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RESEARCH MEMORANDUM

for the

Bureau of Aeronautics, Department of the Navy

STABILITY AND CONTROL FLIGHT TESTS OF A VERTICALLY RISING AIRPLANE MODEL SIMILAR TO THE LOCKHEED XFV-1 AIRPLANE

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NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

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SUMMARY

This paper presents the results of an investigation of the dynamic stability and controllability of a model which approximately represents the Lockheed XFV-1 airplane to a 1/8 scale. The investigation consisted of hovering flights in still air at a considerable height above the ground, hovering flights very close to the ground, vertical take-offs and landings, flights through the transition range from hovering to normal forward flight, and sideways translational flights.

The model could be flown smoothly and easily in hovering flight despite the fact that the uncontrolled pitching and yawing motions were unstable oscillations. There was a noticeable reduction in the controllability of the model when hovered very close to the ground but take-offs could be made easily and landings on a given spot could be made accurately in spite of this adverse ground effect. Flights through the transition range from hovering to normal forward flight could be performed fairly easily. The model seemed to have stability of angle of attack and angle of roll over most of the transition range. The yawing motion was divergent in the very high angle-of-attack range but could be controlled easily. At the lower angles of attack, the model seemed to become stable in yaw. In sideways flight there was an increasingly strong tendency to diverge in roll as the speed was increased and finally, at a speed of about 25 knots (full scale), the model rolled off despite efforts of the pilot to control it.

INTRODUCTION

An investigation is being conducted to determine the dynamic stability and control characteristics of a general research propeller-driven vertically rising airplane model which can be equipped with interchangeable swept or unswept wings and X or + tails. The present paper presents the results of an investigation of the dynamic stability and controllability of the model in a configuration which approximately represents the Lockheed XFV-1 airplane to a 1/8 scale. The model has a counterrotating propeller, a tapered unswept wing, and a sweptback X-tail. There are no control surfaces on the wing. All the control (roll, yaw, and pitch) is provided by the tail control surfaces, which have been termed "tailerons" by Lockheed.

Tests of a 1/4-scale flying model of the Lockheed XFV-1 airplane were made at the Ames Aeronautical Laboratory and the results are reported in reference 1. In that investigation the pilot was unable to fly the model without automatic stabilization - a result which appeared to be in disagreement with results obtained at the Langley Laboratory with a number of other vertically rising airplane configurations. In order to resolve this apparent discrepancy and to study the stability and control of the Lockheed XFV-1 configuration in more detail, the present investigation was undertaken.

The investigation included hovering flights in still air at a considerable height above the ground, hovering flights very close to the ground, and vertical take-offs and landings in still air. Flight tests were also made to study the performance of the model during slow constant-altitude transitions from hovering to normal forward flight with several center-of-gravity locations. Flight tests were also made in sideways translational flight. The results consist primarily of pilots' observations of the stability and controllability of the model. In some cases, however, time histories of the motions of the model were obtained from motion-picture records of the flights.

NOMENCLATURE AND SYMBOLS

The terminology used in this paper in referring to the model motions at all angles of attack is the same as that used for a conventional airplane with respect to a body system of axes as shown in figure 1. Angular motion about the fuselage (X) axis is referred to as roll, angular motion about the spanwise (Y) axis is referred to as pitch, and angular motion about the normal (Z) axis is referred to as yaw. Figure 1 shows the positive directions of the forces, moments, and linear and angular displacements.

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

θ	angles of pitch of thrust axis relative to horizontal, deg
ψ	angle of yaw, deg
ϕ	angle of bank, deg
α	angle of attack, deg
V	tunnel airspeed in forward-flight tests, knots
M	pitching moment, ft-lb
L	rolling moment, ft-lb
N	yawing moment, ft-lb
y	displacement along Y-axis, ft
z	displacement along Z-axis, ft
h	height of landing gear above ground, ft
t	time, sec
w	weight, lb
δ_e	deflection of tailerons as elevator, deg
δ_r	deflection of tailerons as rudders, deg
δ_a	deflection of tailerons as ailerons, deg
I_X	moment of inertia about fuselage axis, slug-ft^2
I_Y	moment of inertia about spanwise axis, slug-ft^2
I_Z	moment of inertia about normal axis, slug-ft^2

APPARATUS AND TESTS

Model

A photograph of the model is shown in figure 2 and a sketch showing some of the more important dimensions along with a table of geometric characteristics is presented in figure 3. The model approximately represents the Lockheed XFV-1 airplane to a 1/8 scale. It has a tapered unswept wing, a sweptback X-tail, and an 8-blade, counterrotating, fixed-pitch propeller (two four-blade elements in tandem) powered by a 5-horsepower electric motor, the speed of which was changed to vary the thrust. The model was provided with shock struts which used metered oil damping and an air spring. The wire propeller guard, shown in the photograph of figure 2, prevents the slack in the flight cable from becoming fouled in the propellers during flight. The curved steel rod, which extends from the nose of the model around the propeller guard to a point on the fuselage near the center of gravity is part of the safety cable system which will be explained in the section entitled "Test Equipment and Setup."

There are no control surfaces on the wing. All the control is provided by the tail control surfaces (which are called "tailerons" by Lockheed.) All four tailerons on the X-tail move to give either pitch, yaw, or roll. These control surfaces were remotely operated by the pilots by means of flicker-type (full-on or off) pneumatic actuators which were controlled by electric solenoids. These actuators were equipped with an integrating-type trimmer which trimmed the control a small amount in the direction the control was moved each time a control deflection was applied.

The weight and moments of inertia of the model were:

Weight, lb	40
I_X, slug-ft^2	0.35
I_Y, slug-ft^2	1.65
I_Z, slug-ft^2	1.78

As pointed out previously, the model was not an exact scale model of the Lockheed XFV-1 airplane because it was designed as a simplified general research model which could be equipped with various wings and tails. It is believed, however, that the results presented in this paper would not differ appreciably from results that would be obtained with an exact scale model.

Test Equipment and Setup

The take-off, landing, and hovering tests were conducted in a large building which provides protection from the random effects of outside air currents. The forward and sideways flight tests were conducted in the Langley full-scale tunnel.

The test setup used in the hovering tests is illustrated in figure 4(a). The power for the motor and electric solenoids and the air for the control actuators were supplied through wires and plastic tubes which, for most of the tests, were suspended from above and taped to the safety cable from a point about 15 feet above the model down to the model itself. The safety cable, which was attached to the nose of the model for the hovering tests, was used to prevent crashes in case of control failure. In the investigation reported in reference 1 on the 1/4-scale model of the Lockheed XFV-1 airplane, the flight cable trailed downward from a point near the center of gravity and only the safety cable came in from above. A few flights were therefore made in hovering in the present investigation by using this trailing-cable technique to determine whether the cable configuration had any significant effect on the flight results.

The test setup for the transition tests in the Langley full-scale tunnel is illustrated in figure 4(b). The arrangement of the power and control cable and the safety cable was similar to that for hovering except for the attachment of the cables to the model. For the transition tests, a curved steel rod was attached to the nose of the model and to the fuselage at a point near the center of gravity as shown in figure 5. The cable was attached to a pulley which could run on the steel rod from the nose to a point near the center of gravity as the model went from hovering to forward flight. With this setup, the line of action of the drag of the flight cable passed approximately through the center of gravity of the model and did not cause large pitching moments when the model was in forward flight.

For most of the tests, separate pilots were used to control the model in pitch, roll, and yaw in order that they might give careful attention to studying the motions of the model about each of the axes. In the tests reported in reference 1 a single pilot operated all the controls. For this reason, a few hovering flights were made in the present investigation with one pilot operating all the controls to demonstrate the controllability of the model with a single pilot. Two operators in addition to the pilots were used in flying the model - one to control the power to the propellers and one to operate the safety cable to maintain a reasonable amount of slack.

No automatic stabilization was used in the tests except for a few of the transition flights in which a rate-gyro yaw-damping device was used. This damping device consisted of a rate gyroscope which provided the signal to a proportional-type control actuator which moved the yaw control in proportion to the yawing velocity. The yaw damper was equipped with manual override with which the pilot could bias the output of the yaw-control actuators and could thereby control the model in yaw.

Tests

The investigation consisted entirely of flight tests to study the stability and control characteristics of the model. The stability and controllability were determined in various cases, either qualitatively from the pilots' observations or quantitatively from motion-picture records of the flights.

The take-off tests were made by rapidly increasing the power to the propellers until the model rose from the ground. The power operator then adjusted the power for hovering and the model was stabilized at a height of about 8 feet above the ground. For the landing tests, the power operator reduced the power so that the model descended slowly until the landing gear was about 8 inches above the ground. At this point, the power was reduced as quickly as possible and the model settled to the ground on the shock struts.

Hovering-flight tests were made in still air at a height of 15 to 20 feet above the ground to determine the basic stability and control characteristics of the model. For all these flights, it was possible to obtain the pilots' opinion of the stability and controllability of the model. In some of the flights, quantitative indications of the stability of the model were obtained by taking motion-picture records of the uncontrolled pitching and yawing oscillations. In other flights, quantitative data on the controllability of the model were obtained by making motion-picture records to show the ability of the pilot to stop the pitching and yawing oscillations after they had been allowed to build up. Hovering-flight tests at altitude were made with both the overhead and trailing-cable techniques to determine whether the cable arrangement had any significant effect on the uncontrolled motions of the model.

Hovering-flight tests were also made near the ground with the overhead-cable technique to determine the effect of the proximity of the ground on the flight behavior of the model. These tests were made with the control surfaces from about 3 to 12 inches above the ground. They consisted entirely of controlled flights since it was impossible to maintain the height of the model in uncontrolled flight.

The transition tests were made by starting with the model hovering in the test section of the full-scale tunnel at zero airspeed. As the airspeed was increased, the pitch pilot tilted the model progressively farther into the wind to hold its fore-and-aft position in the test section during the transition. These flights were slow constant-altitude transitions covering a speed range from about 0 to 45 knots which corresponded to full-scale airspeeds of 0 to 120 knots. Since small adjustments or corrections could not be made readily in the tunnel airspeed, the pitch pilot and power operator had continually to make adjustments to hold the model in the center of the test section. Flights were also made in which the airspeed was held constant at intermediate speeds so that the stability and control characteristics at constant speed could be studied.

Flights were made to determine whether the model could be flown at fairly high translational speeds sideways. The full-scale airplane might have to approach for a landing in this manner because of the limited visibility along the Z-axis. The technique used for these tests was the same as that used for the forward flights. The tests were started with model in hovering flight and as the airspeed was increased the controls were operated so that the model flew sideways into the wind. These tests covered a speed range of about 0 to 9 knots. These flights were of necessarily limited duration since they took place while the tunnel speed was building up to the minimum steady speed of 23 knots provided by the tunnel control.

The center of gravity was at 0.12 mean aerodynamic chord for the hovering tests and was varied from 0.12 to the leading edge of the mean aerodynamic chord for the transition tests. For the sideways translational flights, the center of gravity was at the 0.07 mean-aerodynamic-chord location. The vertical position of the center of gravity was approximately 0.05 mean aerodynamic chord above the thrust line for all test conditions.

The control travels from the trim position provided by the control actuators were approximately:

δ_e, (each surface) . . . . $\pm 13^\circ$
δ_r, (each surface) . . . . $\pm 13^\circ$
δ_a, (each surface) . . . . $\pm 12^\circ$

For one condition in the transition tests, 1-inch constant chord-extensions were added to all the tail-control surfaces.

RESULTS AND DISCUSSION

The results of the present investigation are more clearly illustrated 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 NACA Headquarters, Washington, D. C.

Hovering Flight

Hovering flight at altitude.- The hovering flights in which one pilot operated all the controls demonstrated that the model could be flown satisfactorily by a single pilot without any automatic stabilization. It was found that a single pilot could fly the model for an indefinite length of time and a long flight using this technique is shown in the film supplement to this paper. Because it required considerable concentration on the part of the pilot just to fly the model under these conditions, the detailed studies of stability and control in this investigation were made with three pilots flying the model.

The model could be flown smoothly and easily in hovering flight and could be maneuvered to any desired position either in yaw or pitch. Figure 6 presents time histories of flights in which the pilots intentionally moved the model from one position to another in the test area and flew it steadily for a short time in each position. It is evident from these records that the pilot could move the model rapidly from one position to another and restore it to a fairly steady flight condition quickly in either pitch or yaw with very little overshoot or evidence of tendency to overcontrol.

These results appear to be in disagreement with the results of reference 1, which indicated that the pilot was unable to fly the model without automatic stabilization. Although the reasons for this disagreement have not been definitely determined, there are two factors which are probably largely responsible for the disagreement. Extensive experience at the Langley Laboratory with free-flying models has indicated that excessive lag in the control system can lead to difficulties similar to those experienced in flying the model of reference 1 without automatic stabilization. The work at the Langley Laboratory has also indicated that a pilot must have extensive experience at flying dynamic models before he can be expected to perform flight tests of vertically rising airplane models satisfactorily. The pilot of reference 1 had not previously flown dynamic models and it seems likely that during the tests of reference 1 he acquired only a small fraction of the experience normally required for such work.

