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RESEARCH MEMORANDUM

A PRELIMINARY GUST-TUNNEL INVESTIGATION OF LEADING-EDGE SEPARATION ON SWEPT WINGS

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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A PRELIMINARY GUST-TUNNEL INVESTIGATION OF LEADING-EDGE SEPARATION ON SWEPT WINGS

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SUMMARY

The results of a series of qualitative studies with tufts on three wings having sweepback angles of 30°, 45°, and 60° show that under certain conditions a leading-edge vortex can exist in the unsteady flow associated with a gust. It was indicated that, if a wing in steady flight prior to entering a gust is at an angle of attack several degrees less than that at which vortex flow first begins in steady flow, it may penetrate the gust without having the vortex develop, even if its angle of attack is increased by the gust into the vortex-flow regime. However, if the wing is within the vortex-flow regime prior to entering a gust, the vortex flow can progress rapidly.

INTRODUCTION

Wings having certain degrees of sweep and leading-edge radii have been found to develop a flow separation in the form of a leading-edge vortex in steady flow (references 1 and 2). These vortices have been found to affect the total lift of the wings as well as the chordwise pressure distribution and other characteristics. During past investigations in the Langley gust tunnel with swept-wing models, conditions have occurred which according to steady-flow data should be conducive to vortex formation. The gust condition, however, is one of unsteady flow and it is not immediately apparent that the flow behavior over a swept wing in a gust would be the same as that in steady flow. Some qualitative tuft studies were therefore made in the Langley gust tunnel to determine whether leading-edge vortices would occur in the unsteady flow conditions of a gust.

A series of swept-wing models, previously used in load studies, were flown in the gust tunnel under the same conditions as in the load studies to determine whether leading-edge vortices were present during the load tests. Additional studies were then made with two of the models in order to compare the results for steady and unsteady flow conditions. This paper presents the results of these studies.

APPARATUS

Three models having the semichord lines sweptback 30°, 45°, and 60° were used for the tests. The 30° and 60° sweptback-wing models used for these tests were those of references 3 and 4. A new 45° sweptback-wing model identical to the one used in the test of reference 5 was used for the present tests. All of the model characteristics were maintained as in the tests of references 3, 4, and 5 except that tufts were placed on the upper surfaces of the left semispan of each wing. Photographs of the three models are shown as figure 1, and some pertinent characteristics are given in the following table:

	30° swept-back wing	45° swept-back wing	60° swept-back wing
Weight, lb	9.75	9.25	9.63
Wing area, sq ft	6.05	6.05	6.17
Wing loading, lb/sq ft	1.61	1.53	1.56
Span, ft	5.2	4.25	3.00
Aspect ratio	4.44	2.99	1.44
Chord measured parallel to plane of symmetry:			
Mean geometric chord, ft	1.16	1.48	2.06
Root chord, ft	1.55	1.90	2.29
Tip chord, ft	0.77	0.95	1.412
Taper ratio	0.50	0.50	0.50
Airfoil section perpendicular to 50-percent-chord line	NACA 0012	NACA 0012	NACA 0012

The Langley gust tunnel and its standard equipment are described in reference 6. Special photographic equipment, consisting of five speed flash lamps, an electronic timing and triggering device, a photoelectric cell, and three overhead cameras were used for these tests. Two of the cameras were placed in the upper section of the gust tunnel so as to view straight down on the flight path of the model and the third was placed above and in front of the test section so as to view it at an angle of about 45°.

TESTS

The tests consisted of flights through sharp-edge gusts in the gust tunnel under the conditions indicated in the following table:

Sweepback of wing, Λ, deg	Forward velocity, fps	Gust velocity, fps	Angle of attack in steady flight, α, deg
30	88	10	3.7
45	88	10 and 15	3.6
60	88	10	6
	65	5 and 10	7

Photographs were taken from above so that five views were obtained of the model for each flight through the gust.

Photographs were also made of the tufts on the 45° and 60° sweptback wings through a range of angles of attack in steady flow. The 45° sweptback wing was tested with a stream velocity of 88 feet per second in the 6- by 6-foot test section of the Langley stability tunnel, and the 60° sweptback wing, with a stream velocity of 65 feet per second in the Langley free-flight tunnel (reference 7). The Reynolds number for the gust-tunnel flights and the steady-flow tests was of the order of 800,000.

