NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 3899

EFFECTS OF WING POSITION AND VERTICAL-TAIL CONFIGURATION ON STABILITY AND CONTROL CHARACTERISTICS OF A JET-POWERED DELTA-WING VERTICALLY RISING AIRPLANE MODEL

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SUMMARY

An investigation has been conducted to determine the effects of wing position and vertical-tail configuration on the stability and control characteristics of a jet-powered delta-wing vertically rising airplane model. A ducted-fan powerplant was used because there was no hot-jet powerplant of sufficiently small size and adequate reliability available. In addition to conventional flap-type control surfaces on the wings and vertical tails, the model had jet-reaction controls provided by movable eyelids at the rear of the tail pipe and by air bled from the main duct and exhausted through movable nozzles near the wing tips. The investigation consisted of flight and force tests of three model configurations: a high wing with a top-mounted vertical tail, a high wing with top- and bottom-mounted vertical tails, and a low wing with a top-mounted vertical tail. The flight tests, which were made in the Langley full-scale tunnel, represented slow constant-altitude transitions from hovering to normal unstalled forward flight.

About half the transition flights made with the configuration with the high wing and top-mounted vertical tail without artificial stabilization were unsuccessful because of a lateral divergence at angles of attack between about 50° and 60°. The use of artificial damping in roll greatly improved the lateral stability and made the model easy to fly throughout the entire speed range. No successful transition flights could be made with the configuration with the high wing with both top- and bottom-mounted vertical tails because of an uncontrollable rolling divergence at low airspeeds. Artificial damping in roll did not provide any noticeable improvement in the lateral stability of this configuration. No successful transition flights could be made with the configuration with the low wing and top-mounted vertical tail without artificial stabilization because of an unstable lateral oscillation at angles of attack near 60°. The use of artificial damping in roll or yaw made it possible to perform the transition successfully.

INTRODUCTION

An exploratory investigation has been conducted to determine the effects of wing position and vertical-tail configuration on the dynamic stability and control characteristics of a jet-powered delta-wing vertically rising airplane model. A ducted-fan powerplant was used because there was no hot-jet powerplant of sufficiently small size and adequate reliability available. When the test results are interpreted, it should be borne in mind that the effects of the gyroscopic moments of the jet engine on the stability and control characteristics were not simulated because the two motors of the model turned in opposite directions so that the gyroscopic forces canceled.

A previous flight-test investigation made with the same basic model is reported in reference 1. The basic model was a high-wing configuration with a triangular vertical tail mounted on top of the fuselage. In the present investigation the model was modified for one series of tests by adding a vertical tail below the fuselage and for another series, by removing the original vertical tail, adding a tail below the fuselage, and inverting the model to make it a low-wing configuration. The investigation consisted of force tests and flight tests in the transition range between hovering and normal forward flight. The results of the flight tests were determined from visual observation, from the pilots' impressions of the flying qualities of the model, and from time histories of the motions of the model prepared from motion-picture records of the flights.

Some of the flight-test results presented in reference 1 for the basic configuration are repeated in the present paper to facilitate comparison of the three related configurations. The present paper also includes force-test results for the basic configuration which were not available at the time of publication of reference 1.

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.

M_X rolling moment, ft-lb

M_Y pitching moment, ft-lb

M_Z yawing moment, ft-lb

u,v,w	velocity components along the X-, Y-, and Z-axis, respectively, knots
V	free-stream velocity, knots
X,Y,Z	orthogonal axis system having origin at center of gravity and in which X-axis is in plane of symmetry and alined with longitudinal axis, Z-axis is in plane of symmetry and perpendicular to X-axis, and Y-axis is perpendicular to plane of symmetry
β	angle of sideslip, deg
θ	angle of pitch of fuselage longitudinal axis relative to horizontal, deg
ϕ_b	angle of roll, deg
ψ'	angle of yaw, positive for right yaw, measured from the vertical in plane shown by rear camera, deg
ψ_b	angle of yaw, deg

SYSTEM OF AXES

All the force-test data are presented with reference to the system of body axes about which the data were measured. This system of axes was chosen because it was felt that the motions of an airplane at very high pitch angles would be interpreted or sensed by the pilot relative to the body axes of the airplane. Also, the initial rolling motion of an airplane during an aileron roll tends to be about the axis of least inertia, that is, the principal axis of inertia which generally is fairly closely alined with the X body axis.

The sequence by which the body axes are displaced from the reference axes (in this case, the tunnel axes) is important and was specified for this investigation as follows: With the two systems of axes initially alined, (1) pitch the model about the Y-axis through the angle θ, (2) yaw the model about the Z body axis through the angle ψ_b, and (3) roll the model about the X body axis through the angle ϕ_b. The relations of θ, ψ_b, and ϕ_b to α and β for this sequence are as follows:

$$\left.\begin{aligned} \tan\alpha &= \frac{w}{u} = \tan\theta\,\frac{\cos\phi_b}{\cos\psi_b} + \tan\psi_b\,\sin\phi_b \\ \sin\beta &= \frac{v}{V} = \sin\theta\,\sin\phi_b - \cos\theta\,\sin\psi_b\,\cos\phi_b \end{aligned}\right\} \qquad (1)$$

Equations (1) reduce to the following approximations when it is assumed that ϕ_b and ψ_b are small and are varied separately:

$$\left.\begin{aligned} \alpha &= \theta \\ \beta &= \phi_b \sin \theta \\ \beta &= -\psi_b \cos \theta \end{aligned}\right\} \tag{2}$$

APPARATUS

Model

Photographs of the basic model showing the powerplant installation and controls are presented as figure 2, and sketches showing some of the more important dimensions for all three configurations are shown in figure 3. A multiple-exposure photograph showing the basic model in various stages of a transition flight is presented as figure 4. The modifications to the basic model included (1) the mounting of another vertical tail below the fuselage, and (2) the removal of the original vertical tail and installation of a vertical tail on the bottom of the fuselage and inversion of the model to make it a low-wing configuration with a top-mounted vertical tail. The geometric characteristics of the different configurations are presented in table I.

The model was powered by two 5-horsepower electric motors turning 14.25-inch-diameter oppositely rotating propellers in a duct 4 feet long. The duct was made of cellular plastic 0.25 inch thick covered both inside and outside with laminated-glass-fiber fabric. A rounded lip was provided on the forward end of the duct to increase the static thrust of the ducted fan. Although the amount of increase provided by this lip is not known exactly, tests of another ducted fan indicate that an increase in thrust of 60 percent over that of a ducted fan with a sharp lip might be expected.

The model had wing and vertical-tail surfaces of modified delta plan form with conventional flap-type elevon and rudder controls for use in forward flight. Pitch and yaw controls for hovering flight were provided by eyelids at the rear of the fuselage which deflected the jet. Roll control was provided by air routed from the main duct through the wings to differentially moving nozzles near the wing tips. About 10 percent of the air was bled off from the main duct to the nozzles.

In most flights, the jet-reaction controls were operated by the flicker-type (full-on or off) pneumatic actuators used on all models by the Langley free-flight tunnel section. 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. With actuators of this type, a model becomes accurately trimmed after flying a short time in a given flight condition.

In some of the flights an artificial stabilizing device was used to move the controls automatically in proportion to the rate of roll or rate of yaw. The sensing element for this device was a rate gyroscope which, in response to rate of roll or rate of yaw, provided signals to the proportional-control actuators which moved the controls to oppose the rolling or yawing motions. The operation of these devices was such that they provided damping in roll or yaw regardless of the attitude of the model. A pilot-operated override was provided in the gyroscope-operated devices so that the pilot could have all the available control power at his command. If there had not been an override, the damping devices would have applied controls to oppose those applied by the pilot and would thus reduce the control effectiveness available to the pilot. For all model configurations the roll damper operated the elevons. The yaw damper operated the rudder in tests of the basic configuration and the yaw eyelid, in tests of the low-wing configuration.

Test Equipment and Setup

Figure 5 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. The three pilots were located at positions which gave them good 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.

A safety cable was used for catching the model to prevent crashes in case of a power or control failure or in the event that the pilots lost control of the model. This cable was attached to the top of the fuselage at the front motor mount and was then run over a pulley at the ceiling of the test chamber and to the safety-cable operator who adjusted the length of the cable to keep it slack during flight.

The power and control cable consisted of plastic tubes, which provided air for the electro-pneumatic control actuators, and electric wires, which supplied power for the motors and carried the remote-control signals to the control actuators. This cable was led from the power sources and suspended from the ceiling from a point near the safety-cable pulley. The power and control cable was then taped to the safety cable from about 15 feet above the model down to the model.

TESTS

Flight Tests

The investigation consisted of flight tests to determine the stability and control characteristics of the two modified configurations for comparison with the previously determined characteristics of the high-wing and top-mounted-tail configuration. 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 flights, and time histories of the angular motions and control displacements made from the motion-picture records.

The flight tests were started with the model in hovering flight in the test section of the Langley full-scale tunnel and, as the airspeed was increased, the controls were operated so that the model tilted progressively into the wind to maintain its fore-and-aft position in the test section. These flights corresponded to very slow constant-altitude transitions and covered a range of angle of attack from the hovering attitude of about 83° to an angle of attack of about 10°. Since small corrections or adjustments to the tunnel airspeed could not be made quickly, the pitch pilot and power operator had to make adjustments continually to hold the model in the center of the test section.

During the flight tests of the high-wing configuration with top- and bottom-mounted tails, the effects of a roll damper on the stability and control characteristics were studied; and during the flight tests of the low-wing configuration, the effects of both a roll damper and a yaw damper on the stability and control characteristics were studied. Damping-in-roll and damping-in-yaw devices were used one at a time in the tests and moved the control surfaces approximately 3° for each degree per second of rolling or yawing velocity.

For all the flight tests, the eyelids were deflected $\pm 11^\circ$ for pitch control and $\pm 8^\circ$ for yaw control and the roll nozzles were deflected $\pm 60^\circ$. The elevons were deflected $\pm 18^\circ$ for roll control. For those tests in which the rudder was used, a deflection of about $\pm 15^\circ$ was used.

Force Tests

Force tests were made for all configurations used in the flight tests in addition to some made with no tails on the model. The tests were run at one-half the rated rotational speed of the model motors with the tunnel airspeed adjusted to produce zero net drag on the model when all controls were at zero deflection. The data have been scaled up to correspond to the flying weight of the model.

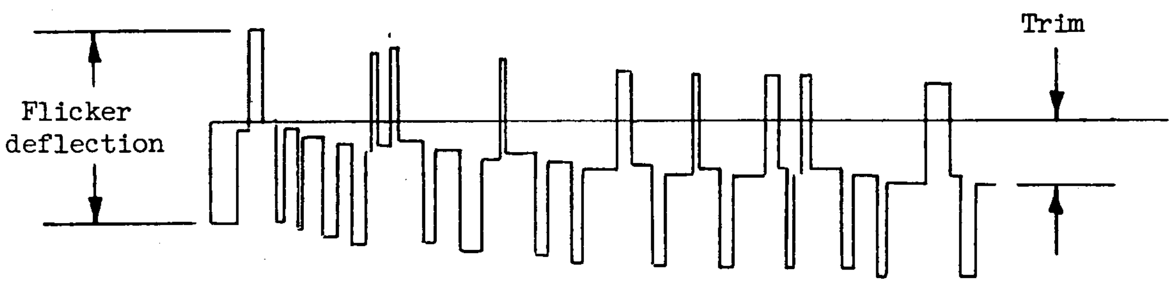
No tunnel wall or blockage corrections have been applied to the force-test data. It is expected that these corrections might be large since the model was large in relation to the test section of the Langley free-flight tunnel where the force tests were made.

RESULTS AND DISCUSSION

The results of the 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.

When the test results are interpreted, it should be borne in mind that the effects of the gyroscopic moments of the jet engine on the stability and control characteristics were not simulated because the two motors of the model powerplant turned in opposite directions so that the gyroscopic forces canceled.

An explanation of the control record plots shown in all flight-test data figures is given below



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 so that, 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. Control applications caused by the automatic devices are not shown in the control plots.

Configuration With High Wing and Top-Mounted Vertical Tail

The basic model configuration had a high wing and a top-mounted vertical tail. The stability and control characteristics of the basic model are described in detail in reference 1 but some of the results of the investigation of reference 1 are repeated herein for comparison with the results of the present investigation.

About half of the attempted transition flights made without automatic-stabilization devices were unsuccessful because the model diverged in roll and yaw at angles of attack between about 50° and 60° despite the efforts of the pilots to stop it. In all cases, the divergence started with the model rolling to the left about 20° or 30°, flying in a sideslipped attitude for 1 or 2 seconds, and then diverging in yaw to the right. Figure 6 shows time histories of two attempted transition flights which ended in such divergences. Since no accurate records of the rolling motions could be obtained from the motion-picture records, the only purpose of the roll records in figure 6 is to indicate the time at which the model started the rolling divergence. The roll records do, however, illustrate the difficulty of controlling the motions since, at the time of the divergence, they indicate that the pilots were holding full corrective control (right aileron and left rudder) as the model diverged. The divergence could not be studied in detail because of the speed-control limitations in the Langley full-scale tunnel. The minimum steady airspeed available was 22 knots which corresponds to an angle of attack of 33°; thus, when the airspeed reached the minimum steady-state value, the model had already passed through the critical angle-of-attack range.

