NACA TN 3745

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 3745

TRANSITION-FLIGHT TESTS OF A MODEL OF A LOW-WING TRANSPORT VERTICAL-TAKE-OFF AIRPLANE WITH TILTING WING AND PROPELLERS

By Powell M. Lovell, Jr., and Lysle P. Parlett

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NACA

Washington
September 1956

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SUMMARY

An investigation of the stability and control of a low-wing four-engine transport vertical-take-off airplane during the transition from hovering to normal forward flight has been conducted with a remotely controlled free-flight model. The model had four propellers distributed along the wing with thrust axes in the wing-chord plane, and the wing could be rotated to 90° incidence so that the propeller thrust axes were vertical for hovering flight.

With the wing pivoted at the 30-percent mean-aerodynamic-chord location, successful transition flights could be made when the center of gravity was at the most forward position at which the model could be flown in hovering flight, but uncontrollable pitch-ups occurred when the center of gravity was behind this position. With this wing-pivot location, therefore, the model had virtually no range of allowable center-of-gravity positions. With the wing pivoted at the 15-percent mean-aerodynamic-chord location, successful transition flights could be made when the center of gravity was located anywhere in the forward half of the range of positions that could be trimmed in hovering flight; therefore, the model had an allowable center-of-gravity range of 8 percent mean aerodynamic chord. The lateral stability and control characteristics were considered generally satisfactory even though for certain conditions of airspeed and fuselage attitude the Dutch roll oscillation was lightly damped.

INTRODUCTION

With the recent development of turboprop engines with high ratios of power to weight, it has become possible to build transport airplanes capable of vertical take-off and landing. One configuration which has been proposed to accomplish vertical take-off and landing while maintaining a fuselage-level attitude is a conventional airplane with the wings and propellers capable of being rotated through 90°. In order to determine whether such an airplane is feasible from a stability and control standpoint, a flying model has been used to study the flight characteristics in both hovering- and forward-flight conditions. The results of the hovering-flight tests are presented in reference 1 and the results of the forward-flight tests are presented herein.

The model used in this investigation had four propellers mounted on a low wing with the thrust axes in the chord plane. The wing could be rotated from 0° to 90° incidence so that the propeller thrust axes were vertical for hovering flight and essentially horizontal for forward flight.

The investigation consisted primarily of flight tests. The stability and controllability were determined from visual observation, from the pilots' impressions of the flying qualities of the model, and also from motion-picture records of the flights. In addition to the flight tests a few force tests were made to determine the stability and the control effectiveness in forward flight.

SYMBOLS

The motions of the model are referred to the body system of axes. Figure 1 shows these axes and the positive directions of the forces, moments, and angular displacements. For simplicity in reducing the records, linear displacements in time histories of the model motions are presented with reference to horizontal and vertical space axes.

c_t mean aerodynamic chord of horizontal tail

i_w wing incidence, deg

M_X rolling moment, ft-lb

M_Y pitching moment, ft-lb

M_Z yawing moment, ft-lb

M_{X_β} rate of change of rolling moment with angle of sideslip, ft-lb/deg

M_{Z_β} rate of change of yawing moment with angle of sideslip, ft-lb/deg

X,Y,Z body axes

α angle of attack, deg

β angle of sideslip, deg

δ_e deflection of pitch controls, deg

θ angle of pitch of fuselage longitudinal axis relative to horizontal, deg

ϕ angle of roll, deg

ψ angle of yaw, deg

MODEL

The model was designed to represent a possible turboprop transport airplane. A photograph of the model in the hovering configuration is presented in figure 2 and three-view drawings of the model are presented in figure 3. Table I lists the mass and geometric characteristics of the model. The model was powered by a 10-horsepower electric motor which turned four 2-blade propellers with the thrust axes in the wing-chord plane. The speed of the motor was changed to vary the thrust of the model.

The wing could be pivoted at either the 15-percent or the 30-percent mean-aerodynamic-chord station and could be rotated from 0° to 90° incidence during flight. The propellers on each semispan overlapped and were of such span that virtually the entire wing was immersed in the slipstream. In addition to the conventional elevator and rudder controls the model had full-span 25-percent-chord control flaps on the wing which provided pitch and yaw control during hovering and low-speed flight. Roll control in hovering and low-speed flight was provided by differentially varying the pitch of the outboard propellers.

The controls were deflected by flicker-type (full-on or off) pneumatic actuators which were remotely operated by the pilots. The control actuators were equipped with integrating-type trimmers which trimmed the controls a small amount each time a control was applied. With actuators of this type a model becomes accurately trimmed after flying a short time in a given flight condition.

TEST SETUP AND FLIGHT-TEST TECHNIQUE

Figure 4 shows the test setup for the flight tests which were made in the Langley full-scale tunnel. The sketch shows the pitch pilot, the safety-cable operator, and the power operator on a balcony at the side of the test section. The roll pilot was located in an enclosure in the lower rear part of the test section, and the yaw pilot was at the top rear of the test section. An additional operator (not shown in fig. 4) was located on the balcony near the pitch pilot to control the wing incidence in these tests. Separate pilots operated the pitch, roll, and yaw controls in order that careful attention might be given to the study of the motions of the model about each of these three axes. The three pilots were located at positions which gave the best vantage points for observing and controlling the particular phase of the motion with which they were concerned. Motion-picture records were obtained with fixed cameras mounted near the pitch and yaw pilots.

The power for the main propulsion motor, the wing tilting motor, and the electric control solenoids was supplied through wires, and the air for the control actuators was supplied through plastic tubes. These wires and tubes were suspended from above and taped to a safety cable (1/16-inch braided aircraft cable) at a point about 15 feet above the model down to the model. The safety cable, which was attached to the model above the wing pivot point, was used to prevent crashes in the event of a power or control failure or in the event that the pilots lost control of the model. During flight the cable was kept slack, so that it did not appreciably influence the motions of the model.

Pitch control in hovering and low-speed flight was obtained by deflecting the wing control flaps together $\pm 25^{\circ}$. Since the elevator could not be switched out of the pitch-control circuit it also operated during hovering flight. An elevator deflection of $\pm 25^{\circ}$ was used for low-speed flight but provision was made for reducing the deflection to $\pm 8^{\circ}$ for high-speed flight in order to prevent overcontrolling. As the airspeed increased, the elevator became progressively more effective; and at a speed of about 45 knots, the pilot reduced the elevator deflection and switched out the wing flaps.

Yaw control in hovering and low-speed flight was obtained by deflecting the wing control flaps differentially $\pm 10^{\circ}$. Since the rudder could not be switched out of the yaw-control circuit it also operated during hovering flight. As the airspeed increased, the rudder became effective, and at a speed of about 13 knots, the wing control flaps were switched out and only the rudder was used for yaw control for the remainder of the flight. At a speed above about 13 knots, deflection of the wing flaps for yaw control caused a slight rolling motion; therefore, the yaw pilot switched out the wing flaps at the first indication that he was disturbing the model in roll. The rudder deflection for all airspeeds was $\pm 25^{\circ}$.

Roll control in hovering and low-speed flight was obtained by differentially varying the pitch of the outboard propellers $\pm 2^{\circ}$. At a speed of about 25 knots the wing control flaps with deflections of $\pm 10^{\circ}$ were switched in, and for the remainder of the flight both the outboard propellers and the wing control flaps were used for roll control. Since the pitch control to the outboard propellers could not be switched out, this control continued to operate throughout the entire flight range.

The test technique is explained by describing a typical flight. The model hangs on the safety cable and the power is increased until the model is in steady hovering flight. At this point the tunnel drive motors are turned on and the airspeed begins to increase. As the airspeed increases, the attitude of the fuselage is kept essentially horizontal, the wing incidence is reduced, and the power is adjusted to provide the necessary thrust to balance the drag of the model. At an airspeed of about 13 knots the yaw pilot switches out the wing-flap yaw control and uses only the rudder for the remainder of the flight; at an airspeed of about 25 knots the roll pilot switches in the wing flaps for use as roll control in conjunction with the variable-pitch propellers. At an airspeed of about 45 knots the pitch pilot reduces the elevator deflection to $\pm 8^{\circ}$, switches out the wing flap, and uses only the elevator for pitch control for the remainder of the flight. The controls and power are operated to keep the model as near the center of the test section as possible until a particular phase of the stability and controllability is to be studied. Then, the pilots perform the maneuvers required for the particular tests and observe the stability and control characteristics. The flight is terminated by gradually taking up the slack in the safety cable while reducing the power to the model.

TESTS

Flight Tests

Most of the flight tests were made with the wing pivoted at the 15-percent-chord location but some preliminary flight tests were made with the wing pivoted at the 30-percent-chord location. The flight-test results were obtained in the form of pilots' observations and opinions of the behavior of the model, motion-picture records of the motions of the model, and time histories of the tests made from the motion-picture records.

During the flight tests the stability and control characteristics were studied for a range of center-of-gravity locations: from 2 percent mean aerodynamic chord behind the wing pivot to 8 percent mean aerodynamic chord forward of the wing pivot. The center-of-gravity locations are referred to in this paper as the locations when the wing was in the hovering-flight position (90° incidence). As the wing rotated to 0° incidence, the center of gravity of the model moved upward and backward. The following table shows the longitudinal and vertical center-of-gravity locations for hovering and normal forward flight in percent mean aerodynamic chord with relation to the wing pivot axis (positive values indicate that the center of gravity is above or forward of the wing pivot axis):

Wing-pivot-point location	Hovering flight		Normal forward flight	
	Longitudinal	Vertical	Longitudinal	Vertical
30 percent mean aerodynamic chord	0 4 8	2 2 2	-5 -1 3	7 7 7
15 percent mean aerodynamic chord	-2 0 2 4 8	-7 -7 -7 -7 -7	-12 -10 -8 -6 -3	3 3 3 3 3

The flight tests were made at airspeeds from 0 to 65 knots. If the model is considered as a 1/10-scale model of an airplane, the highest speed reached in the tests corresponds to about 210 knots full scale.

Force Tests

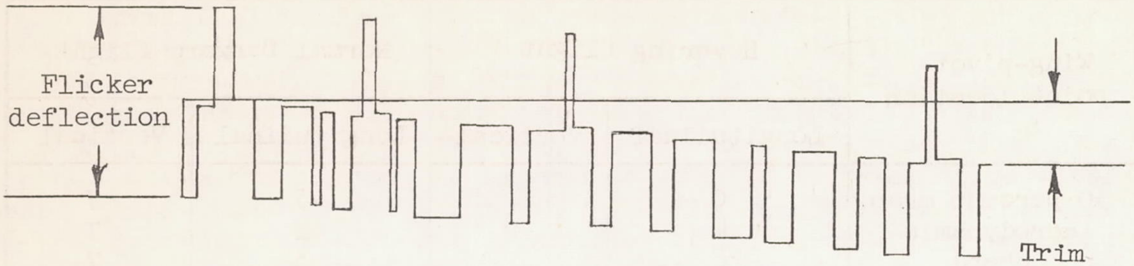
Some preliminary force tests were made with the wing pivoted at the 30-percent mean-aerodynamic-chord location before the flight tests were started. The force-test data were computed for the center-of-gravity locations corresponding to each angle of incidence for the hovering case with the center of gravity directly over the wing pivot. The tests were run at one-half the rated speed of the model motor, with the tunnel airspeed adjusted to produce zero net drag on the model when all controls were at zero deflection.

