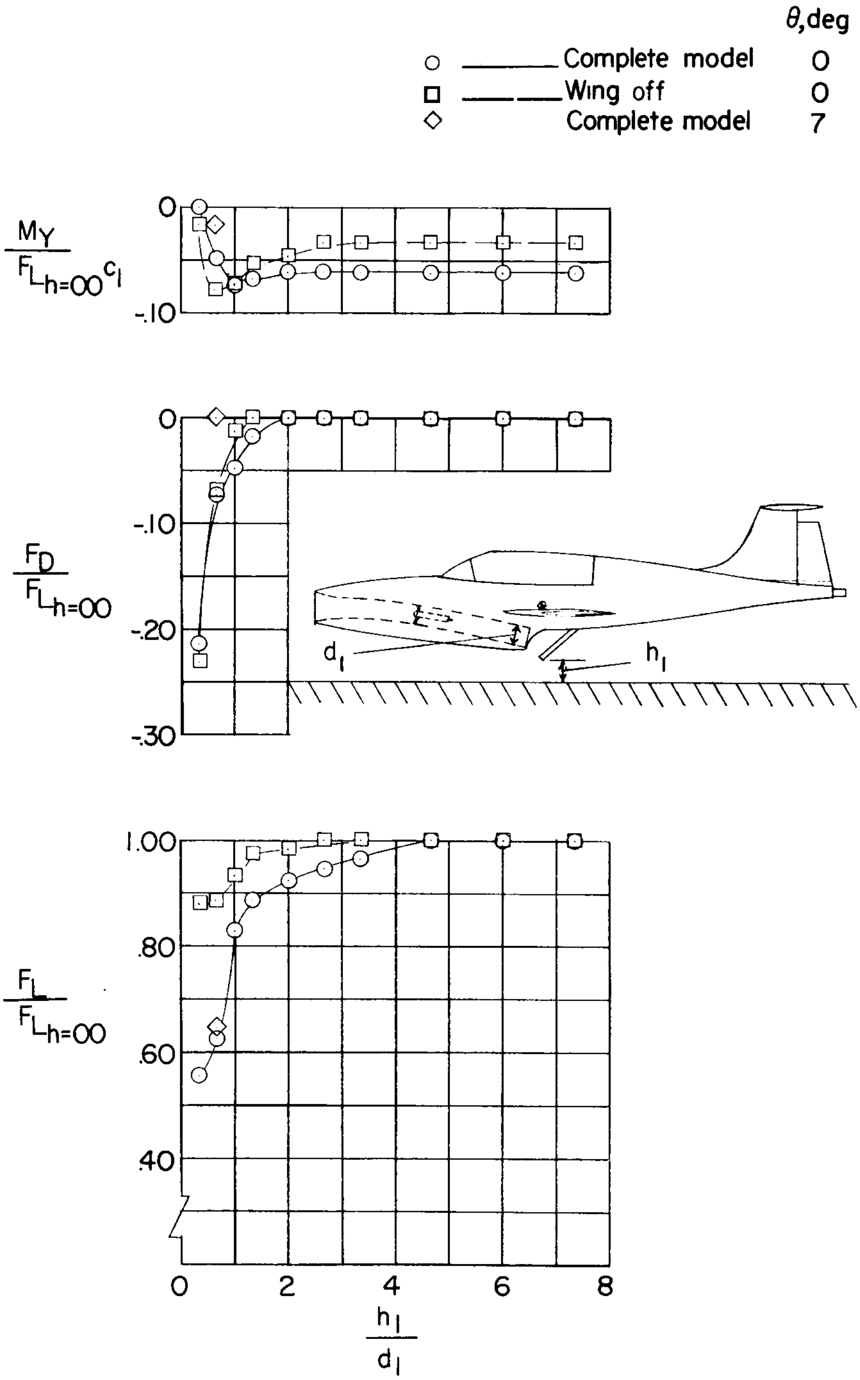
(a) Complete model; side view.

Figure 4.- Results of flow survey on the tilt-wing model. $\frac{h_2}{d_2} = 0.63$.