PRECISION

The measured quantities are estimated to be accurate within the following limits:

Forward velocity, ft/sec . . . . ±0.5
Gust velocity, ft/sec . . . . ±0.1
Angle of attack for gust-tunnel flights, deg . . . . ±0.5
Angle of attack for wind-tunnel tests, deg . . . . ±0.25

The angles of attack in a gust for the gust-tunnel flights were determined by measuring the angle of the wing with respect to the direction of flight, adding the gust angle, and subtracting the angle resulting from the instantaneous vertical velocity of the model. The steady-flight angles of attack for the gust-tunnel flights were obtained by measuring the angle of the wing with respect to the flight path during steady free flight with no gust. Those for the wind-tunnel tests were measured with respect to the horizontal center line of the tunnel.

RESULTS AND DISCUSSION

The results from the tests are presented in the form of photographs grouped to show comparisons of the tuft patterns for the three wings under the various test conditions. The nature of leading-edge separation on swept wings in steady flow is described in references 1 and 2. The characteristic pattern which is formed by surface tufts in the presence of a leading-edge vortex is identified by the first row of tufts being lined up along the leading edge of the wing and those just aft showing a flow almost normal to the direction of flight. Where the vortex region does not extend over the full chord of the wing, the tufts near the trailing edge remain more in line with the stream direction and thus indicate reattachment of the flow behind the region of the vortex.

Figure 2 shows the tufts on the three wings flying under conditions identical to those of the load tests of references 3, 4, and 5. Under these conditions the wings were flown at identical velocities (88 ft/sec) and lift coefficients through a sharp-edge gust with a velocity of 10 feet per second. Consequently, the three wings were subjected to the same initial angle-of-attack change due to the gust. The photographs in figure 2 show some spanwise flow near the trailing edges of the 30° and 45° sweptback wings, but the pattern of the tufts on the 60° sweptback wing indicates that a leading-edge vortex was present during this flight.

Thus, it was shown by these preliminary flights that a leading-edge vortex can exist under certain conditions in the unsteady flow associated with a gust.

Studies of the initiation of the vortex flow were made by comparing the flow behavior at corresponding angles of attack for the wind-tunnel and gust-tunnel tests. The steady-flow test of the 45° sweptback wing model indicated that a leading-edge vortex developed over this wing at an angle of attack between 8.6° and 9.6°. Since figure 2 indicates that there was no leading-edge vortex over the 45° sweptback wing at 7.9°, it would appear, as might be expected, that the unsteady conditions of a gust will not cause a leading-edge vortex to develop at a lower angle of attack than it would ordinarily develop in steady flow.

The results from the steady-flow and unsteady-flow tests of the 60° sweptback wings are shown in figure 3. At 11° and 15° angle of attack in steady flow, and at 11° and 15.4° angle of attack in unsteady flow, leading-edge vortex patterns are shown by the tufts on the 60° sweptback wing. The tuft pattern before the model entered the gust was the same as shown for 7° angle of attack in the gust tunnel. It is interesting to note in figure 3 that the vortex appears to become stronger before the wing is completely within the gust. The tuft patterns for the steady and unsteady flow conditions appear to be almost identical at the same angle of attack. The reason for the difference between the two steady-flow tuft patterns for the 7° angle of attack is unknown, however it may be due to differences in the flow conditions of the gust tunnel and the free-flight tunnel. Both of the patterns are indicative of a leading-edge vortex, that for the wind tunnel indicating a somewhat stronger vortex. In figure 4, the tufts on the 45° sweptback wing in steady flow at 3.6° and 7.6° and in unsteady flow at 7.9° and 12° angle of attack show no indication of a leading-edge vortex. At 9.6° in steady flow, however, a vortex pattern is shown. In unsteady flow at 10.1° angle of attack there is a region of separated flow at the leading edge near the wing tip. The flow appears to reattach behind this region as it does when a vortex occurs, but the pattern of the tufts in this case is not definitely characteristic of a leading-edge vortex.

