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TECHNICAL NOTE 3912

FLIGHT TESTS OF A MODEL OF A HIGH-WING TRANSPORT
VERTICAL-TAKE-OFF AIRPLANE WITH TILTING WING
AND PROPELLERS AND WITH JET CONTROLS AT
THE REAR OF THE FUSELAGE FOR
PITCH AND YAW CONTROL

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

Langley Aeronautical Laboratory
Langley Field, Va.



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SUMMARY

An investigation of the stability and control of a high-wing transport vertical-take-off airplane with four engines during constant-altitude transitions from hovering to normal forward flight was 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, which was pivoted at 15 percent mean aerodynamic chord, could be rotated to 90° incidence so that the propeller thrust axes were vertical for hovering flight. Jet-reaction controls at the rear of the fuselage provided pitch and yaw control for hovering and low-speed flight. The wing had a trailing-edge flap which was undeflected for one series of tests and deflected 30° for another series.

The model experienced a nose-up change in pitch trim at low speeds in the transition from hovering to forward flight. Because of this trim change, the most rearward center-of-gravity location at which the model could be flown was limited to 8 percent mean aerodynamic chord rearward of the wing pivot point with the wing flaps deflected and 6 percent mean aerodynamic chord rearward of the wing pivot point with the flaps undeflected. When the center of gravity was located rearward of these points, the model experienced a nose-up pitching divergence. The most forward center-of-gravity location at which the model could be flown, which was established only for the flap-deflected case, was 12 percent mean aerodynamic chord forward of the wing pivot point. The lateral stability and control characteristics were generally satisfactory even though the Dutch roll oscillation was lightly damped for certain conditions of air-speed and fuselage attitude. The jet controls at the rear of the fuselage provided good pitch and yaw control throughout the entire speed range.

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 essentially a conventional airplane with the wings and propellers capable of being rotated through an angle of incidence of 90° . In order to determine the feasibility of such an airplane from a stability and control standpoint, a flying model was used to study the flight characteristics in both hovering- and forward-flight conditions. The results of some hovering- and forward-flight tests of a low-wing configuration are presented in references 1 and 2, respectively.

The model used in the investigations of references 1 and 2 was converted into a high-wing model for use in the present investigation. The model had four propellers mounted with the thrust axes in the wing chord plane. The wing was pivoted at 15 percent mean aerodynamic chord, and 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 control characteristics were determined by means of visual observation, the pilots' impressions of the flying qualities of the model, and motion-picture records of the flights. In addition to the flight tests, a few force tests were made in order to provide additional information regarding the static longitudinal stability in forward flight.

SYMBOLS

Force-test data are referred to wind axes, which in this case are the same as stability axes because the model was not yawed. For simplicity in reducing the flight records, time histories of the motions of the model are presented with reference to horizontal and vertical axes which are fixed in space.

The definitions of the symbols used in the present paper are as follows:

D drag, lb

L lift, lb

I_X	moment of inertia about longitudinal body axis, slug-ft ²
I_Y	moment of inertia about spanwise body axis, slug-ft ²
I_Z	moment of inertia about normal body axis, slug-ft ²
M_X	rolling moment, ft-lb
M_Y	pitching moment, referred to center of gravity of model, ft-lb
M_Z	yawing moment, ft-lb
X,Y,Z	body axes
\bar{c}	mean aerodynamic chord
c_t	tail chord
i_w	wing incidence, deg
θ	angle of pitch of fuselage longitudinal axis relative to horizontal, deg
ϕ	angle of roll, deg
ψ	angle of yaw, deg
δ_f	wing flap deflection, deg

MODEL

The model was designed to represent a possible turboprop transport airplane. A photograph of the model is presented in figure 1 and three-view drawings are presented in figures 2 and 3. Table I lists the geometric characteristics of the model. Although the moments of inertia of the high-wing configuration were not measured, they are probably very close to those of the low-wing configuration given in reference 1. 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 of the model, which was pivoted at 15 percent mean aerodynamic chord, 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. The model had a trailing-edge wing flap; the four inboard segments were deflected down in some of the tests to provide pitch trim and additional lift. Conventional elevator, rudder, and ailerons provided control in the normal high-speed flight condition. The outboard segments of the wing flap were used as the ailerons. Jet-reaction controls at the rear of the fuselage provided good pitch and yaw control in hovering and low-speed forward flight. Compressed air, at a pressure of approximately 100 pounds per square inch, was supplied to the jet control unit, and control of pitch and yaw was obtained by varying the amount of discharge. Roll control for hovering and low-speed forward flight was provided by differentially varying the pitch of the outboard propellers.

The controls were deflected by flicker-type (full-on or full-off) pneumatic actuators which were remotely operated by the pilots. The control actuators (equipped with integrating-type trimmers) 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 in order to control the wing incidence. The pitch, roll, and yaw pilots were located at the best available vantage points for observing and controlling the particular phase of the motion with which each was 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. The air for the jet controls and for the control actuators was supplied through plastic tubes. These wires and tubes were suspended overhead and taped to a safety cable (1/16-inch braided aircraft cable) from a point approximately 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 would not appreciably influence the motions of the model.

Pitch control in hovering and low-speed flight was obtained by varying the amount of discharge through the top and bottom orifices of the jet at the rear of the fuselage. The jet control could provide a maximum pitching moment of about ± 11 foot-pounds. The elevator could be switched into or out of the pitch-control circuit, but it usually operated during the entire flight; therefore, it had some effectiveness as soon as the airspeed began to build up. An elevator deflection of $\pm 25^\circ$ was used for low-speed flight and provision was made for reducing the deflection to $\pm 8^\circ$ for high-speed flight in order to prevent overcontrol. 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 pitch-control jet.

Yaw control in hovering and low-speed flight was obtained by varying the amount of discharge through the side orifices of the jet at the rear of the fuselage. The jet control could provide a maximum yawing moment of about ± 6 foot-pounds. The rudder could be switched into or out of the yaw-control circuit at will, but it was seldom used because it was not needed very often in forward flight, and, of course, it was ineffective in hovering and low-speed flight.

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 ailerons with deflections of $\pm 10^\circ$ were switched in, and for the remainder of the flight both the outboard propellers and the ailerons 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.

The test technique is best explained by describing a typical flight. The model hung from the safety cable and the power was increased until the model was in steady hovering flight. At this point the tunnel drive motors were turned on and the airspeed began to increase. As the airspeed increased, the attitude of the fuselage was kept essentially horizontal, the wing incidence was reduced, and the power was adjusted in order to provide the thrust required to balance the drag of the model. At an airspeed of about 25 knots, the roll pilot switched in the ailerons for use as roll control in conjunction with the variable-pitch propellers. At an airspeed of about 45 knots, the pitch pilot reduced the elevator deflection to $\pm 8^\circ$, switched out the pitch-control jet, and used the elevator alone for pitch control for the remainder of the flight. The controls and power were operated to keep the model as near as possible to the center of the test section until a particular phase of the stability and control characteristics was to be studied. Then the pilots performed

the maneuvers required for the particular tests and observed the stability and control characteristics. The flight was terminated by gradually taking up the slack in the safety cable while reducing the power to the model.

TESTS

Flight Tests

Flight tests were made with the wing flaps undeflected, and also with the four inboard segments of the wing flaps deflected 30° . 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 flight characteristics 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 8 percent mean aerodynamic chord behind the wing pivot point to 12 percent mean aerodynamic chord forward of the wing pivot point. The center-of-gravity locations are referred to in the discussion of the flight tests in terms of the location 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 rearward. 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):

δ_f , deg	Center-of-gravity location, percent \bar{c} , for -			
	Hovering flight		Normal forward flight	
	Longitudinal	Vertical	Longitudinal	Vertical
0	8	-9	3	-4
	0	-7	-5	-2
	-6	-8	-11	-3
30	12	-10	7	-5
	0	-7	-5	-2
	-8	-9	-13	-4

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 for the full-scale configuration.