No tunnel-wall or blockage corrections have been applied to the force-test data. It is expected that these corrections would be large since the model was large in relation to the test section of the free-flight tunnel where the force tests were made.

RESULTS AND DISCUSSION

The results of the present investigation are more easily seen in motion pictures of the flights of the model than is possible in a written presentation. For this reason a motion-picture film supplement to this paper has been prepared and is available on loan from the National Advisory Committee for Aeronautics, Washington, D. C.

An explanation of the control-record plots contained in all the flight records is shown in the following sketch:



The horizontal line is a reference line which has its origin not necessarily at 0° deflection but at the control trim position required for hovering flight. The flicker deflection is the control deflection applied by the pilot. Each time a flicker deflection is applied, the control is trimmed a small amount in that direction; if the control is deflected more times in one direction than in the other, a change in trim occurs. The trim change is indicated at the right of the plot. Since the times at which the pilots switched the various controls in or out could not be determined from the control lights, it is not possible to tell from the control records whether combination controls or individual controls were being used or whether the large or small elevator deflection was being used. In the pitch-control records, control deflections of ±25° are shown in all cases, although at the higher speeds the elevator deflection was reduced to ±8° and the flap control was switched off. The changes in trim shown by the pitch-control records were computed by adding a small increment of trim in the proper direction each time the control was deflected. The trim changes shown were based on the characteristics of the integrating trimmer used with the large elevator deflection and are not actually applicable to the small elevator deflection or to the wing control flap.

Wing Pivot at 30 Percent Mean Aerodynamic Chord

Figure 5 shows time histories of flights made with the center of gravity located at and 4 percent mean aerodynamic chord ahead of the wing pivot. Both of these flights ended in uncontrollable pitch-ups at low forward speeds. When the center of gravity was located at 8 percent mean aerodynamic chord ahead of the wing pivot, successful transition flights could be made as indicated by figure 6. It was necessary for the pitch pilot to exercise extreme care during the low-speed portion of the flight, however, in order to prevent an uncontrollable pitch-up with this center-of-gravity location. Since the 8-percent forward center-of-gravity location was the most forward one at which the model could be trimmed in hovering flight, the model had virtually no allowable center-of-gravity range.

The flights illustrated in figure 5 were made with the horizontal-tail incidence set at 10°, but it was found in other flights that neither increasing the tail incidence to 20° nor increasing the chord of the wing control surfaces to 40 percent wing chord was successful in preventing the pitch-up. In some cases the pitch-up tendency illustrated by the records in figure 5 was aggravated by the application of control required to keep the model flying in the test section of the tunnel. For example, at the point where the model starts to pitch up (see fig. 5(a)), it is also moving forward. In order to prevent it from going too far forward into the throat of the tunnel the pitch pilot was forced to apply a nose-up control momentarily. This, of course, made the model nose up more rapidly than it would have otherwise and caused it to move downstream in the tunnel. The time history shows that as the model started to move downstream, the pilot was unable to prevent the pitch-up with full-down pitch control. The pilot of a full-scale airplane would not be faced with exactly the same problem as the pilot of the model, since he would not be forced to accomodate the airplane to a given rate of increase in speed and since he could immediately apply all available control without being limited by a separate trimmer. It is possible, therefore, that the pilot of an airplane could make successful transitions with slightly more rearward positions than were possible with the model.

To a person not familiar with the flying of small remotely controlled models with flicker-type controls the motions shown in figure 5 may appear erratic, but this record actually represents smooth flight for these tests. A full-scale airplane could be flown considerably more smoothly than the model because the angular velocities of the airplane would be much lower than those of the model and because the pilot could sense the movements of the airplane more quickly and apply the proper amount of corrective control more exactly than was possible with the model.

Some force-test data which illustrate the effectiveness of the pitch controls are presented in figure 7. A nose-up pitching moment, which increases with decreasing wing incidence, exists when no controls are deflected. There is sufficient control moment contributed by 30° deflection of the wing flaps to trim the pitching moment to zero between 90° and 70° incidence but not below 70° incidence. The moment produced by the wing flaps and the elevator combined is sufficient to trim the model over the entire angle-of-attack range; but, in the angle-of-attack range in which the pitch-ups occurred (between about 70° and 55° incidence), only a small additional amount of control moment is available for maneuvering the model or correcting for disturbances. Since these data were not corrected for tunnel-wall effects they are probably not quantitatively accurate and are intended only to indicate trends. It may be, therefore, that the control effectiveness was actually not great enough to trim the model in the critical range.

On the basis of these force-test data and the flight-test results with the 30-percent mean-aerodynamic-chord pivot point, the wing pivot was moved to the 15-percent mean-aerodynamic-chord location. With this modification the control flaps had a longer moment arm and produced more control and the propellers and wing aerodynamic center had a shorter moment arm and less instability. Since both the control effectiveness and the stability were changed when the wing was moved, the data in figure 7 are not considered applicable to the configuration in which the wing was pivoted at 15 percent mean aerodynamic chord. No force tests were made with the revised configuration.

No detailed studies of the lateral stability and control characteristics were made with the wing pivot located at 30 percent mean aerodynamic chord. In general, these characteristics appeared to be similar to those obtained with the wing pivot at 15 percent mean aerodynamic chord which are discussed in the following section.

Wing Pivot at 15 Percent Mean Aerodynamic Chord

Longitudinal stability and control.- With the wing pivot moved forward to 15 percent mean aerodynamic chord, successful transition flights could be made when the center of gravity was located at the wing pivot. Figure 8 shows a time history of a typical transition flight with this center-of-gravity location. It was necessary, however, for the pitch pilot to exercise extreme care during the low-speed portion of flight in order to prevent an uncontrollable pitch-up. If the fuselage attitude was allowed to exceed an angle of pitch of about 10°, the model would nose-up and diverge despite the efforts of the pilot to stop it. The control record in figure 9 shows that the pilot applied about 20° of nose-down trim (from the trim position required for hovering flight) in order to get successfully through the angle-of-attack range in which the pitch-ups occurred. After passing through this range, the pitch pilot was required to trim the model nose up as the airspeed increased because the horizontal tail became more effective and therefore produced more nose-down trim as the speed increased.

Two typical time histories of flights in which pitch-ups occurred with the longitudinal center-of-gravity location at the wing pivot are shown in figure 9. The pitch-ups occurred between airspeeds of 9 and 18 knots. The control records in figure 9 show that the pilot was trimming the model nose down throughout the entire flight and that even with the controls deflected 25° downward from the trim position of 20° (total of 45° nose-down control) the model diverged in pitch. At the airspeed at which the pitch-up tendency was most pronounced it was found that if the fuselage was kept at a zero or slightly negative angle of pitch, successful transitions could be made; whereas if the fuselage was allowed to reach a nose-up attitude as high as 5° the model usually diverged.

No successful transition flights could be made with the center of gravity located behind the wing pivot, although numerous unsuccessful attempts were made with the center of gravity located 2 percent mean aerodynamic chord behind the wing pivot. In all these cases - even when the horizontal-tail incidence was increased to 20° - the flights were terminated by an uncontrollable pitch-up.

With the center of gravity at 4-percent or 8 percent mean aerodynamic chord forward of the wing pivot, successful transition flights could be made consistently and easily. Figure 10 presents a time history of a typical transition flight made with the 4 percent center-of-gravity location.

Lateral stability and control.- In general, the lateral stability and control characteristics were satisfactory throughout the flight range, except that for certain flight conditions the Dutch roll oscillation was lightly damped. If only the propeller pitch was used for roll control and the fuselage was kept horizontal, the Dutch roll oscillation was easily excited at speeds above about 25 knots, and occasionally the model became uncontrollable. A time history of a flight made with only the propeller pitch used for roll control is shown in figure 11. In this figure it may be seen that when the fuselage was kept at about a 10° nose-up angle of pitch the model could be controlled without too much difficulty; but, when the fuselage angle was reduced to about 0° (at about 14 seconds), the Dutch roll oscillation became violent, and, in this particular flight, uncontrollable. It is probable that the reason the model could be flown with a 10° nose-up attitude and not with the fuselage level lies in the increased Dutch roll stability when the principal longitudinal axis of inertia is inclined upward. The alternate left and right control applications from about halfway through the flight to the end of the flight indicate that the pilot was trying to stop the oscillation. In this particular case, however, some lag existed between the time the pilot saw the need for control and the time he applied the control. For lightly damped oscillations when lag such as this exists, the controls may actually aggravate the motion.

When both the propeller pitch and the ailerons were used for roll control at speeds higher than about 25 knots the Dutch roll oscillation was not excited, probably because the adverse yawing moments caused by the ailerons tended to compensate for the excessive favorable yawing moments caused by the use of propeller pitch for roll control. Figure 12 presents a time history of a flight in which the model was being controlled in roll with both the propeller pitch and the ailerons. When this combination of controls was used, the Dutch roll oscillation was not noticeable and the pilot felt that the model was much easier to fly than it was when only the propeller pitch was used for roll control. There was no noticeable difference in the flight behavior of the model with the fuselage either 10° nose up or level when this combination for roll control was used. Figure 12 shows that the model could be flown about as smoothly at 0° angle of pitch as it could at 10° angle of pitch.

The propeller pitch control was not switched off when the ailerons were switched on since the propellers produced favorable yaw which counteracted the adverse yaw of the ailerons. The resultant yawing due to application of the propeller pitch and ailerons was very small as was evidenced by the very few rudder control applications required at speeds above about 25 knots.

The force-test data in figure 13 explain the flight results obtained with the propellers alone and with the combination of the propellers and ailerons for roll control. These data show that the propellers alone give very little yawing moment at wing incidences above about 50°; but, at lower incidences, the propellers alone produce large favorable yawing moments. In fact, at wing incidences below about 25° the yawing moment produced by the propellers is greater than the rolling moment. Since the wing control flaps produce large adverse yawing moments at wing incidence angles below about 50°, the net result of combining the propellers and ailerons is to provide a roll control that produces favorable yawing moments at the lower wing incidences. Figure 13 also shows that the combination of propellers and ailerons for roll control was necessary at low incidence angles because the rolling effectiveness of the propellers alone decreased to zero whereas that of the ailerons increased rapidly at the low incidence angles. Although the data in figure 13 were obtained when the wing pivot was at the 30-percent mean-aerodynamic-chord location, they are probably essentially correct for the configuration with the wing pivot at the 15-percent mean-aerodynamic-chord location because the modifications to the model should not have changed the lateral control characteristics to any extent.

Figure 14 presents some lateral stability characteristics of the model with the fuselage at angles of attack of 0° and 20°. These data show that, in general, the model had positive dihedral effect and static directional stability for both angle-of-attack conditions covered in the tests although a slight directional instability existed at low wing incidence angles when the fuselage was at an angle of attack of 20°. Figure 15 presents the directional stability and the effective dihedral parameters determined from the slopes of the curves of figure 14.