The data as presented appear inconsistent in that the vortex patterns for the 60° sweptback wing in steady and unsteady flow are almost identical at given angles of attack, whereas there is no definite vortex pattern for the 45° sweptback wing in unsteady flow at 10.1° and 12° angle of attack, and yet, in steady flow, a vortex pattern is shown at an angle of attack of 9.6°. This apparent anomaly suggests that the type of flow prevalent about a wing prior to its entering a gust may dictate the manner of flow development within the gust. With the 60° sweptback wing in steady flight at an angle of attack of 7°, a vortex pattern was present. As the model penetrated the gust the vortex apparently became stronger. The 45° sweptback wing in steady flight, however, at 3.6° angle of attack was about 6° from the angle of attack at which the vortex began to develop in the wind tunnel. The angle-of-attack change due to the 10-foot-per-second gust was about 6.5°. Thus, the total angle of attack of the 45° sweptback wing should have been great enough for a leading-edge vortex to develop in steady flow. It therefore seems that there must be a lag in flow development over wings in gusts if the flow must develop from one regime to another. Further study in the gust tunnel appears to be necessary to augment the present knowledge of air-flow development about sweptback wings in unsteady flow conditions.

CONCLUSIONS

The indicated results of tuft studies made in the Langley gust tunnel with three wings having sweepback angles of 30°, 45°, and 60° may be stated as follows:

1. Under certain conditions, a leading-edge-vortex flow can exist over a swept wing in the unsteady flow associated with a gust.

2. If a wing in steady flight prior to entering a gust is at an angle of attack several degrees less than that at which vortex flow first begins in steady flow, it may penetrate the gust without having the vortex develop immediately even if the angle of attack is increased by the gust into the vortex-flow regime.