The force-test data of figures 7 and 8 indicate that at high angles of attack the model had unstable variations of yawing moment and almost neutrally stable or slightly unstable variations of rolling moment with angle of yaw and angle of roll. In fact, as indicated by a comparison of the data of figure 7 with the tail-off data of figure 9, the basic configuration was more unstable directionally with the tail on than with the tail off at high angles of attack. It should be borne in mind that the data are referred to the body axes so that roll, as well as yaw, introduces a sideslip angle. The angle of sideslip introduced by the roll angle is equal to the roll angle times the sine of the angle of attack. Consequently, at high angles of attack the angle of sideslip introduced by rolling is almost as large as the roll angle. The control motions of figure 6 indicate that a considerable amount of trimming in roll was required during the early portion of the transition. The same result is indicated by the force-test data of figure 8 which show a rather abrupt change in roll trim between angles of attack of 40° and 50°. This change in roll trim made flying the model in a wing-level attitude very difficult because the trim had to be set into the controls very quickly. If the model was allowed to roll to the left as much as 15° while flying at high angles of attack, the rolling moment caused by the slight negative dihedral effect augmented the out-of-trim rolling moment to such an extent that the pilot was unable to correct the roll. The model then diverged in yaw because of the directional instability at these angles of attack.

In some cases it was possible to complete the transition if the model was flying very steadily as it passed through the critical angle-of-attack range in which the strong divergent tendency was encountered and if this critical range was passed through rapidly. Figure 10 shows a time history of a transition flight in which there was no divergence. Although this yaw record indicates that the model did not fly very smoothly in yaw at the low angles of attack, the yaw pilot felt that the model was easy to control in this angle-of-attack range. In this flight range, the lateral motions of the model were easy to control and, in most cases, the roll pilot could quit his controlling of the model and the yaw pilot alone could control the lateral motions. The model tended to wander but the yaw pilot could stop it at any time he desired. The lateral motions could not be controlled satisfactorily with the roll controls alone in the unstalled flight range because of the adverse aileron yawing moments.

The pitch and power controls were somewhat difficult to coordinate since variations in thrust also changed the pitching moment because the center of gravity was not on the thrust axis. Despite the coordination difficulty, the model could be flown smoothly in pitch at the low angles of attack. At times the model seemed to have stability of angle of attack since, at constant tunnel airspeeds, it could be flown occasionally with hands off for a short period of time without any indication of a tendency to diverge.

The use of a roll damper, which moved the elevons, greatly improved the stability in both the critical angle-of-attack range (50° to 60°) and at the low angles of attack so that all the transition flights attempted with this device installed were successful. Apparently, the roll damper reduced the tendency of the model to sideslip by keeping it steady in roll about the body axis. During the low-angle-of-attack portions of these flights, the roll pilot had to apply very little control; in fact, the record of figure 11 shows that the roll pilot did not have to apply any control after the model reached angles of attack below about 50°. The flights with the roll damper installed were much smoother than those for any other condition covered in the investigation. The yaw record is similar to that made without any automatic stabilization but the roll and yaw pilots found that, although a slight tendency to diverge was still evident, the model could be controlled fairly easily in the critical angle-of-attack range. The roll pilot was able to trim the model for level flight early in the flight and then he could stop flying the model and let the yaw pilot alone control the lateral motions at high speeds. This procedure was followed in most of the flights because of the excessive roll control at the low angles of attack.

Configuration With a High Wing and Top- and Bottom-Mounted Vertical Tails

All the transition flights attempted with the high-wing configuration with both top- and bottom-mounted vertical tails were terminated by an uncontrollable rolling divergence at very low airspeeds. The use of artificial damping in roll did not provide any noticeable improvement in this divergence. Figure 12 shows time histories of these divergences both with and without artificial roll stabilization. In all cases the records show that the model diverged in roll at an angle of attack between 60° and 70° against full control. The airspeed at which the roll divergence occurred was approximately 13 knots. The force-test data of figures 13 and 14 show that at high angles of attack the model had unstable variations of rolling and yawing moments with roll and yaw angles. The high degree of negative effective dihedral was evidently the cause of the divergence. Representative data from figures 7, 9, and 14 have been cross-plotted in figure 15 for an angle of attack of 50°. A comparison of these data indicates that the configuration with both top- and bottom-mounted tails had less directional instability than the basic configuration but was still more unstable directionally than the tail-off configuration. Comparison of the data of figure 15 shows that, as would be expected, the bottom-mounted tail was the cause of the large negative dihedral effect. Although no attempt was made to fly the model without any vertical tails, it would appear from the force-test data that this configuration may have had better low-speed stability characteristics than the top- and bottom-mounted tail configuration. Of course, at the low angles of attack during the transition flight, the top- and bottom-mounted tail configuration becomes less unstable directionally whereas the tailless configuration becomes more unstable.

Configuration With a Low Wing and Top-Mounted Vertical Tail

With the low-wing configuration with a top-mounted vertical tail, no successful transition flights could be made without automatic stabilization because of an unstable lateral oscillation which became uncontrollable at an angle of attack of about 60°. The use of artificial damping in roll or yaw provided a considerable improvement in the flight characteristics but the pilot still lost control of the model occasionally. Figure 16 shows a time history of a flight made without artificial damping in roll. The alternate left- and right-roll-control applications (fig. 16) from about halfway through the flight to the end of it 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 a control and the time he applied the control. For unstable or lightly damped oscillations when lag such as this exists, the use of controls may actually aggravate the motion. With a roll damper installed (see fig. 17), the flights were very smooth provided the pilots did not aggravate the lateral oscillation by improper use of roll or yaw control. Replacing the roll damper with a yaw damper made the model slightly easier to fly, and a larger percentage of the attempted flights were successful with the yaw damper operating than with the roll damper operating. Near the end of the flight-test program after the pilots had gained experience in flying the model, successful transition flights could be made consistently with the yaw damper operating.

The force-test data of figures 18 and 19 show that the model had unstable variations of yawing moment with angles of yaw and roll and that it had large stable variations of rolling moment with angles of yaw and roll. Figure 20 presents representative data from figure 18 which have been cross-plotted for an angle of attack of 50° and compared with similar plots for all other configurations that were force tested. These data show the high positive dihedral effect associated with the low-wing and top-mounted vertical-tail configuration. The Dutch roll oscillation was probably caused by this high positive dihedral effect combined with the directional instability.

SUMMARY OF RESULTS

The results of a flight- and force-test investigation to determine the effects of wing position and vertical-tail configuration on the stability and control characteristics of a jet-powered delta-wing vertically rising airplane model can be summarized as follows:

1. Transition flights with a high-wing configuration with a top-mounted vertical tail were difficult to accomplish without automatic stabilization because of a lateral divergence which occurred between angles of attack of about 50° to 60°. The use of a roll damper eliminated the lateral divergent tendency during the low-speed portion of the transition flight and also made the high-speed portion of the flights much smoother.

2. No successful transition flights could be made when the model had a high wing and both a top- and bottom-mounted vertical tail because of an uncontrollable rolling divergence at low airspeeds. The use of a roll damper did not provide any noticeable improvement in the lateral stability of this configuration.

3. No successful transition flights could be made with the configuration with a low wing and a top-mounted vertical tail without artificial stabilization because of an unstable lateral oscillation at angles of

attack near 60°. The use of either a roll damper or a yaw damper made it possible to perform the transition flight successfully.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., September 24, 1956.

REFERENCE

1. Lovell, Powell M., Jr.: Flight Tests of a Delta-Wing Vertically Rising Airplane Model Powered by a Ducted Fan. NACA RM L55B17, 1955.

TABLE I.- GEOMETRIC CHARACTERISTICS OF THE MODEL

Weight, lb	46.50
Overall length of model, in.	77.00
Wing (modified triangular plan form):	
Sweepback of leading edge, deg	60
Airfoil section	NACA 65A006
Aspect ratio	1.65
Taper ratio (root to theoretical tip)	3.41
Area, sq in.	1765.00
Span, in.	54.00
Mean aerodynamic chord, in.	38.00
Span of elevon, in.	18.00
Chord of elevon, in.	5.25
Span of roll-control nozzle flaps, in.	6.00
Chord of roll-control nozzle flaps, in.	2.13
Top-mounted tail for high-wing configurations (modified triangular plan form):	
Sweepback of leading edge, deg	50
Airfoil section	NACA 65A006
Aspect ratio	0.85
Taper ratio	2.94
Area, sq in.	574.3
Span, in.	22.50
Span of rudder, in.	19.50
Chord of rudder, in.	4.75
Bottom-mounted tail for high-wing configuration; also top-mounted tail for low-wing configuration (modified triangular plan form):	
Sweepback of leading edge, deg	50
Airfoil section	NACA 65A006
Aspect ratio	0.92
Taper ratio (root to theoretical tip)	3.72
Area, sq in.	303.80
Span, in.	16.70
Span of rudder, in.	15.63
Chord of rudder, in.	4.75
Fuselage:	
Duct length, in.	48.00
Inside diameter, in.	14.50
Outside diameter, in.	15.00

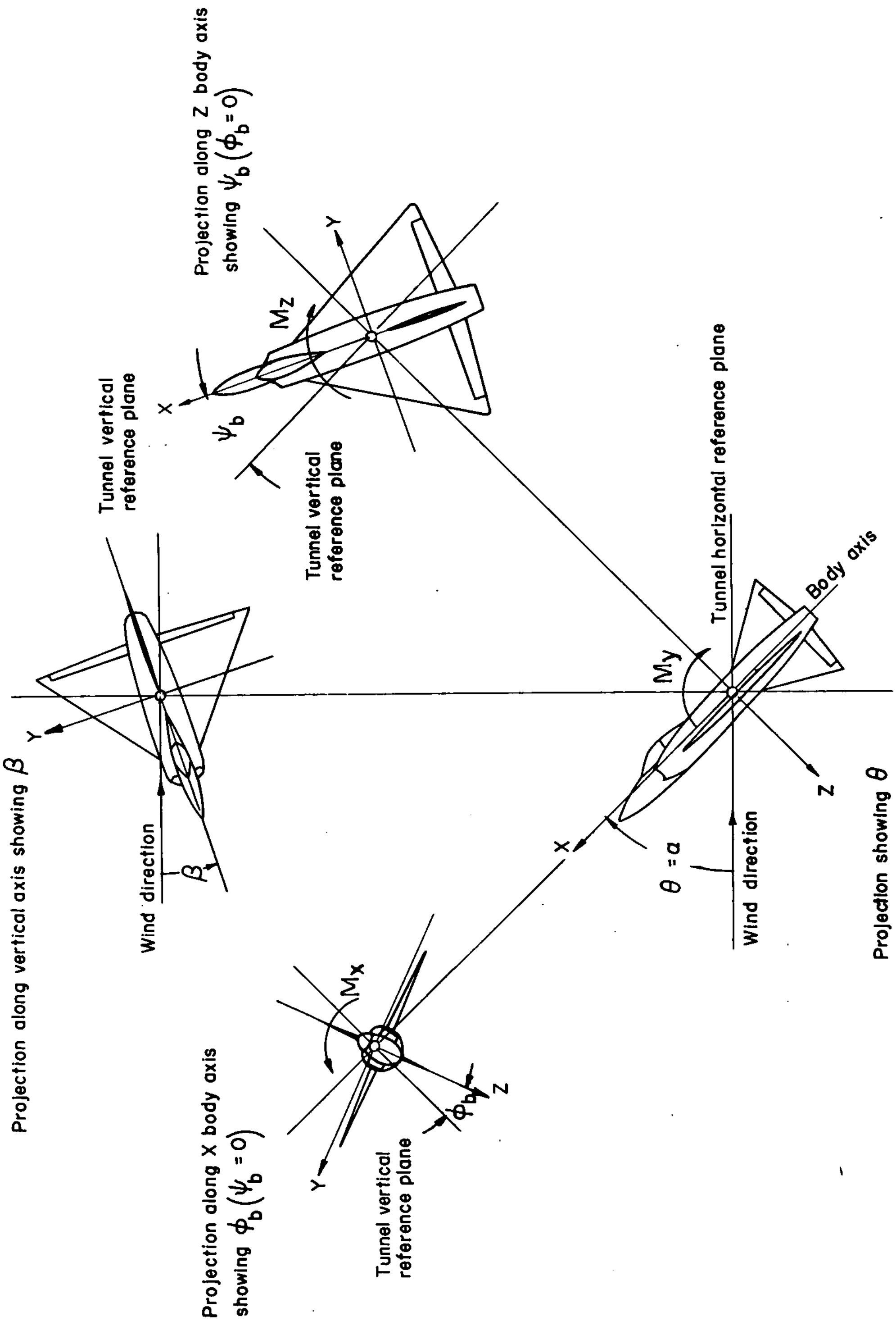
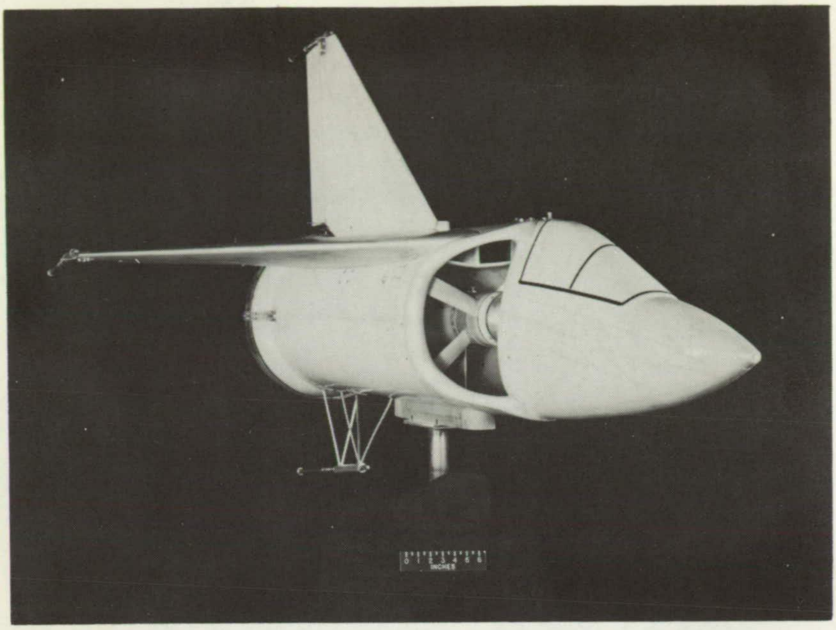


Figure 1.- Body system of axes. Arrows indicate positive directions of moments, forces, and angles.