SUMMARY OF RESULTS

The following results were obtained from transition flight tests of a model of a low-wing transport vertical-take-off airplane with tilting wing and propellers:

1. With the wing pivoted at the 30-percent mean-aerodynamic-chord location, successful transition flights could be made when the center of gravity was 8 percent forward of the wing pivot, but uncontrollable

pitch-ups occurred when the center of gravity was at the wing pivot or only 4 percent forward.

2. With the wing pivoted at the 15-percent mean-aerodynamic-chord location, successful transition flights could be made when the center-of-gravity position ranged from directly below to 8 percent mean aerodynamic chord forward of the wing pivot point, but uncontrollable pitch-ups occurred for center-of-gravity positions behind the wing pivot.

3. The lateral stability and control characteristics were considered generally satisfactory even though for certain conditions of airspeed and fuselage attitude the Dutch roll oscillation was lightly damped.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., May 28, 1956.

REFERENCE

1. Lovell, Powell M., Jr., and Parlett, Lysle P.: Hovering-Flight Tests of a Model of a Transport Vertical-Take-Off Airplane With Tilting Wing and Propellers. NACA TN 3630, 1956.

TABLE I

MASS AND GEOMETRIC CHARACTERISTICS OF MODEL

Weight:	
Wing pivoted at 30 percent mean aerodynamic chord, lb	64.4
Wing pivoted at 15 percent mean aerodynamic chord, lb	67.7
Moment of inertia for center of gravity directly above wing pivot (wing pivoted at 30 percent mean aerodynamic chord):	
Moment of inertia about X-axis, I_X, slug-ft^2	2.58
Moment of inertia about Y-axis, I_Y, slug-ft^2	3.05
Moment of inertia about Z-axis, I_Z, slug-ft^2	5.13
Fuselage length, in.	84.8
Propellers (two blades each):	
Diameter, in.	20.0
Solidity (each propeller)	0.079
Design	Modification of modified NACA propeller A described in NACA Report 237
Wing:	
Sweepback (leading edge), deg	6
Airfoil section	NACA 0015
Aspect ratio	5.85
Tip chord, in.	9.4
Root chord (at center line), in.	17.6
Taper ratio	0.54
Area (total to center line), sq in.	988
Span, in.	76.0
Mean aerodynamic chord, in.	13.0
Control-flap hinge line, percent chord	75
Dihedral angle, deg	0
Vertical tail:	
Sweepback (leading edge), deg	5.0
Airfoil section	NACA 0009
Aspect ratio	1.94
Tip chord, in.	7.54
Root chord (at center line), in.	11.12
Taper ratio	0.68
Area (total to center line - excluding dorsal area), sq in.	169.1
Span, in.	18.125
Mean aerodynamic chord, in.	9.45
Rudder (hinge line perpendicular to fuselage center line):	
Tip chord, in.	2.5
Root chord, in.	4.05
Span, in.	14.03
Horizontal tail:	
Sweepback (leading edge), deg	7.3
Airfoil section	NACA 0009
Aspect ratio	5.81
Tip chord, in.	4.6
Root chord (at center line), in.	8.3
Taper ratio	0.55
Area (total to center line), sq in.	241.9
Span, in.	37.5
Mean aerodynamic chord, in.	6.62
Elevator (hinge line perpendicular to fuselage center line):	
Tip chord, in.	2.13
Root chord, in.	3.30
Span (each), in.	16.94

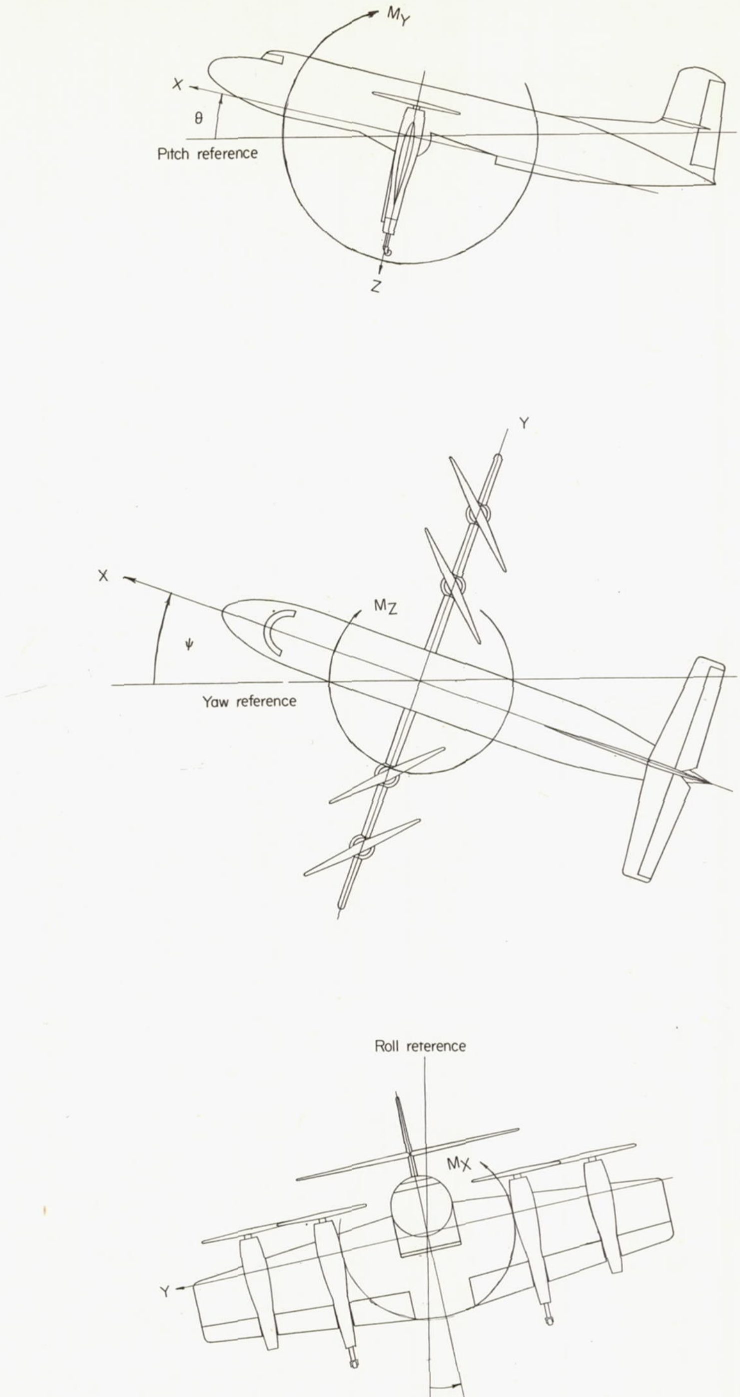


Figure 1.- The body system of axes. Arrows indicate positive directions of forces, moments, and angular displacements.

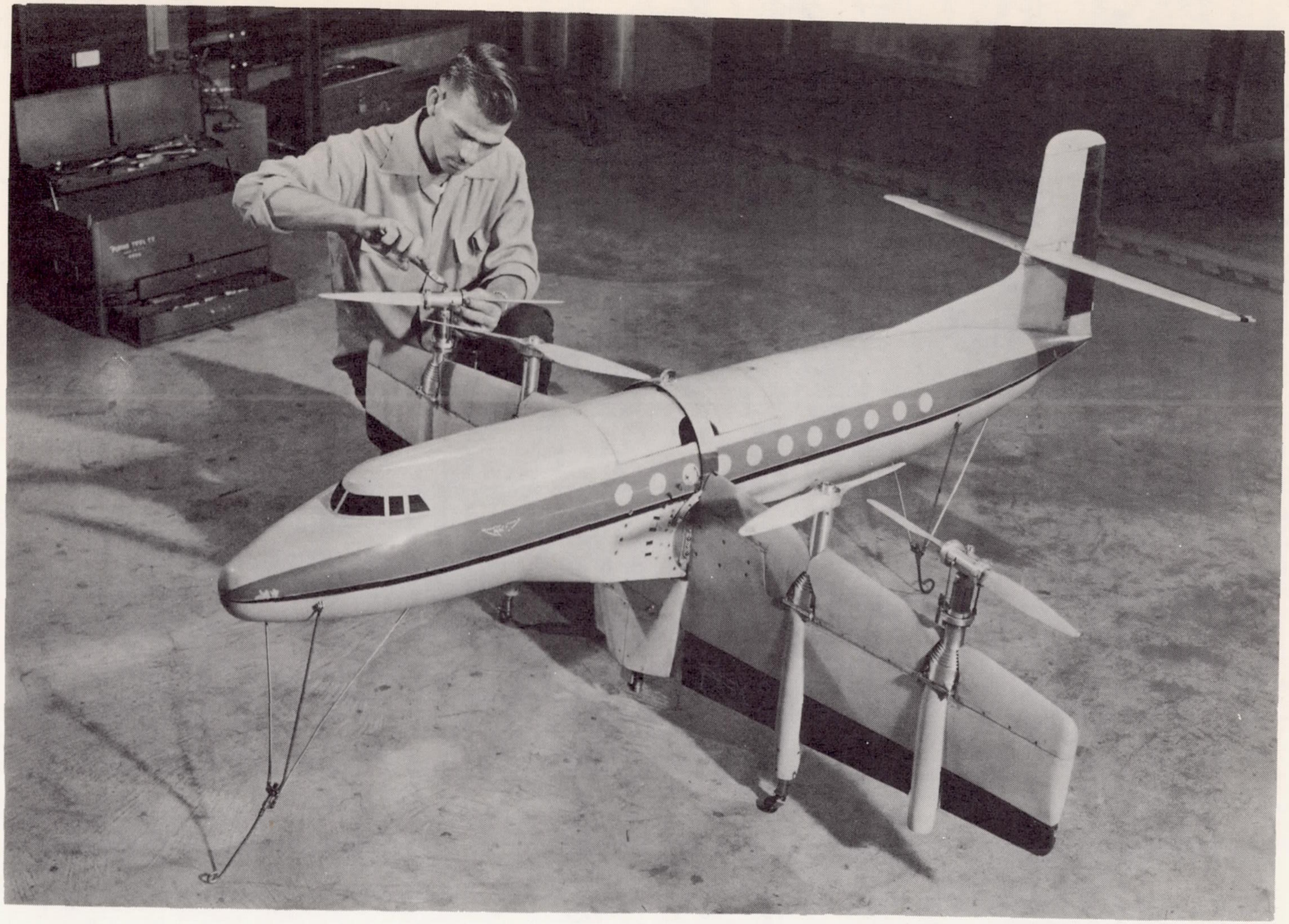


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Figure 2.- Photograph of model in hovering configuration. Wing pivot located at 30 percent mean aerodynamic chord.