Static Force Tests

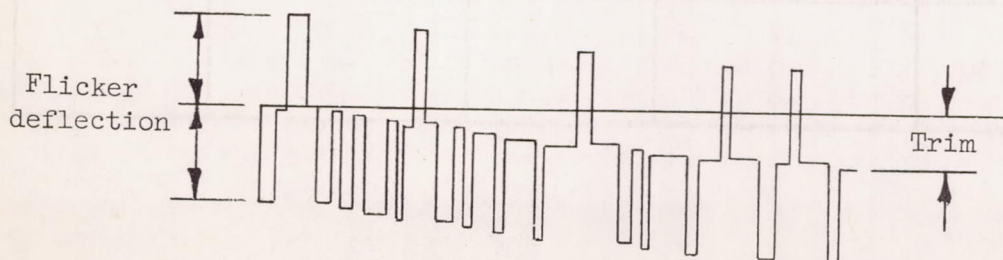
Static force tests were made with the four inboard segments of the wing flap undeflected for one series of tests and deflected 30° down for the remaining tests. Most of the tests were run at one-half the rated rotational speed of the model motor, with the tunnel airspeed adjusted to produce zero net drag on the model for the particular test condition. A few tests were run at less than one-half the rated speed in order to prevent overheating the model motor. The tests were made by pitching the model up and down from a given angle of pitch when the drag had been adjusted to zero for that angle of pitch. All forces and moments have been scaled up to correspond to the flying weight of the model. The pitching moments were computed for the center-of-gravity positions actually obtained at each angle of incidence for the case in which the center of gravity was located directly under the wing pivot point with the wing at 90° incidence.

No tunnel wall or blockage corrections were applied to the static-force-test data because of the lack of an appropriate method of determining them. It is expected that these corrections would be large, since the model was quite large in relation to the test section of the Langley free-flight tunnel where the force tests were made.

RESULTS AND DISCUSSION

The results of the present investigation are illustrated more graphically by 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 as follows:



The horizontal line is a reference line which has its origin at the control trim position required for hovering flight, but not necessarily at 0° deflection. 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 so that if the control is deflected more times in one direction than in the other a change in trim occurs. The trim change, which is indicated at the right of the plot, was computed by adding a small increment of trim in the proper direction each time a control was deflected.

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. The pitch-control records are not completely accurate because control deflections of $\pm 25^\circ$ were assumed in all cases, although at the higher speeds the elevator deflection was reduced to $\pm 8^\circ$ and, usually, the pitch-control jet was switched off.

Longitudinal Stability and Control

Wing flaps undeflected.- With the wing flaps undeflected, successful transition flights were made within a center-of-gravity range from 8 percent mean aerodynamic chord forward to 6 percent mean aerodynamic chord rearward of the wing pivot point. Figure 5 shows a time history of a typical transition flight made with the center of gravity located 8 percent mean aerodynamic chord forward of the wing pivot point. Flights with this center-of-gravity location could be made consistently and easily. No attempt was made to determine the most forward center-of-gravity location for which successful transition flights could be made. Successful flights could probably have been made, however, with the center of gravity located more than 8 percent mean aerodynamic chord forward of the wing pivot point.

When the center of gravity was moved rearward to a position directly under the wing pivot point, successful transition flights could still be made consistently but the model was slightly more difficult to control longitudinally (fig. 6). A comparison of the control-record plots of figures 5 and 6 indicates that more control applications were necessary during the low-speed portion of the flight made with the center of gravity located directly under the wing pivot point.

When the center of gravity was moved rearward still farther to 6 percent mean aerodynamic chord behind the wing pivot point, only about one-half of the transition flights were successful. It was necessary for the pilot to exercise extreme care in the manipulation of the controls in order to prevent a nose-up pitching divergence. Figure 7 shows

a time history of a successful transition flight made with this center-of-gravity location. A comparison of the pitch-control plots of figures 5, 6, and 7 shows the increased difficulty in controlling the longitudinal motions with the more rearward center-of-gravity locations in that more control applications were necessary during these flights than during the flight made with the most forward center-of-gravity location.

The force-test data of figures 8, 9, and 10, which were computed for the center-of-gravity positions actually obtained at each angle of incidence for the case in which the center of gravity was located directly under the wing pivot point with the wing at 90° incidence, indicate that the model had almost neutral longitudinal stability at high wing incidence angles and positive stability at wing incidence angles below 40° . These force-test data also show the pronounced nose-up change in pitch trim which occurred at high incidence angles in the transition. The force-test data of reference 2 show that the low-wing configuration was longitudinally unstable throughout the wing-incidence range when the fuselage was at 0° angle of pitch. The data of reference 2 were obtained with the wing pivoted at the 30-percent mean-aerodynamic-chord location; therefore, those data are not directly comparable with the data of the present investigation. Although no force tests were made with the low-wing configuration for the 15-percent mean-aerodynamic-chord wing pivot location, the flight tests indicated that the model was more unstable with the 30-percent than with the 15-percent mean-aerodynamic-chord wing pivot location. A comparison of the flight-test results for the two model configurations indicates that the high-wing configuration was more stable than the low-wing configuration. This stability is indicated by the fact that the high-wing configuration was much easier to fly than the low-wing configuration within a given center-of-gravity range, and also by the fact that the high-wing configuration was flown satisfactorily with more rearward center-of-gravity locations than the low-wing configuration.

Wing flaps deflected.- The four inboard segments of the wing flaps were deflected 30° downward in an effort to increase the allowable center-of-gravity range and, as demonstrated possible in the tests of reference 3, to reduce the power required during the low-speed portions of the flights. With the flaps deflected, successful transition flights were made within a range of center-of-gravity locations from 12 percent mean aerodynamic chord forward to 8 percent mean aerodynamic chord rearward of the wing pivot point. Figure 11 shows a time history of a typical transition flight made with the center of gravity located at 8 percent mean aerodynamic chord rearward of the wing pivot point and with the wing flaps deflected 30° . Flights with this rearward center-of-gravity location could be made rather easily if the pilot exercised moderate care during the low-speed portions of the flights. The model had a tendency to nose up at low speeds but, by careful use of the controls, the pilot was usually able to prevent a divergence.

With the center of gravity moved forward to the 12-percent mean-aerodynamic-chord location forward of the wing pivot point, successful transition flights were made consistently and easily. A time history of a flight made with this center-of-gravity location is shown in figure 12. This was the most forward center-of-gravity location which could be trimmed in hovering flight while still maintaining satisfactory pitch control.

The force-test data of figures 13, 14, and 15 show that, in general, the model had almost neutral longitudinal stability for wing incidence angles from 70° to about 40° and positive stability at lower incidence angles.

Figure 16 presents a time history of a flight made with the wing flaps deflected 30° and with the center of gravity located directly under the wing pivot point. In this flight an attempt was made to demonstrate a transition to high speed and back again to hovering flight, but the model motor became overheated and it was necessary to terminate the flight before the tunnel airspeed dropped to zero.

Lateral Stability and Control

In general, the lateral stability and control characteristics were satisfactory throughout the flight range except that, for certain conditions of airspeed and fuselage attitude, the Dutch roll oscillation was lightly damped. The lightly damped Dutch roll oscillation, however, did not present any problem in controlling the model if the ailerons were switched into the roll-control circuit at the proper time - at about 25 knots. Reference 2 contains a detailed discussion of the Dutch roll characteristics of the low-wing configuration. The model of the present investigation had similar Dutch roll stability characteristics, and since proper use of the roll controls - switching in the ailerons at speeds above 25 knots - eliminated the difficulty in controlling the model, the detailed discussion is not repeated herein.

CONCLUDING REMARKS

The following remarks are based on data obtained from constant-altitude transition flight tests of a model of a high-wing transport vertical-take-off airplane model with tilting wing and propellers, and with jet controls at the rear of the fuselage for pitch and yaw control:

1. The model experienced a nose-up change in pitch trim at low speeds in the transition from hovering to forward flight. Because of this trim change, the most rearward center-of-gravity location at which

the model could be flown was limited to 8 percent mean aerodynamic chord rearward of the wing pivot point with the wing flaps deflected 30° down and 6 percent mean aerodynamic chord rearward of the wing pivot point with the flaps undeflected. When the center of gravity was rearward of these points, the model experienced a nose-up pitching divergence. The most forward center-of-gravity location at which the model could be flown, which was established only for the flap-deflected case, was 12 percent mean aerodynamic chord forward of the wing pivot point.

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

3. The jet controls at the rear of the fuselage provided good pitch and yaw control throughout the entire speed range.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., October 11, 1956.

REFERENCES

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.
2. Lovell, Powell M., Jr., and Parlett, Lysle P.: Transition-Flight Tests of a Model of a Low-Wing Transport Vertical-Take-Off Airplane With Tilting Wing and Propellers. NACA TN 3745, 1956.
3. Kuhn, Richard E., and Draper, John W.: An Investigation of a Wing-Propeller Configuration Employing Large-Chord Plain Flaps and Large-Diameter Propellers for Low-Speed Flight and Vertical Take-Off. NACA TN 3307, 1954.