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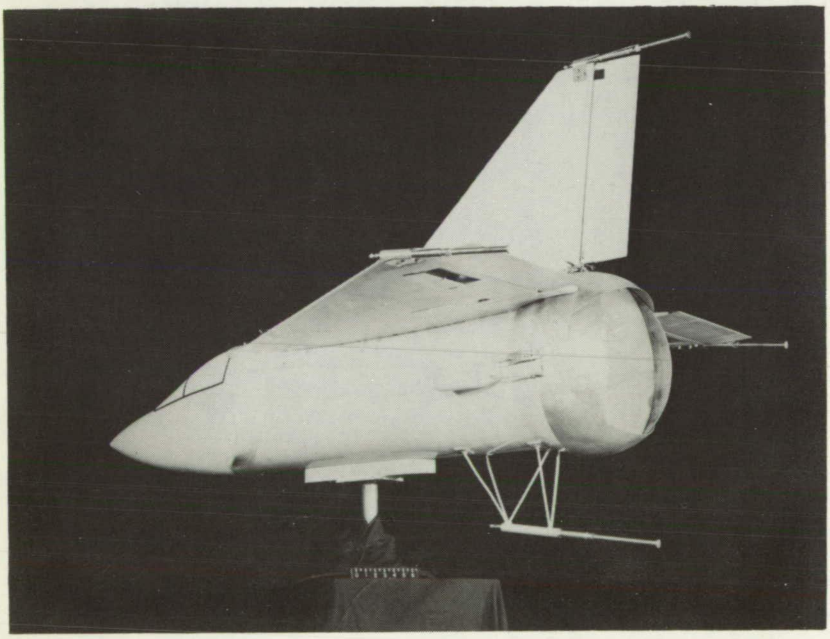

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Figure 2.- Photographs of delta-wing ducted-fan powered model.

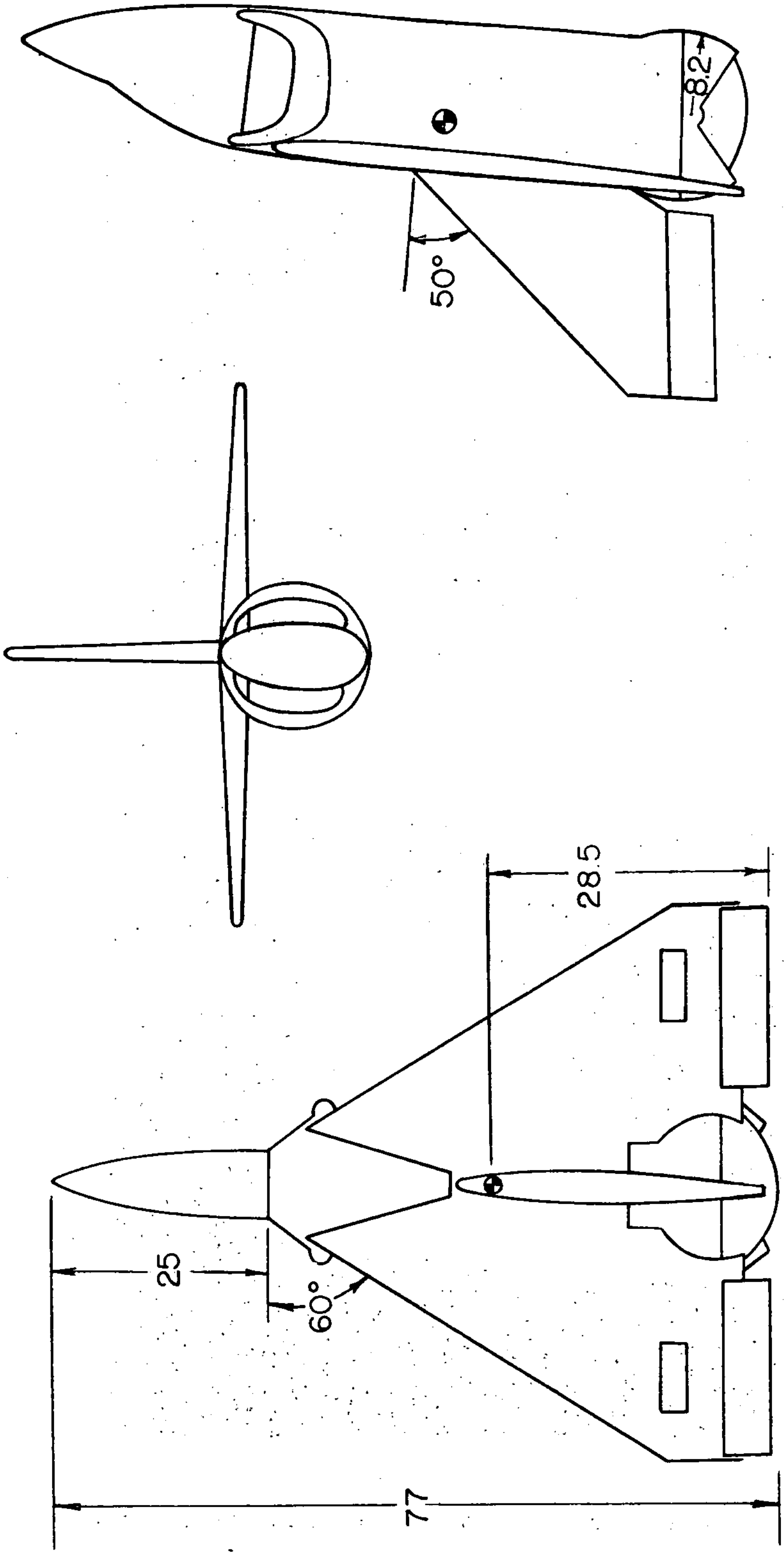

Figure 3.- Sketch of model. All dimensions are in inches.

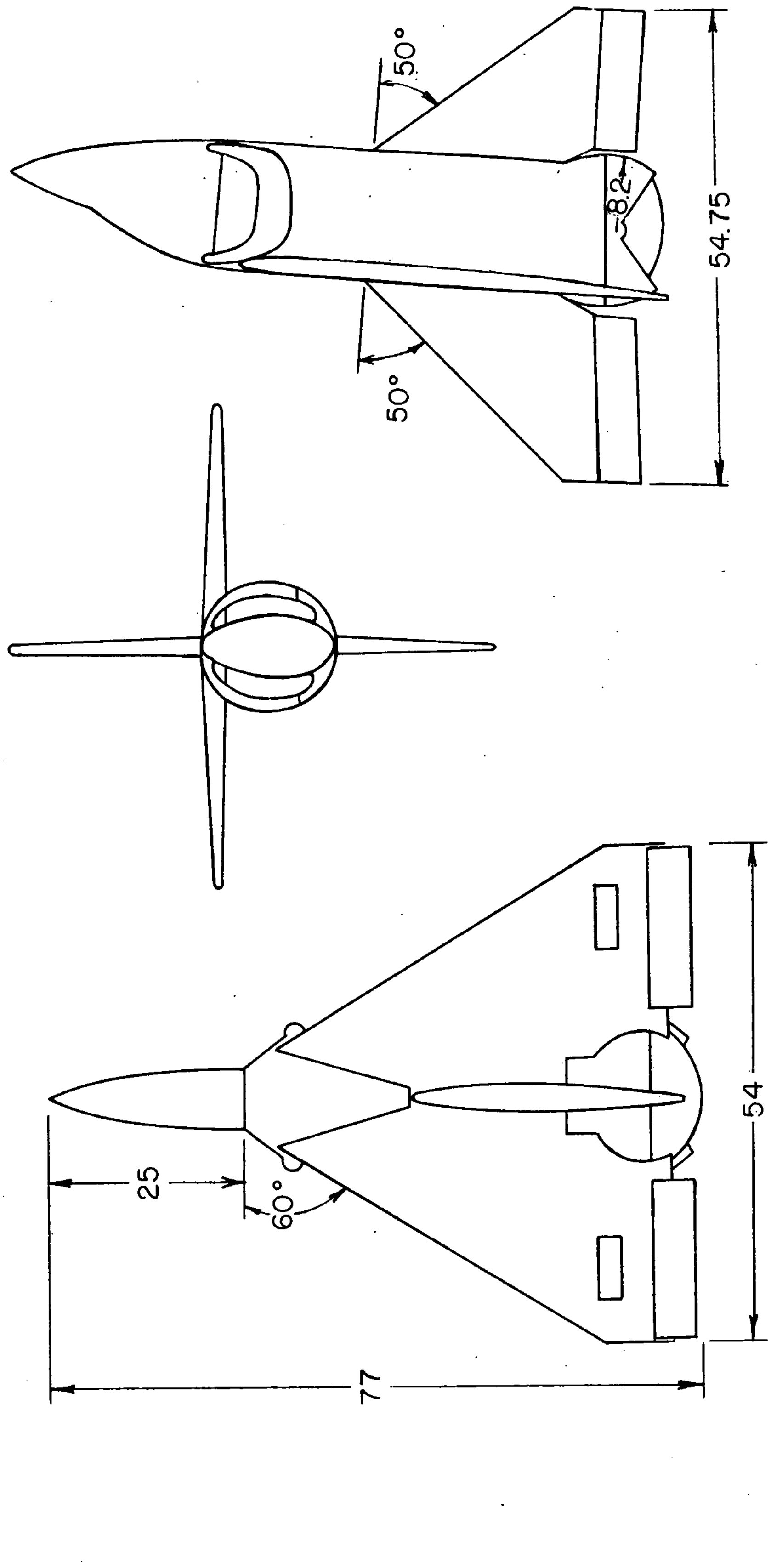

Figure 3.- Continued.

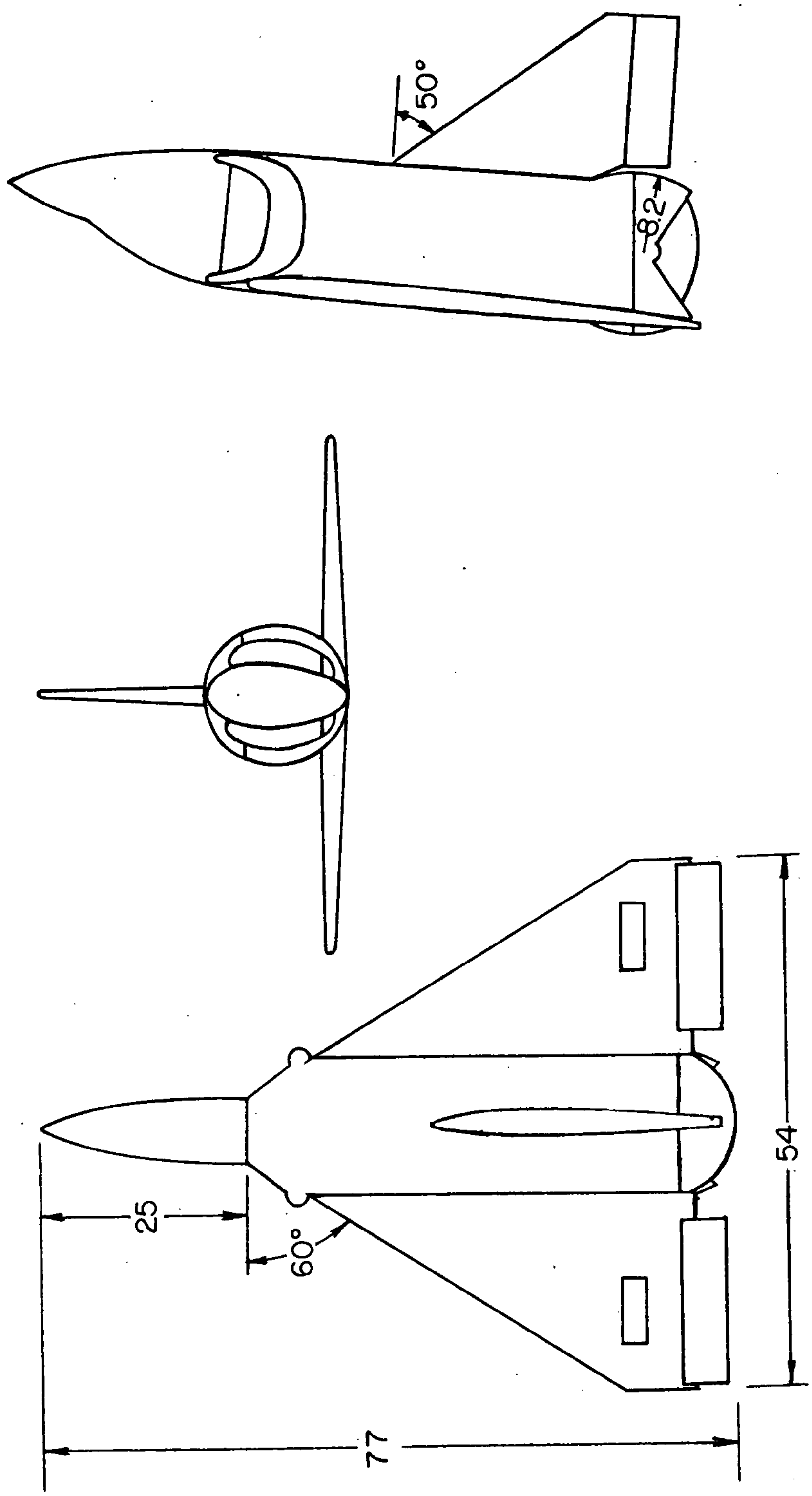

Figure 3.- Concluded.

