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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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FLIGHT-TEST INVESTIGATION ON THE LANGLEY CONTROL-LINE FACILITY OF A MODEL OF A PROPELLER-DRIVEN TAIL-SITTER-TYPE VERTICAL-TAKE-OFF AIRPLANE WITH DELTA WING DURING RAPID TRANSITIONS

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SUMMARY

A flight-test investigation has been made on the Langley control-line facility to determine the longitudinal stability and control characteristics of a model of a propeller-driven tail-sitter-type vertical-take-off airplane with delta wing during rapid transitions from hovering flight to forward flight and back to hovering. The control-line facility provides for the flying of models in a large-diameter circle by means of a control-line technique similar to that used by model-airplane enthusiasts. The present investigation showed that the facility was generally satisfactory for investigating the characteristics of vertical-take-off models during rapid transitions. It was found that rapid transitions from hovering flight to forward flight could be performed fairly easily, but precise longitudinal control was necessary to perform the transitions smoothly. The transitions from forward flight to hovering flight were more difficult to perform because there was a greater variation of power settings which require closer coordination of the power and pitch control.

INTRODUCTION

During the past several years the Langley full-scale tunnel has been used for making transition-flight tests of vertical-take-off airplane models. (For example, see refs. 1, 2, and 3.) The maximum rate of transition for these tests, however, has been relatively low because of the slow rate of change of airspeed in the tunnel. As a result of the need for making much faster transitions, the Langley control-line facility has been developed. This report covers the results of some of the first tests made with this facility in an investigation to determine the longitudinal stability and control characteristics of a propeller-driven tail-sitter-type vertical-take-off model during rapid transitions. Because this report is the first to present results obtained with the control-line facility, a detailed description of the facility and its operation is presented.

The investigation consisted of essentially constant-altitude rapid transitions from hovering flight to normal, unstalled, forward flight and from normal, unstalled, forward flight to hovering. The results are presented in the form of time histories of the motions of the model obtained from motion-picture records of the flights and from comments based on observations of the stability and control characteristics of the model.

APPARATUS

The investigation was conducted on the Langley control-line facility illustrated in figure 1. This facility combines the free-flying-model technique with the control-line technique developed by model-airplane enthusiasts in which tethered models are flown in a large circle. The facility provides a relatively simple means of studying the longitudinal stability and control characteristics of vertical-take-off configurations in either slow or fast transitions from hovering flight to normal, unstalled, forward flight and back to hovering. It may also be used to study the longitudinal stability and control characteristics of conventional airplane configurations in normal, forward flight.

Basically, the control-line technique consists of flying a semi-restrained model in a circular flight path. The restraint is provided by wires from the model to the center of the circle which oppose the centrifugal force on the circling model. In order to keep the wires taut in hovering flight of vertical-take-off models (where there is no centrifugal force), the models are flown with the resultant thrust vector tilted slightly outward from the center of the circle. With use of the control-line technique, only longitudinal stability and control characteristics can be studied because the other phases of the model motions are at least partly restrained.

The control-line facility shown in figure 1 consists essentially of a standard crane with its circular track mounted on concrete pillars. The crane is in the center of a 130-foot-diameter concrete circle which is located in a wooded area that serves as a windbreak and permits testing even on fairly windy days. The crane, which has a standard-four-speed transmission, can be rotated in either direction at speeds up to 20 revolutions per minute and can accelerate from a standing start to top speed in approximately one-fourth of a revolution. In addition to having this rapid acceleration, the crane can also be rotated smoothly and accurately so that vertical-take-off models can be followed closely even in rapid transitions. In order to provide control stations for the model-controls operator, safety-cable operator, model-power operator, and crane operator, the standard cab on the right side of the crane was enlarged and a duplicate cab was added to the left side of the crane.

The arrangement of the overhead safety cable and power and control cables is the same as that used in the free-flying-model technique described in references 1 and 2. The power and safety cable is attached to a pulley which runs on a curved steel rod from the nose to a point near the center of gravity as the model goes from hovering flight to forward flight. With this setup the line of action of the drag of the flight cable passes approximately through the center of gravity of the model and does not cause large pitching moments when the model is in forward flight. The support for the overhead cable is provided by a special jib attached to the vertical boom. The point of attachment of the overhead cable at the end of the jib is about 30 feet above the ground and 50 feet from the center of the circle. The safety cable is led from the model through the jib and down the boom to the safety-cable operator in the cab of the crane. (See fig. 1.)