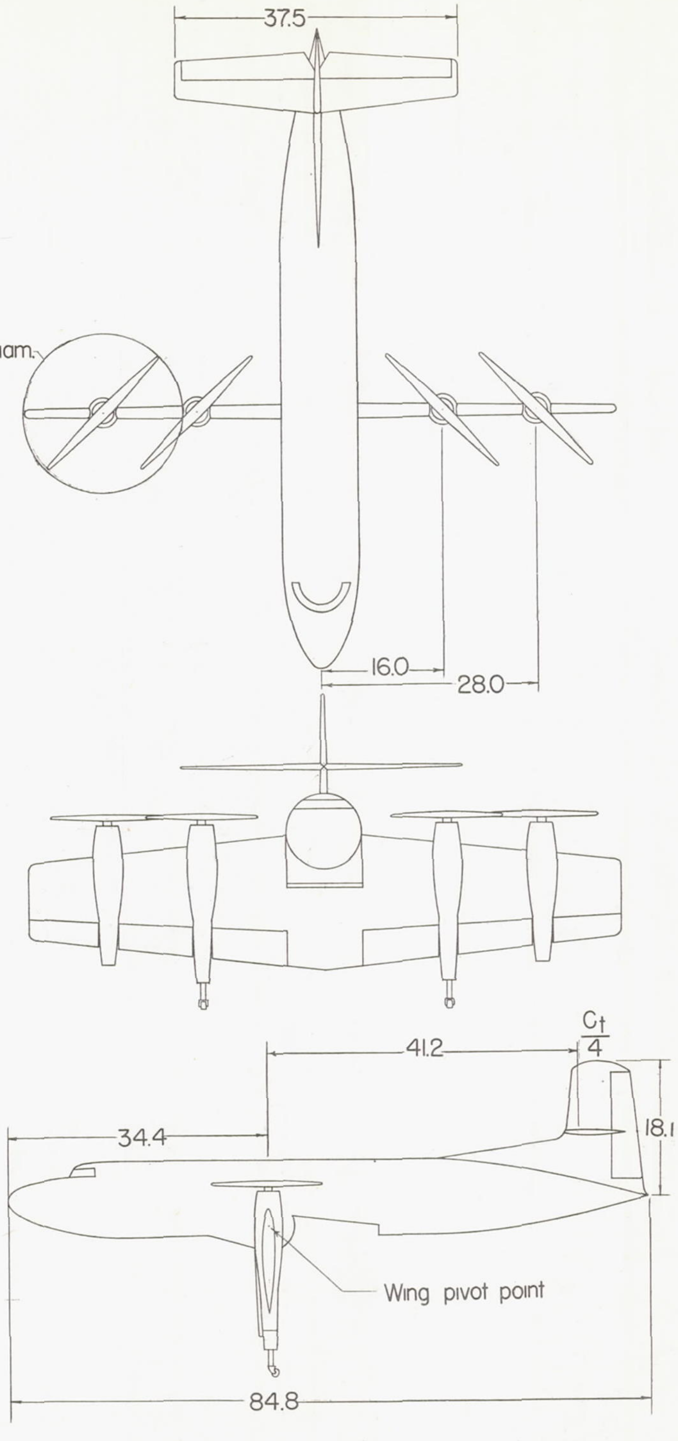


Figure 3.- Three-view sketches of model. Wing pivot at 15 percent mean aerodynamic chord. All dimensions are in inches.

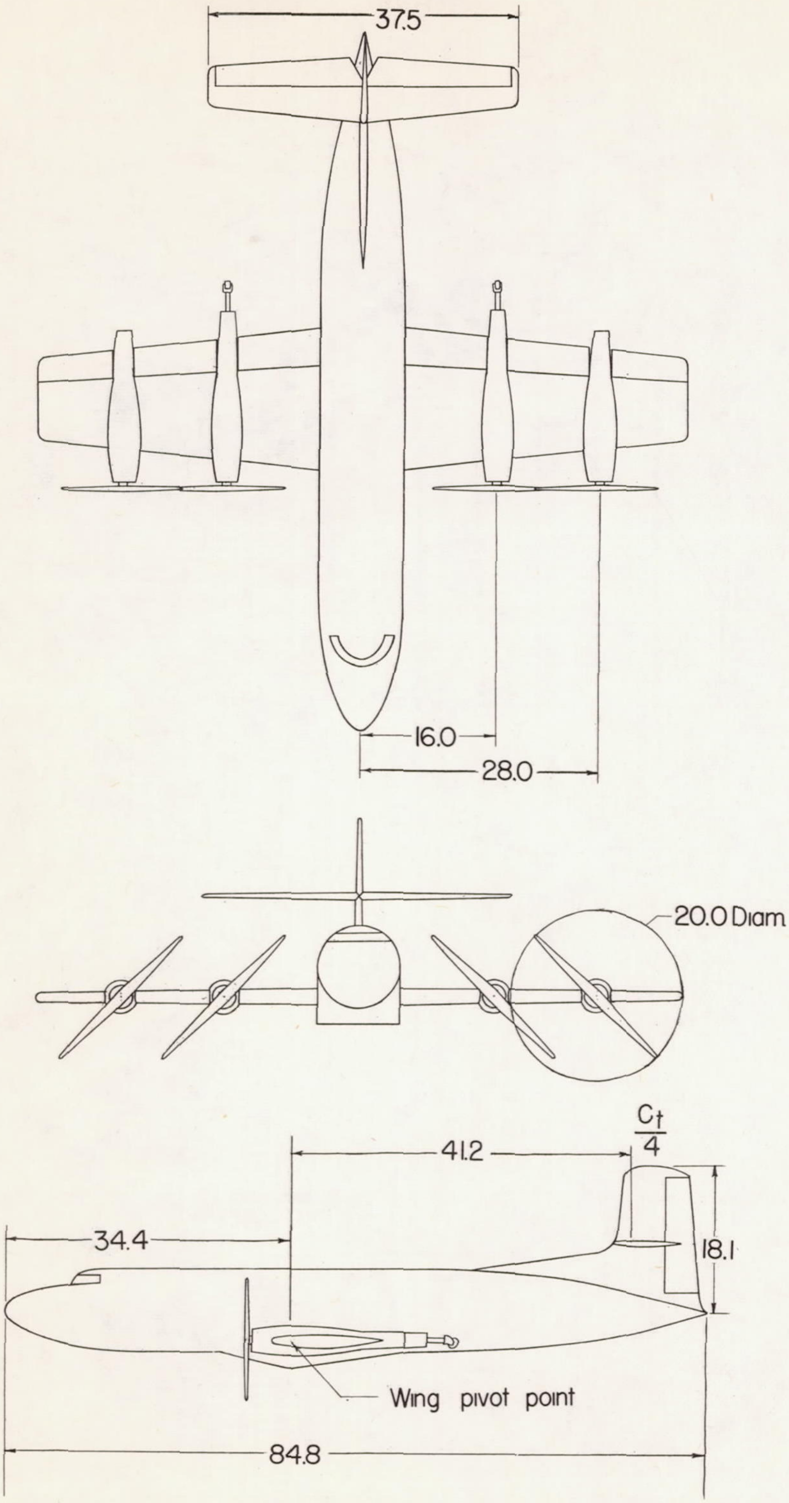


Figure 3.- Concluded.

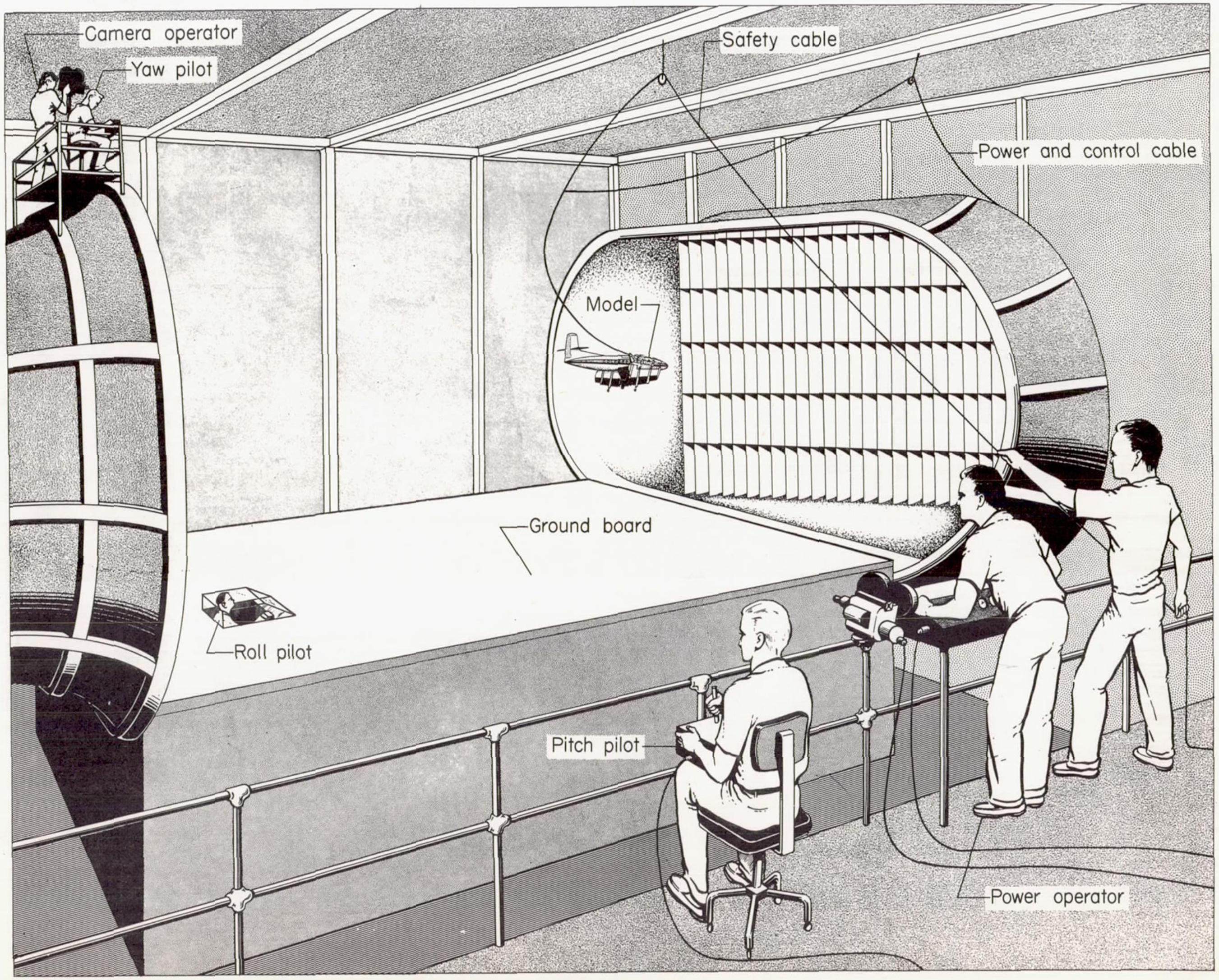
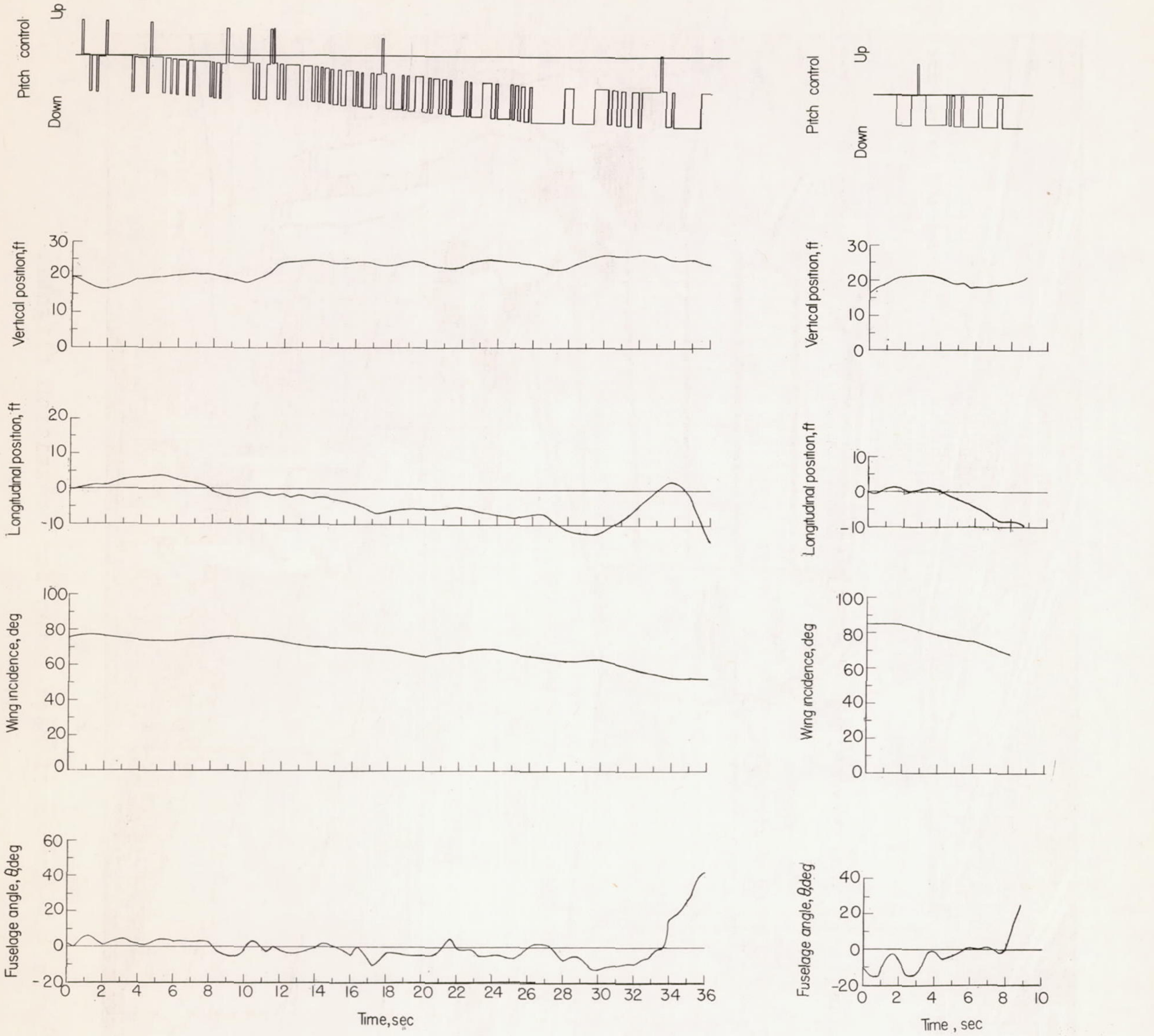