3. If a wing is within the vortex-flow regime prior to entering a gust, the vortex flow can progress rapidly.

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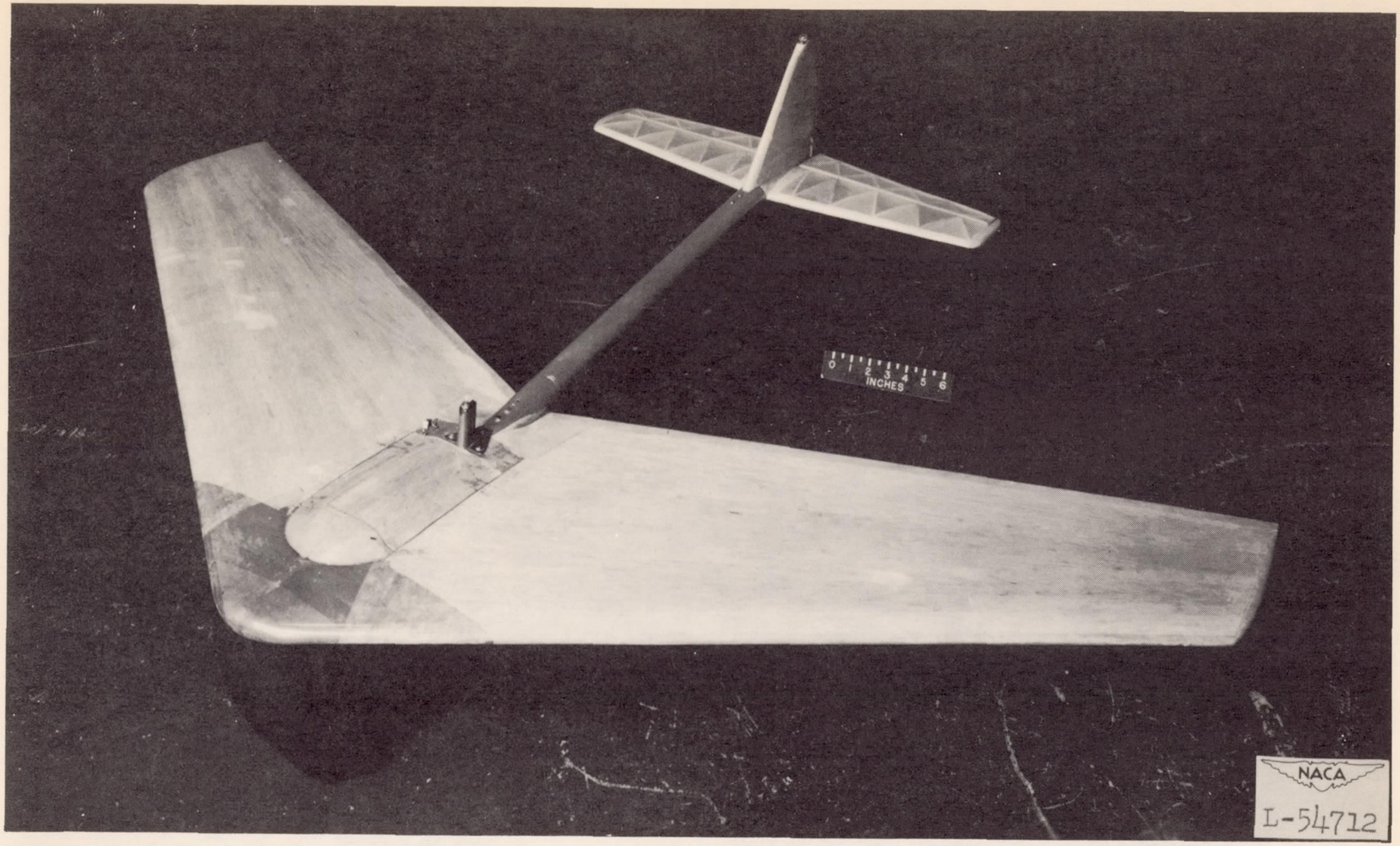
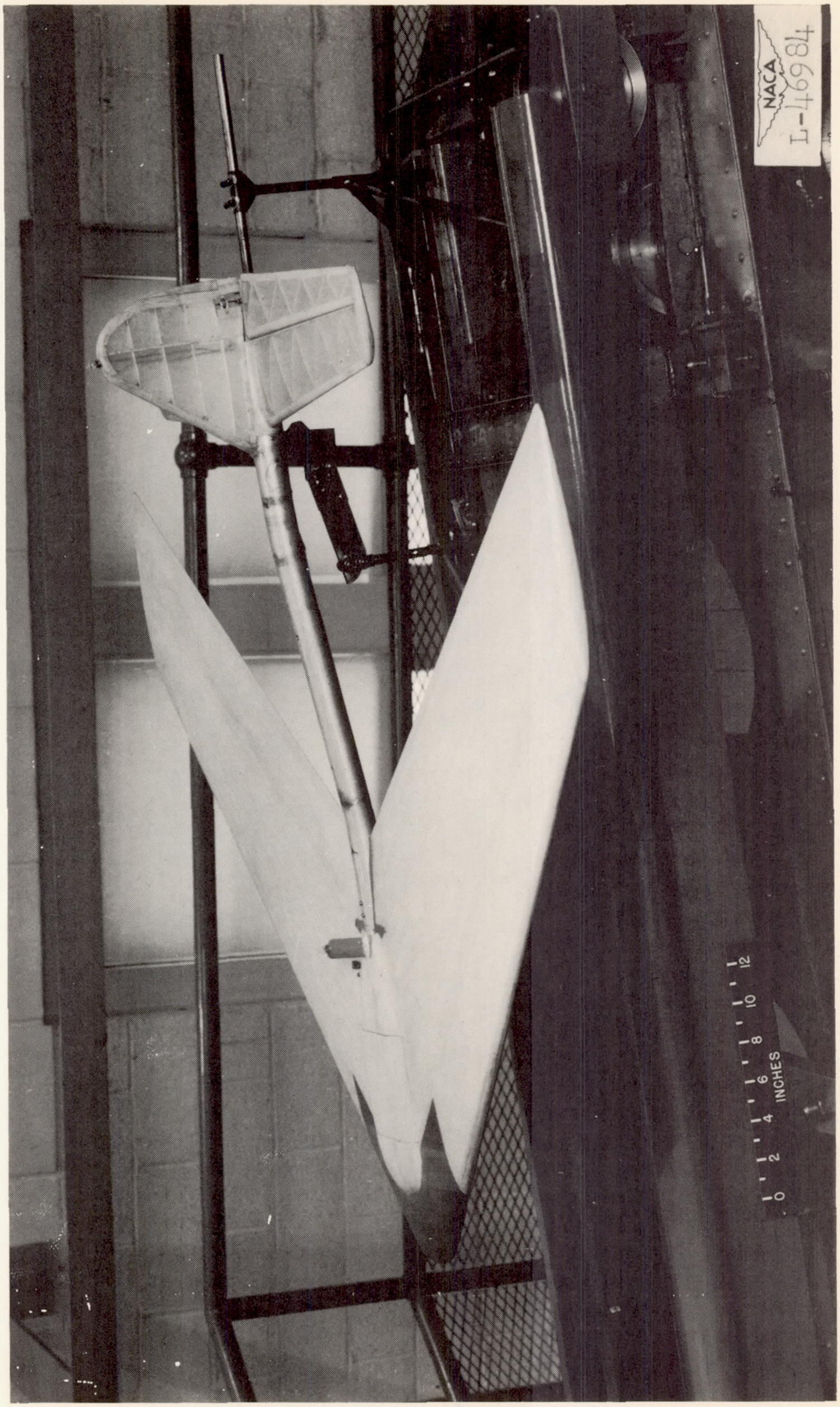