Two control lines run from an attachment on the left side of the model at the location of the center of gravity to attachments on the vertical boom about 15 feet above the ground. Differential movement of these two lines was used to vary the position of the longitudinal-control surfaces (elevons) of the model. The model-controls operator had two control sticks which were used simultaneously to perform transitions. A left-hand stick which produced elevon trim proportional to stick position was used for relatively slow changes in trim setting; whereas, a right-hand stick operated a flicker-type (full-on or off) system which provided rapid up or down control movement from this trim setting.

In an alternate arrangement (not used in these tests), the model is controlled by actuators in the model that are identical to those used in the free-flying models described in reference 1, and the two control lines are replaced by a single restraining line that opposes the centrifugal force of the model. The restraining line is attached to the boom by a device which automatically keeps the line horizontal regardless of the height at which the model is flying. This device consists of a vertical track installed on the boom and a small motor-driven carriage to which the restraining line is attached. When the restraining line is not horizontal, it operates a switch to an electric motor which runs the carriage up or down the track to make the line horizontal again. In this system a small amount of dead spot was used to prevent the carriage from overshooting and "hunting." The purpose of this device is to minimize the effective static stability of height which results from centrifugal force. That is, with a fixed attachment point of the restraining line on the boom, the centrifugal force acting on the model tends to make it fly at the same height as the attachment point. With this device, which automatically keeps the restraining line horizontal, models can be taken off the ground and flown at any height up to approximately 30 feet without experiencing an appreciable effect of this type.

The present investigation was conducted before the installation of the device which automatically keeps the restraining line horizontal. This investigation, therefore, served as a means for evaluating the effects of centrifugal force with a fixed attachment point.

TESTING TECHNIQUE

Before a transition test is begun in which the control-line facility is used, a vertical-take-off model is trimmed for steady hovering flight. Then, the model-controls operator operates the model controls in order to perform the transition to forward flight at any desired rate while the model-power operator adjusts the model power in order to maintain the desired altitude (usually 15 feet above the ground). In a variation of this technique, the power operator maintains essentially hovering power and the model-controls operator performs the transition at a rate which results in the model maintaining constant altitude. The crane operator rotates the crane so that the end of the jib is above the model at all times. It should be emphasized that the control movements made by the model-controls operator determine the desired flight speed of the model; the crane merely follows the model and, thus, it has virtually no effect on the model motions. In order to complete the transition tests, the reverse transition from normal, unstalled, forward flight to hovering is made and the model lands.

MODEL

A photograph of the model is shown in figure 2 and a sketch showing some of the more important dimensions is shown in figure 3. The model was assumed to represent a 0.13-scale model of a vertical-take-off fighter airplane. It had a delta wing and delta vertical-tail surfaces mounted symmetrically above and below the fuselage and was powered by a 5-horsepower variable-frequency electric motor driving an eight-blade counterrotating fixed-pitch propeller (two four-blade elements in tandem). Differential movement of the control lines operated a mechanical linkage in the model which actuated the elevon surfaces. The maximum deflections of the elevons were 30° up and 20° down. The center of gravity was at the 0.15 mean-aerodynamic-chord position and was at the 0.02 mean-aerodynamic-chord position above the thrust line. Geometric characteristics are presented in detail in table I.

RESULTS AND DISCUSSION

Transition From Hovering Flight to Forward Flight

In general, rapid transitions from hovering flight to normal, unstalled, forward flight could be made fairly easily but precise longitudinal control was necessary to make the transitions smoothly. Time histories of three typical transition tests are shown in figure 4. No attempt was made to perform these transitions in exactly the same manner but, since the same general technique was used in all cases, the data appear to be generally similar. In general, the transitions from hovering flight down to an angle of pitch of 30° were made fairly rapidly, and the further decrease down to 20° was more gradual. The time required to perform the transition down to an angle of pitch of 30° was approximately 9 seconds for the model or 25 seconds for the full-scale airplane. Based on the experience gained in these tests, it is believed that the transitions could have been made much more rapidly than those shown in figure 4, but no attempt was made during this investigation to perform the transitions as rapidly as possible.