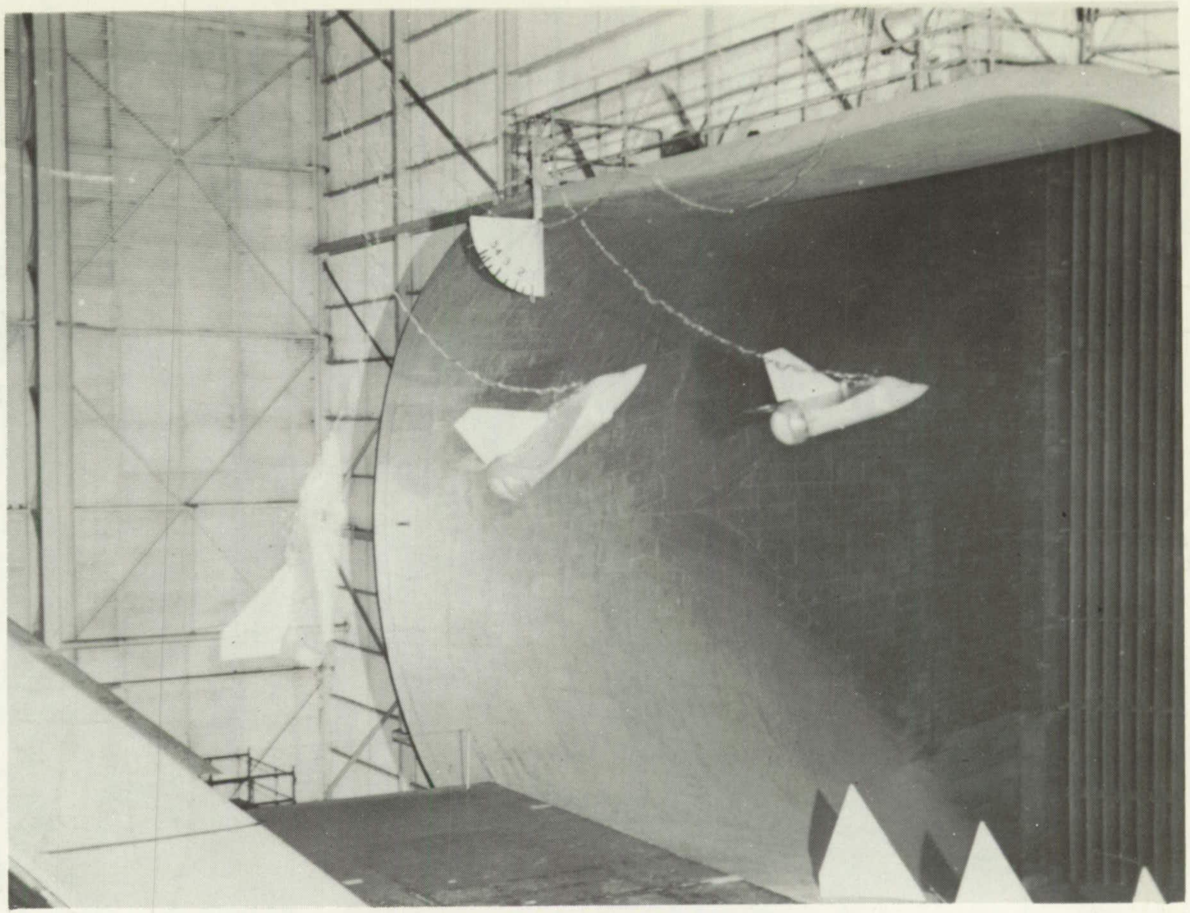

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Figure 4.- Multiple-exposure photograph showing the basic model in three stages of a transition flight.

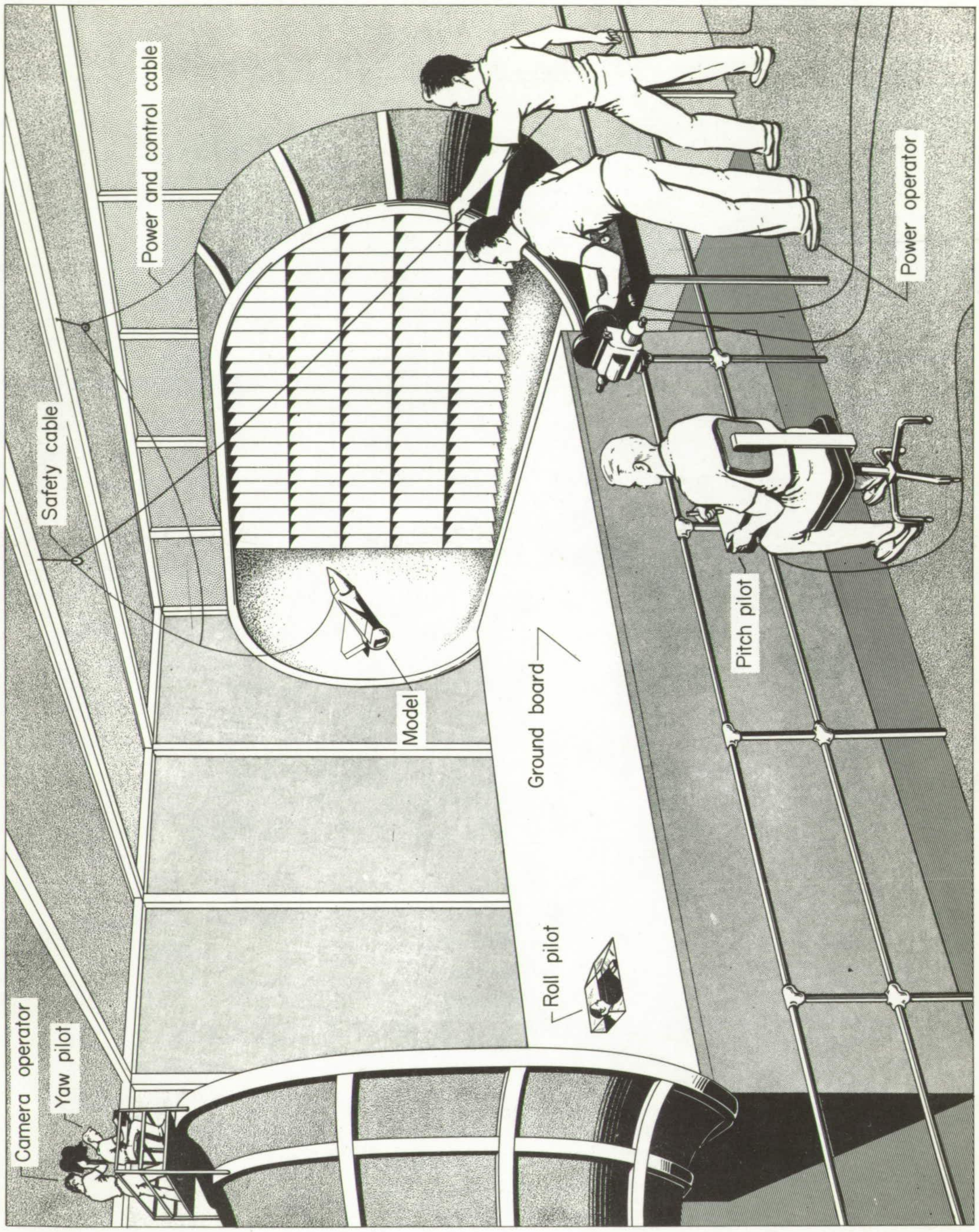


Figure 5.- Sketch of test setup for transition flights.

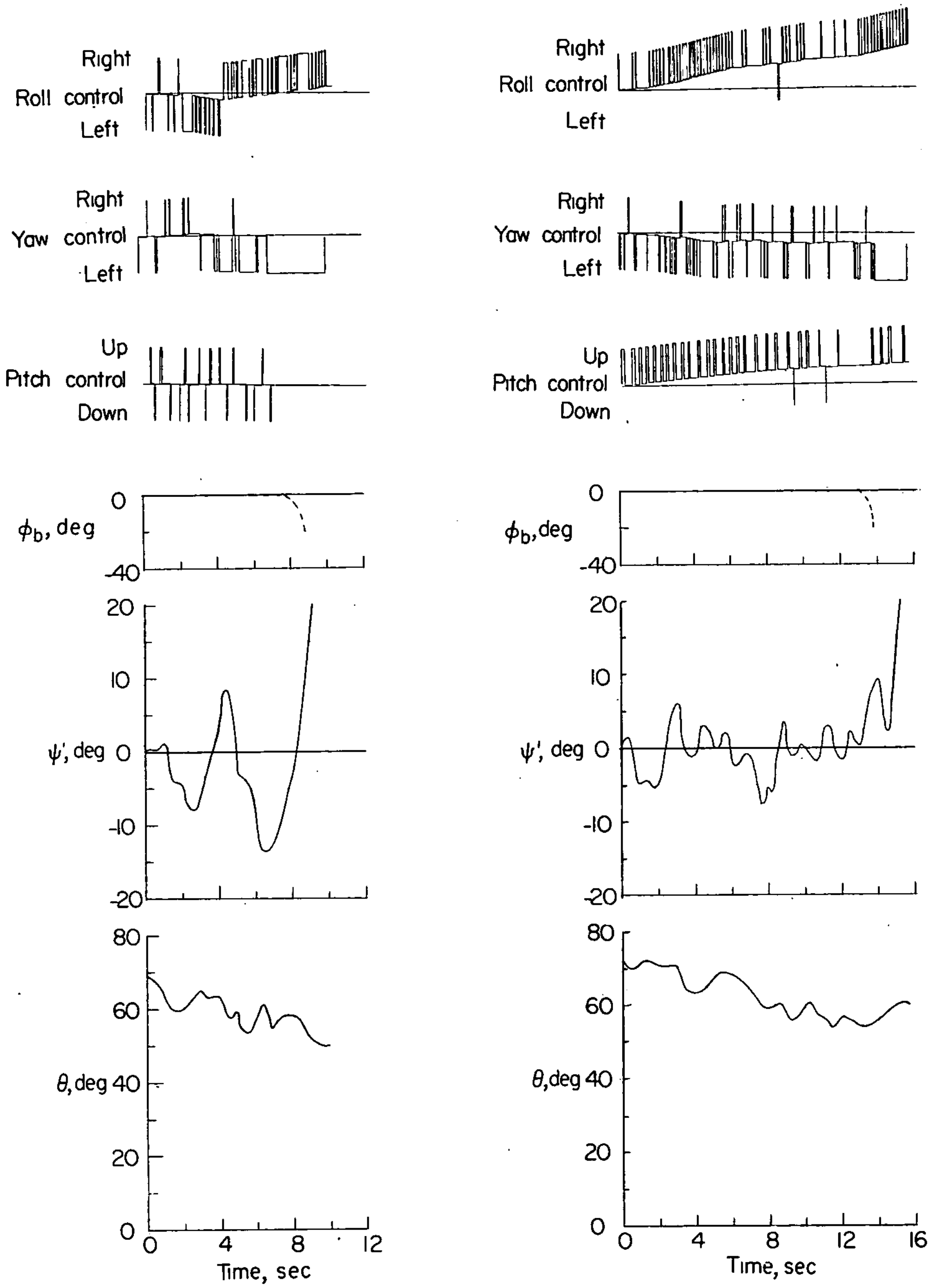


Figure 6.- Time histories of transition flights without automatic stabilization which ended in lateral divergences. The roll records are only approximate and merely indicate when the rolling divergence started. Configuration with high wing with top-mounted vertical tail. Data from reference 1.