Time histories of the uncontrolled pitching and yawing motions with the overhead-cable arrangement are presented in figures 7 and 8, respectively. These figures show that the model had unstable pitching and yawing oscillations with this cable arrangement. The time histories are not symmetrical about the horizontal axis in all cases because the model could not be trimmed perfectly. The oscillation is superimposed on the aperiodic motion caused by the out-of-trim moments. Figures 9 and 10 show time histories of the uncontrolled pitching and yawing motions of the model with the trailing-cable arrangement. Comparison of these time histories with those of figures 7 and 8 shows that there was very little change in the uncontrolled motions of the model because of the cable arrangement. Both arrangements show unstable oscillations and the only noticeable difference is that the instability of the pitching motion with the trailing-cable arrangement seems to be somewhat less than that for the overhead-cable arrangement.

The pitch and yaw controls were very powerful and it was relatively easy for the pilot to stop the pitching and yawing motions of the model. As a demonstration of the controllability of the model, the pilot at times allowed the pitching and yawing oscillations to build up and then applied the controls to stop the oscillation. Figures 11 and 12 present time histories of some of these tests with the overhead-cable arrangement and figures 13 and 14 present time histories from tests with the trailing-cable arrangement. These data indicate that the pilot could stop the oscillations and return the model to a near vertical attitude in less than one cycle. These figures show again that the cable arrangement had very little effect on the motions of the model. The fact that the model did not return to zero displacement is not significant since the pilot was not making any effort to stop the model over a particular spot or to return it to zero displacement. In stopping these oscillations, the pilot had no tendency to overcontrol or to reinforce the oscillation. The ease with which he could stop the oscillations can probably be attributed to the fact that the periods of the oscillations were fairly long as well as to the fact that the controls were powerful.

The rolling motions were neutrally stable in hovering as would be expected for this type of vertically rising airplane. It was found that the model could be controlled in roll fairly easily although at times difficulty was experienced because of abrupt changes in roll trim occurring at fairly long intervals. Another model tested by the Langley free-flight tunnel section (refs. 2 to 4) has experienced these random trim changes when flown indoors in the same test area. When this model was flown outdoors on a calm day, however, the random trim changes were greatly reduced in magnitude and caused little difficulty in flying the model. Previous force tests (ref. 5) on the same propellers indicated that the random changes in trim resulted from fluctuations in the induced flow particularly near the periphery of the propeller. These fluctuations in inflow appeared to be caused by the random recirculation of the propeller slipstream in the test area.

It might be inferred from these results that full-scale propeller-driven airplanes of this general type would experience difficulty with roll trim when hovering in gusty winds or in the turbulence created by the recirculation of the propeller slipstream from nearby structures.

The model, of course, had no vertical-position stability but had positive rate-of-climb stability because of the pronounced inverse variation of the thrust of propellers with axial speed. This rate-of-climb stability tended to offset the effect of the time lag in the thrust control so that the model could be maintained at a given height fairly easily.

Hovering near the ground.- In hovering flight with the control surfaces at least 4 feet (full-scale) above the ground, it was easy to maneuver the model or to keep it hovering over a spot for a considerable length of time. At heights less than 4 feet the model was more difficult to fly, especially in pitch, and an uncontrollable pitching oscillation often built up in spite of the pilots' effort to control the motion. This result might be explained by the test data obtained on the vertically rising airplane model of reference 5. These data indicated that there was a reduction in the slipstream velocity over the rear part of the model as it neared the ground; this change in slipstream velocity caused a reduction in static control effectiveness and presumably also caused a reduction in the damping in pitch and yaw.

These ground-effect tests were made with the center of gravity at the 0.12 mean-aerodynamic-chord location which is probably behind the center-of-gravity location for the actual airplane. It is possible, therefore, that the model would have been more controllable near the ground with a more forward center-of-gravity location since experience has shown that such models tend to be more oscillatory with a rearward center-of-gravity location.

Take-Offs and Landings

Figure 15 presents time histories of two representative take-offs and landings in still air. The figure shows only the motions of the model in yaw because only one camera was used in recording these tests. The behavior of the model, however, was essentially the same in pitch as it was in yaw during take-offs and landings. In general, take-offs and landings were easy to perform because the model responded quickly to a control deflection and could be maneuvered fairly easily after leaving the ground. In most of the take-offs, the model moved sideways just as it was leaving the ground. The pilot could not prevent this motion but could usually limit it to less than one-half a span. This behavior is believed to result mainly from the fact that the model had little excess thrust so it could not take off rapidly and thereby minimize the time spent at heights at which ground effect reduced the control effectiveness. Since the control surfaces were trimmed for hovering at a considerable height above the ground, these settings were not sufficient for trim in the region where the control effectiveness was low.

Transition Flight

Preliminary tests.- The transition test program was started with the center of gravity at 0.12 mean aerodynamic chord which was the location used for the hovering tests and the center of gravity was moved successively forward to 0.07 and to the leading edge of the mean aerodynamic chord in order to get satisfactory flight results. When the model was designed, it was thought that 0.12 mean aerodynamic chord was the design location on the Lockheed XFV-1 airplane. Actually, according to later information, the design center-of-gravity location for the full-scale airplane varies from about 0.04 to 0.08 mean aerodynamic chord depending on the loading (pods, fuel, ammunition, etc.).

With the center of gravity at 0.12 mean aerodynamic chord, the model could not be flown longitudinally at the start of the transition flights because the pitch control was not sufficiently powerful to keep the model from nosing up and diverging in pitch when the tunnel airspeed was started. When the center of gravity was moved forward to the 0.07 mean-aerodynamic-chord location, a slightly higher airspeed could be reached but again the model could not be kept from pitching nose up. Since the pitch-control travel could not be increased without decreasing the yaw- and roll-control travels, one-inch chord-extensions were added to the "tailerons" to increase their effectiveness. The pitch pilot was then able to control the model but at an angle of pitch of about 60° the model diverged uncontrollably in yaw. A yaw-damping device was then added to the model and the first complete transitions were made with the model in this condition. Although transitions were made relatively easily and smoothly, down to an angle of attack of about 20°, this condition was not considered entirely satisfactory because of the necessity for the control extensions.

In an effort to get satisfactory flight results without the control extensions and also without the yaw damper, the center of gravity was moved to the leading edge of the mean aerodynamic chord. Generally, it was the pilots' opinion that the model was fairly easy to fly in this condition and therefore the detailed studies of stability and control in the transition range described in the following sections were made with this center-of-gravity location. Transitions were made from hovering flight to angles of pitch of about 20° which corresponded to a full-scale airspeed of approximately 120 knots. It should be pointed out that the center-of-gravity location needed with this model for satisfactory flight would probably not be exactly the same as for the full-scale airplane. The drag of the propeller guard and the flight cable probably contributed to the tendency of the model to nose up and drift back in the test section at the start of transition flights. It would be expected, therefore, that the full-scale airplane could be flown with a somewhat more rearward center-of-gravity location than was possible with the model.

Pitch characteristics.- A time history of a transition flight showing the pitching and yawing motions of the model while the forward speed was slowly increased is shown in figure 16. This time history shows a representative flight with the center of gravity at the leading edge of the mean aerodynamic chord and without the tail extensions or yaw damper. Except at the start of the transition, where the pitch pilot had some difficulty in keeping the model from nosing up and drifting back in the test section, the model was easy to fly in pitch and seemed to have stability of angle of attack over most of the speed range. At times, the model would fly "hands-off" in pitch for reasonably long periods of time when it was trimmed correctly and the airspeed was not being changed. The rapid variations in angle of pitch about the mean value, which are evident in figure 16, did not seem to be caused by poor stability but appeared rather to result partly from the difficulty in coordinating thrust and pitch control as the airspeed increased and partly from over-controlling because the taileron deflection for pitch was excessive at the higher speeds.

A plot of the variation of trim angle of pitch with airspeed for steady flight during transition is presented in figure 17. These angles of pitch are averages taken from the motion-picture records of several flights at different forward speeds when the model appeared to be in steady-flight condition. It was probably necessary to fly at a slightly lower angle of pitch with the model than will be required for the full-scale airplane to attain the same speed because of the added drag of the propeller guard and the power and control cable. It is believed, however, that these differences in operating conditions as well as the previously mentioned small differences in configuration will not materially affect the main results of the present investigation.

Yaw characteristics.- In the detailed stability and control studies with the center of gravity at the leading edge of the mean aerodynamic chord and without the yaw damper, it was found that the uncontrolled yawing motion was divergent in the very high angle-of-attack range but could be controlled easily. As the forward speed of the model increased and the angle of attack became lower the model tended to become stable in yaw. The data of figure 16 show that at angles of pitch above 35° the controlled yawing motions were relatively smooth but that at angles of pitch below 35° the motions became somewhat more erratic. In this condition the flicker controls seemed very powerful and the control deflections (which were needed for hovering and for the first part of the transition) were too great for smooth flight. For this reason the flight records indicate an undue amount of yawing in flight, particularly at low angles of pitch, which would not be expected to occur for the full-scale airplane in which small control deflections can be obtained and in which the controls can be coordinated smoothly.

Roll characteristics.- No difficulty was experienced in roll during the transition flights, and at all forward speeds the model was easier to control in roll than it was in hovering flight. As soon as the tunnel air flow started, the random roll trim changes experienced in hovering appeared to be eliminated. This result is in agreement with the results of reference 5 which indicated that even very low forward speeds were sufficient virtually to eliminate random changes in roll trim. The model seemed to be stable in bank at all forward speeds covered in the tests, and after trimming the model to account for the change in trim with speed the roll pilot had to use very little control. These results were very similar to those obtained with the model of reference 6 which also had stability in bank and a definite tendency to fly with its belly into the wind. Force tests showed that the model of reference 6 had static stability in bank (positive effective dihedral) over a large range of angles of roll with respect to the body axes. The apparent stability in bank of the present model may have been increased by the drag of the flight cable which was attached to the model by means of the curved steel rod shown in figure 5.

Although the model seemed to be stable in bank and easy to fly in the transition range, at angles of attack below 35° the rolling motion was easily excited by either aileron or rudder control. Because of the flicker-type control system and the testing technique used in these tests, it was not possible to obtain smooth coordination of aileron and rudder control; and the control deflections used in the transition tests proved to be too great for smooth flight at the higher speeds. The film supplement to this paper therefore shows an undue amount of rolling in this low angle-of-attack range which probably will not be experienced with the full-scale airplane because smaller control deflections can be obtained and the aileron and rudder controls can be coordinated smoothly.

Sideways Flight

The model was fairly easy to control in roll in hovering flight but, as the sidewise airspeed was increased, it had an increasingly strong tendency to diverge in roll and became more difficult to keep oriented with one wing pointed into the wind. Finally, at a speed of about 9 knots (25 knots full-scale), the model would roll off and fly on its belly or back despite the efforts of the roll pilot to control it. This roll-off is illustrated in figure 18 which presents time histories of the angle of bank as the airspeed was increased. These results are again very similar to those reported in reference 6 in which it was shown that the tendency of the model to diverge was apparently caused by static instability in bank in sideways flight. Force tests of the model of reference 6 indicated that for sideways flight $\phi = 90^{\circ}$ there was an unstable variation of rolling-moment coefficient with angle of bank which increased with increasing speed. The roll divergence encountered in flying either the present model or the model of reference 6 occurred when the model inadvertently rolled to an angle at which the rolling moment produced by the instability was greater than the moment that could be produced by the roll control.

Figure 19 shows the variation of angle of yaw with airspeed in sideways flight for the present model as well as it could be determined from the limited flight-test data available. Very little test data of this type were obtained because the minimum speed provided by the tunnel speed control corresponded to about 23 knots and flights below this speed had to to take place while the tunnel speed was building up to this point.

SUMMARY OF RESULTS

The results of a dynamic stability and control investigation of a vertically rising aircraft model generally similar to the Lockheed XFV-1 airplane can be summarized as follows:

The model could be flown smoothly and easily in hovering flight and could be maneuvered readily to any desired position despite the fact that the uncontrolled pitching and yawing motions were unstable oscillations. The pilots could stop these oscillations quickly even after they had been allowed to build up to a large amplitude because the periods of the oscillations were fairly long and the control surfaces were powerful. There was a noticeable reduction in the controllability of the model when hovered very close to the ground.

Take-offs could be made easily and landings on a given spot could be made accurately in still air.

Flights through the transition range could be performed fairly easily with the center of gravity located at the leading edge of the mean aerodynamic chord. The pitching and rolling motions were easy to control and the model seemed to have stability of angle of attack and angle of roll over most of the transition range. The yawing motion was divergent in the very high angle-of-attack range but could be controlled easily. As the forward speed increased and the angle of attack became lower the model tended to become stable in yaw.

It was possible to fly sideways at speeds up to about 25 knots (full scale). Above this speed the model diverged uncontrollably in roll.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., September 30, 1954.