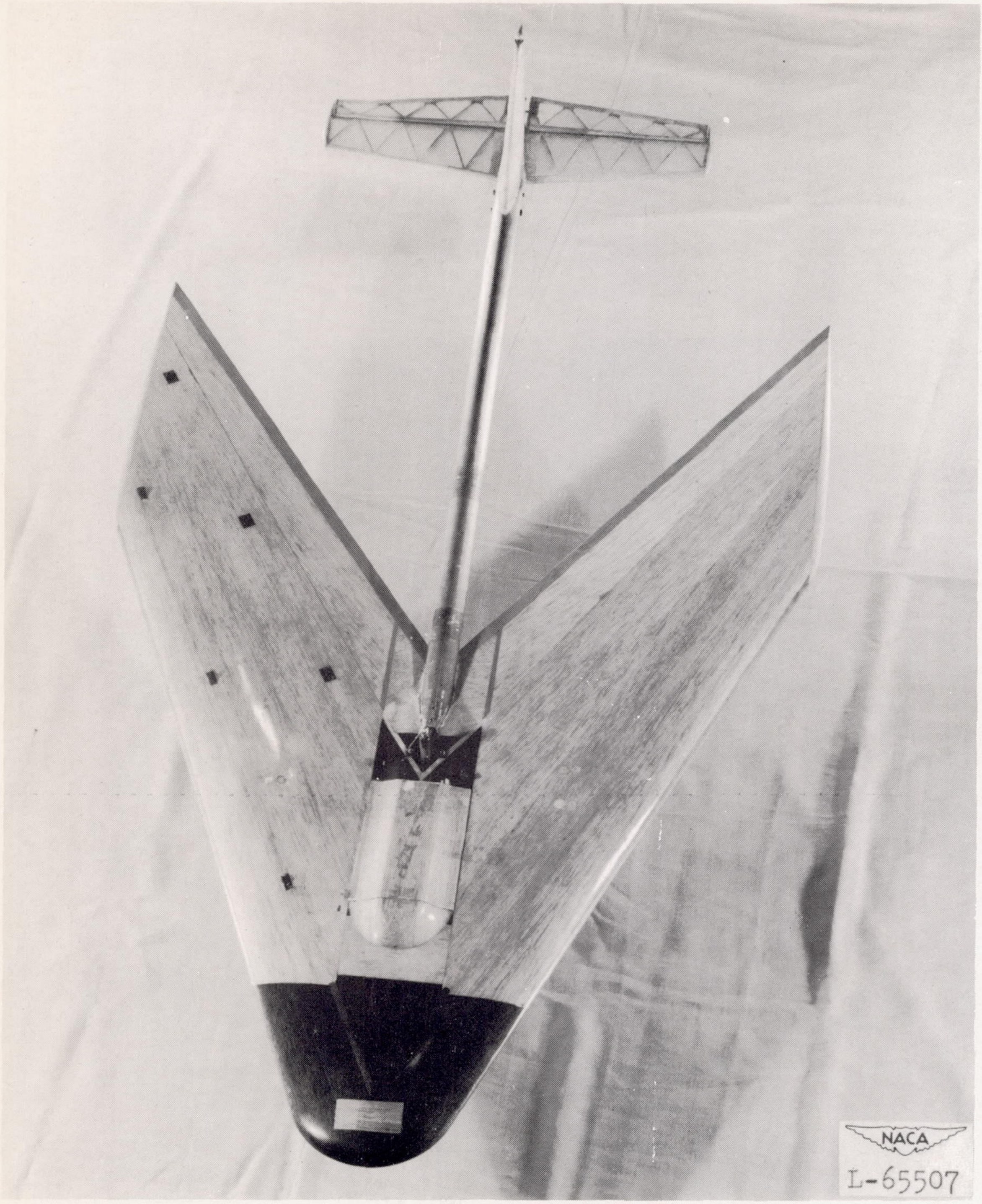
(a) 30° sweptback wing model.