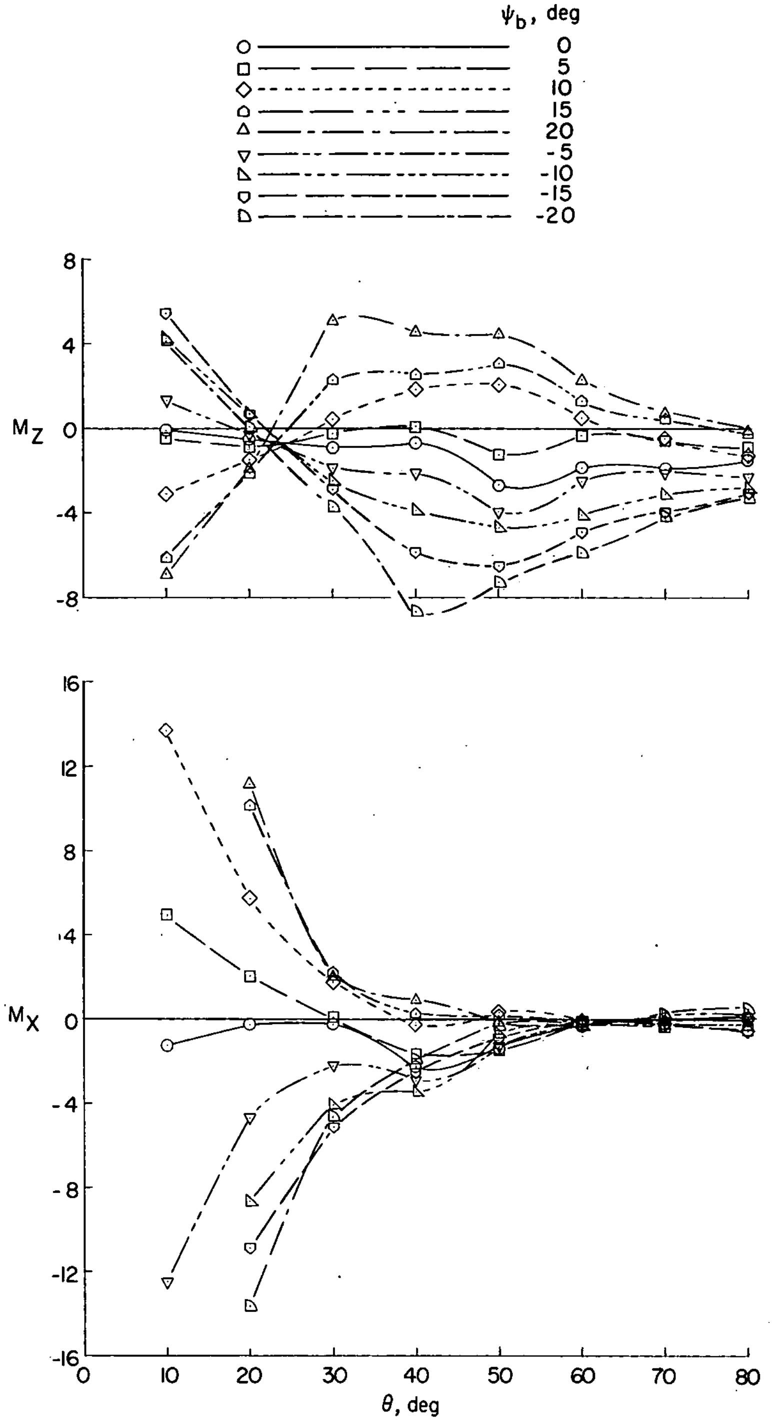


Figure 7.- Lateral stability characteristics of the high-wing configuration with top-mounted vertical tail. Yaw angle varied.

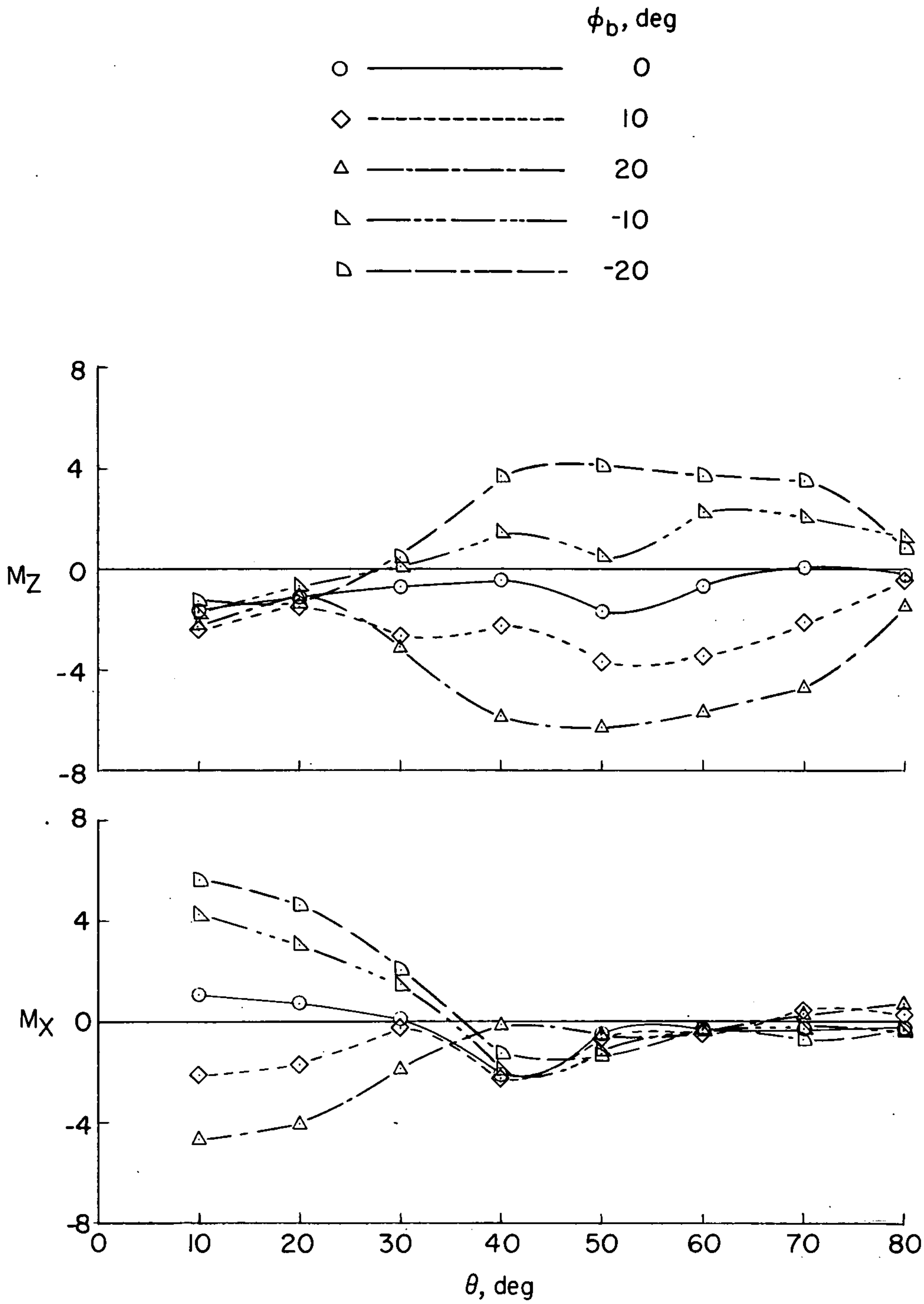


Figure 8.- Lateral stability characteristics of the high-wing configuration with top-mounted vertical tail. Roll angle varied.

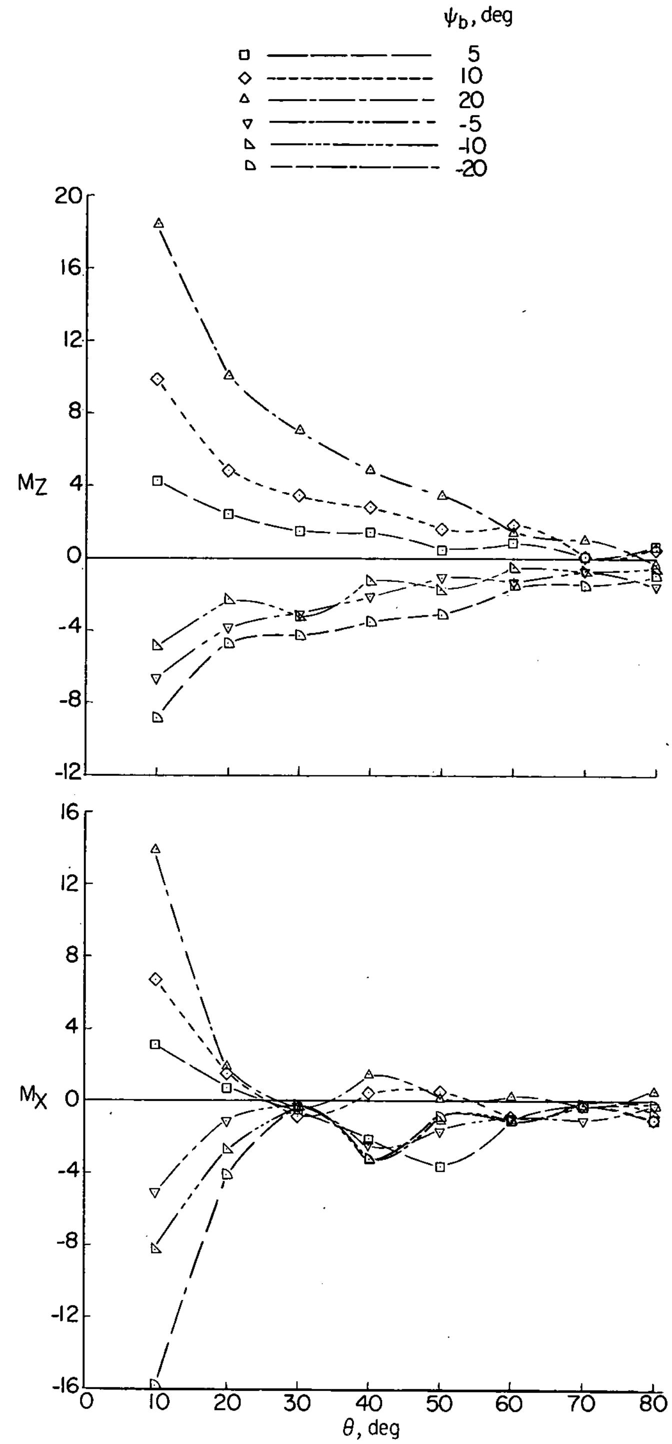


Figure 9.- Lateral stability characteristics of the high-wing configuration with tails off. Yaw angle varied.

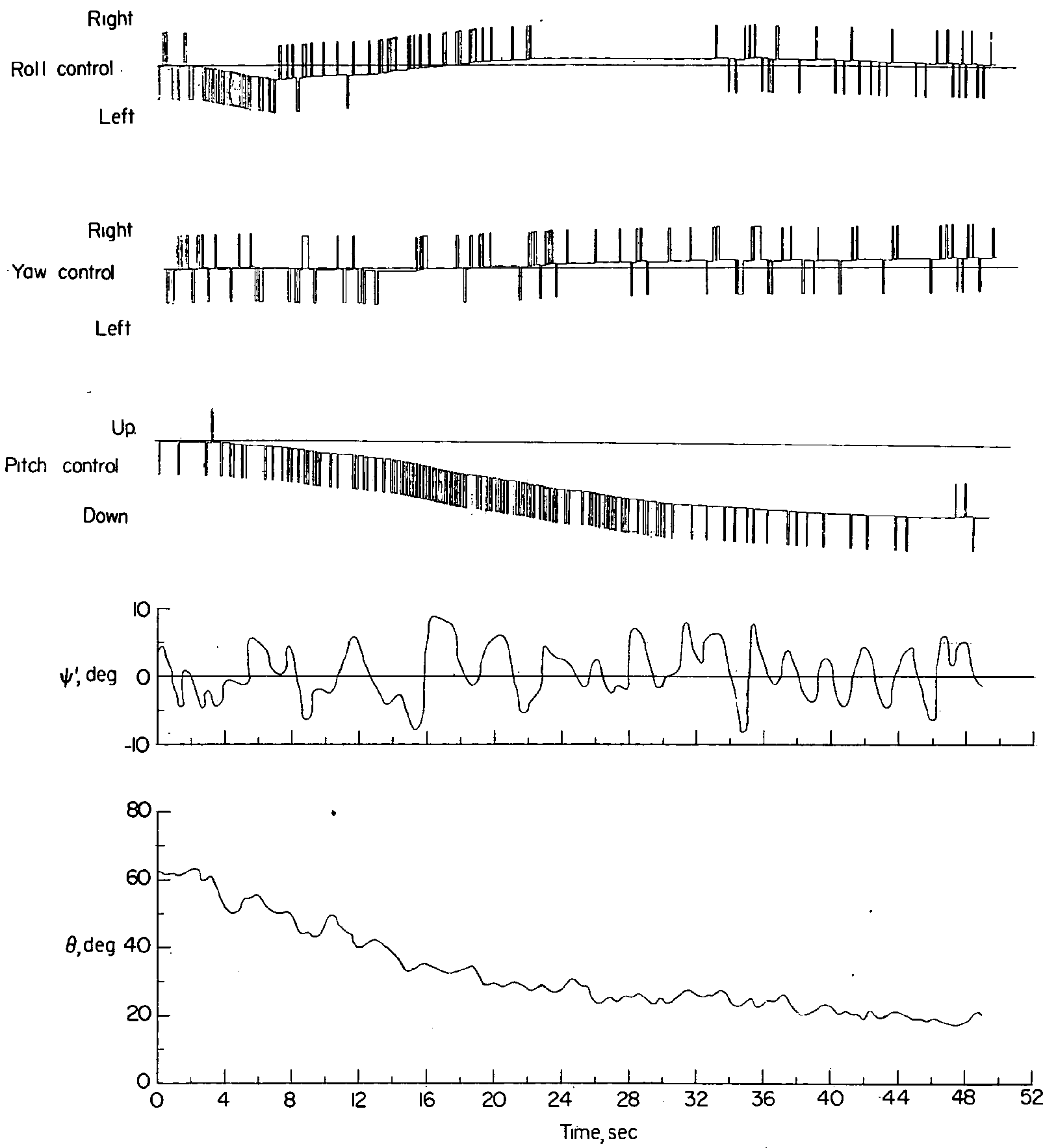


Figure 10.- Time history of a transition made without automatic stabilization in which there was no lateral divergence. Configuration with high wing and top-mounted vertical tail. Data from reference 1.