TABLE I

GEOMETRIC CHARACTERISTICS OF MODEL

Weight, lb	75.0
Moment of inertia for center of gravity directly below wing pivot:	
I_X , slug-ft ²	2.58 (approx.)
I_Y , slug-ft ²	3.05 (approx.)
I_Z , slug-ft ²	5.13 (approx.)
Fuselage length, in.	84.8
Propellers (two blades each):	
Diameter, in.	20.0
Solidity (each propeller)	0.079
Wing:	
Pivot point, percent mean aerodynamic chord	15
Sweepback (leading edge), deg	6.0
Airfoil section	NACA 0015
Aspect ratio	5.85
Tip chord, in.	9.4
Root chord (in plane of symmetry), in.	17.6
Taper ratio	0.54
Area (total to plane of symmetry), 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

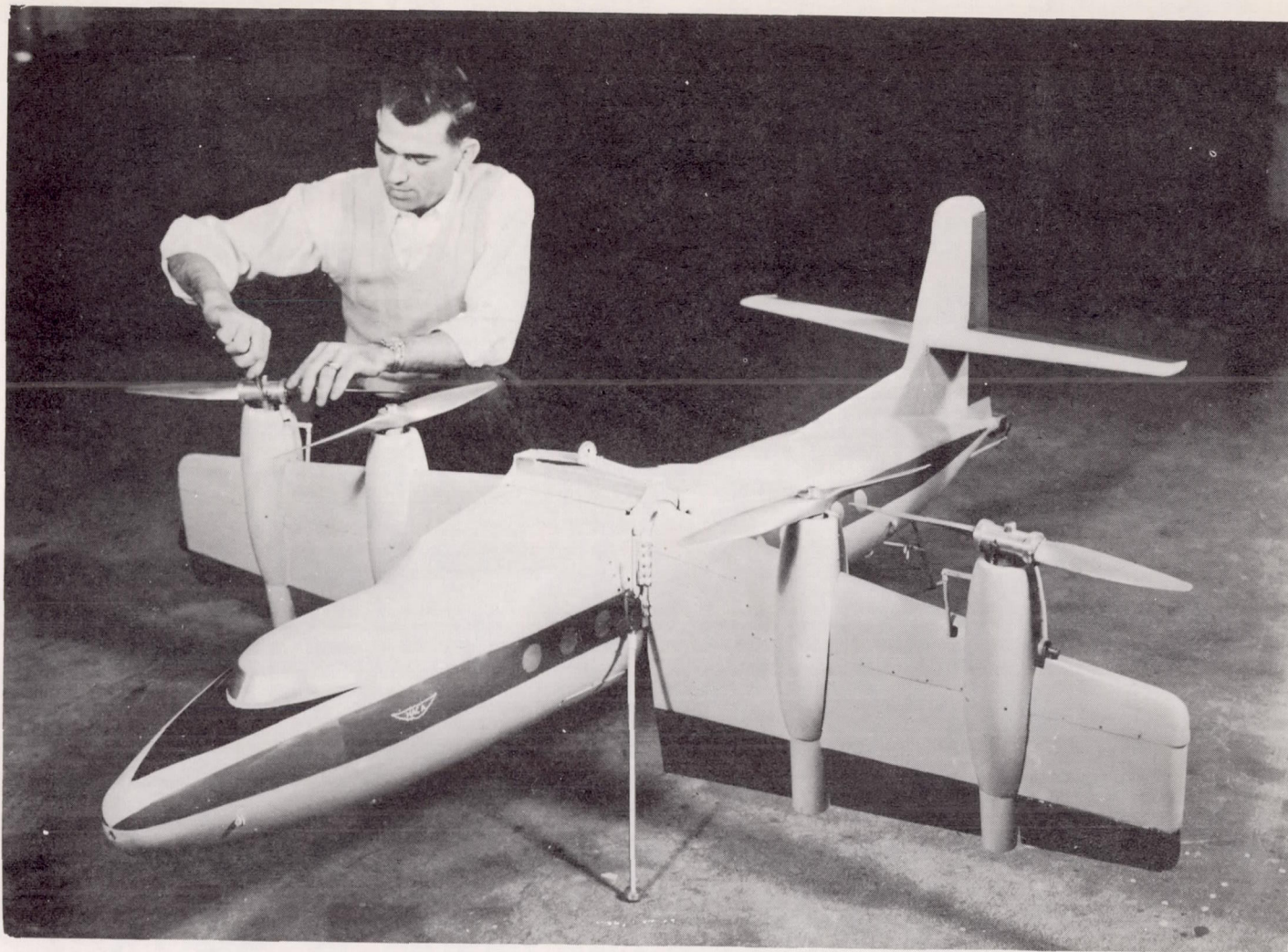


Figure 1.- Photograph of the model in the hovering configuration. L-93039

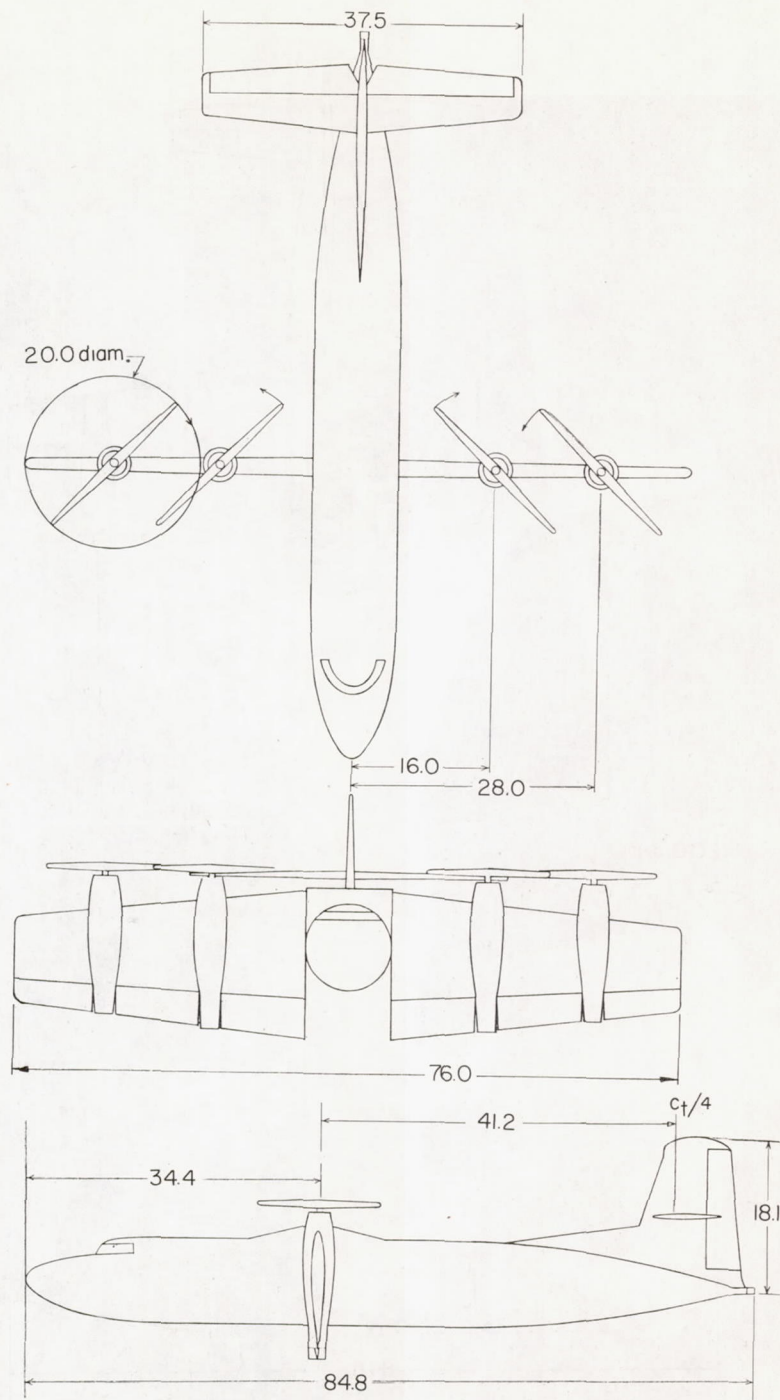


Figure 2.- Three-view sketch of model in hovering configuration. All dimensions are in inches.