Figure 4.- Sketch of test setup for transition flights.



(a) Center of gravity located at wing pivot.

(b) Center of gravity located 4 percent mean aerodynamic chord ahead of wing pivot.

Figure 5.- Time histories of pitch-ups. Wing pivot at 30 percent mean aerodynamic chord.

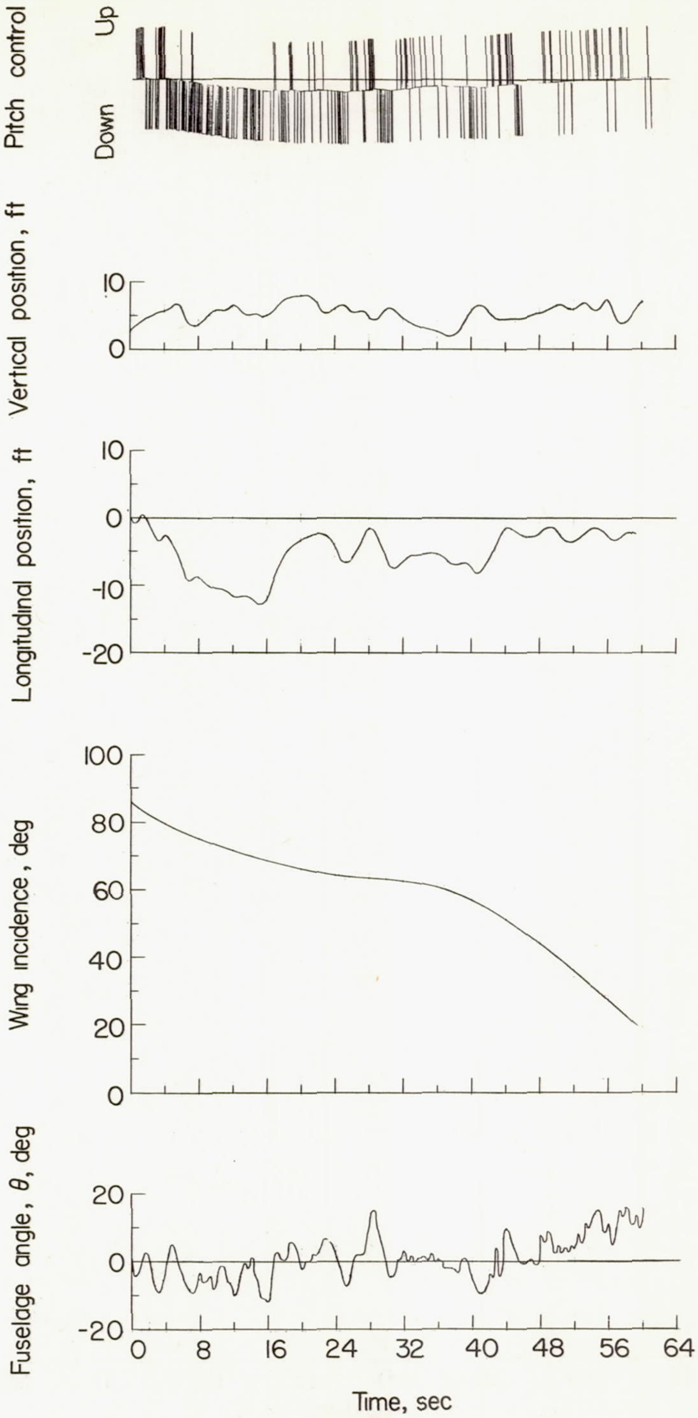


Figure 6.- Time history of a transition flight. Wing pivot at 30 percent mean aerodynamic chord; center of gravity located at 8 percent mean aerodynamic chord ahead of wing pivot.

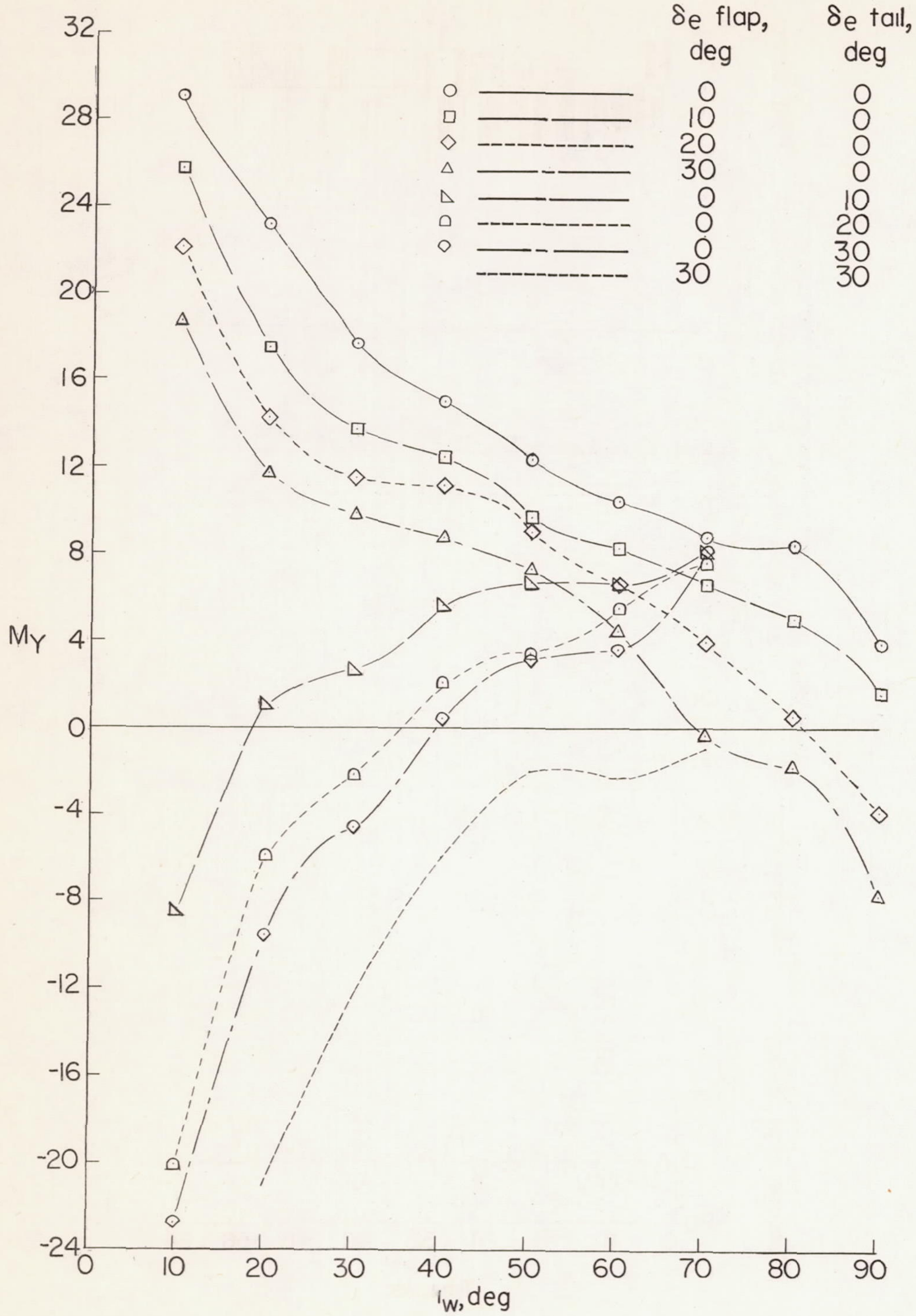


Figure 7.- Longitudinal-control effectiveness.