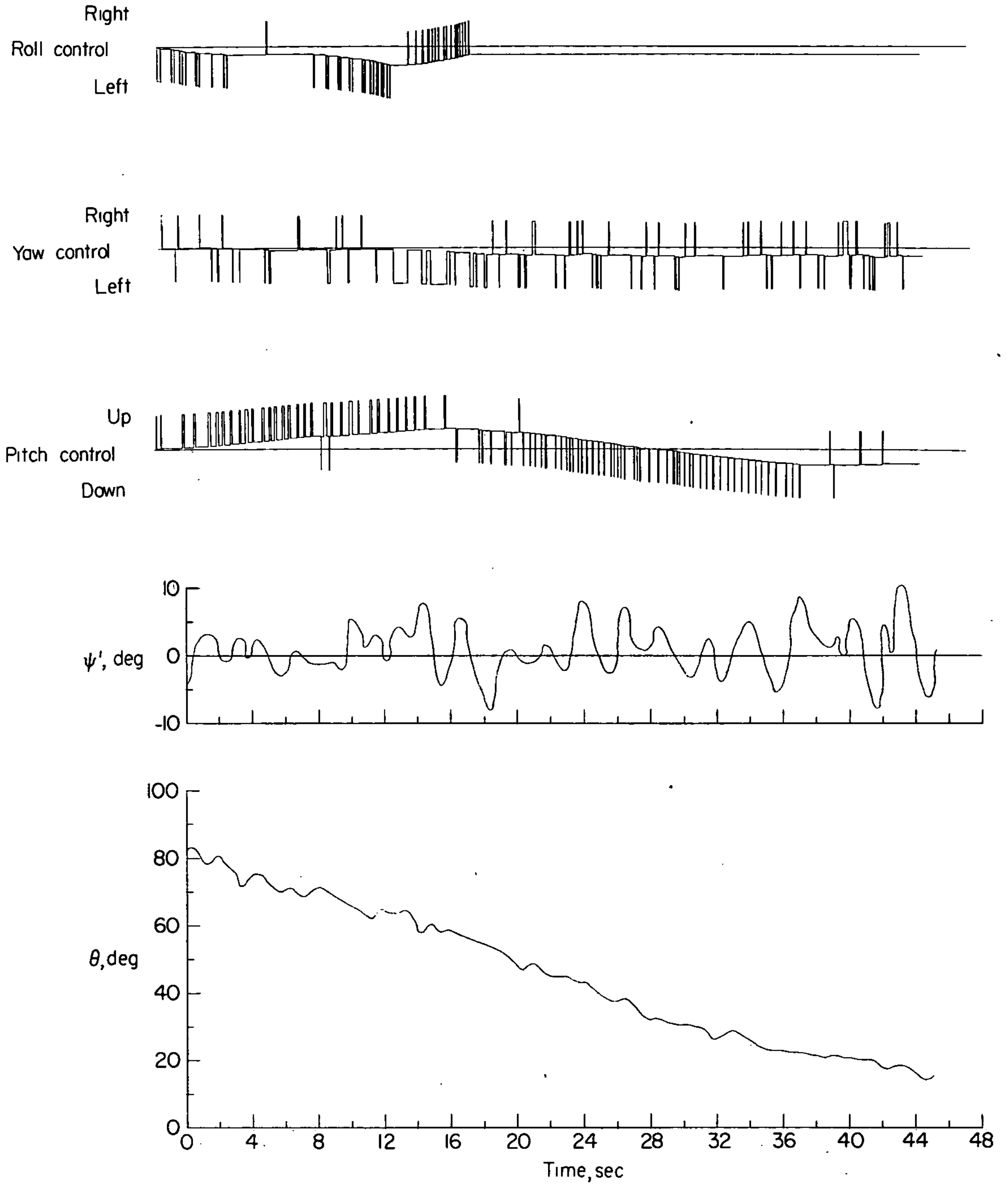
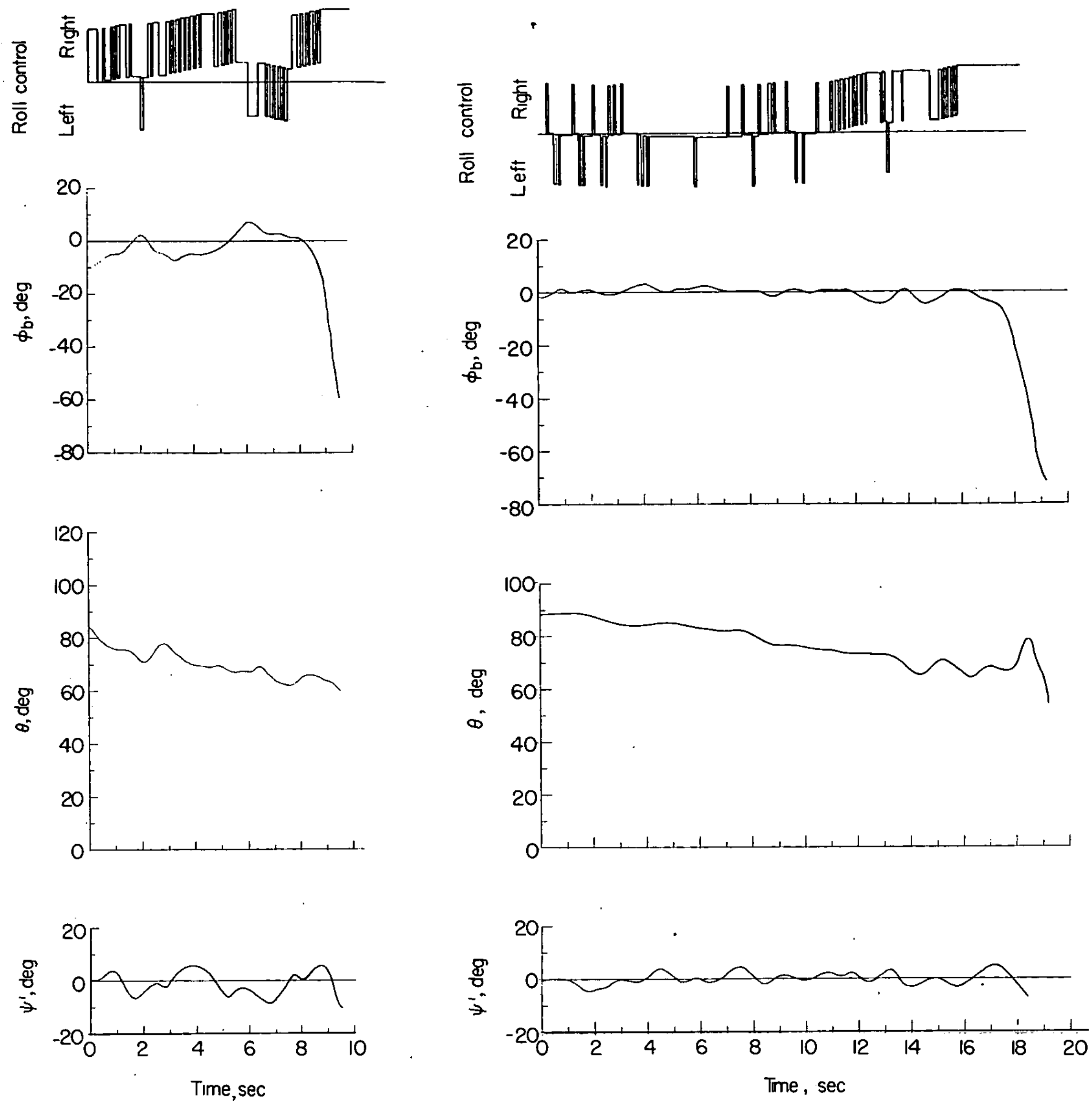


Figure 11.- Time history of a transition flight made with a roll damper operating. Configuration with high wing and top-mounted vertical tail. Data from reference 1.



(a) Without roll damper.

(b) With roll damper.

Figure 12.- Time histories of attempted transition flights made with and without a roll damper. Configuration with high wing and top- and bottom-mounted vertical tails.

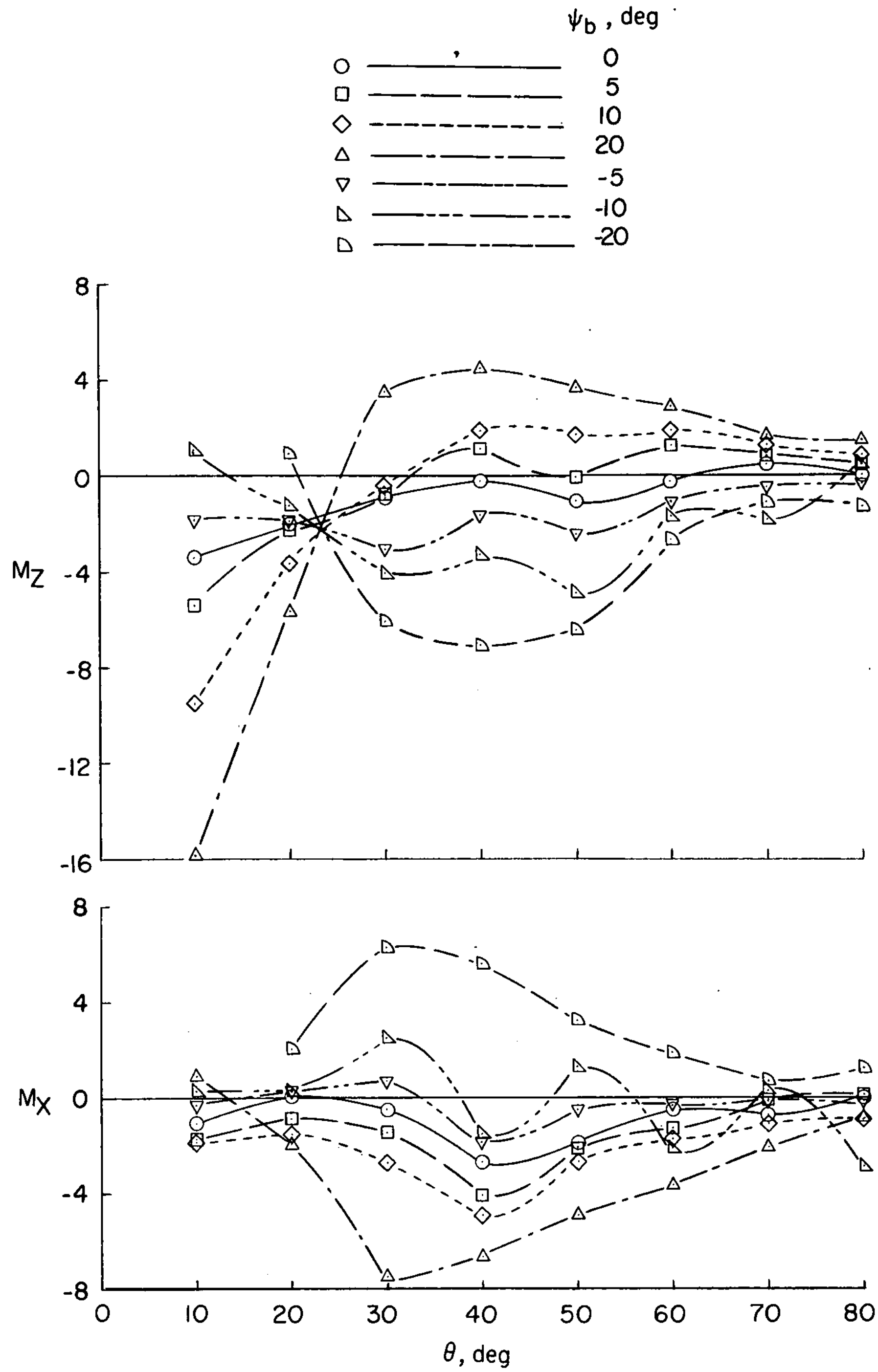


Figure 13.- Lateral stability characteristics of the high-wing configuration with top- and bottom-mounted vertical tails. Yaw angle varied.