Robert H. Kirby
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Approved: Thomas A. Harris
Thomas A. Harris
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BS

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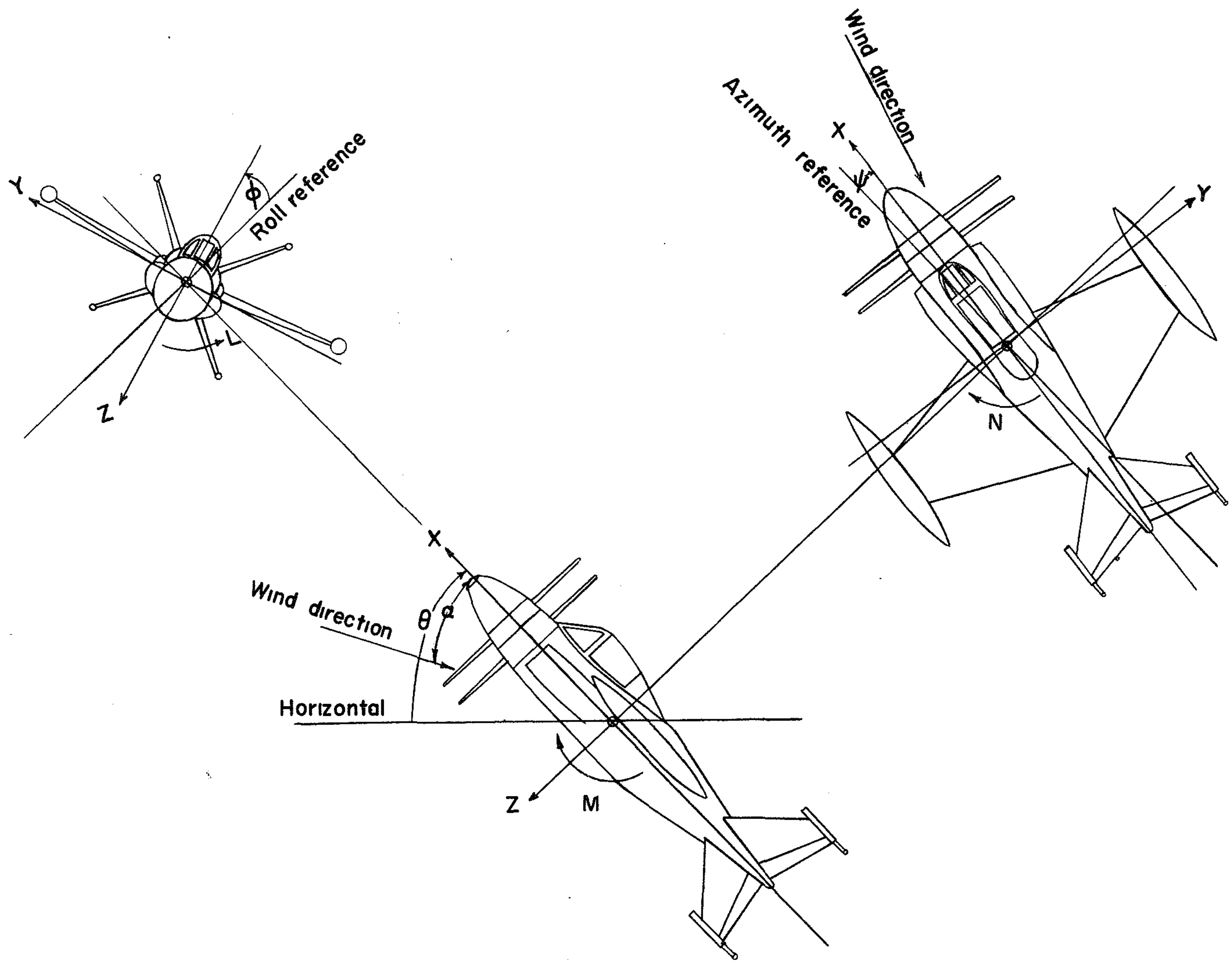

Figure 1.- The body system of axis. Arrows indicate positive directions of forces, moments, and linear and angular displacements.

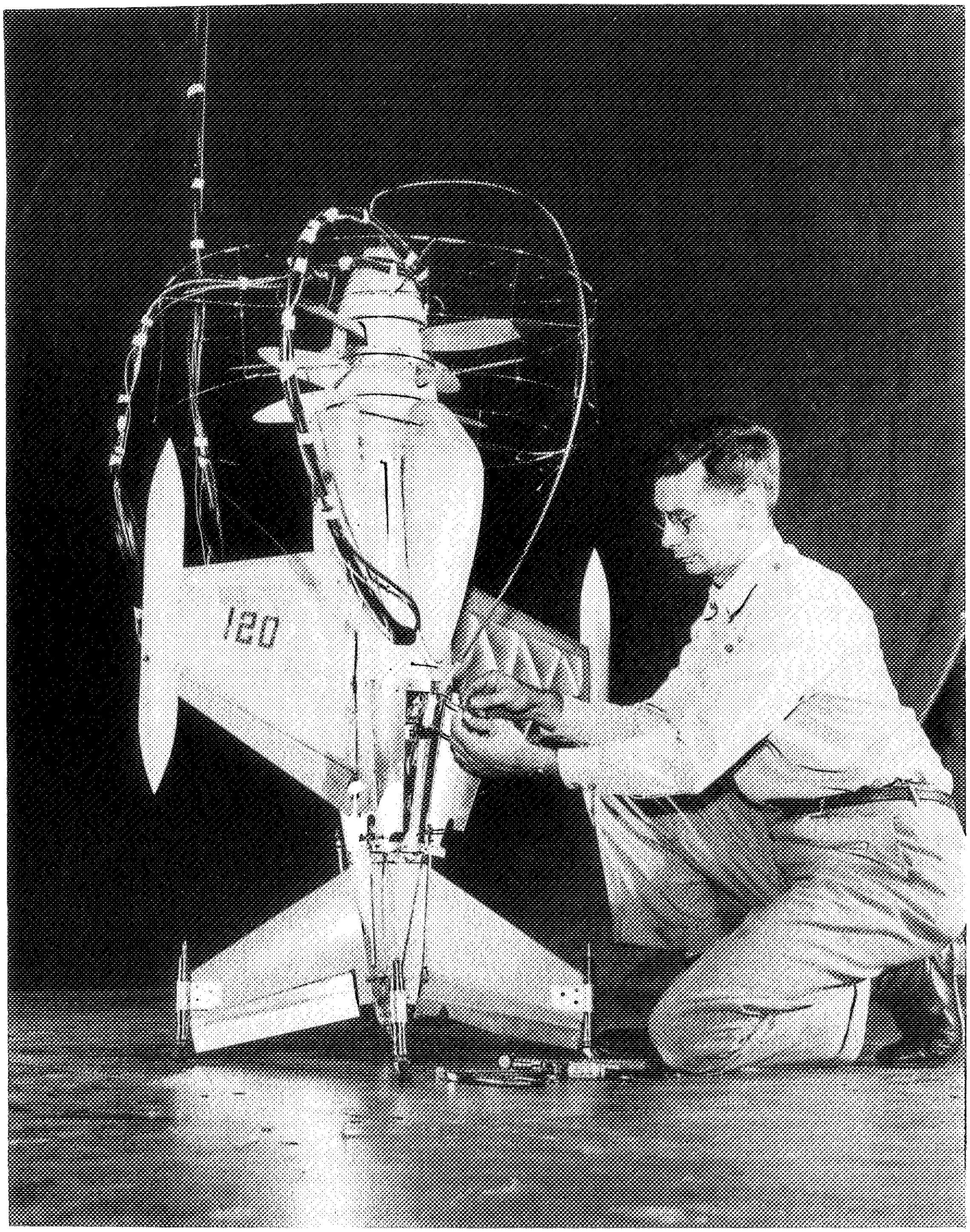

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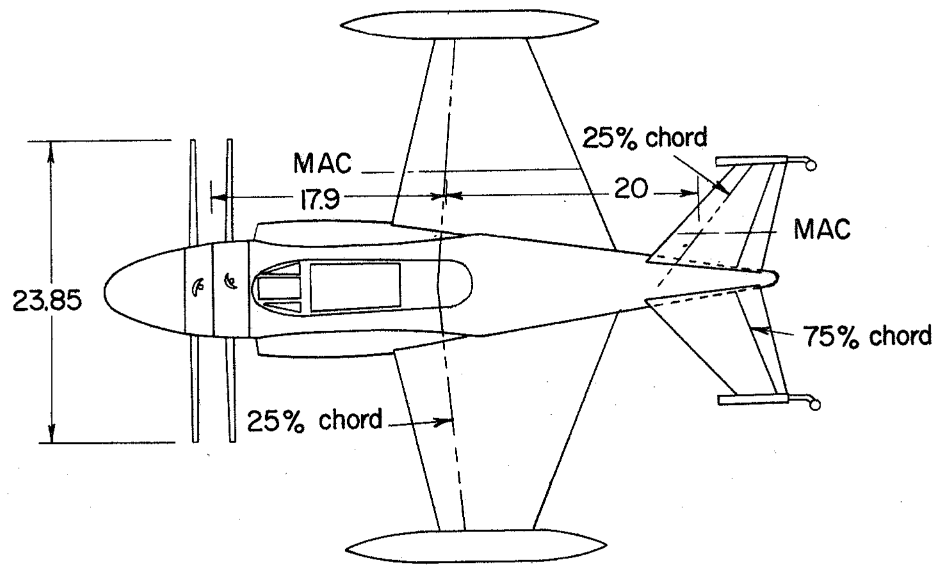
Figure 2.- Photograph of the model with propeller guard and extensions on the tail control surfaces.

GENERAL SPECIFICATIONS

WING:	
Area, total, sq in	553.4
Aspect ratio	3
Sweep $\frac{c}{4}$, deg	5.7
Chord, in	
Root	20.25
Tip	6.63
Airfoil section, root and tip	NACA 64_A206 (Mod)
Mean aerodynamic chord, in	14.6
Incidence - root and tip, deg	1
Pods	
Length, in	21
Diameter, in	2.25
TAIL SURFACES:	
Area, total, sq in	380
Aspect ratio	3.55
Sweep $\frac{c}{4}$, deg	30
Chord, in	
Root	10.62
Tip	4
Airfoil section, root and tip	NACA 65_A007
Incidence - root and tip, deg	-4 (L.E. down)