Figure 1.- Photographs of the models used.



(b) 45° sweptback wing model.

Figure 1.- Continued.



(c) 60° sweptback wing model.

Figure 1.- Concluded.

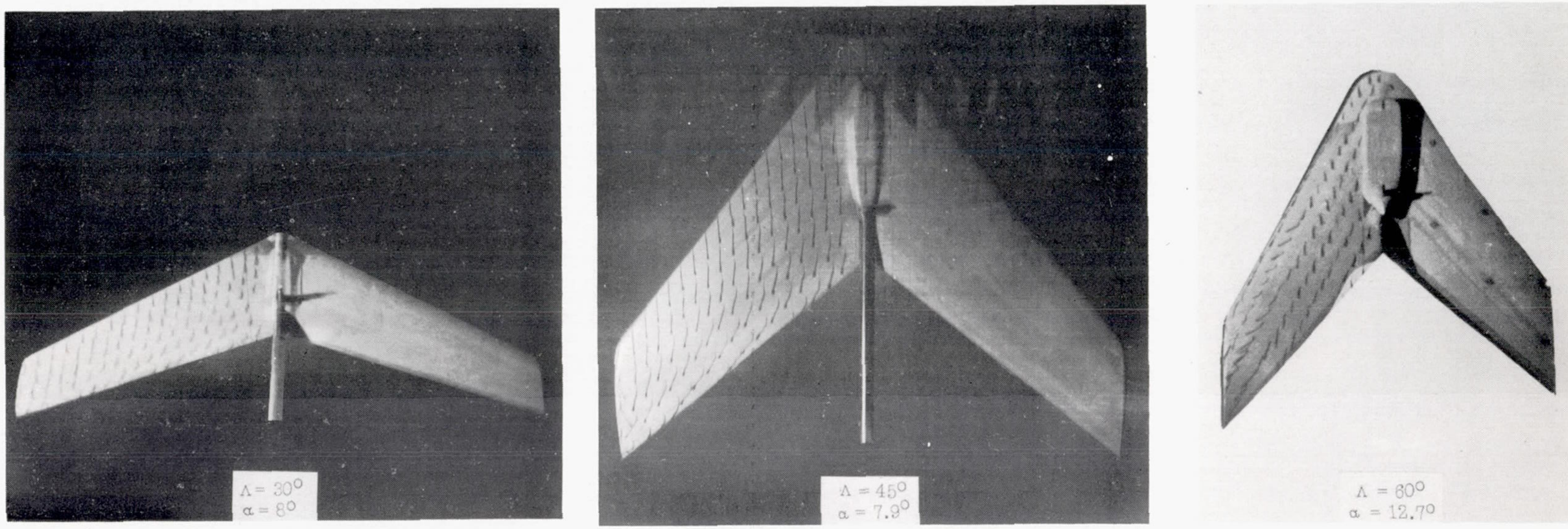


Figure 2.- Comparison of flow over the family of wings in the Langley gust tunnel.