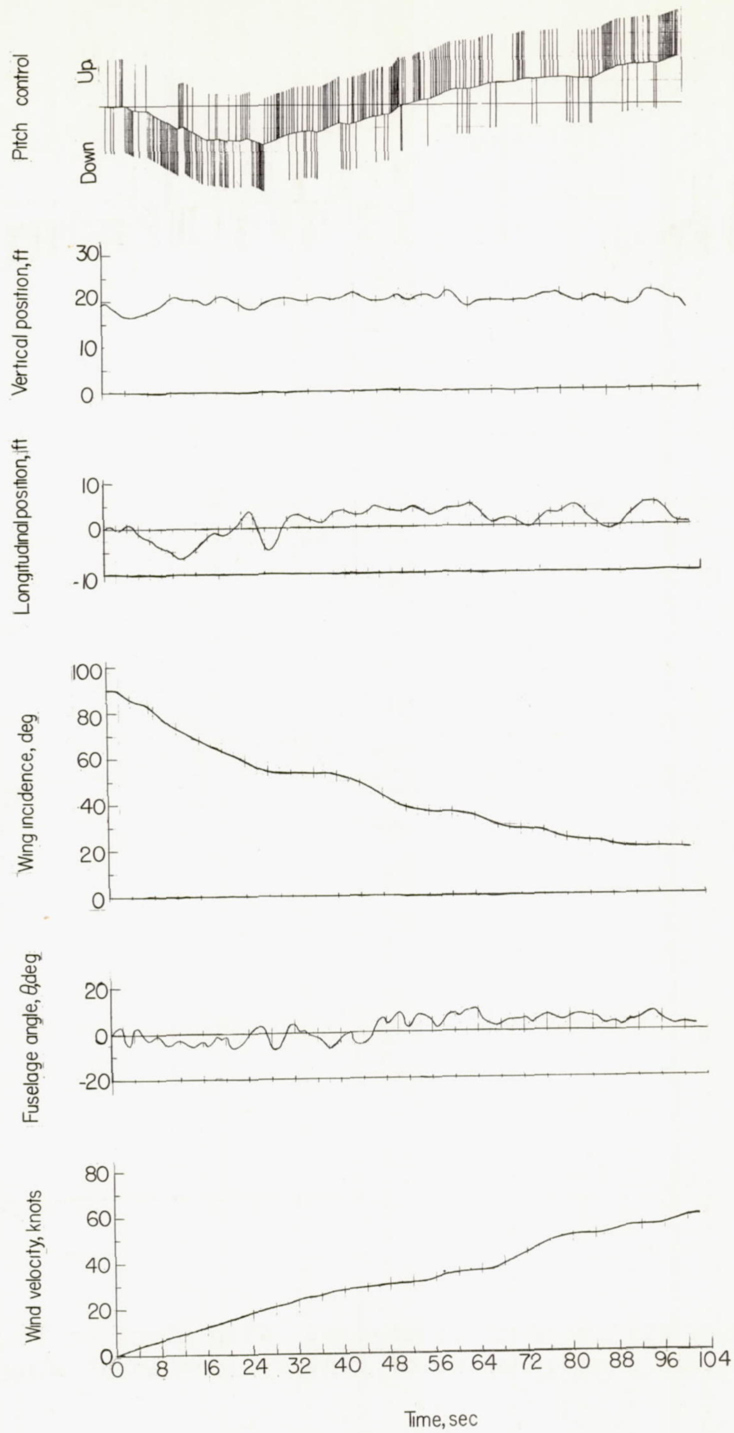


Figure 8.- Time history of a transition flight. Wing pivot at 15 percent mean aerodynamic chord; center of gravity located at wing pivot.

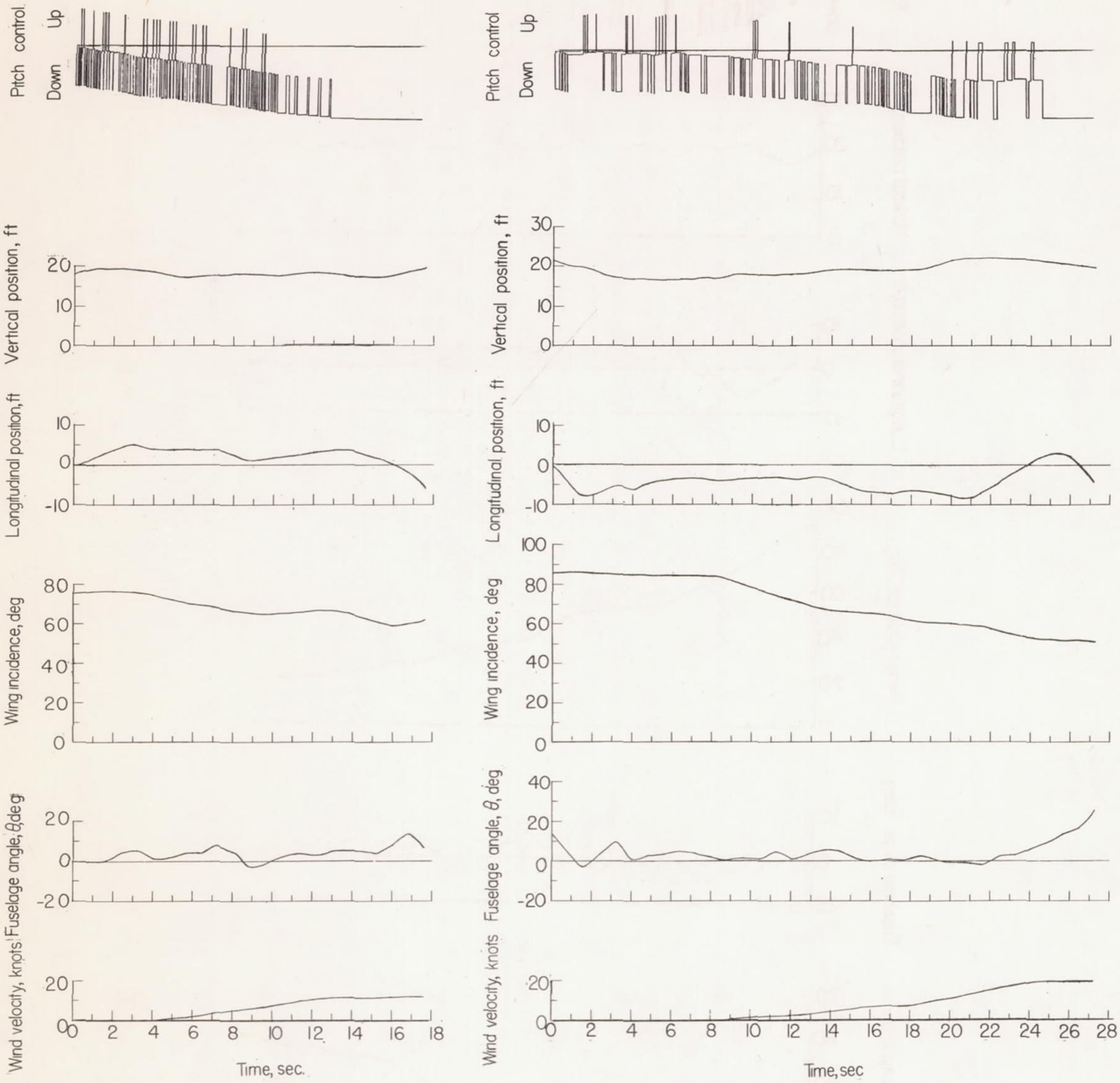


Figure 9.- Time histories of pitch-ups. Wing pivot at 15 percent mean aerodynamic chord; center of gravity located at wing pivot.

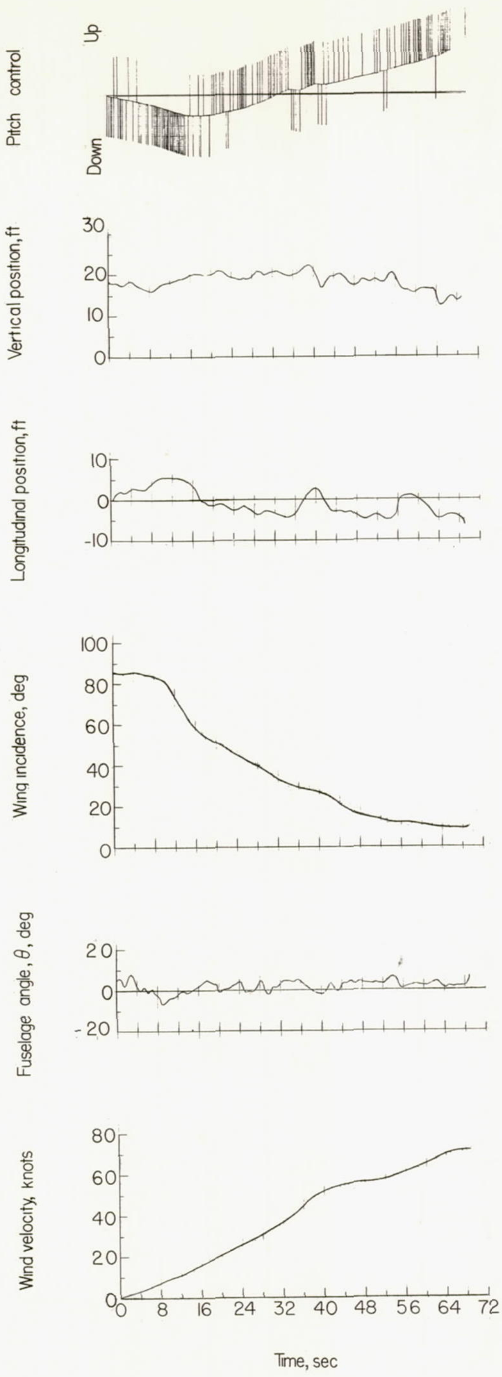


Figure 10.- Time history of a transition flight. Wing pivot at 15 percent mean aerodynamic chord; center of gravity located at 4 percent mean aerodynamic chord forward of wing pivot.