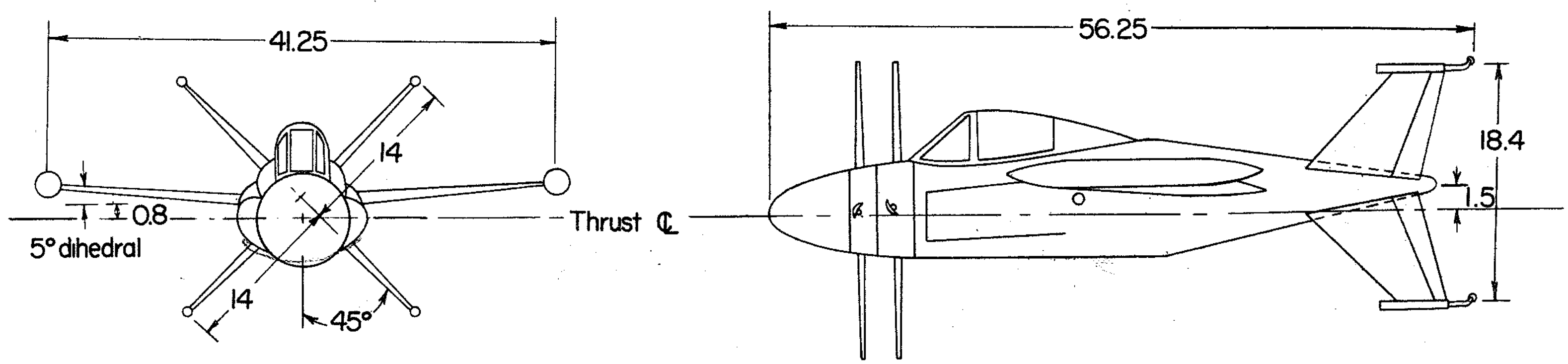
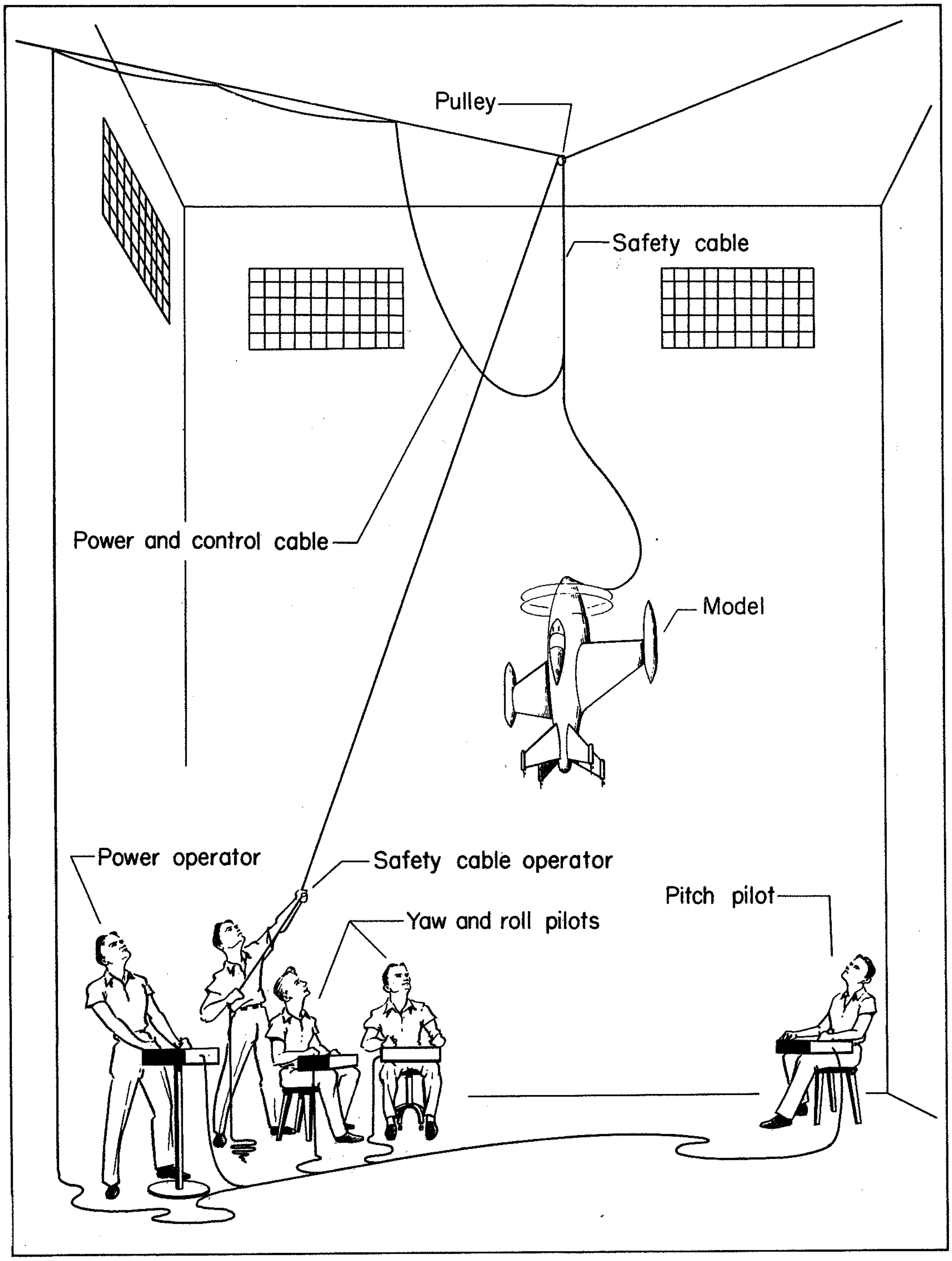
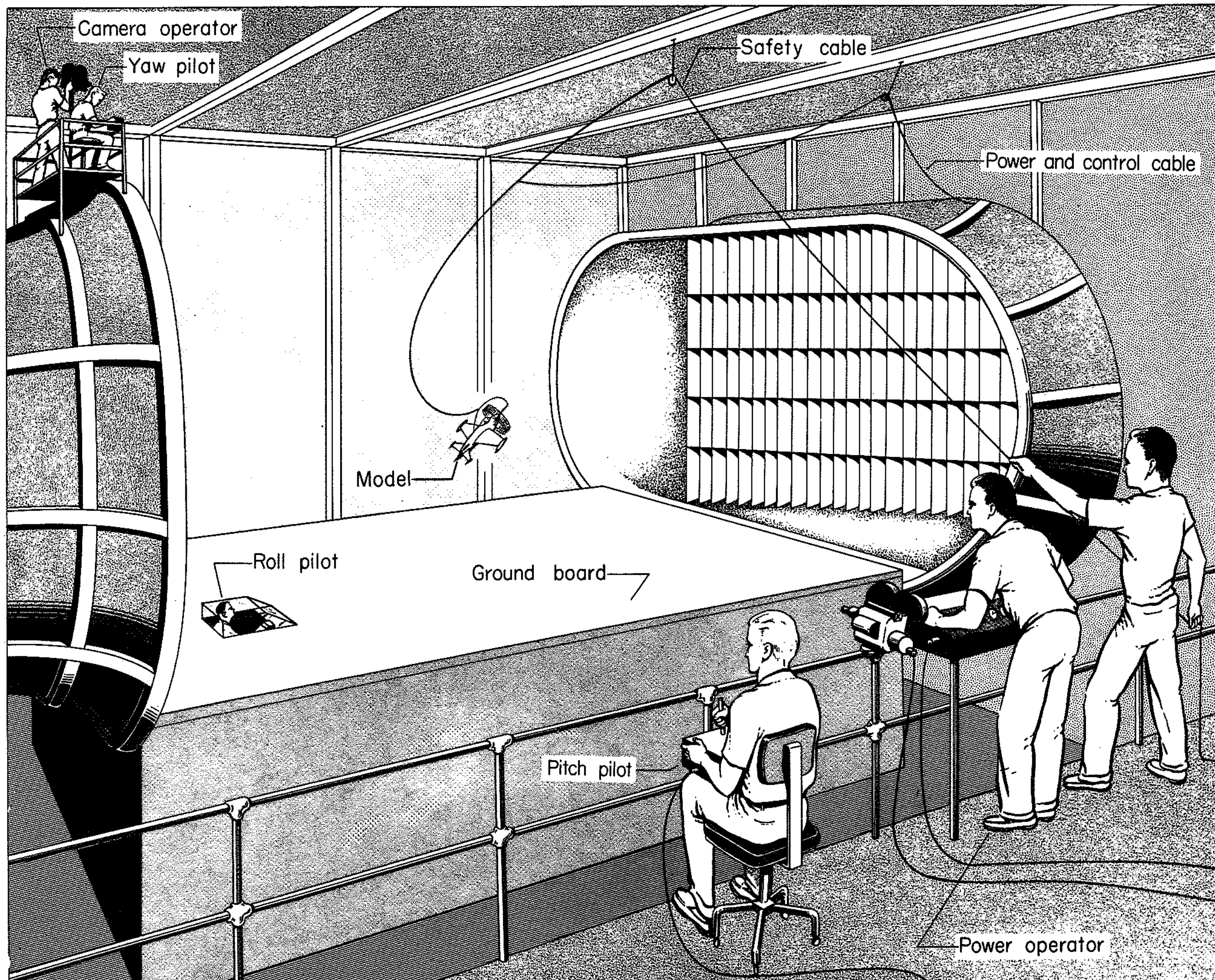


Figure 3.- Three-view drawing of the model.



(a) Hovering tests.

Figure 4.- Test setups.



(b) Transition tests.

Figure 4.- Concluded.

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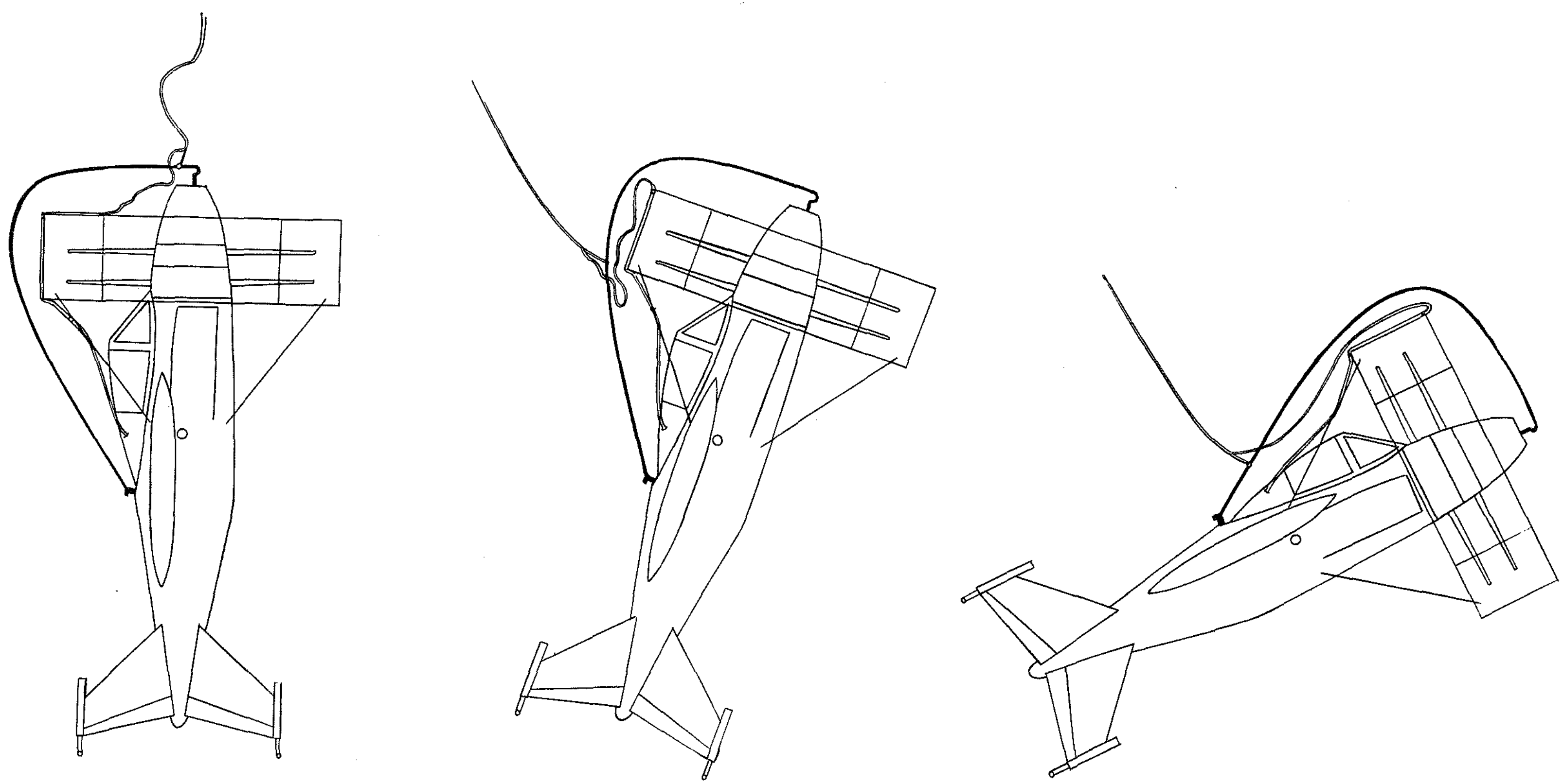

Figure 5.- Method of attaching combined safety and power and control cables to model during transition-flight tests.