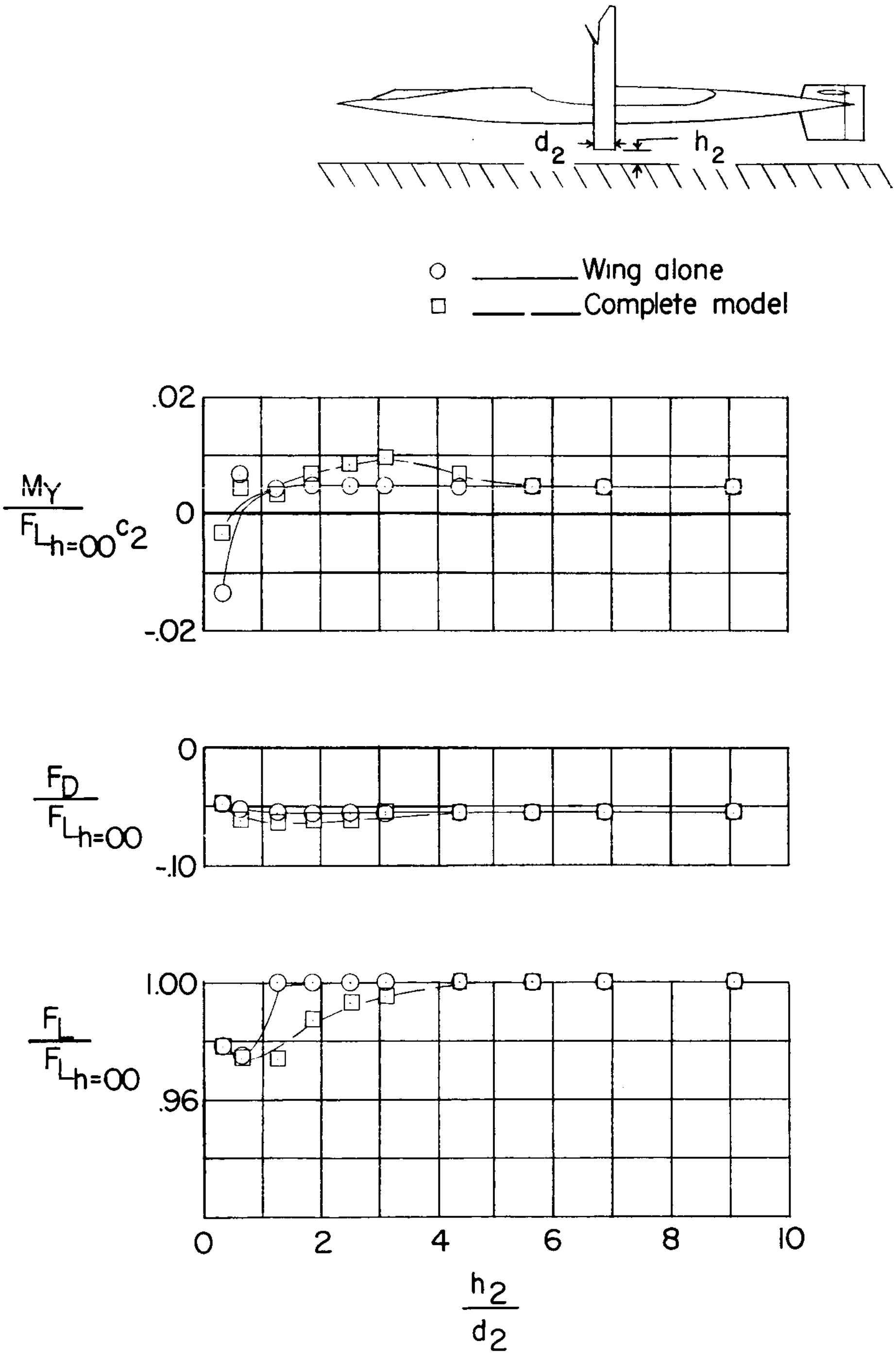
(b) Complete model; plan view.

Figure 4.- Concluded.



(a) Deflected-jet model.

Figure 5.- Variation of lift, drag, and pitching moment with model height.



(b) Tilt-wing model.

Figure 5.- Concluded.