A comparison of transitions made on the control-line facility with those made in the Langley full-scale tunnel is shown in figure 5. Since the only available record from the full-scale-tunnel tests started at an angle of pitch of 80°, the record from the control-line facility is started at the same angle to permit a direct comparison of the data. It is readily apparent from this comparison that the transitions on the control-line facility are much faster than those in the full-scale tunnel.

The transitions made on the control-line facility are not particularly smooth as can be seen by the data of figure 4. This lack of smoothness is attributed to two factors. First, the control system involved a flicker-type control movement which inherently leads to somewhat more erratic flight than does proportional control. Second, it was difficult during these rapid transitions to position the longitudinal-control surface (elevon) with sufficient accuracy to provide the exact setting required for longitudinal trim for each airspeed. An elevon setting of approximately 7° down was required for trim in hovering flight. In order to initiate the transition, the elevon deflection was increased in the down direction and, then, after the model had gained some speed, an upward elevon movement was started so that, when the model reached an angle of pitch of about 30°, the elevon would be at approximately the correct position for longitudinal trim (about 15° or 20° up) for this angle of attack. Then, to obtain higher speeds, the elevon was again moved downward. During the transitions, it was necessary to change the elevon trim precisely, because if the large, down, elevon setting were not removed quickly enough, the model would be forced into an extremely high-speed condition; and, if the setting were removed too quickly, the model would in some cases actually return to hovering flight. The force-test data illustrating these changes in trim are given in figure 6. Although these data are strictly applicable only to steady-flight conditions, they do provide an indication of the changes in trim during accelerating flight. The data show that down elevon is required for hovering and, as the speed builds up to approximately 5 knots, more use of down elevon is required. There is, thus, a region between about 5 and 28 knots where stick-position instability occurs so that trim is obtained with progressively higher elevon settings as the speed increases. Above a speed of 28 knots, stick-position stability is again present and down elevon is required for trim at higher speeds.

In figure 6 an instability of angle of attack (positive value of the variation of pitching moment with angle of attack $\partial M_Y/\partial \alpha$) over the low speed range can be seen. This instability was not evident in the control-line tests, apparently because the instability was small and because the model was accelerated through this speed range at a rather rapid rate. Even in tests in the full-scale tunnel where the same model was flown slowly through this speed range, the instability of the angle of attack was not apparent.

The data of figure 4 and other data from these tests have been used to obtain an average curve of the variation of angle of pitch with velocity in figure 7. For comparison, an average curve based on slow transitions in the full-scale tunnel (essentially steady flight) is also presented. The data show that for a given airspeed the angle of pitch was less for the fast transitions than for the slow transitions. For example, at an airspeed of 20 knots the angle of pitch was about 45° for the slow transitions and was about 35° for the rapid transitions.

The problem of power control during transitions was not very great because hovering power was essentially maintained during the transition. In slow transitions of the model in the full-scale tunnel it was necessary to reduce power as the model started into forward flight, and at some fairly slow forward speed minimum power was required; as the speed was increased above this value, it was necessary to increase power until at a higher speed the power required was again equal to hovering power. In rapid transitions on the control-line facility, the excess thrust required for accelerating flight at constant altitude was obtained by maintaining hovering thrust at the low forward speeds where considerably less than hovering thrust was sufficient for steady trimmed flight.

Transition From Forward Flight to Hovering Flight

Rapid transitions from forward flight to hovering flight were not as easy to make as transitions from hovering flight to forward flight primarily because of the increased difficulty in controlling power. Time histories of some typical transitions from forward flight to hovering flight are shown in figure 8. In general, these data appear to be similar to those of figure 4 in that the motions are not very smooth. In these transitions the angle of pitch was changed rather slowly up to approximately 40° in order to keep from gaining altitude during the initial portion of the deceleration, and then the transition to hovering flight was completed much more rapidly. No attempt was made to perform the transition as rapidly as possible; but it does appear from the data of figure 8, for the most rapid transition obtained, that the transitions from an angle of pitch of 30° to hovering flight could be made in about 7 seconds for the model (approximately 20 seconds for the full-scale airplane).

The technique for performing the transition from forward flight to hovering flight was somewhat different from that for performing the transition from hovering flight to forward flight. In order to start the transition, a decelerating force was produced by trimming the model to a higher angle of pitch than that required for steady trimmed flight at a given airspeed. Rather large upward elevon deflections were required to accomplish this deceleration. Upward deflections were maintained until the model reached angles of pitch well beyond 90° so that rapid deceleration to zero forward speed could be obtained. As the forward motion stopped, it was necessary to apply the down elevon trim for hovering flight very quickly and precisely in order to continue in steady trimmed hovering flight at the point where the model stopped.