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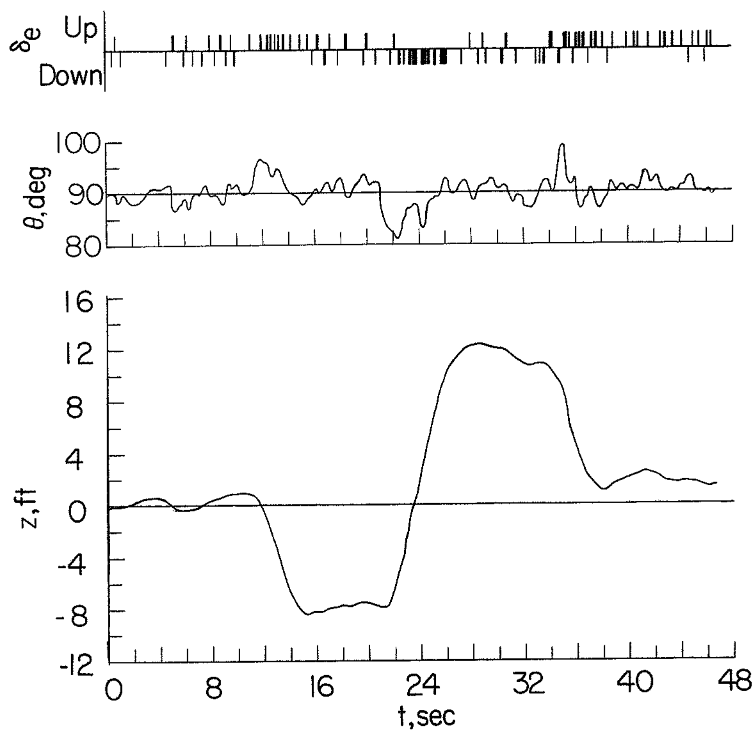
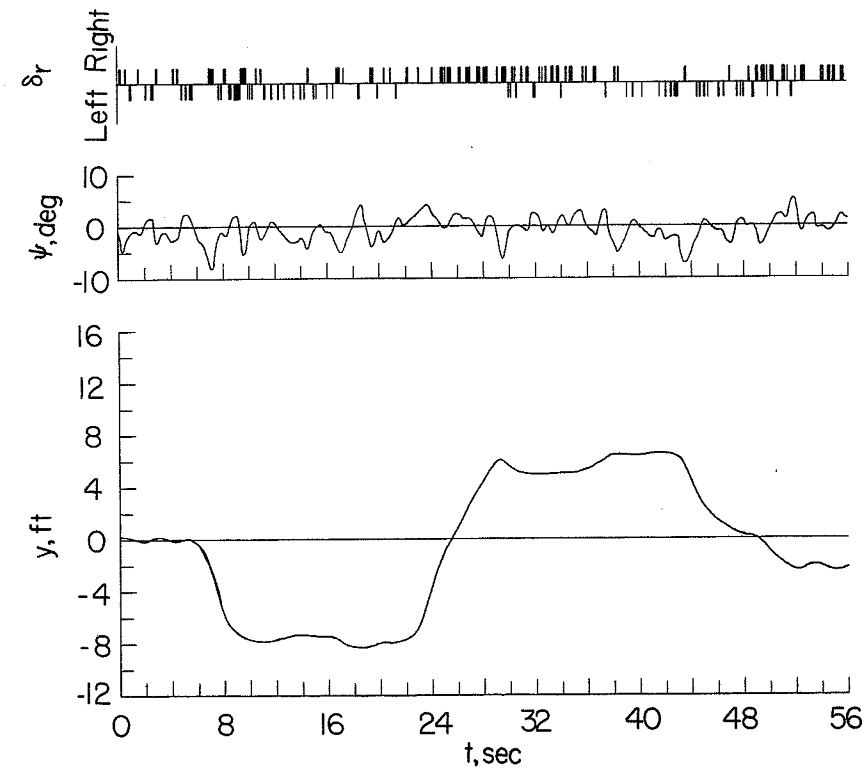


(a) Pitch.



(b) Yaw.

Figure 6.- Time histories of the controlled pitching and yawing motions in the hovering condition showing the ability of the pilot to fly steadily and maneuver quickly from one position to another.

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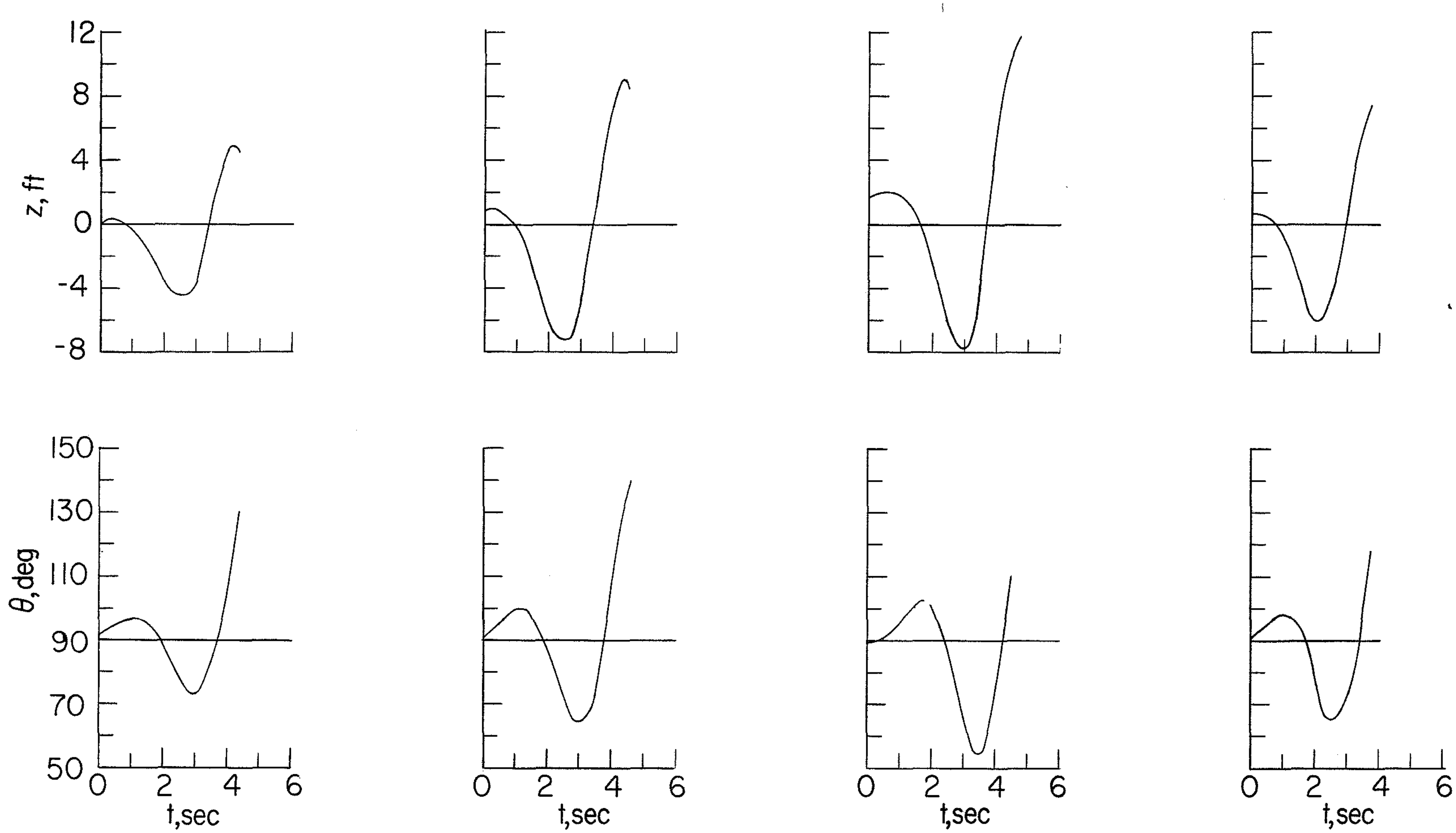

Figure 7.- Uncontrolled pitching motions of the model with the overhead-cable arrangement.

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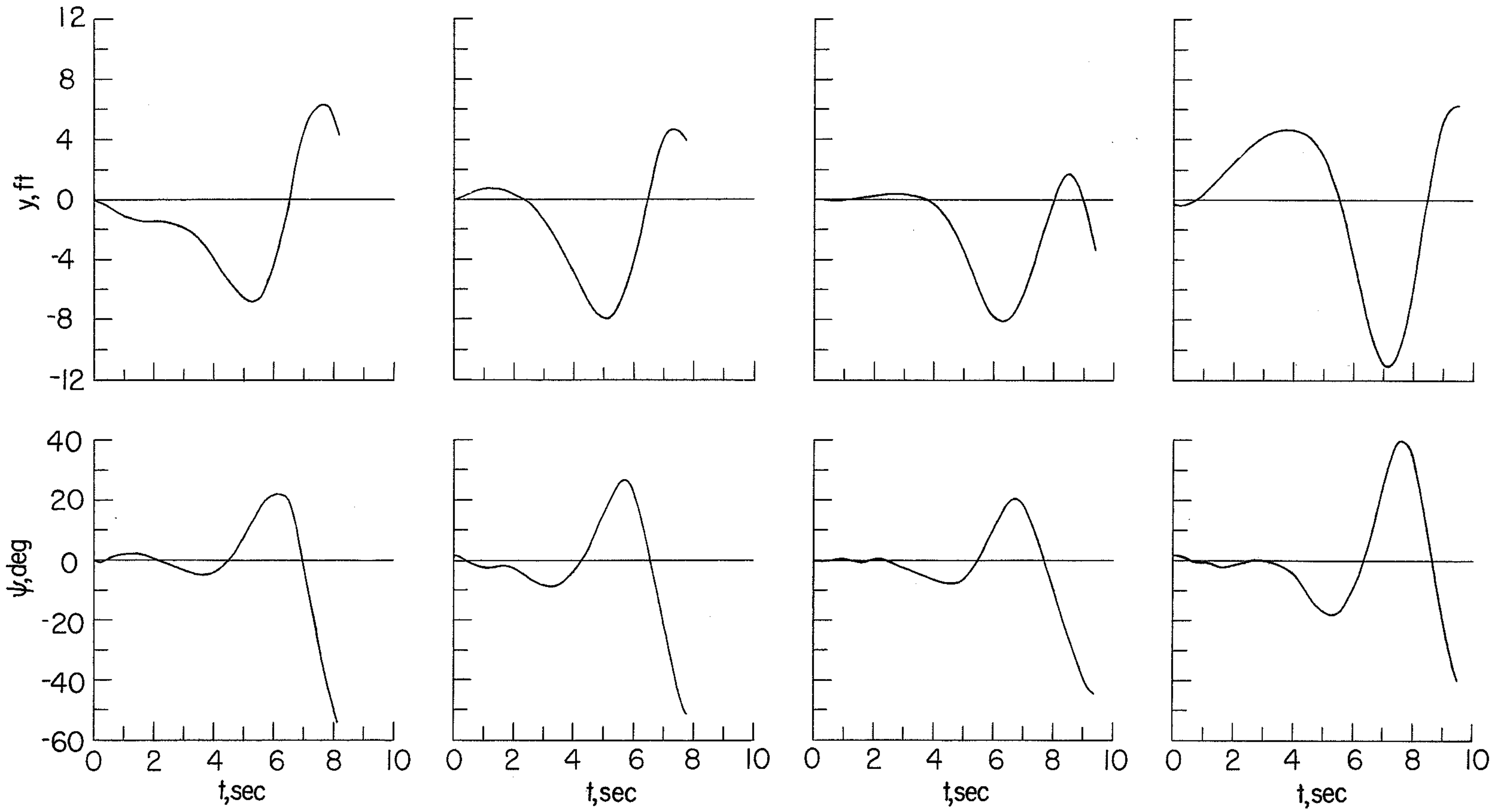

Figure 8.- Uncontrolled yawing motions of the model with the overhead-cable arrangement.

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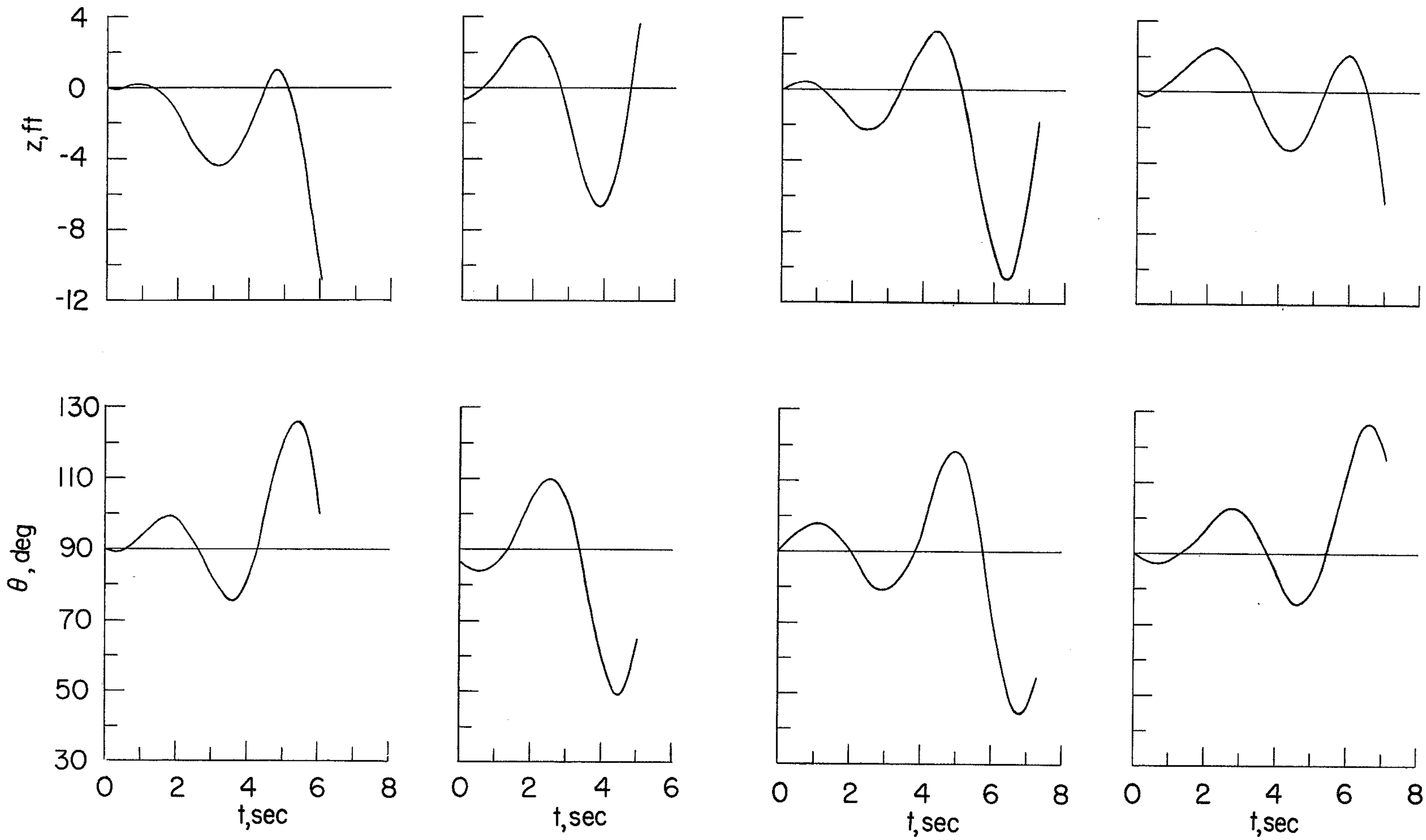

Figure 9.- Uncontrolled pitching motions of the model with the trailing-cable arrangement.