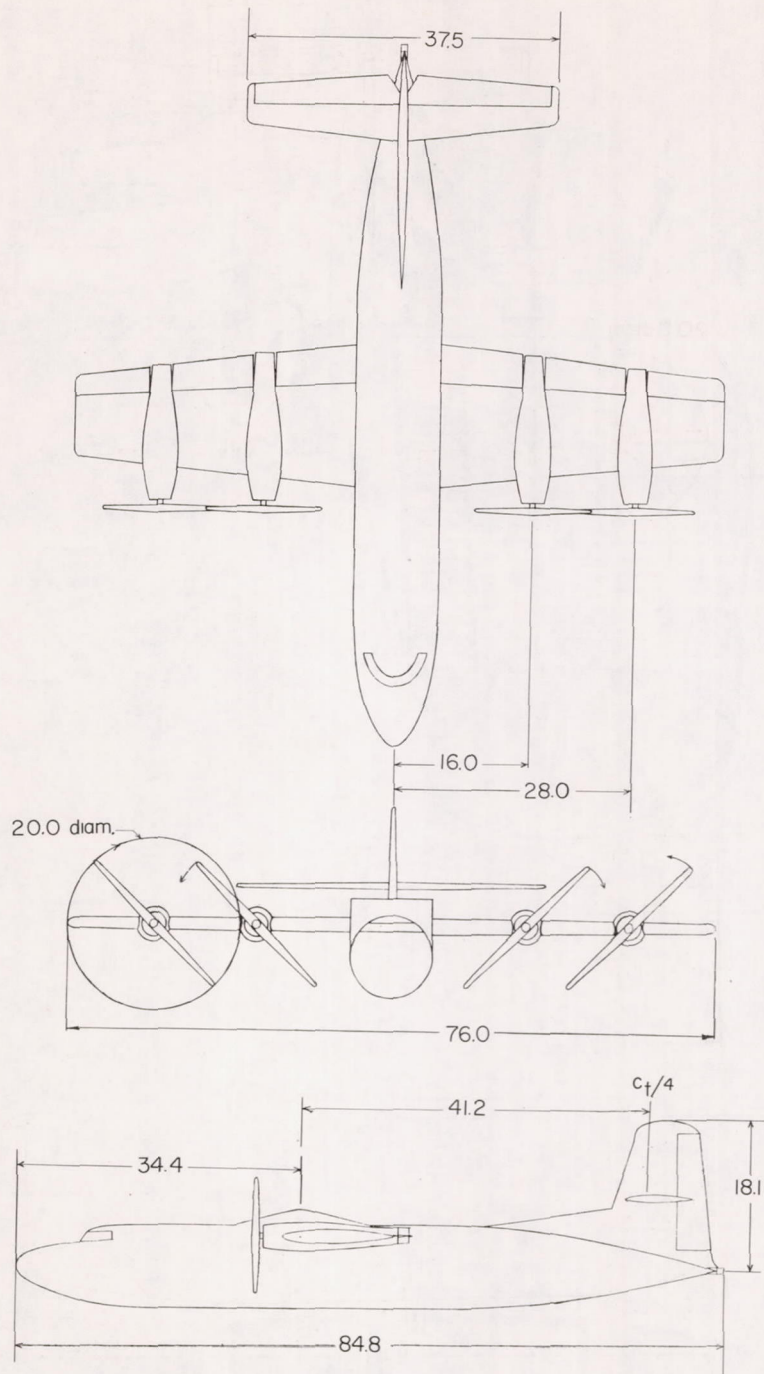


Figure 3.- Three-view sketch of model in forward-flight configuration.
All dimensions are in inches.

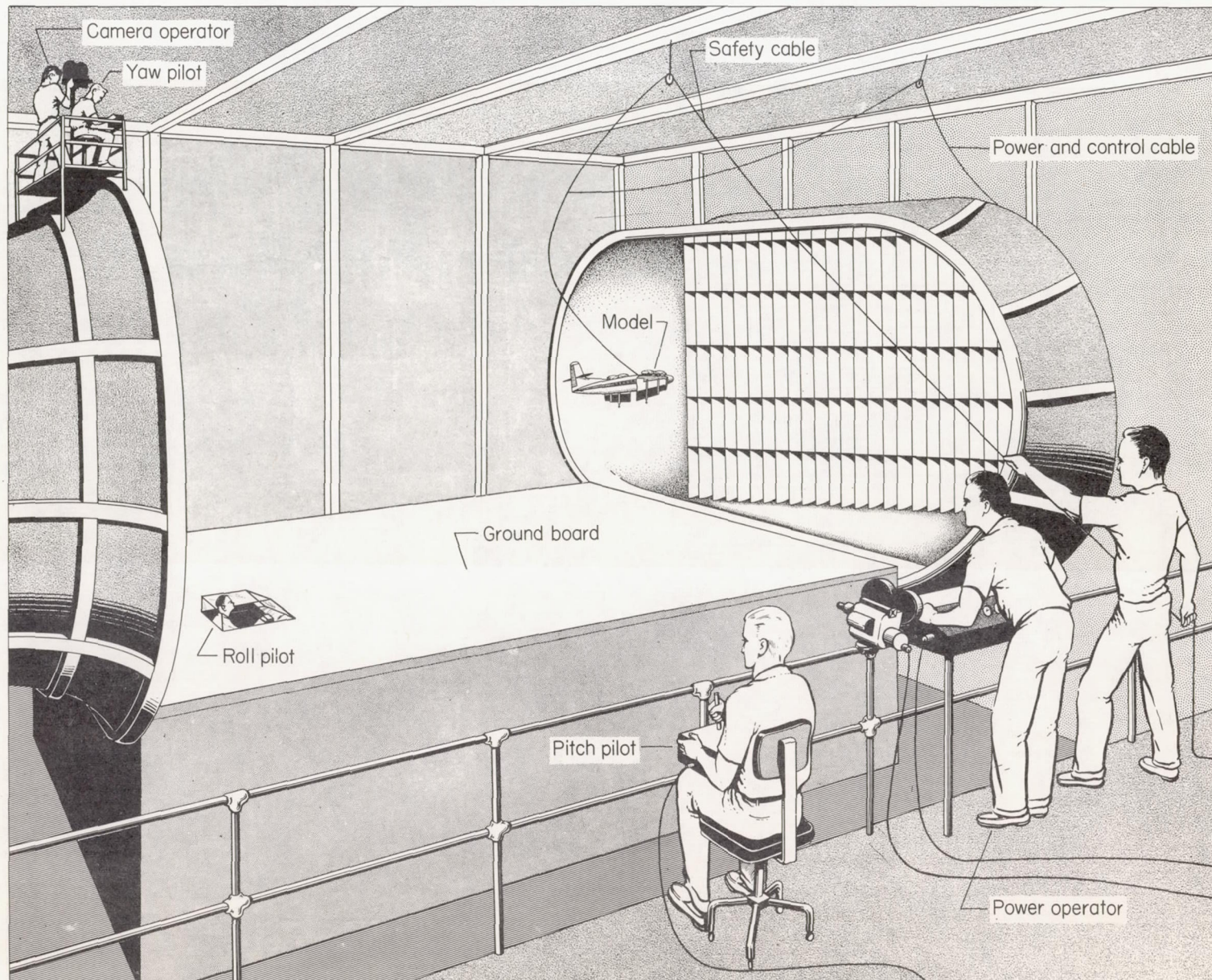


Figure 4.- Sketch of test setup for transition flights.