As the angle of pitch increased and the airspeed decreased in the transition, it was necessary to decrease power progressively to a very low value and then to increase power very quickly to that required for hovering as the airspeed approached zero. In this case, power control was used primarily to maintain constant altitude, whereas in transitions from hovering to forward flight the power was held approximately constant and elevon control was used to maintain constant altitude. Precise control and close coordination of the elevon and power were required to perform transitions from forward flight to hovering flight without gaining or losing altitude. The most critical phase of the transition was near the end when large and rapid changes in elevon and power settings were required.

The data of figure 8 and other similar data obtained in transitions from forward flight to hovering flight have been used to obtain an average curve of the variation of angle of pitch with airspeed shown in figure 9. Also presented in this plot are two curves from figure 7 for comparison purposes. The data show that at an airspeed of 20 knots the angle of pitch was 35° for transitions from hovering to forward flight and was 61° for transitions from forward flight to hovering.

Evaluation of Control-Line Technique

In general, the control-line facility proved to be satisfactory for investigating the characteristics of vertical-take-off models during rapid transitions. The transitions could be made much more rapidly than transitions in the full-scale tunnel and at a rate that more closely duplicated the probable rates of transition of full-scale airplanes. It was found in these tests that the crane could be rotated rapidly and smoothly enough for satisfactory following of the model in rapid transitions. The crane operator attempted to keep the end of the jib directly above the model at all times and he was able to do this with an error of less than ±3 feet.

The differential movement of the two control lines used to vary the position of the elevon of the model did not prove to be entirely satisfactory, because in hovering flight the control lines occasionally slackened momentarily and caused the control of the model to become erratic. As pointed out previously, this difficulty is eliminated in a revised longitudinal-control system now being used which provides for the installation of pneumatic-control actuators in the models and for a single restraining line that opposes centrifugal force.

In general, the effect of the restraining line (or lines) on the longitudinal-stability and control data obtained with the control-line facility appeared to be acceptably small. As previously discussed, the restraint of the line tends to keep the model at the same altitude as the point of attachment of the line on the boom (15 feet above the ground), but this tendency was not great enough to prevent the pilot from easily maneuvering the model for flight at various altitudes. This effective stability of height slightly decreases both the period and damping of the long-period longitudinal oscillation but does not appreciably affect the characteristics of the short-period oscillation. Although the effect of the restraining lines did not appear to be of major importance, these effects will be eliminated in future tests by use of the device described in the section entitled "Apparatus" which makes provision for automatically moving the attachment point of the line on the boom as the model moves up and down. Another reason this device has been installed is that it will permit take-offs and landings to be made without any appreciable effect of restraining lines on the model.

CONCLUSIONS

The following conclusions were drawn from the results of a flight-test investigation of a model of a propeller-driven tail-sitter-type vertical-take-off airplane with delta wing during rapid transitions on the Langley control-line facility:

1. In general, the control-line facility proved to be satisfactory for investigating the characteristics of vertical-take-off models during rapid transitions.

2. Transitions could be made on the control-line facility much more rapidly than transitions in the Langley full-scale tunnel and at a rate that more closely duplicated the rate of transition of full-scale airplanes.

3. Transitions from hovering flight to forward flight could be performed fairly easily but precise longitudinal control was necessary to make the transitions smoothly.

4. Transitions from forward flight to hovering were more difficult to perform because there was a greater variation of power settings which required closer coordination of the power and pitch control.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., May 20, 1957.

REFERENCES

1. Kirby, Robert H.: Flight Investigation of the Stability and Control Characteristics of a Vertically Rising Airplane Research Model With Swept or Unswept Wings and ×- or +-Tails. NACA TN 3812, 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. Lovell, Powell M., Jr., and Parlett, Lysle P.: Effects of Wing Position and Vertical-Tail Configuration on Stability and Control Characteristics of a Jet-Powered Delta-Wing Vertically Rising Airplane Model. NACA TN 3899, 1957.