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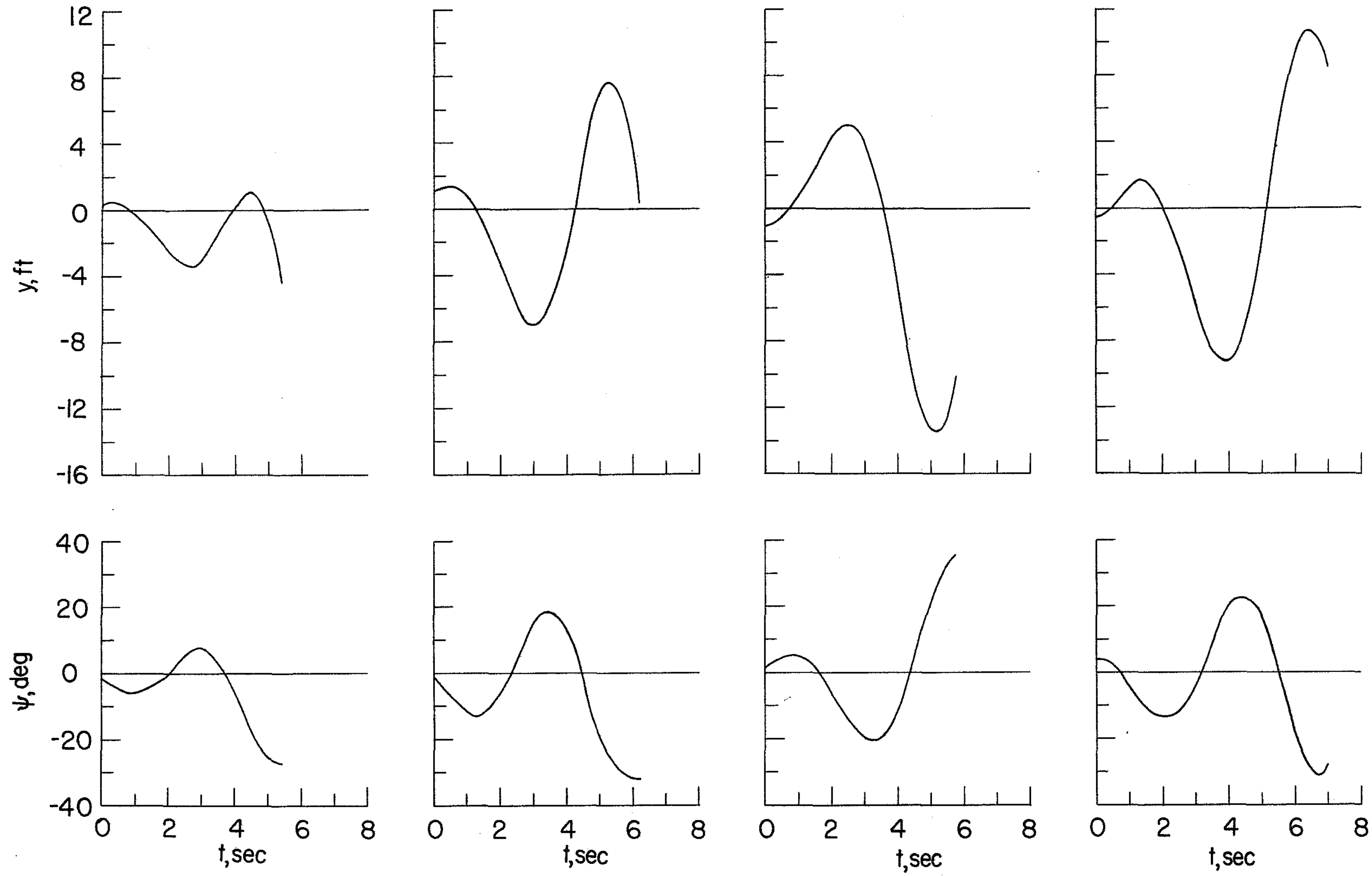

Figure 10.- Uncontrolled yawing motions of the model with the trailing-cable arrangement.

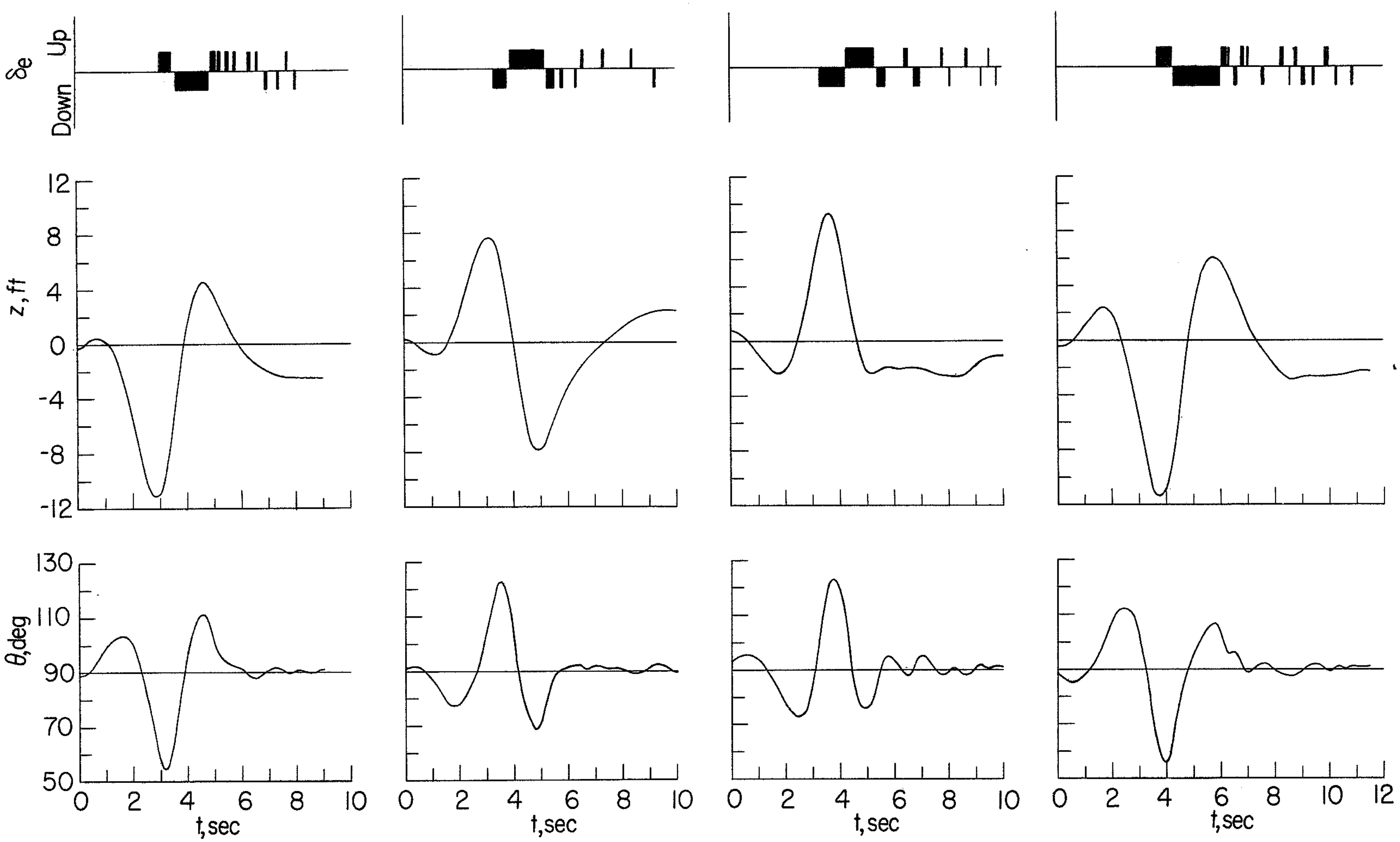

Figure 11.- Time histories with the overhead-cable arrangement showing the ability of the pilot to stop the uncontrolled pitching motions after they had been allowed to build up.

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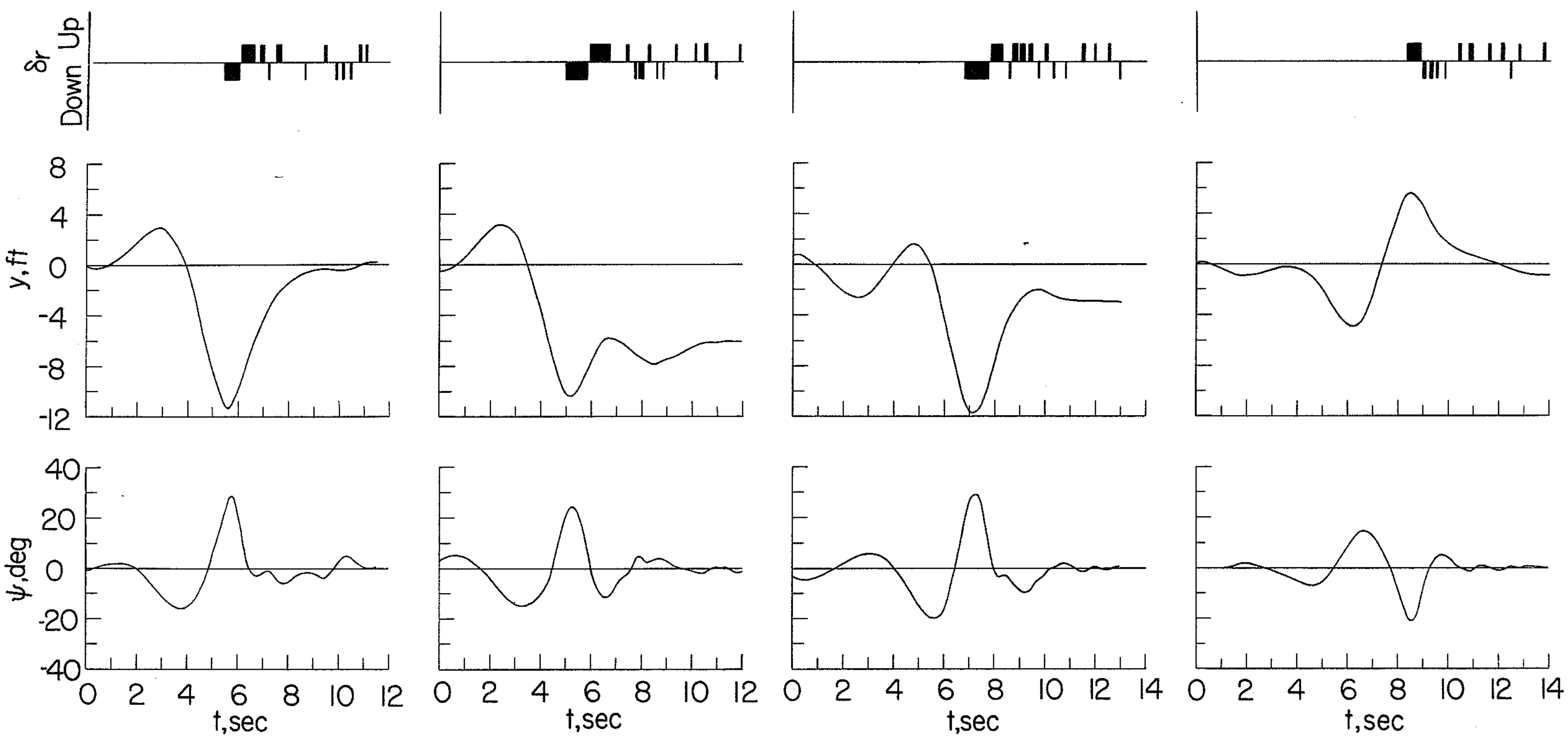

Figure 12.- Time histories with the overhead-cable arrangement showing the ability of the pilot to stop the uncontrolled yawing motions after they had been allowed to build up.