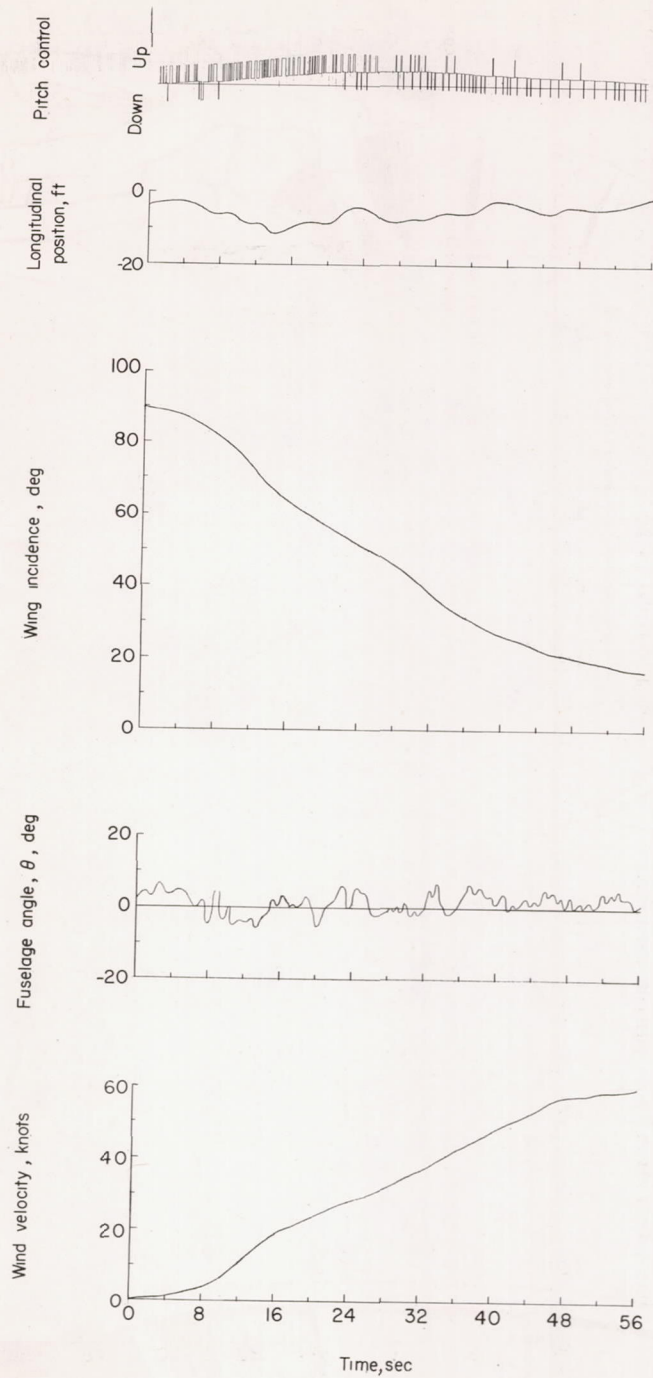


Figure 5.- Time history of a transition flight with center of gravity located 8 percent mean aerodynamic chord forward of wing pivot point. Flaps undeflected.

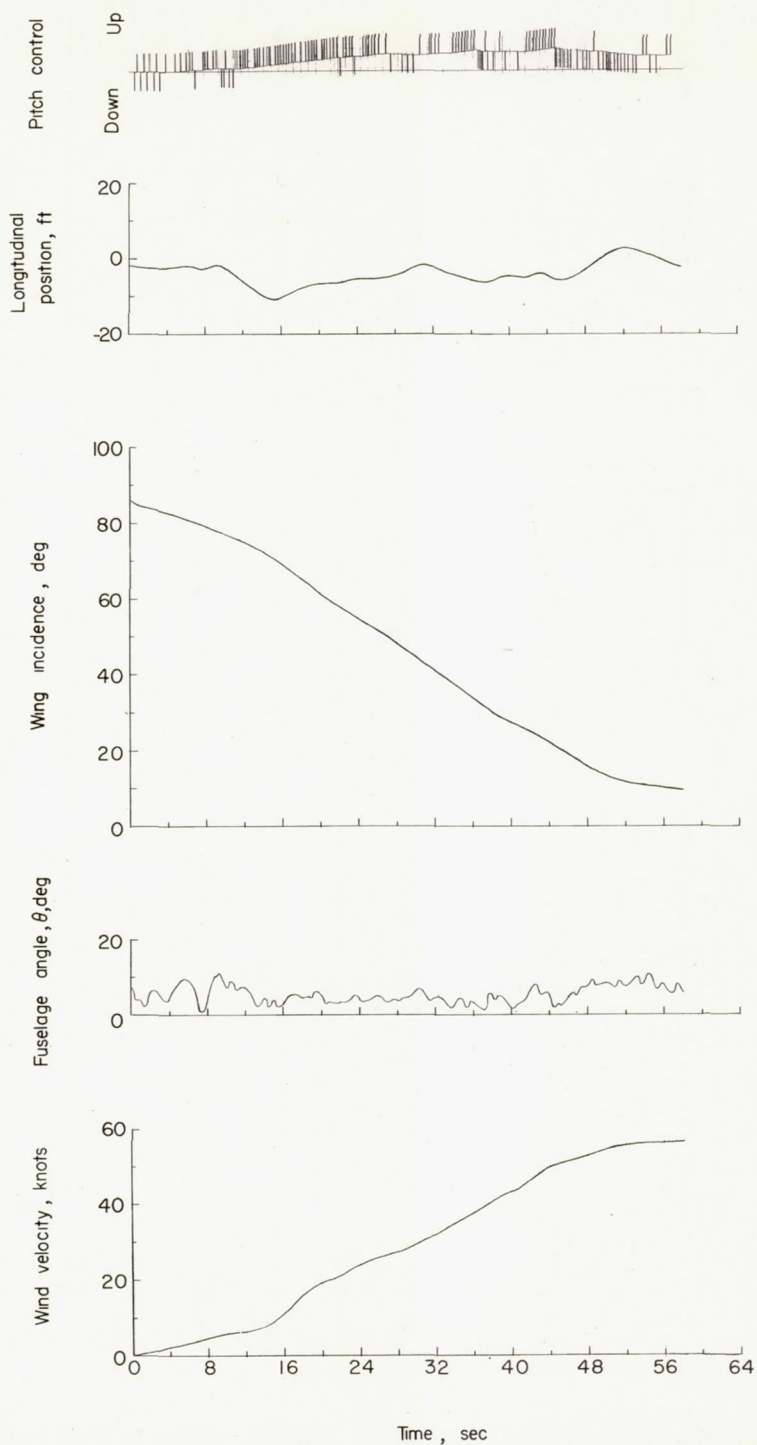


Figure 6.- Time history of a transition flight with center of gravity located directly under wing pivot point. Flaps undeflected.

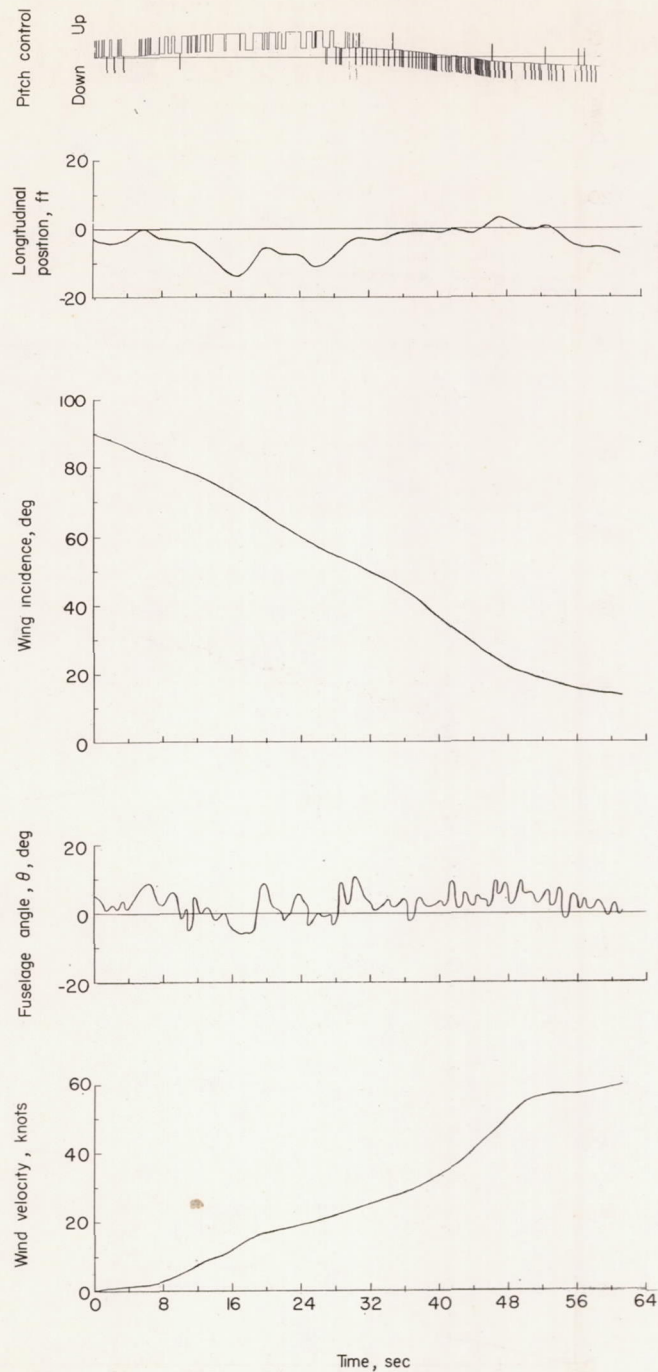


Figure 7.- Time history of a transition flight with center of gravity located 6 percent mean aerodynamic chord rearward of wing pivot point. Flaps undeflected.