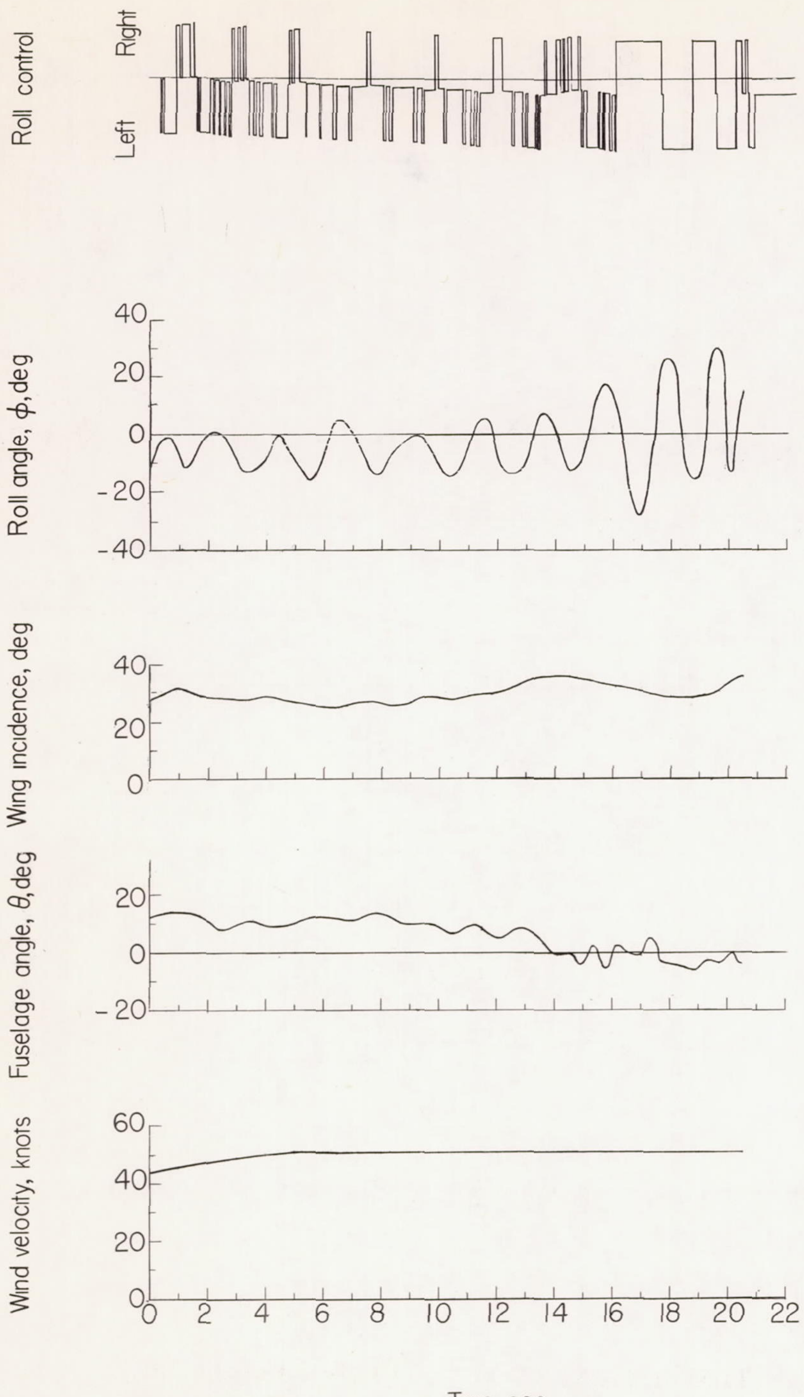


Figure 11.- Time history of a transition flight using only propeller pitch for roll control.

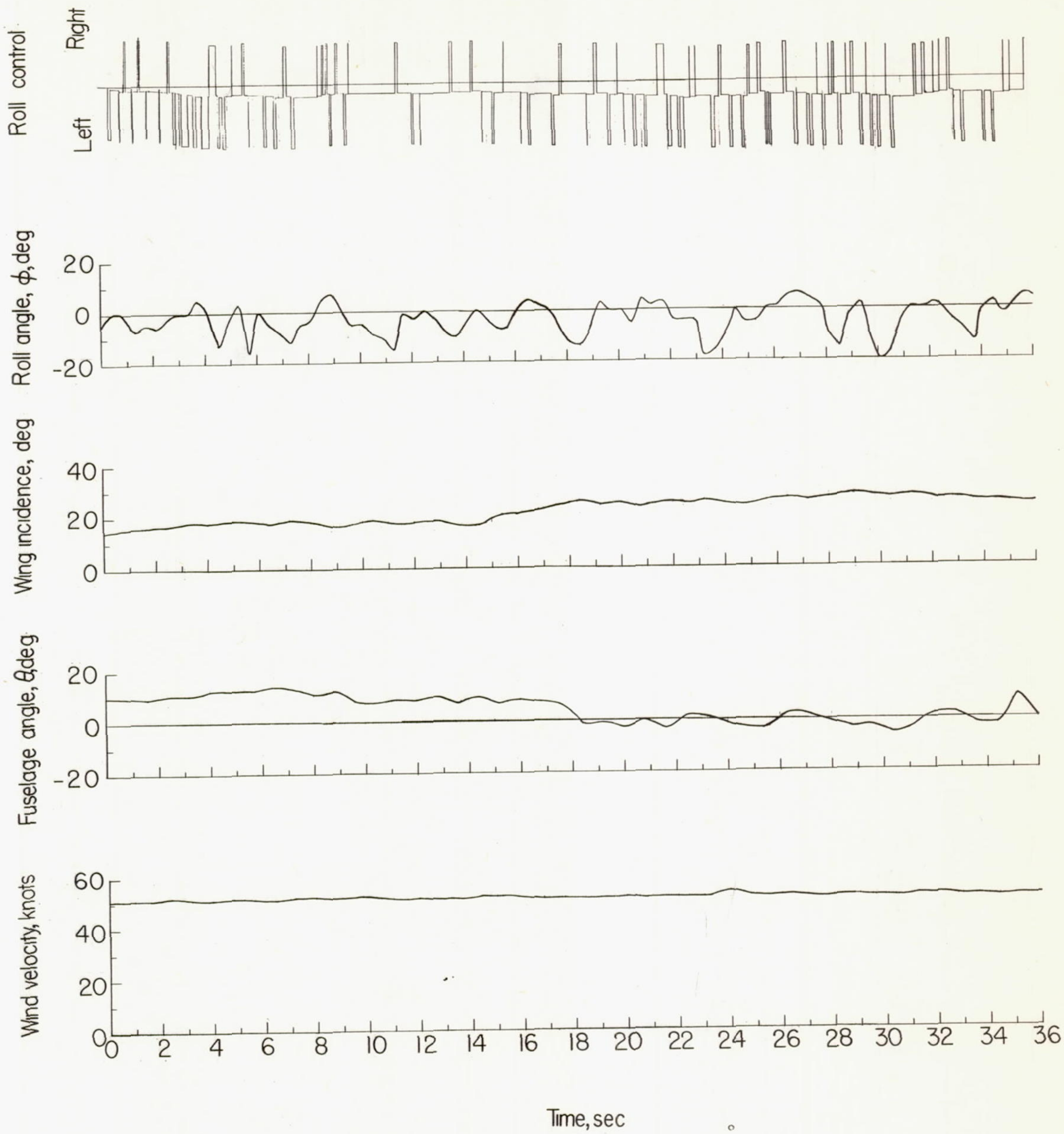


Figure 12.- Time history of a transition flight using both propeller pitch and ailerons for roll control.