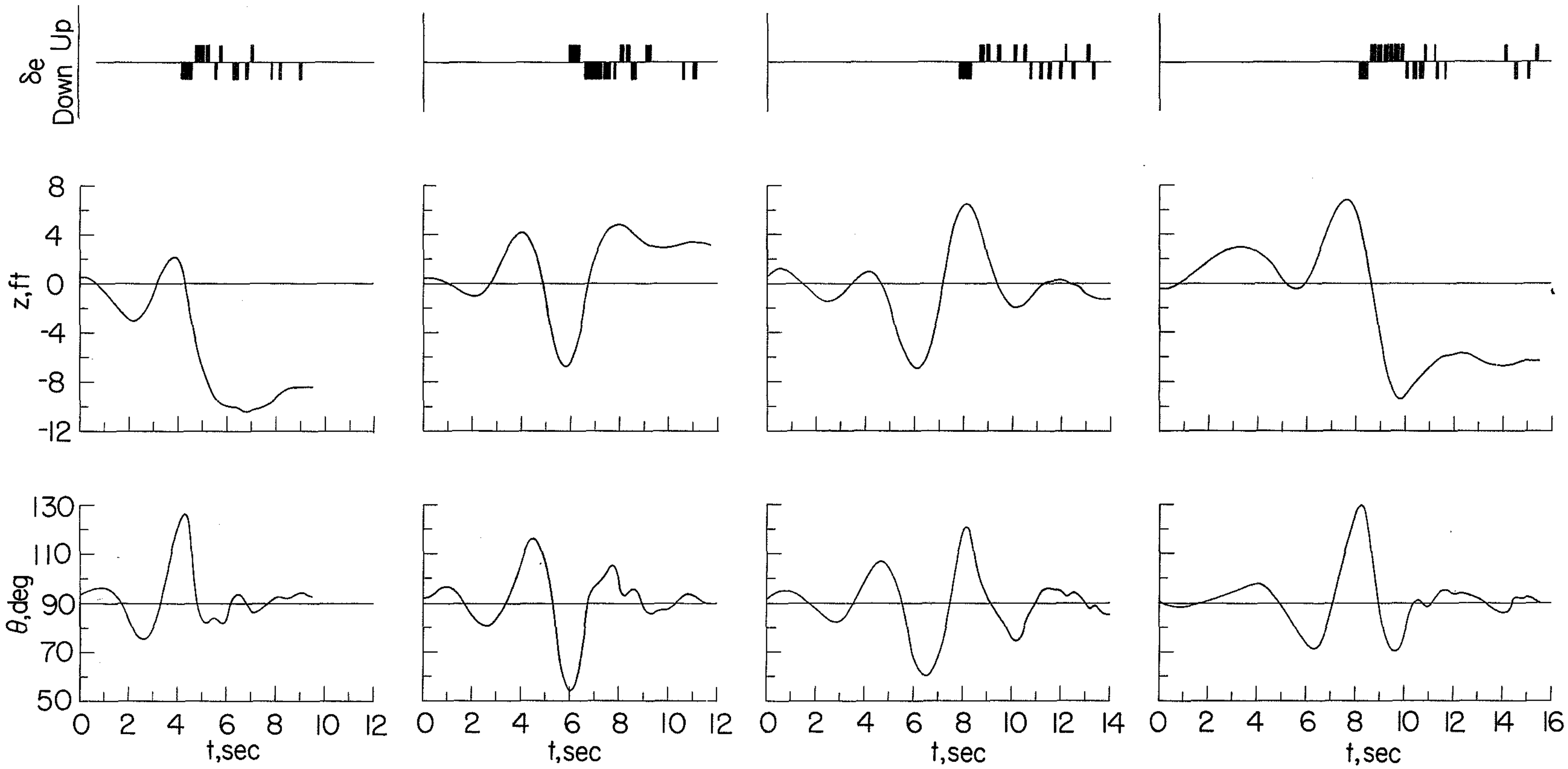

Figure 13.- Time histories with the trailing-cable arrangement showing the ability of the pilot to stop the uncontrolled pitching motions after they had been allowed to build up.

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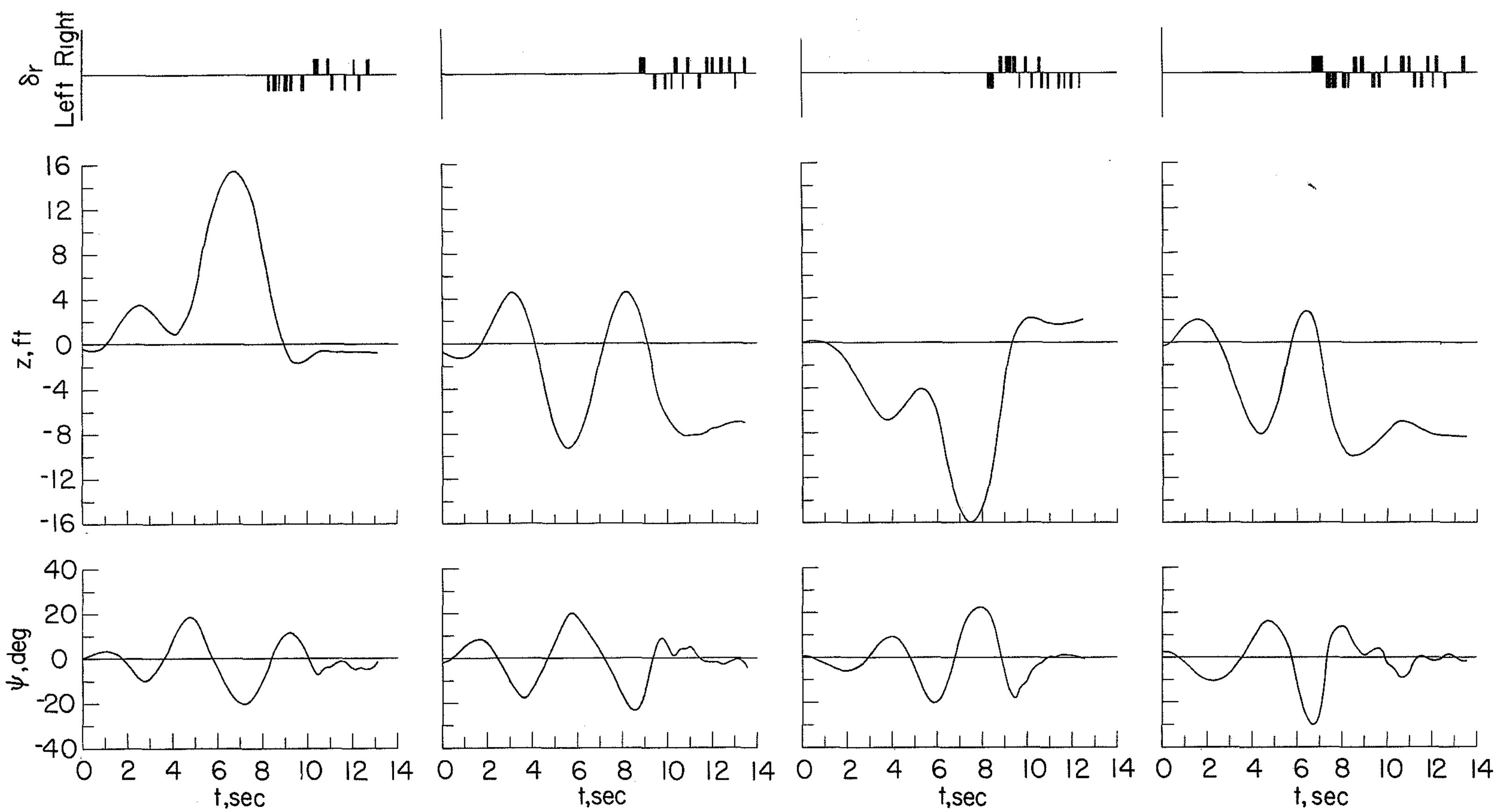

Figure 14.- Time histories with the trailing-cable arrangement showing the ability of the pilot to stop the uncontrolled yawing motions after they had been allowed to build up.

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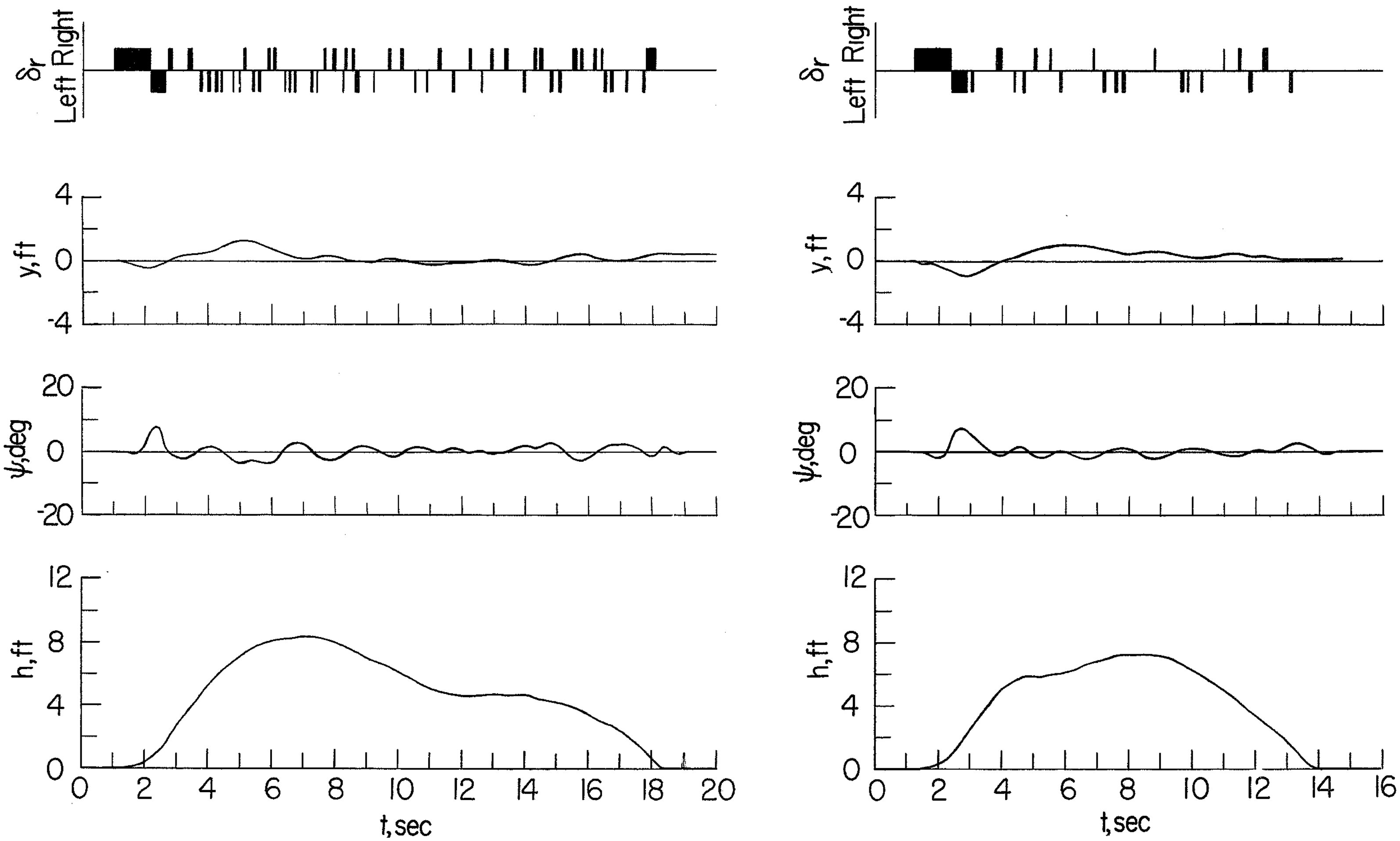

Figure 15.- Time histories of the motions of the model during take-offs and landings.