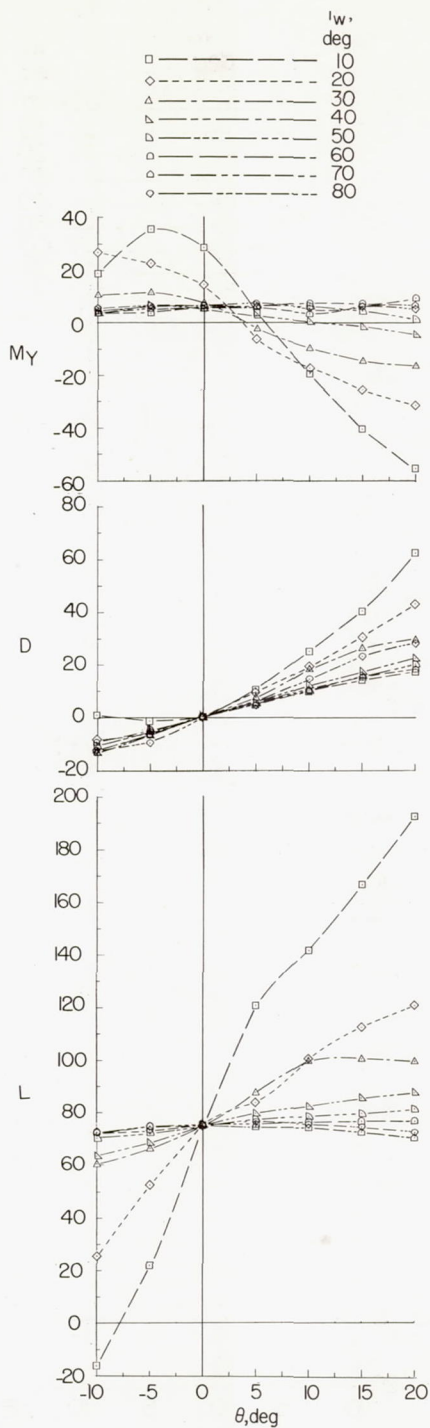


Figure 8.- Longitudinal characteristics of the model with zero drag at 0° fuselage pitch angle. Flaps undeflected.

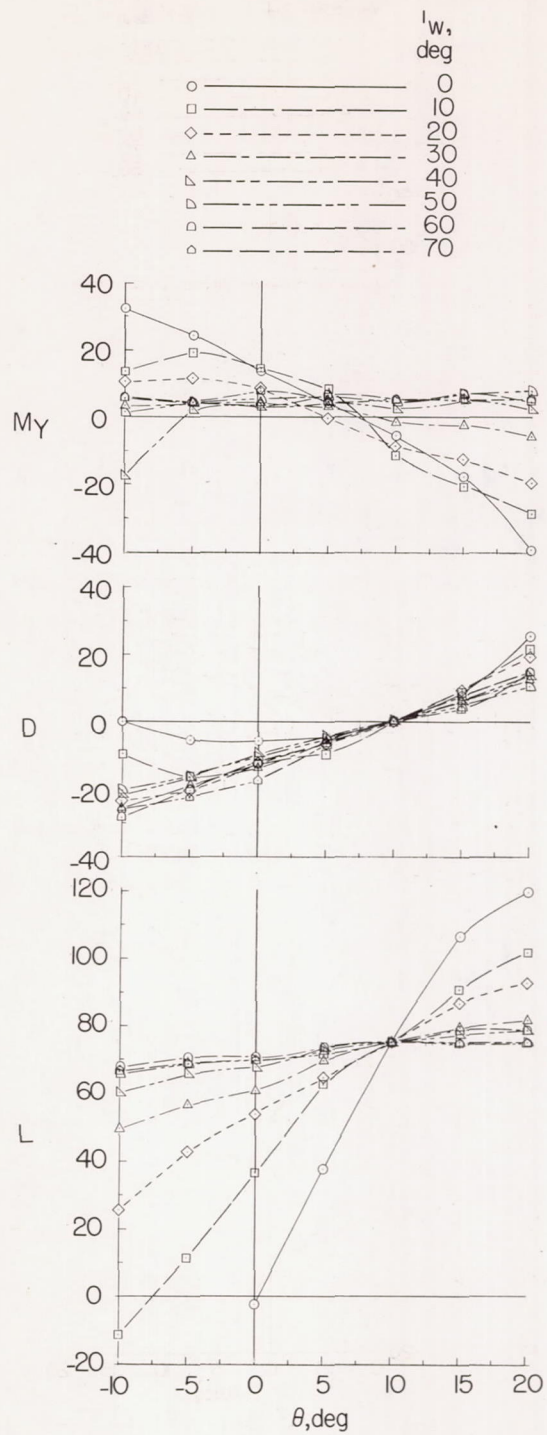


Figure 9.- Longitudinal characteristics of the model with zero drag at 10° fuselage pitch angle. Flaps undeflected.

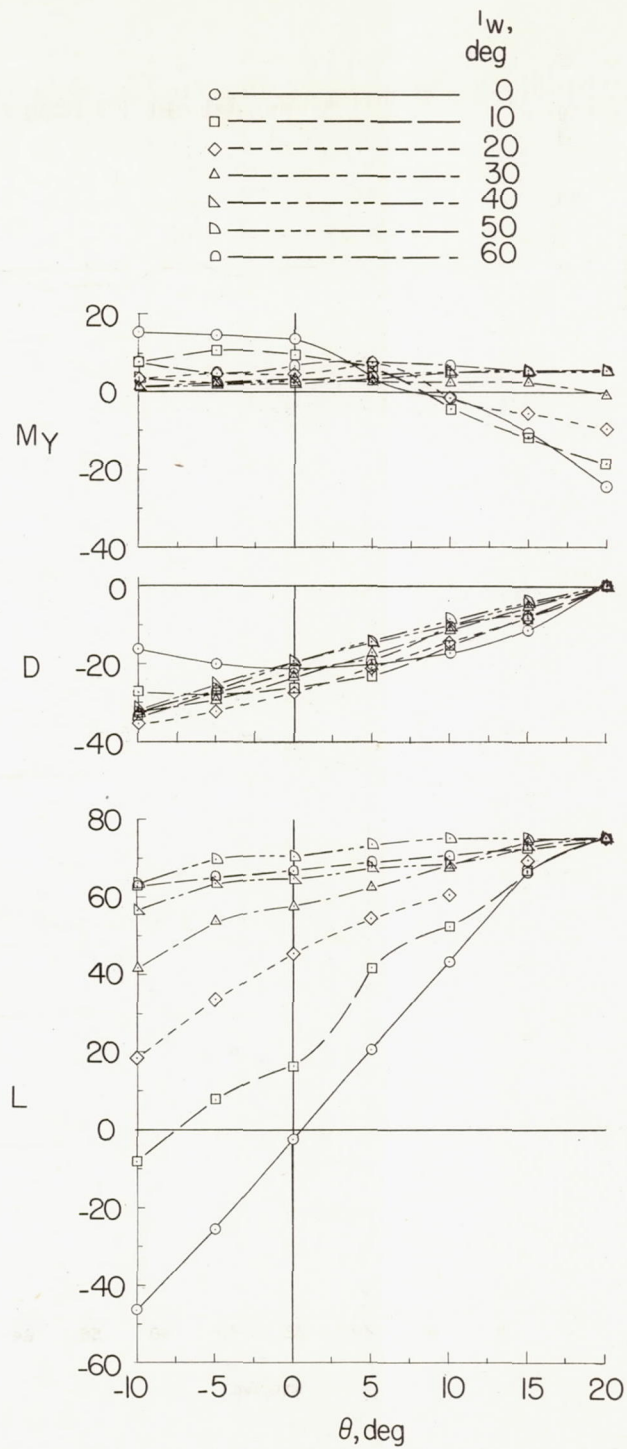


Figure 10.- Longitudinal characteristics of the model with zero drag at 20° fuselage pitch angle. Flaps undeflected.