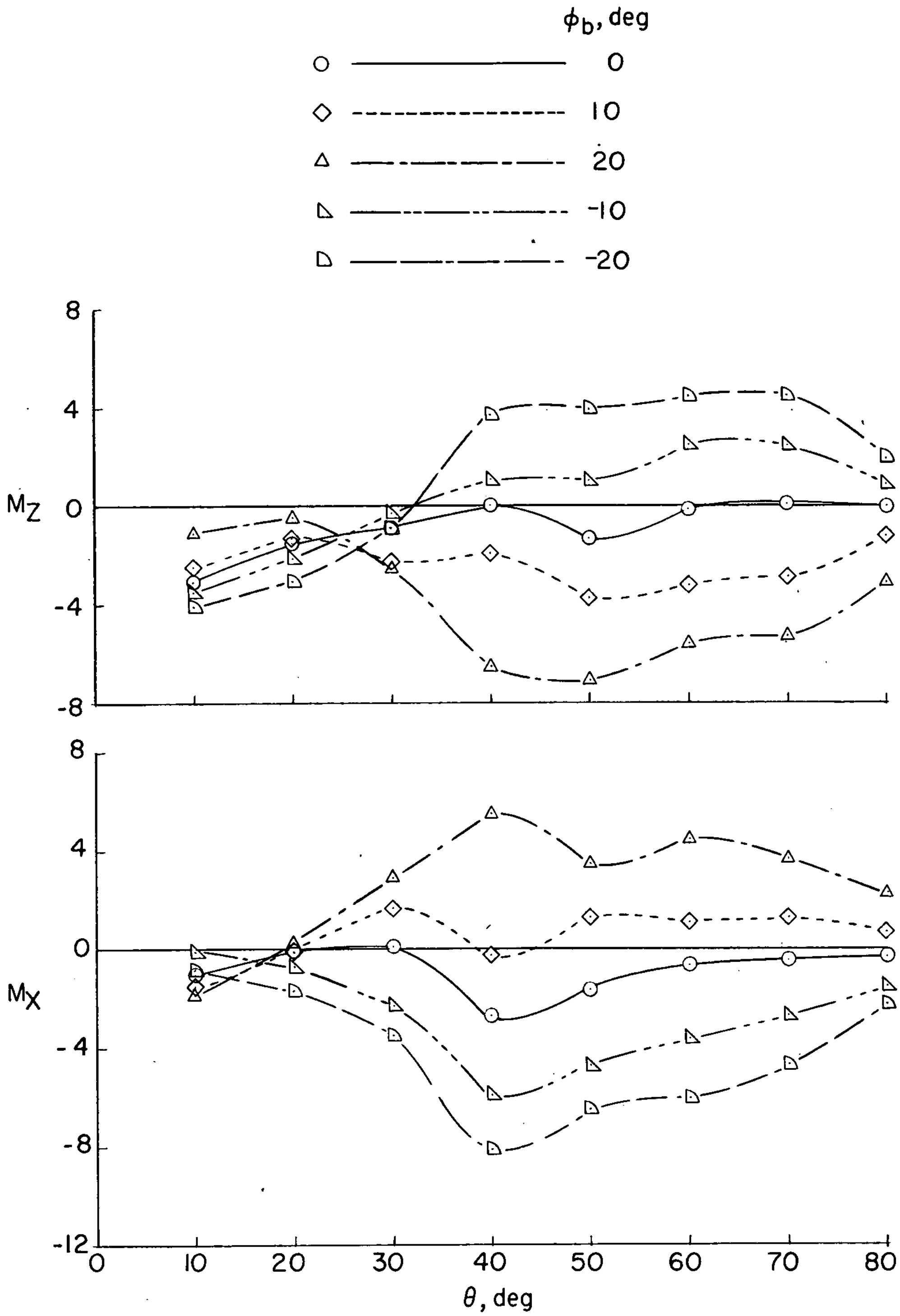


Figure 14.- Lateral stability characteristics of the high-wing configuration with top- and bottom-mounted vertical tails. Roll angle varied.

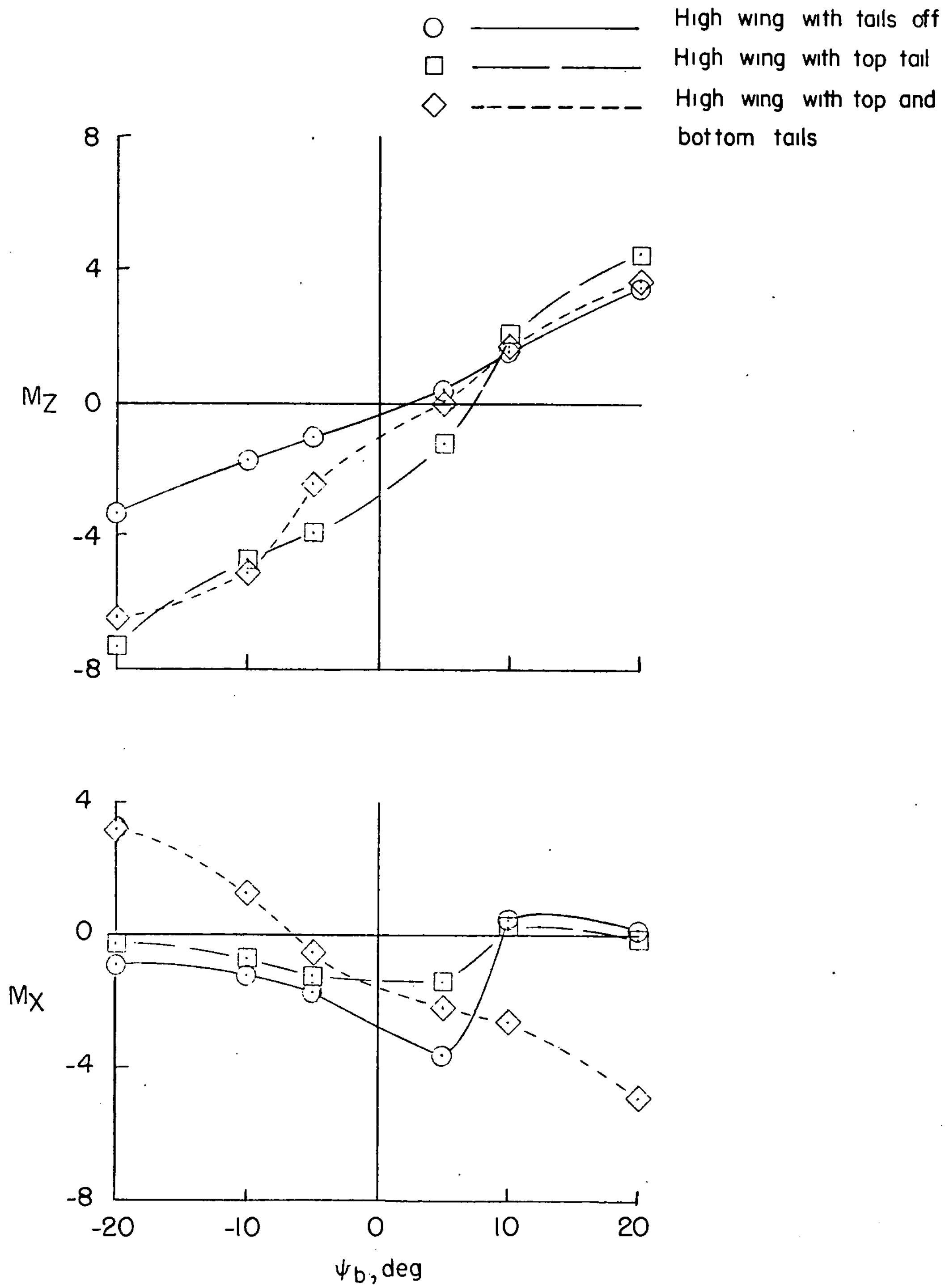


Figure 15.- Lateral stability characteristics of three configurations at an angle of attack of 50°.

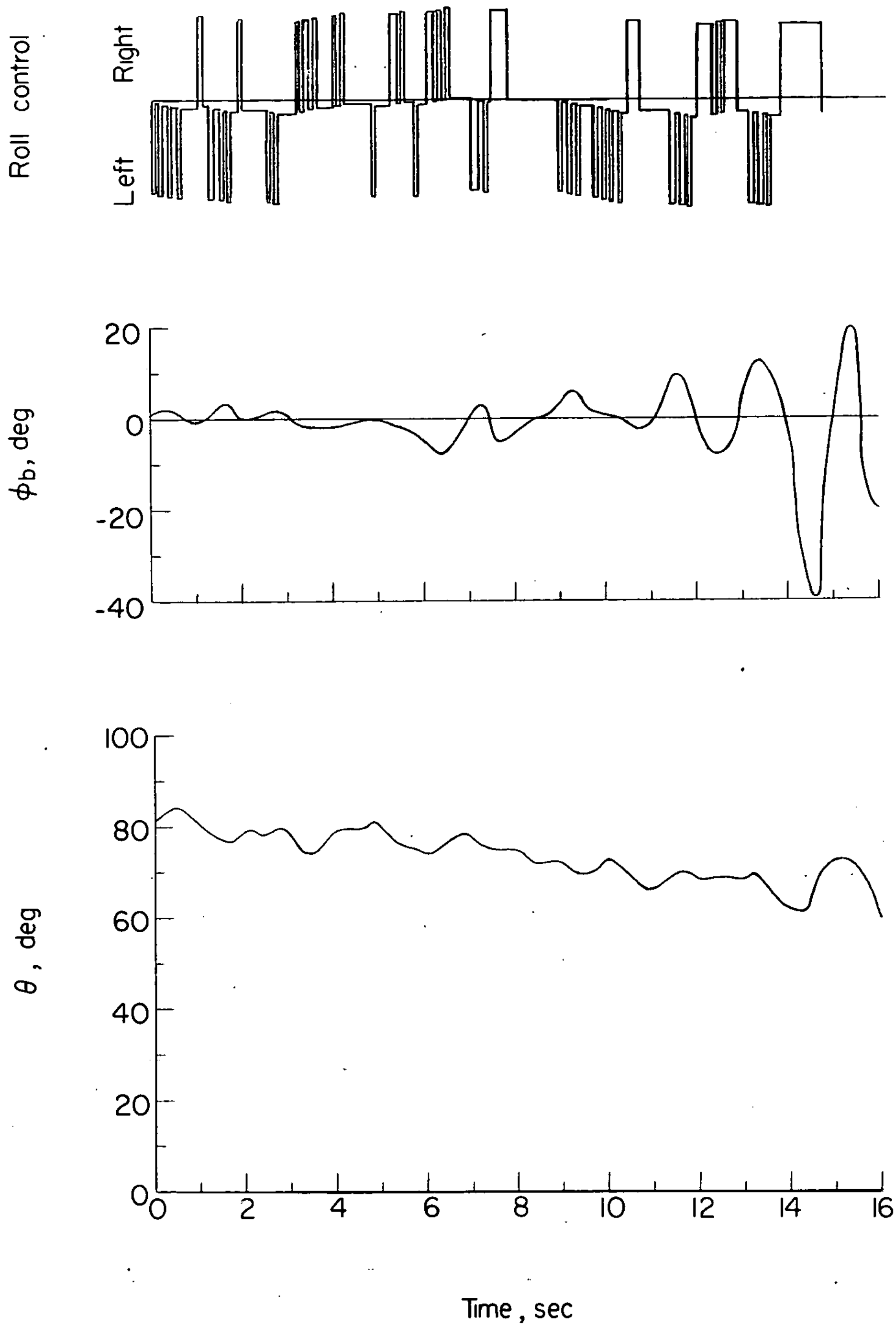


Figure 16.- Time history of an attempted transition flight made without a roll damper. Configuration with low wing and top-mounted vertical tail.