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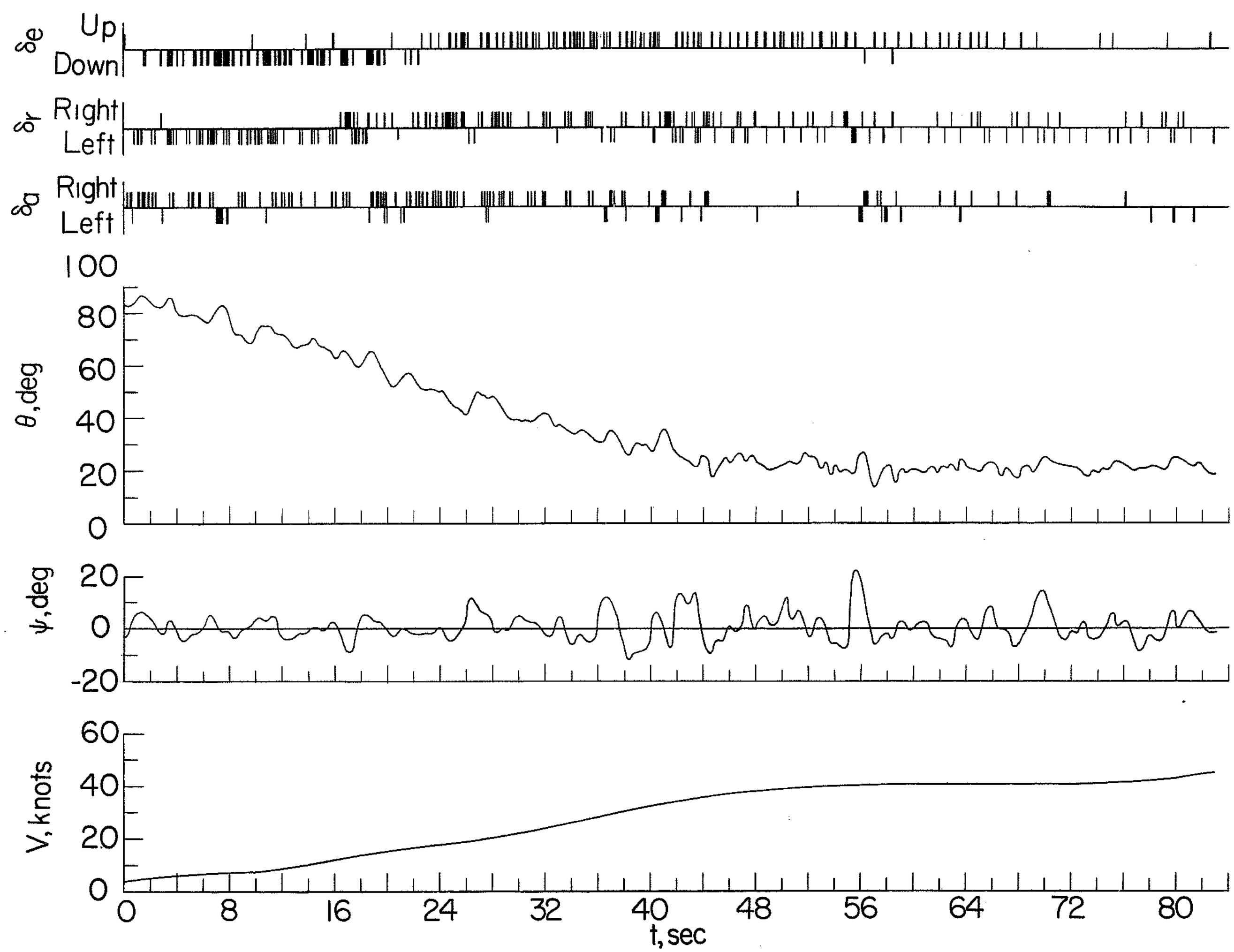

Figure 16.- Time history of the motions of the model in constant-altitude transition with the center of gravity at the leading edge of the mean aerodynamic chord.

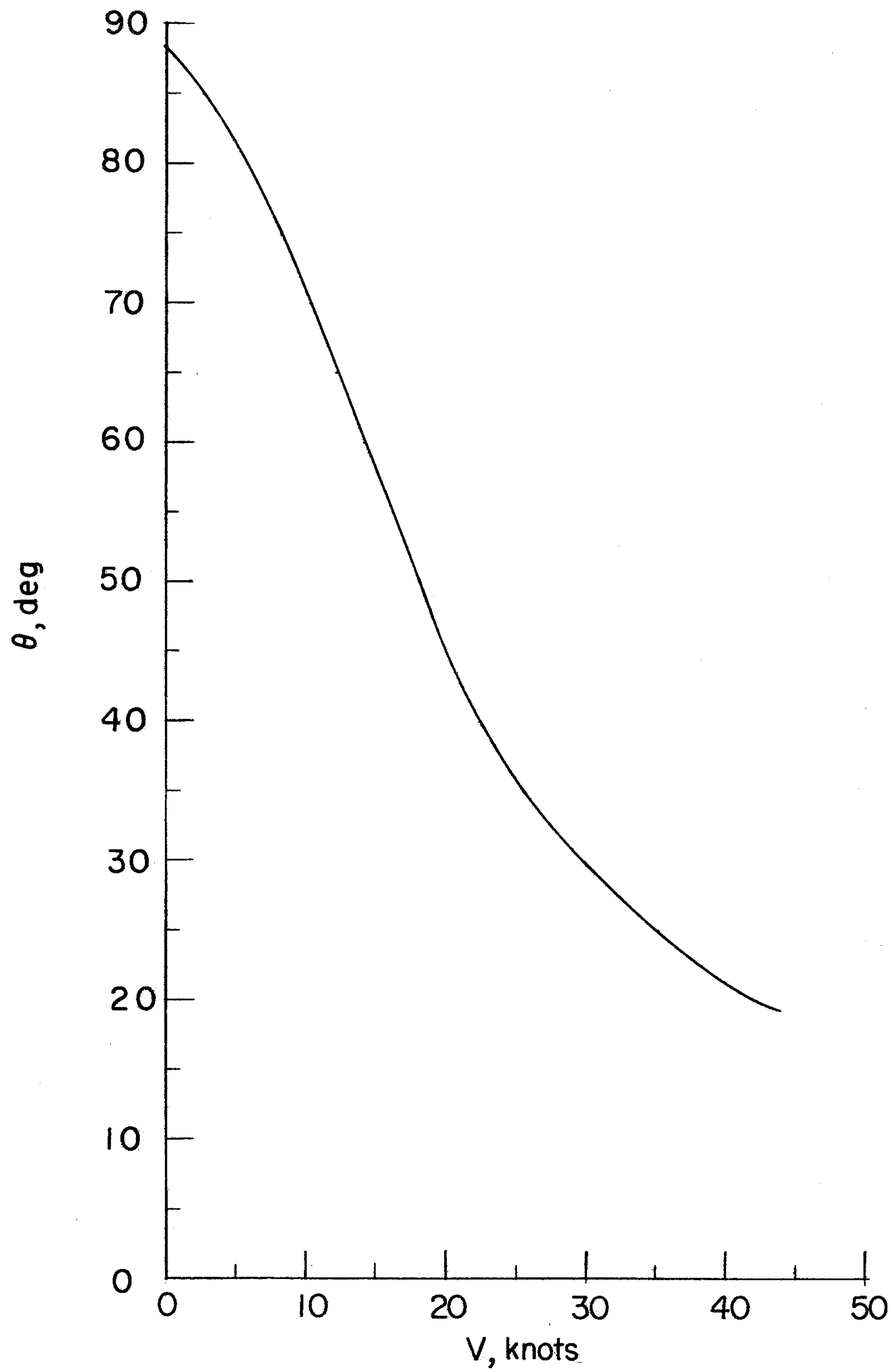

Figure 17.- Variation of angle of pitch with forward transition speed.

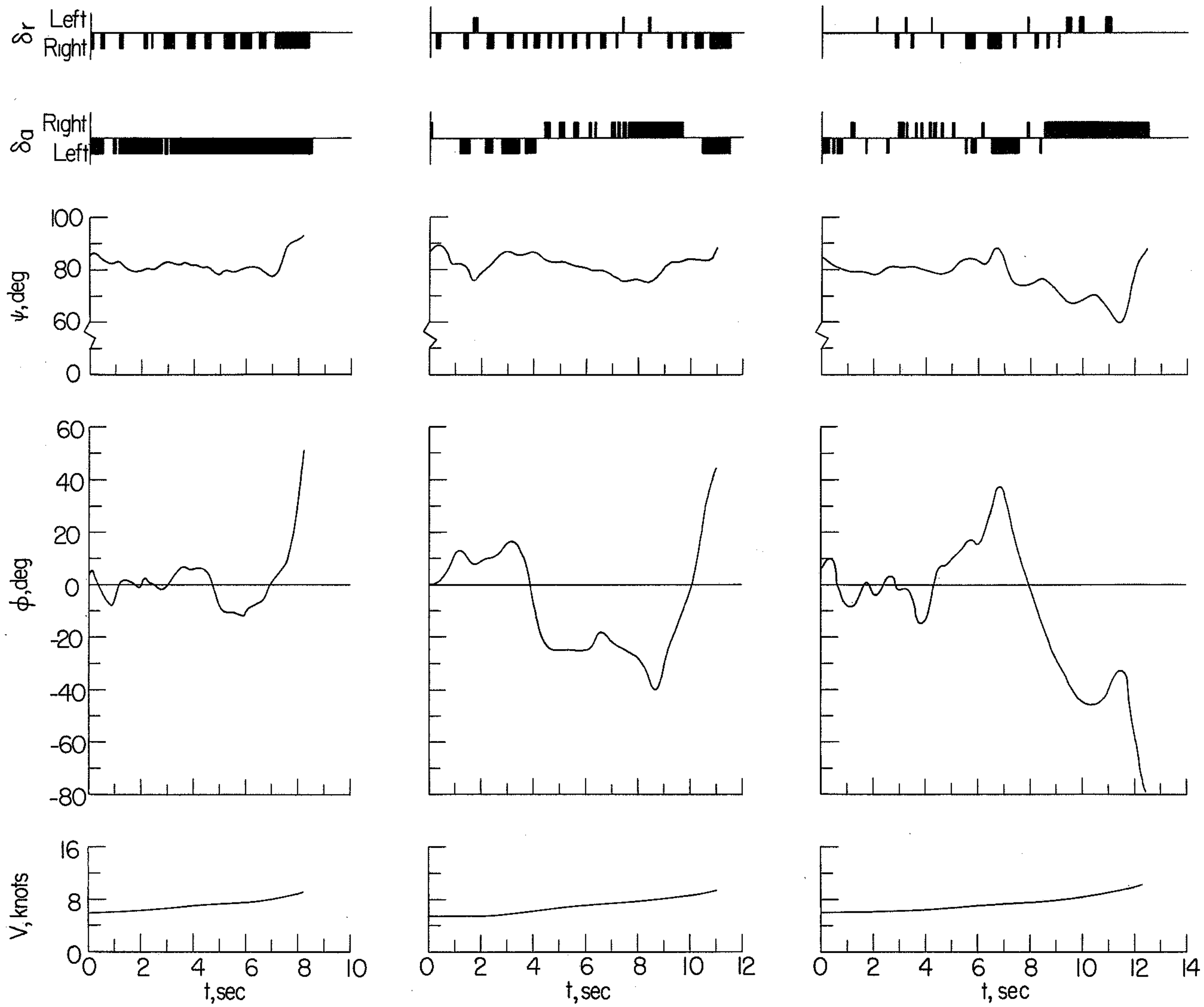

Figure 18.- Time histories of the angles of roll and yaw for sideways flight.

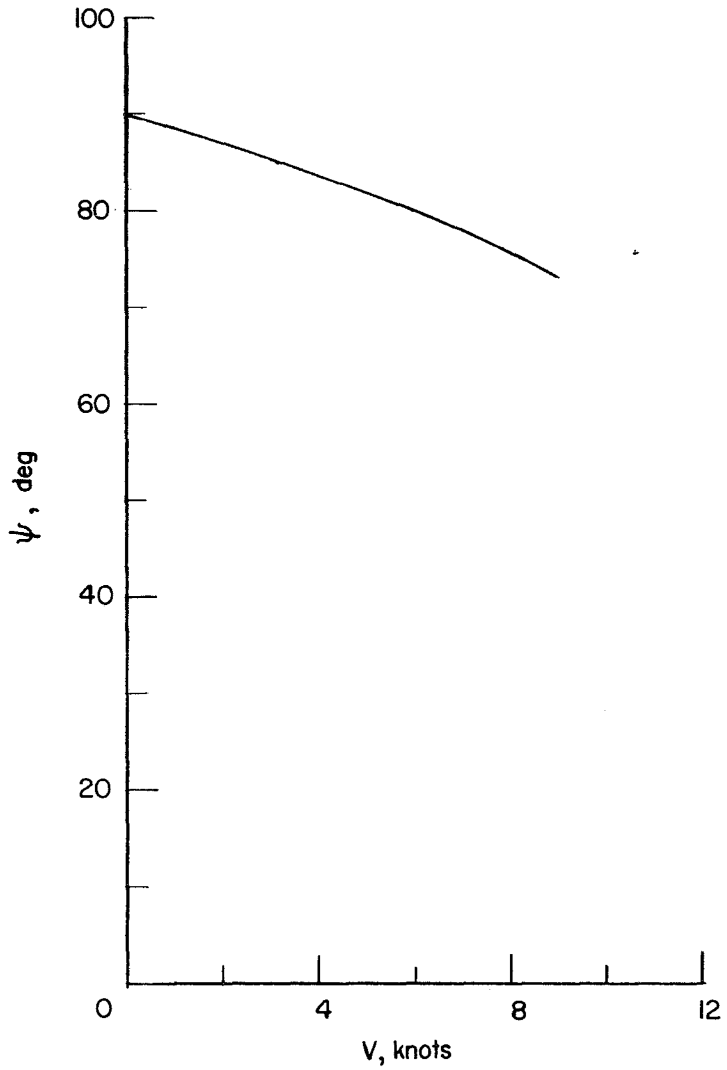

Figure 19.- Variation of angle of yaw with airspeed in sideways flight.