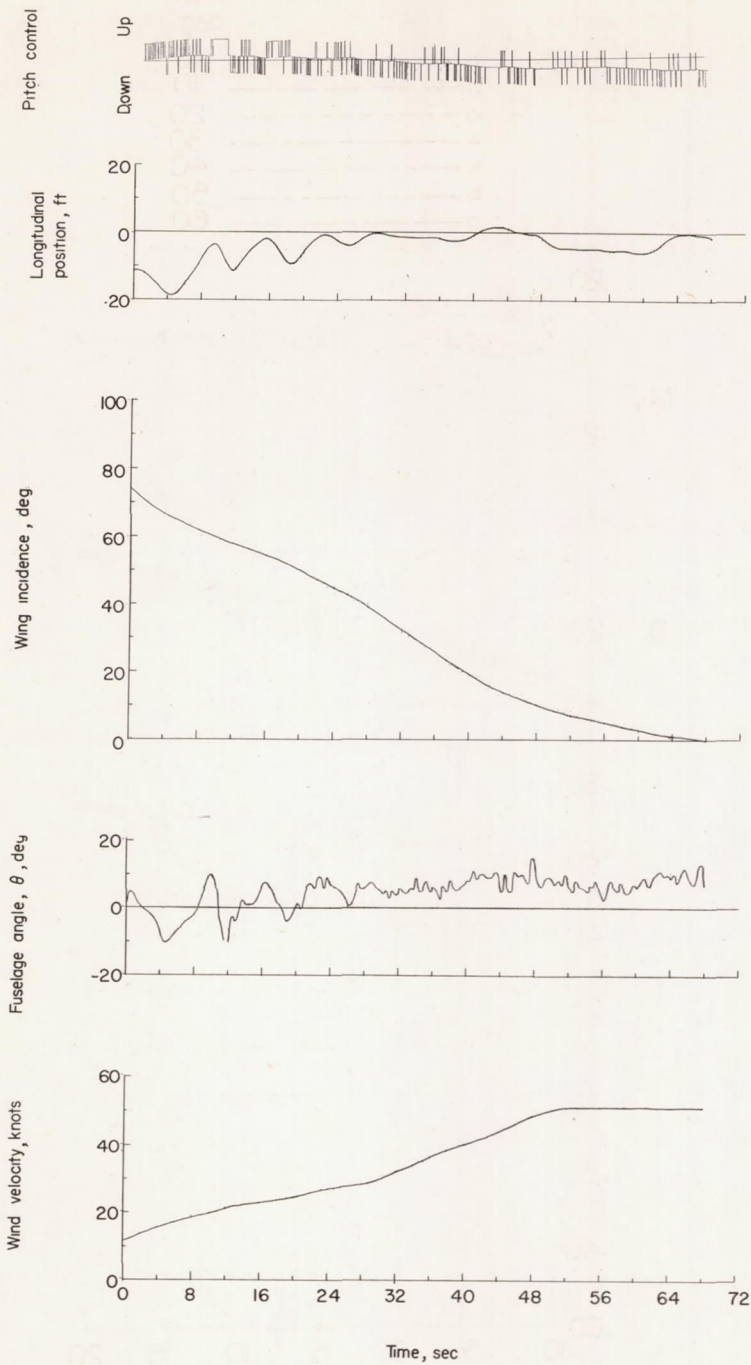


Figure 11.- Time history of a transition flight with center of gravity located 8 percent mean aerodynamic chord rearward of wing pivot point. Flaps deflected 30° .

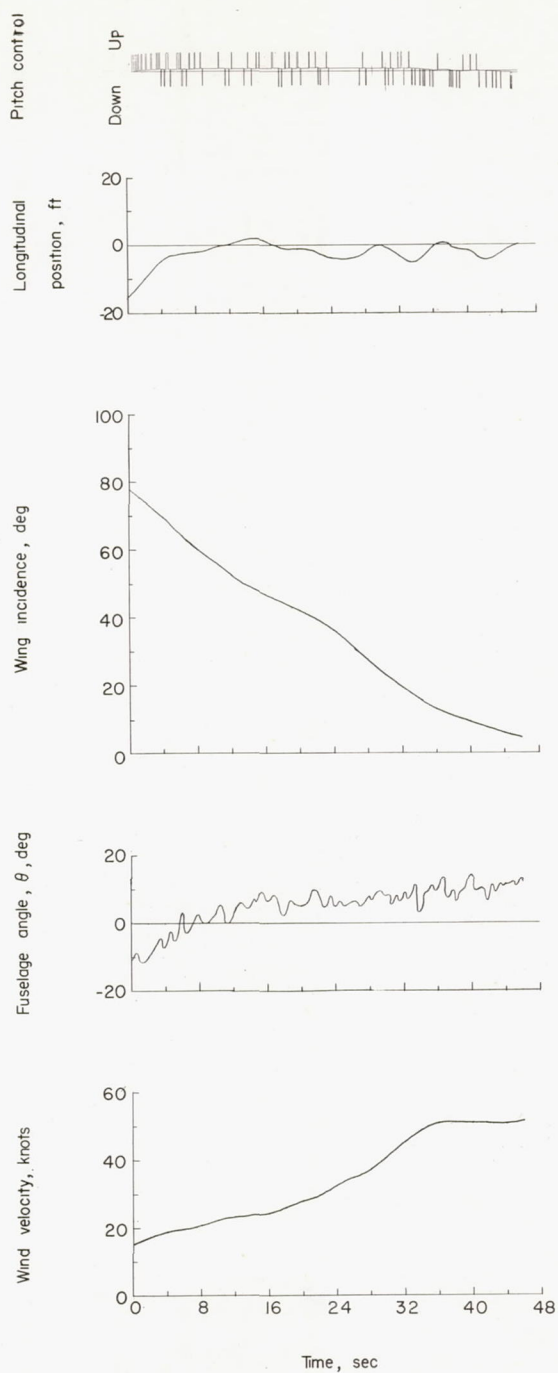


Figure 12.- Time history of a transition flight with center of gravity located 12 percent mean aerodynamic chord forward of wing pivot point. Flaps deflected 30° .

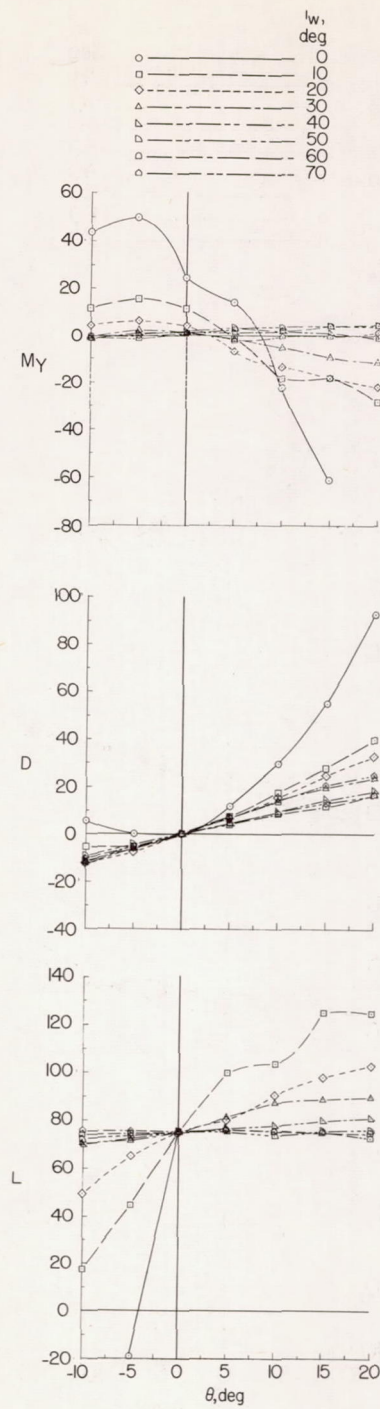


Figure 13.- Longitudinal characteristics of the model with zero drag at 0° fuselage pitch angle. Flaps deflected 30° .