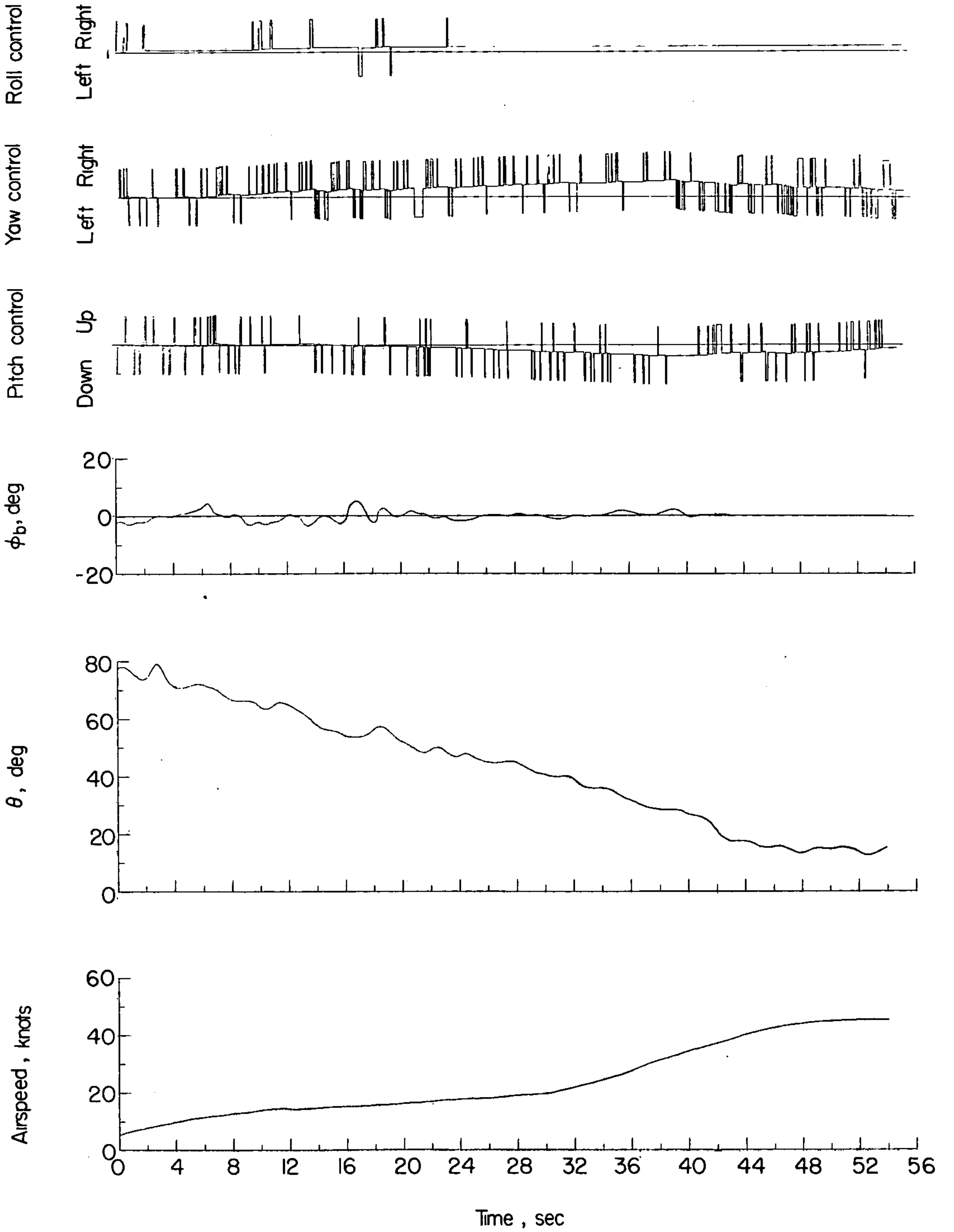


Figure 17.- Time history of a transition flight made with a roll damper. Configuration with low wing and top-mounted vertical tail.

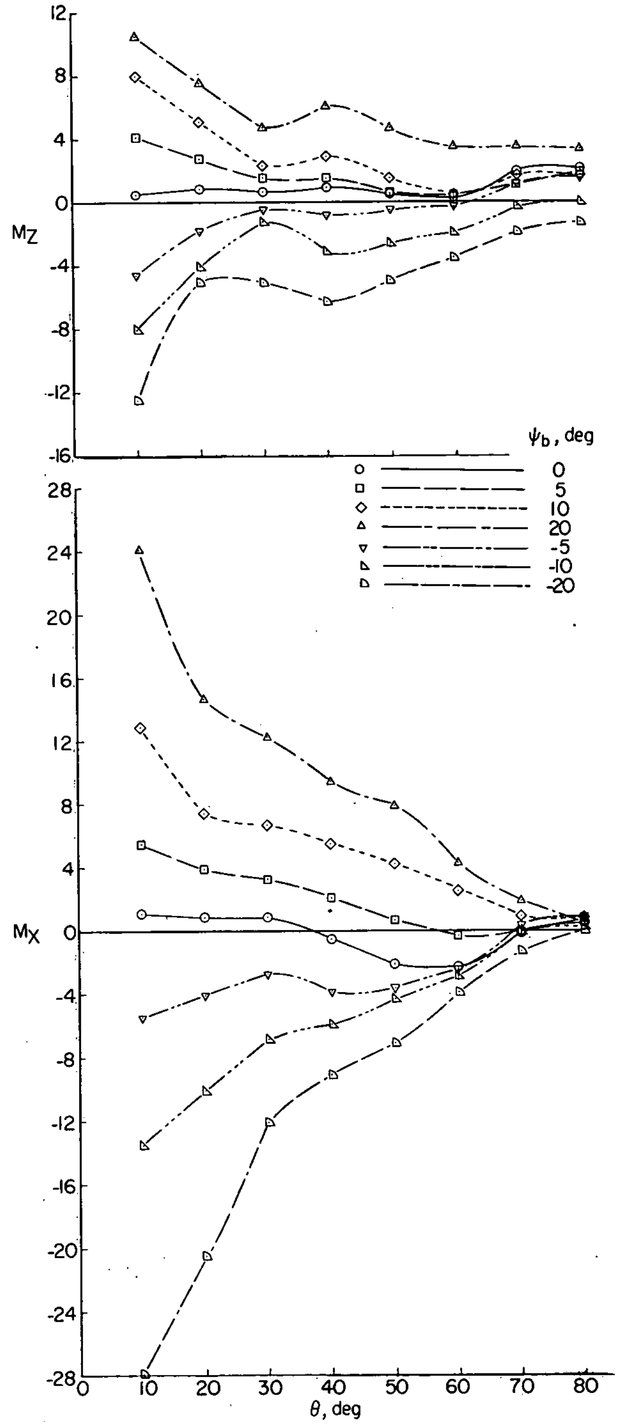


Figure 18.- Lateral stability characteristics of the low-wing configuration with top-mounted vertical tail. Yaw angle varied.

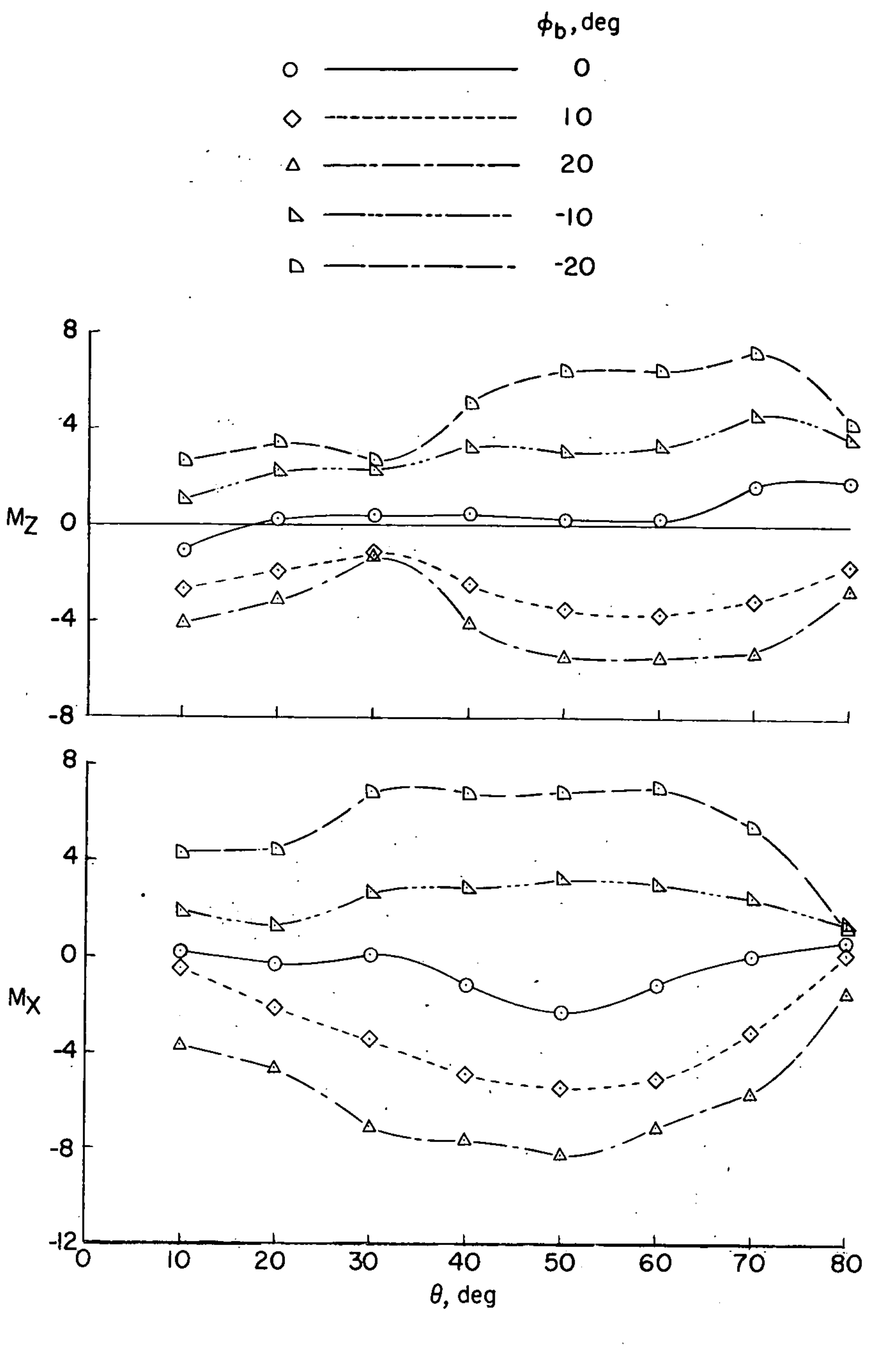


Figure 19.- Lateral stability characteristics of the low-wing configuration with top-mounted vertical tail. Roll angle varied.

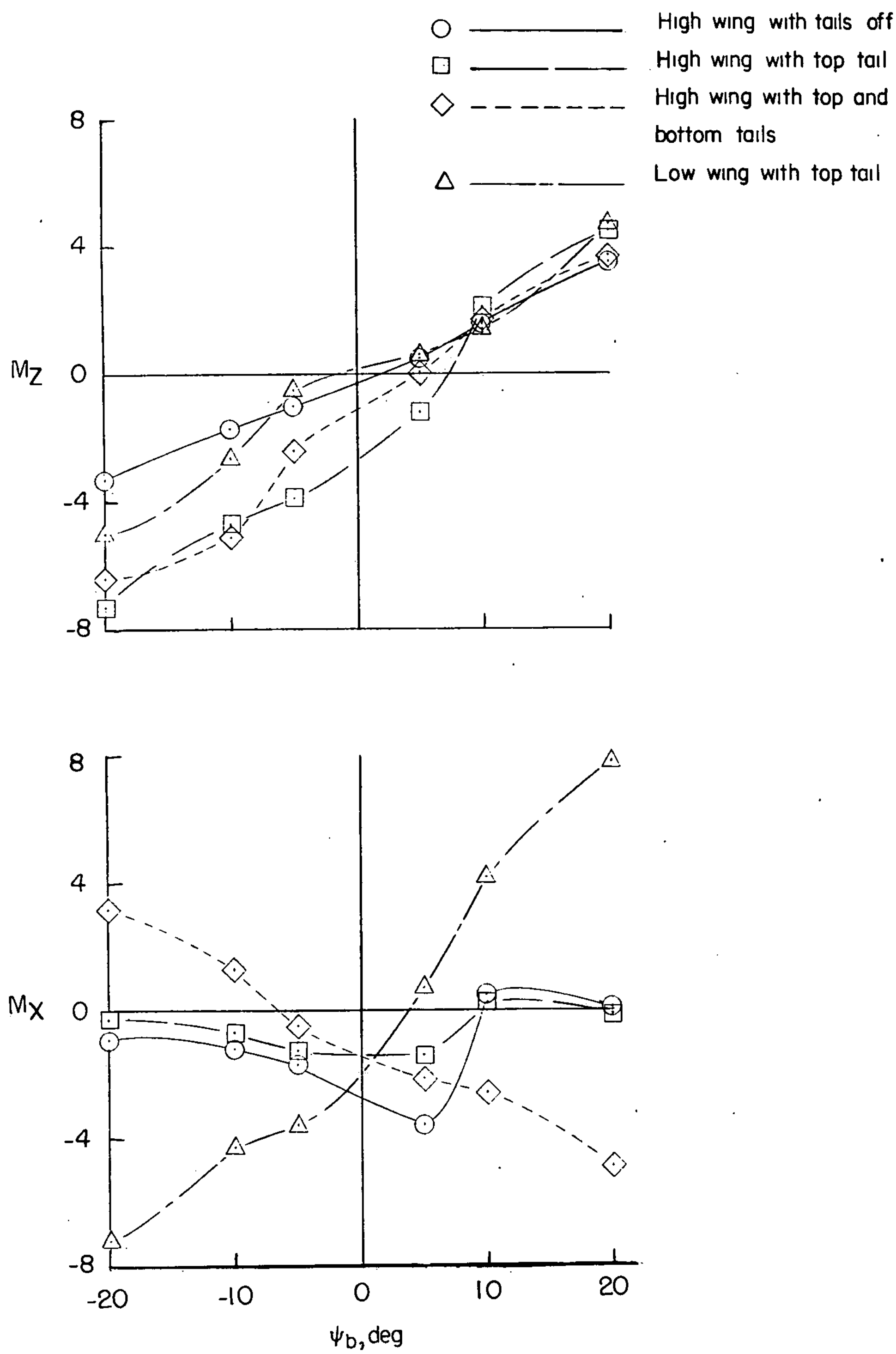


Figure 20.- Lateral stability characteristics at an angle of attack of 50° for the four configurations that were force tested.