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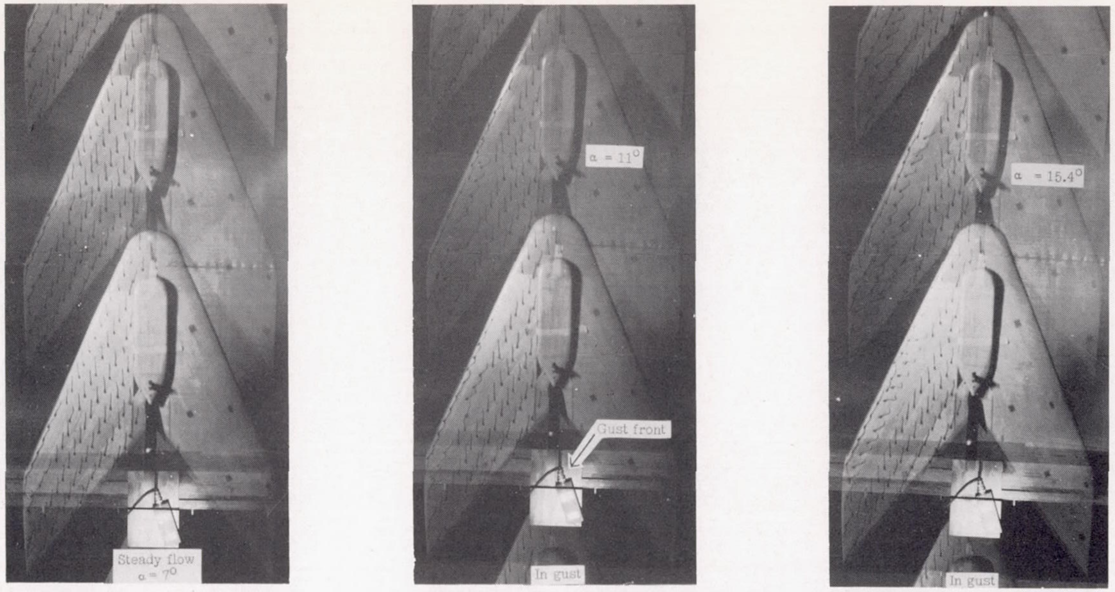
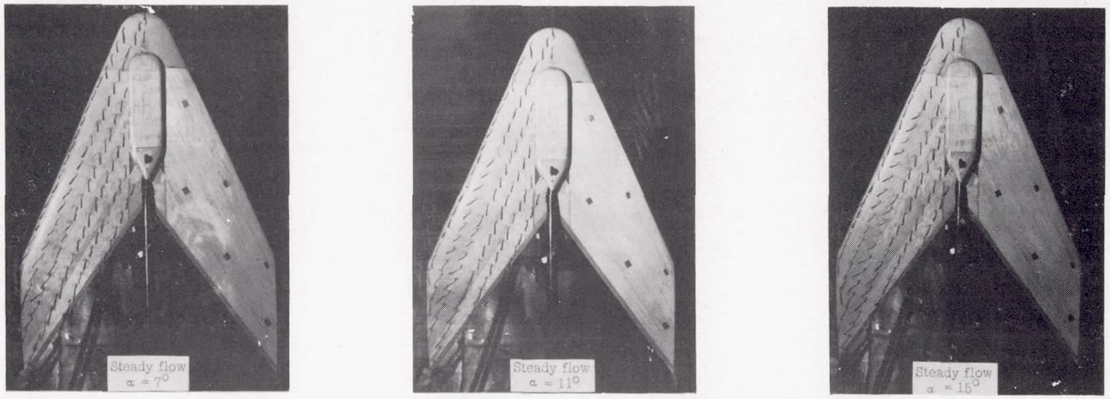


(a) Gust tunnel.



(b) Wind tunnel.

Figure 3.- Comparison of flow over 60° sweptback wing in the Langley gust tunnel and Langley free-flight tunnel at same velocity.