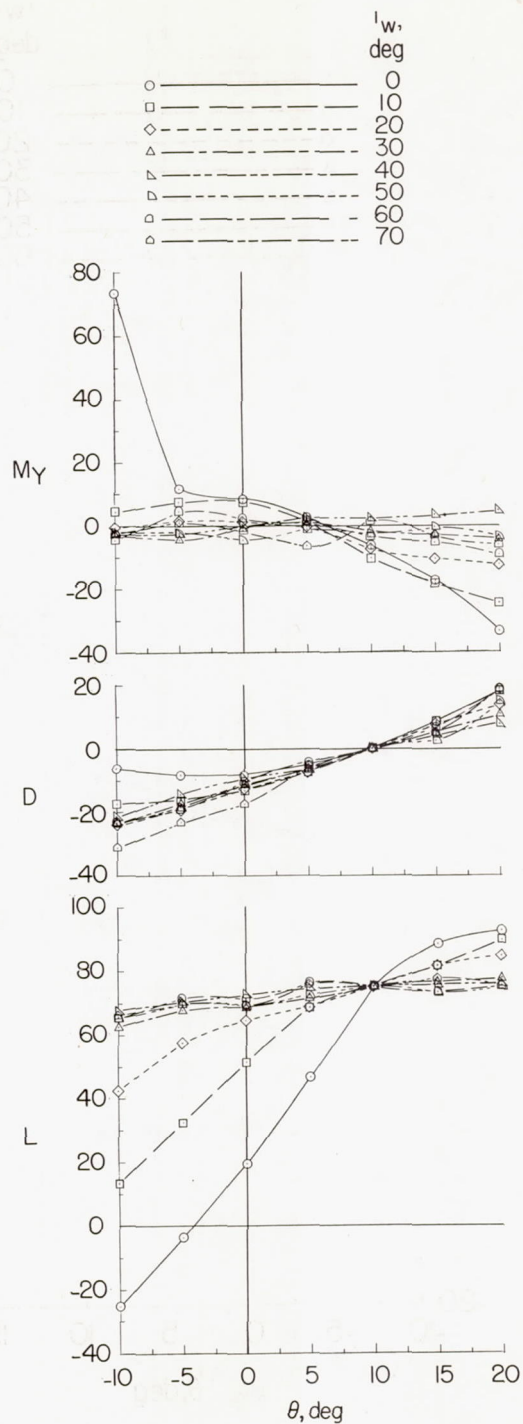


Figure 14.- Longitudinal characteristics of the model with zero drag at 10° fuselage pitch angle. Flaps deflected 30° .

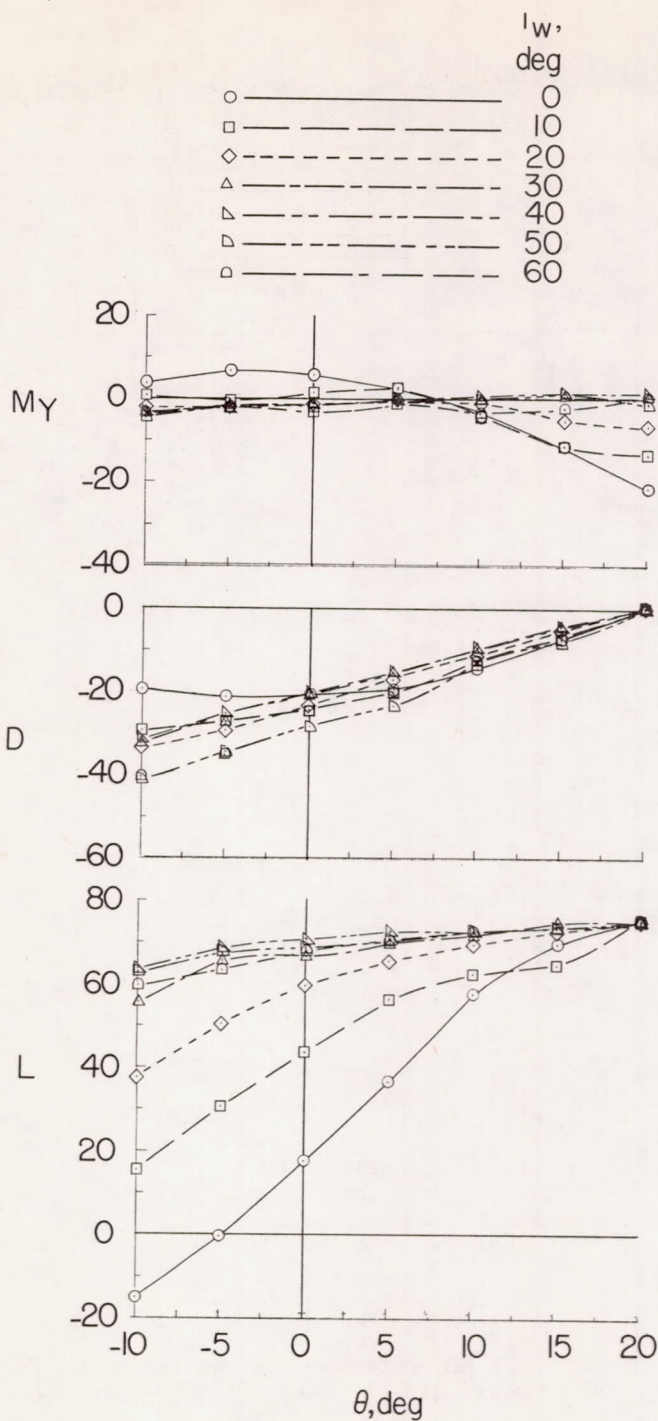


Figure 15.- Longitudinal characteristics of the model with zero drag at 20° fuselage pitch angle. Flaps deflected 30° .

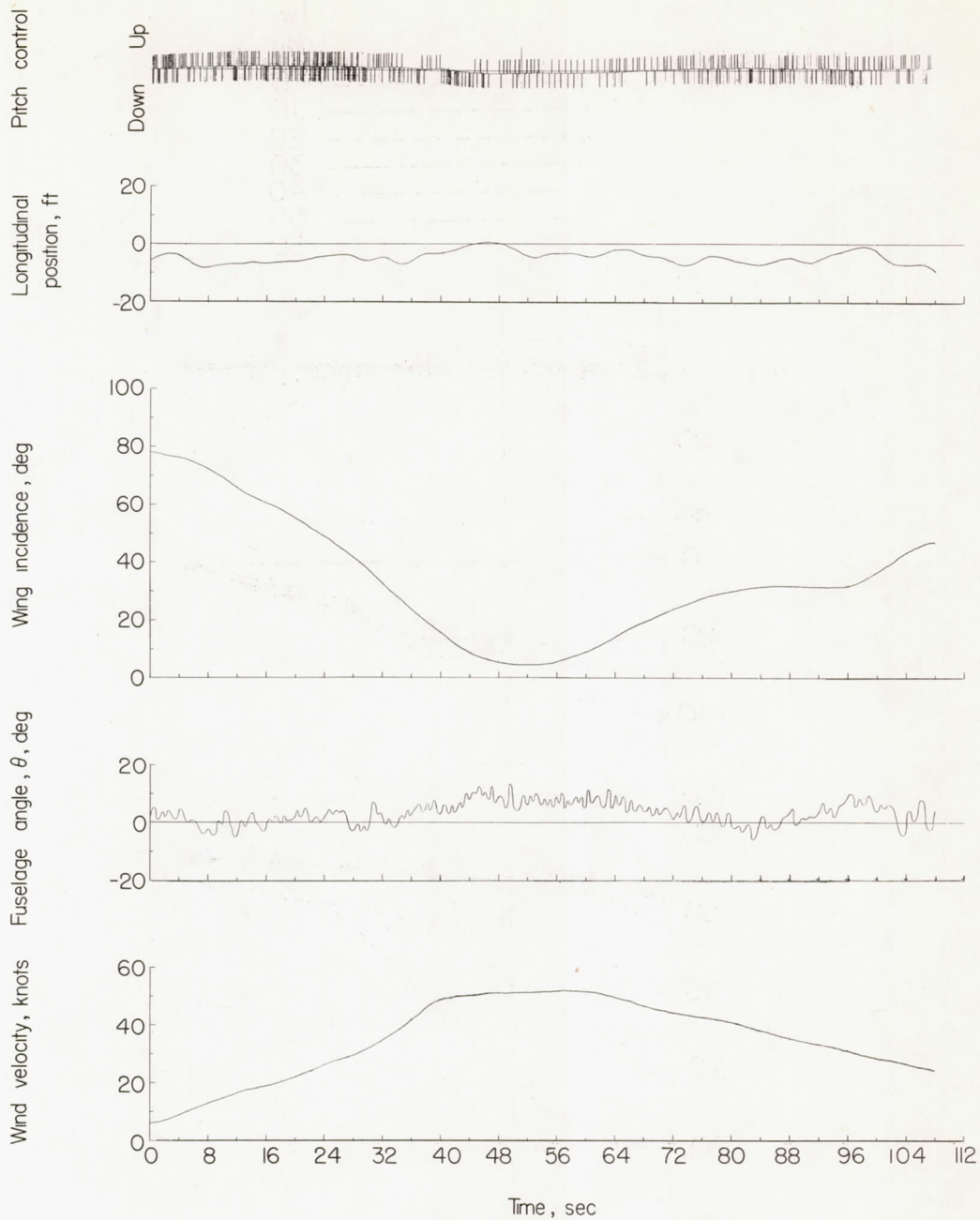


Figure 16.- Time history of an attempted transition to high speed and back to hovering flight with center of gravity directly under wing pivot point. Flaps deflected 30° .