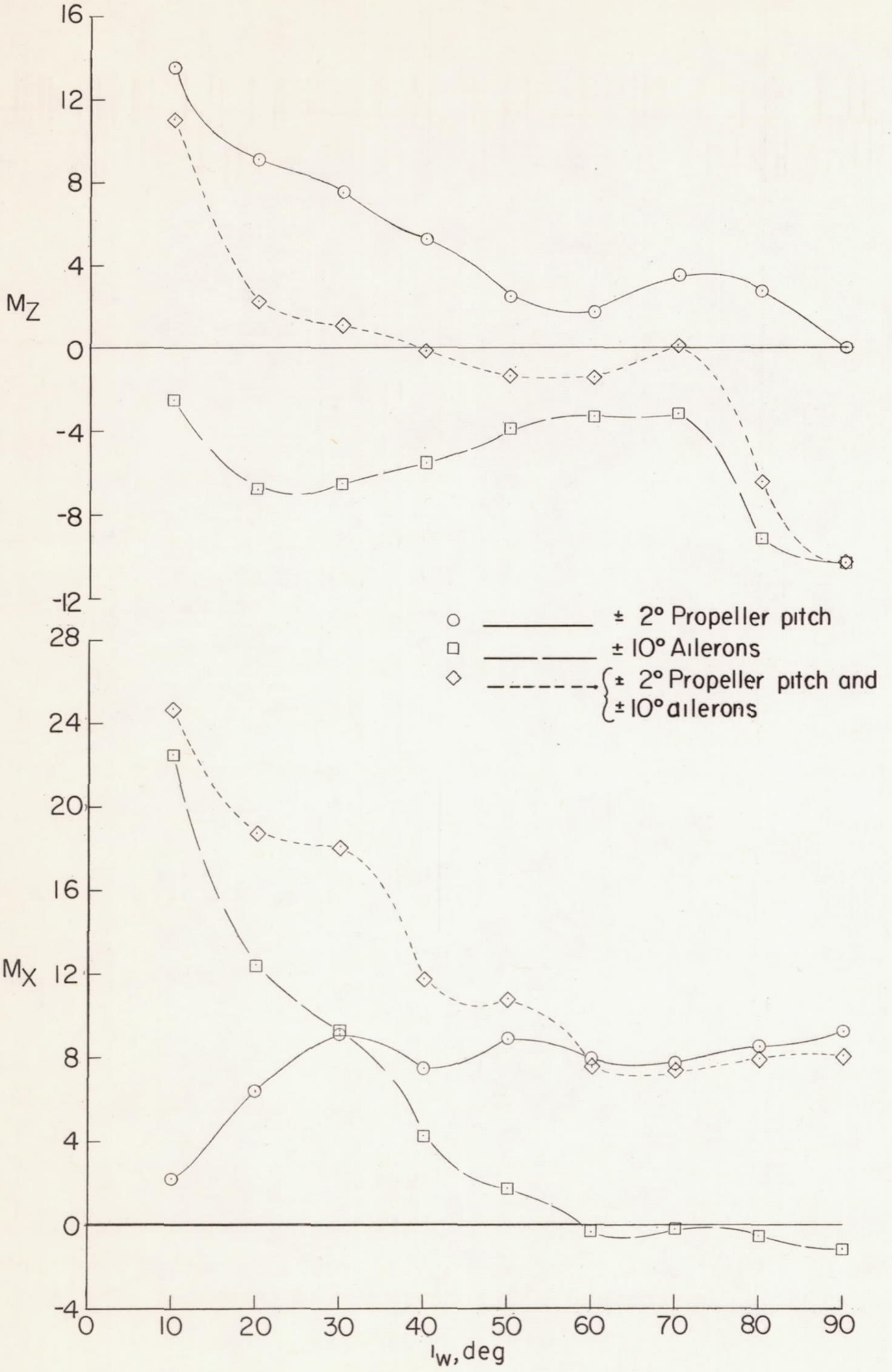
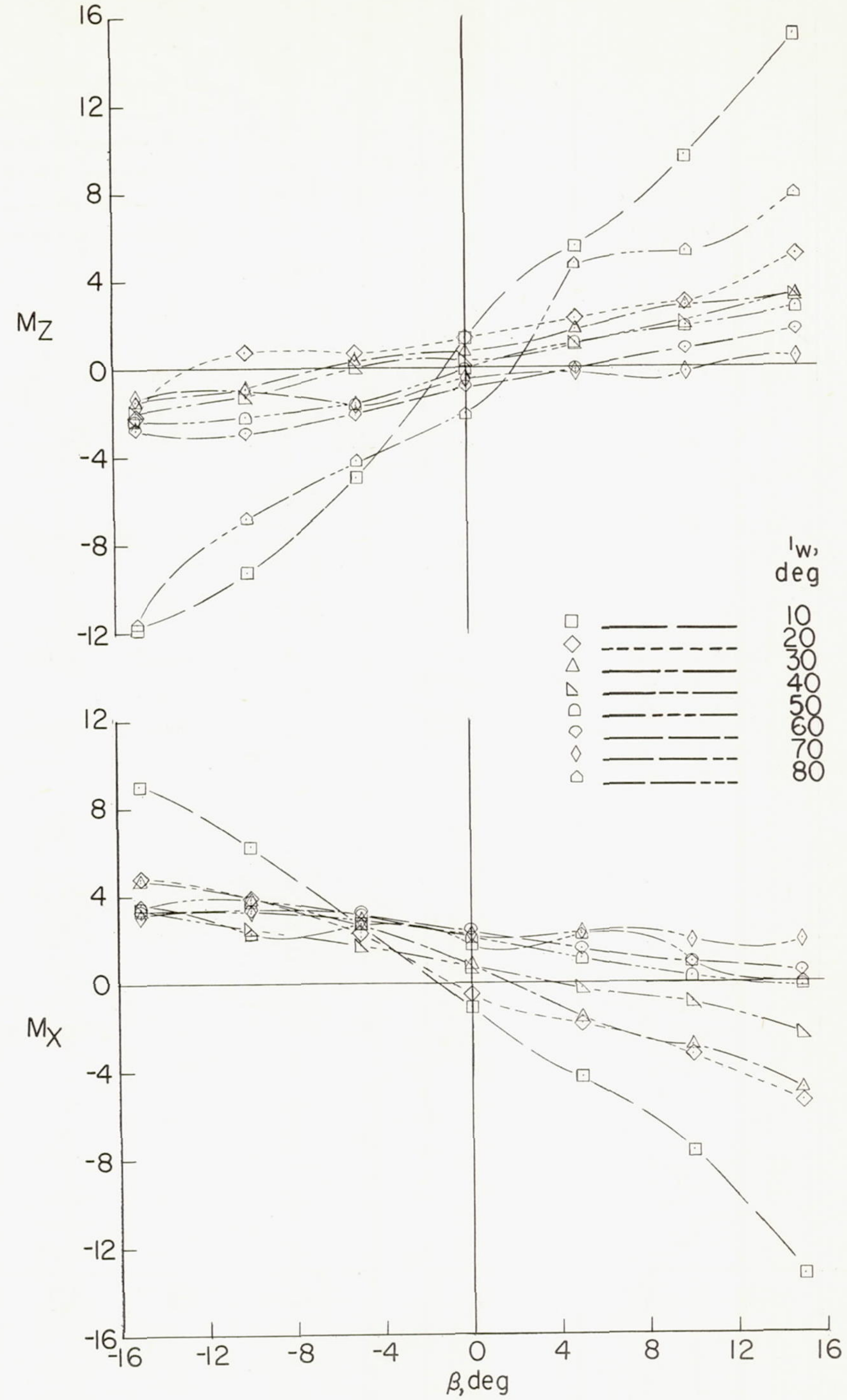
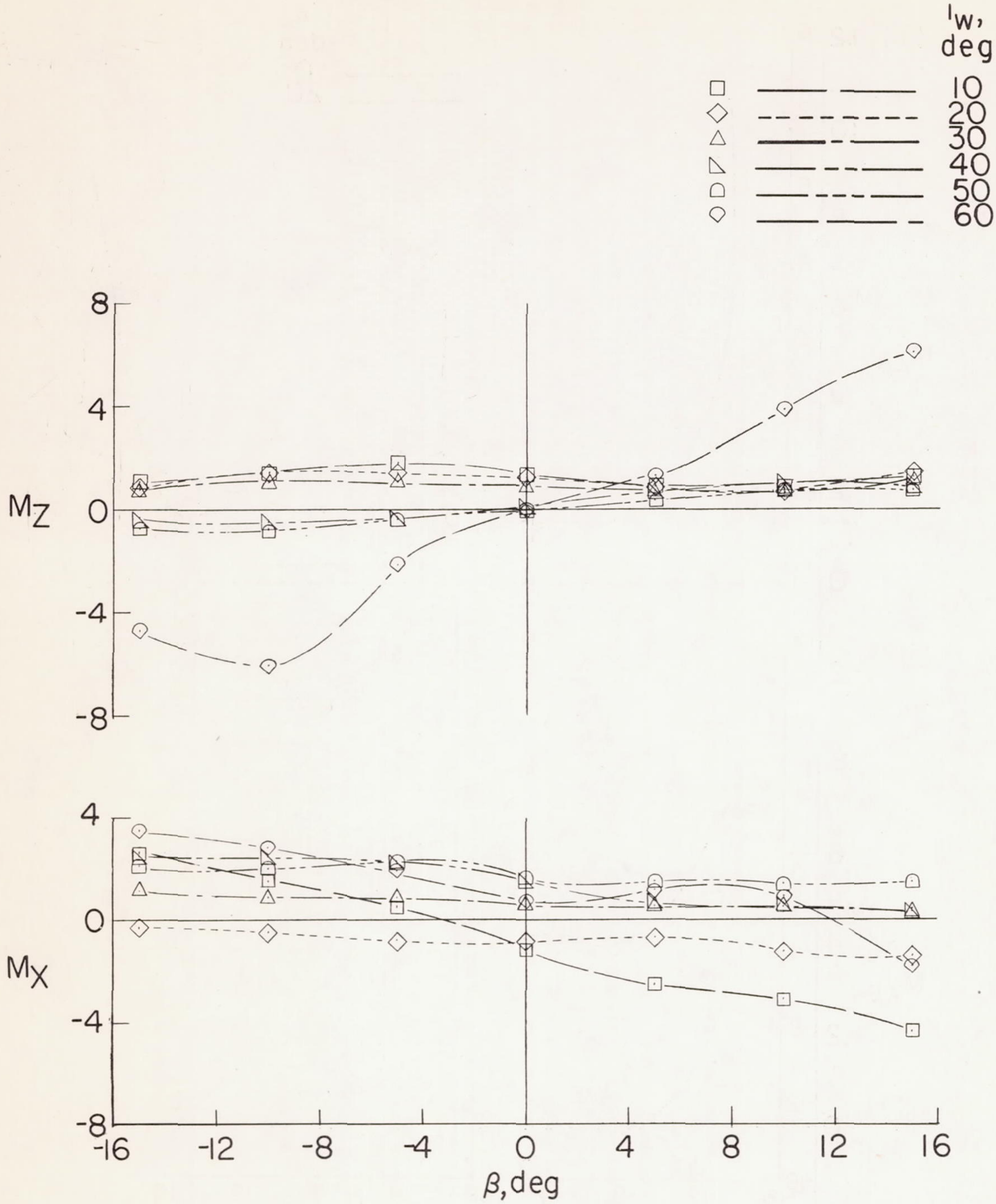


Figure 13.- Roll-control effectiveness.



(a) $\alpha = 0^{\circ}$.

Figure 14.- Lateral stability characteristics of model.



(b) $\alpha = 20^{\circ}$.

Figure 14.- Concluded.

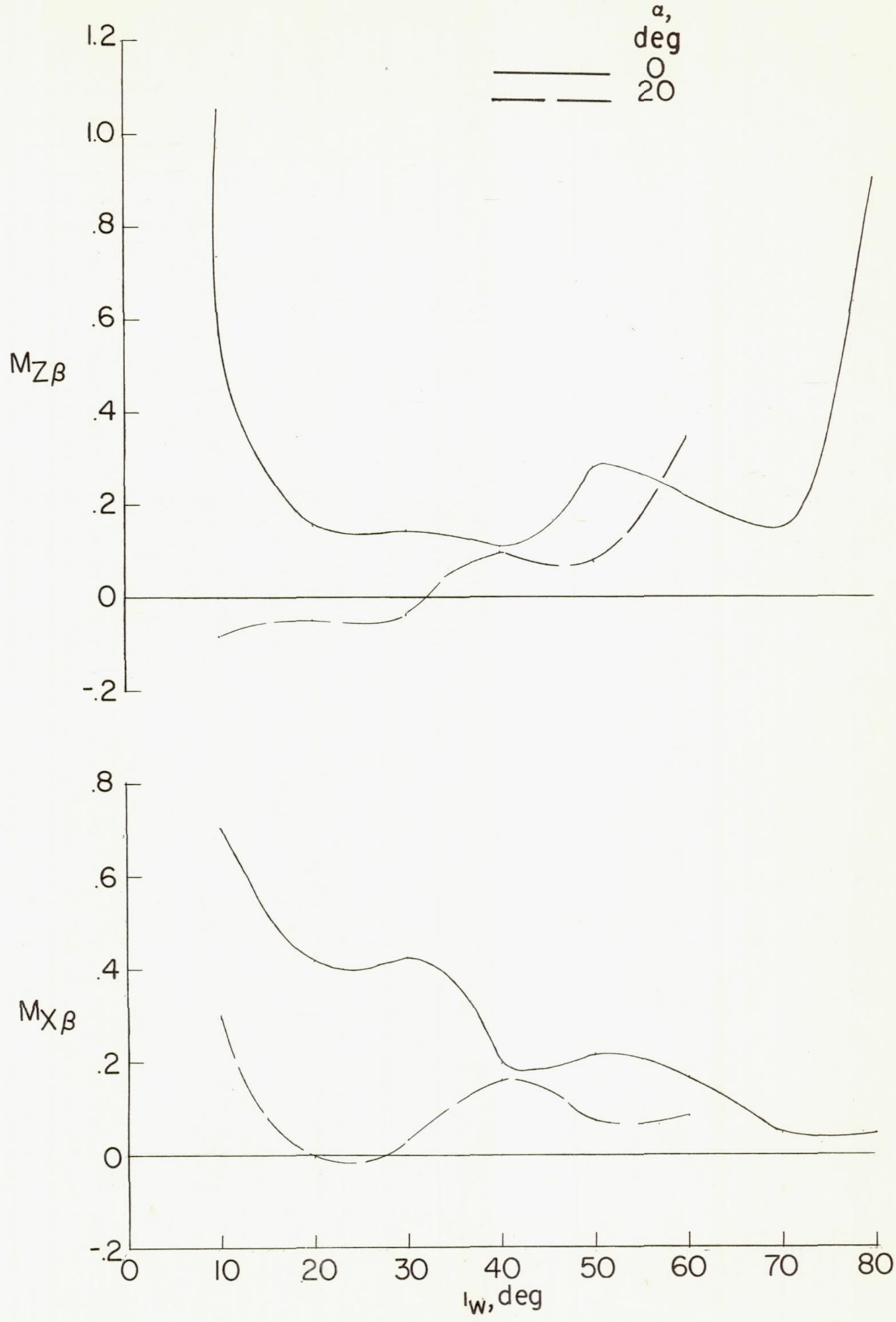


Figure 15.- Directional stability and effective dihedral parameters.