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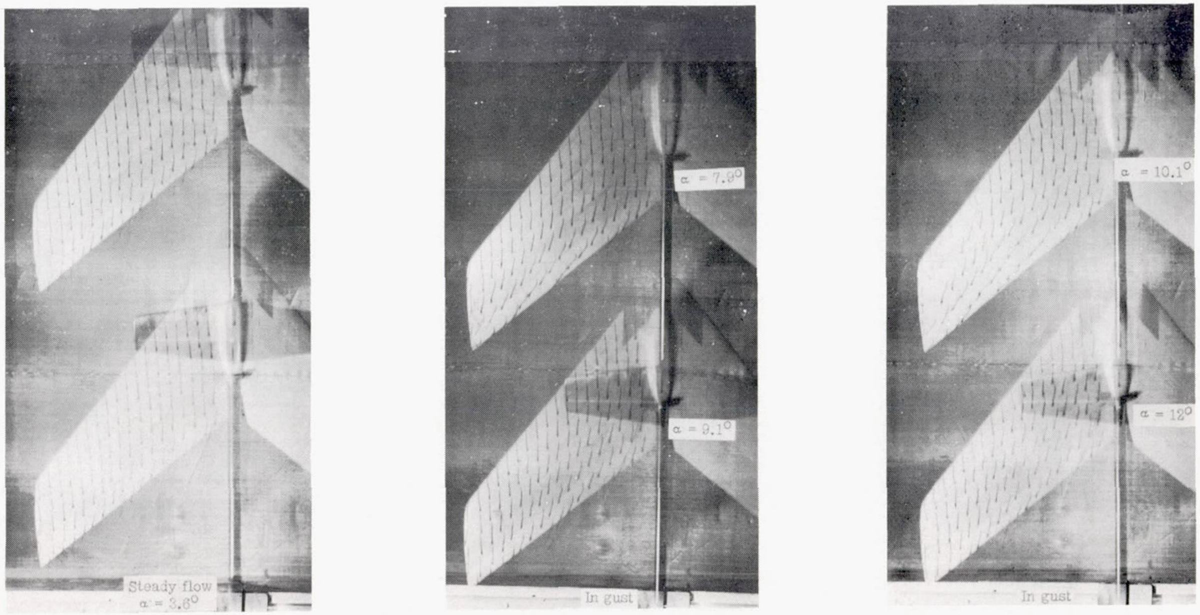
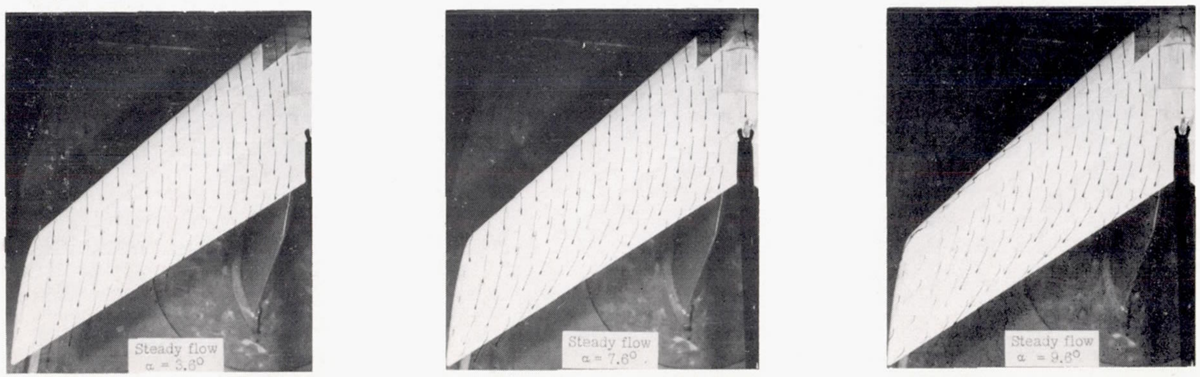


(a) Gust tunnel.



(b) Wind tunnel.

Figure 4.- Comparison of flow over 45° sweptback wing in the Langley gust tunnel and Langley stability tunnel at same velocity.

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