TABLE I.- GEOMETRIC CHARACTERISTICS OF MODEL

Weight, lb	35.00
Moment of inertia about body Y-axis, I_Y, slug-ft^2	0.93
Wing (modified delta plan form):	
Sweepback of leading edge, deg	55
NACA airfoil section	Modified 63-009
Aspect ratio	1.90
Taper ratio	0.188
Area (total to center line), sq in.	818.95
Span, in.	39.49
Mean aerodynamic chord, in.	23.94
Span of elevon (each), in.	15.37
Chord of elevon, in.	2.92
Dihedral angle, deg	0
Overall length of model, in.	49.40
Fuselage length, in.	45.40
Vertical tails (modified delta plan form):	
Sweepback of leading edge, deg	40
NACA airfoil section	Modified 63-009
Aspect ratio	3.18
Taper ratio	0.318
Area (total to center line), sq in.	379.88
Span, in.	34.73
Mean aerodynamic chord, in.	13.07
Span of top rudder, in.	14.13
Span of bottom rudder, in.	11.13
Chord of rudders, in.	2.85
Propellers (eight-blade counterrotating):	
Diameter, in.	23.85
Hamilton Standard design	3155-6-1.5
Solidity (one blade)	0.0475
Gap, in.	3.00

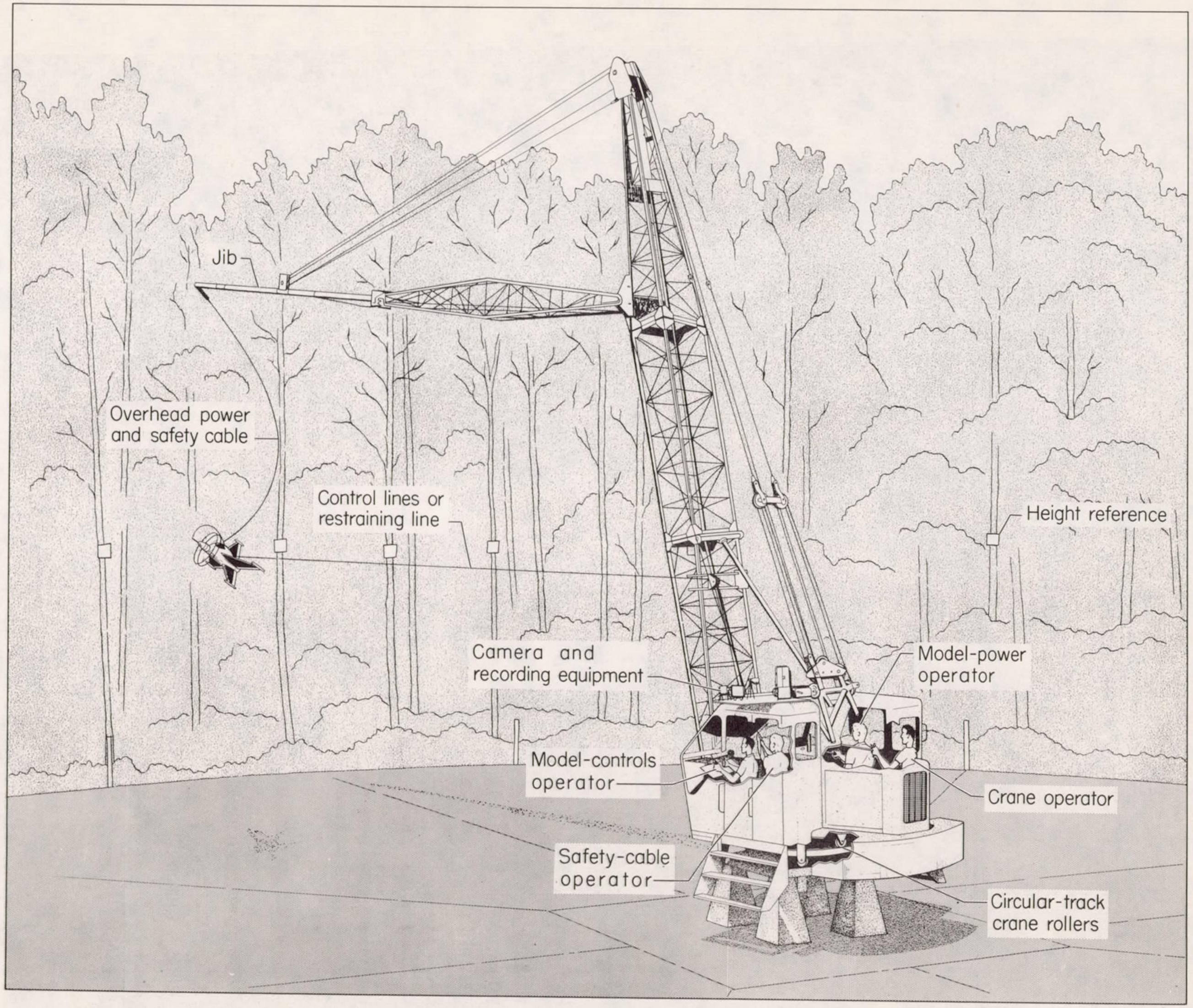

Figure 1.- Langley control-line facility.

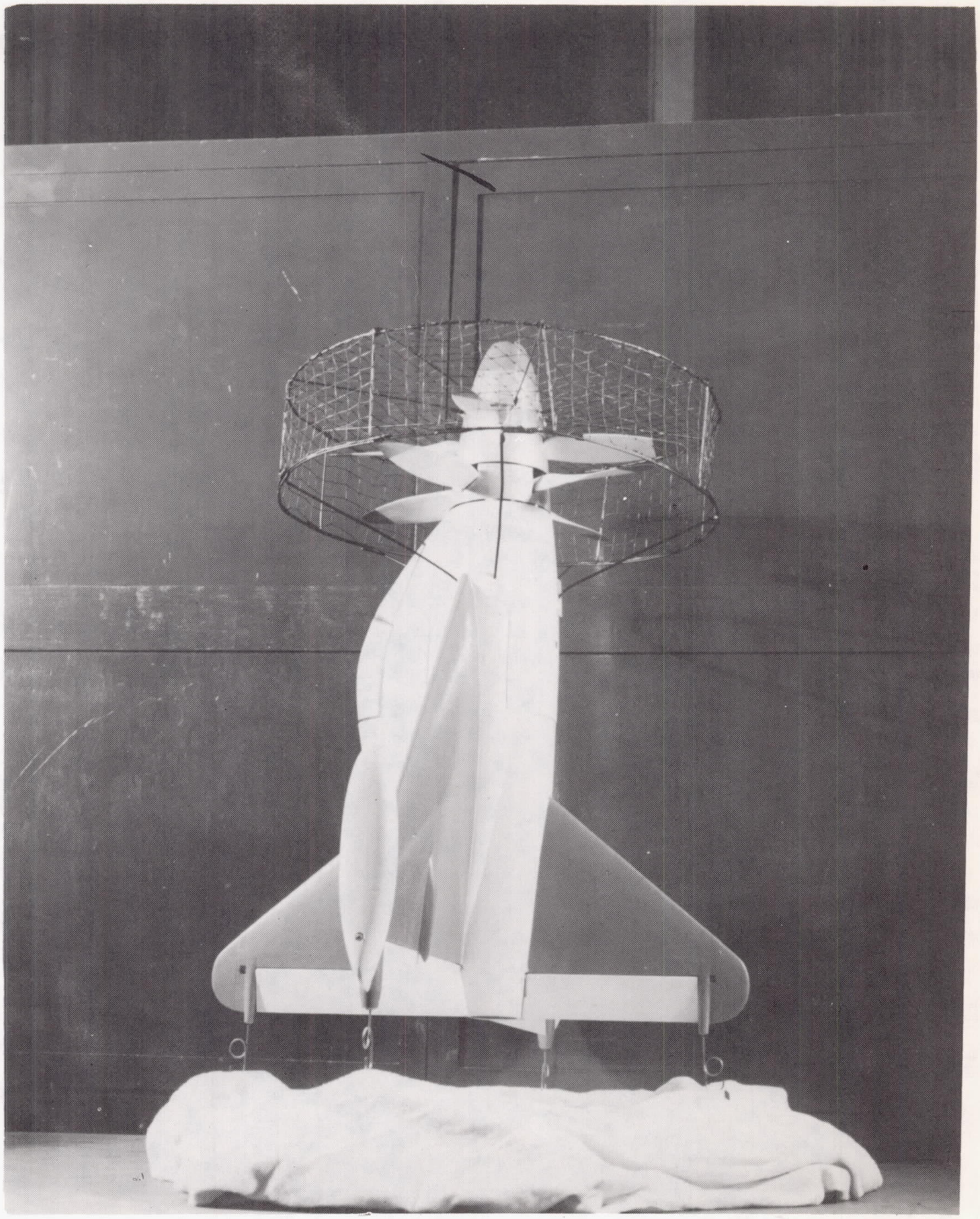

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Figure 2.- Photograph of delta-wing vertical-take-off model.

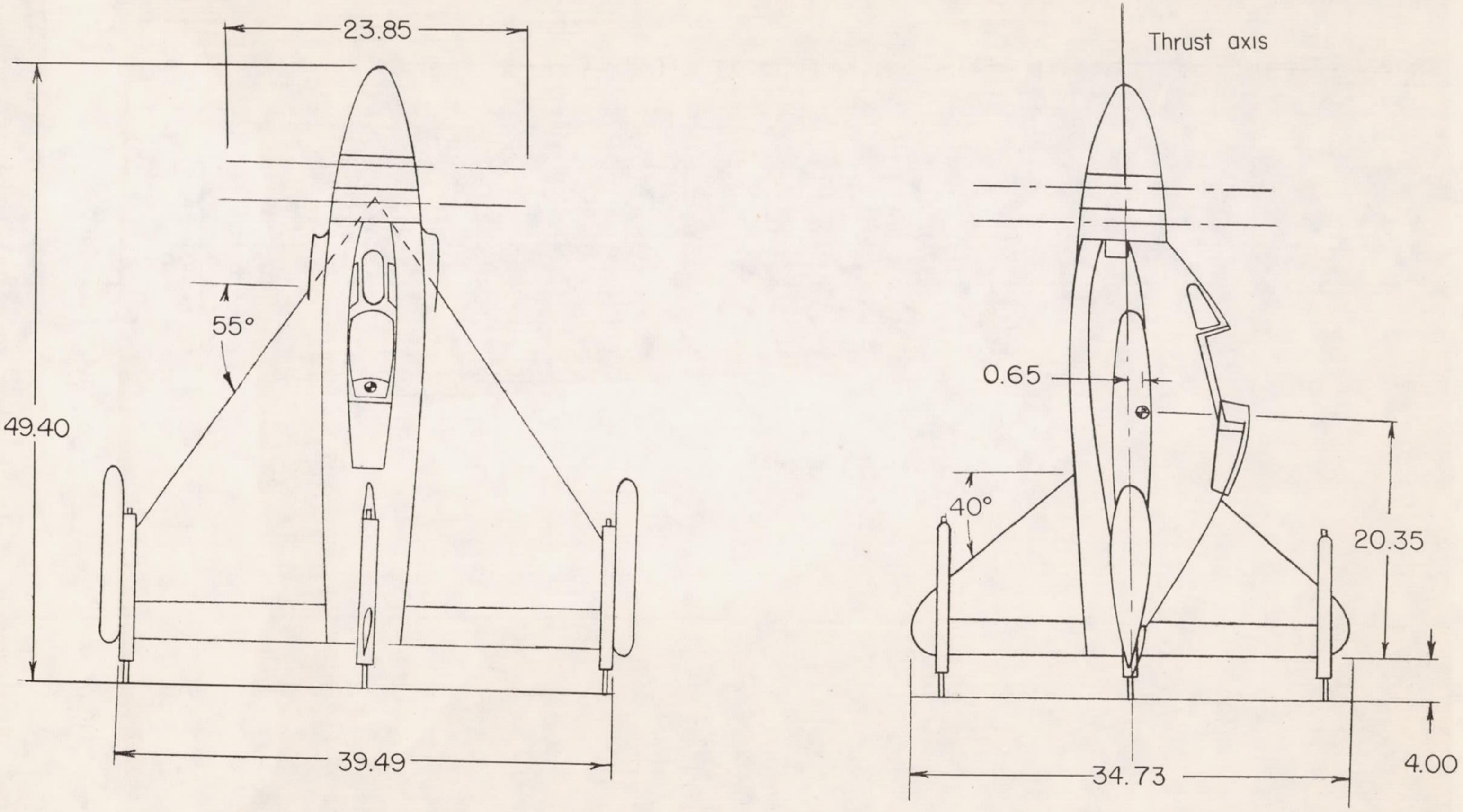

Figure 3.- Drawing of delta-wing vertical-take-off model. All dimensions are in inches.

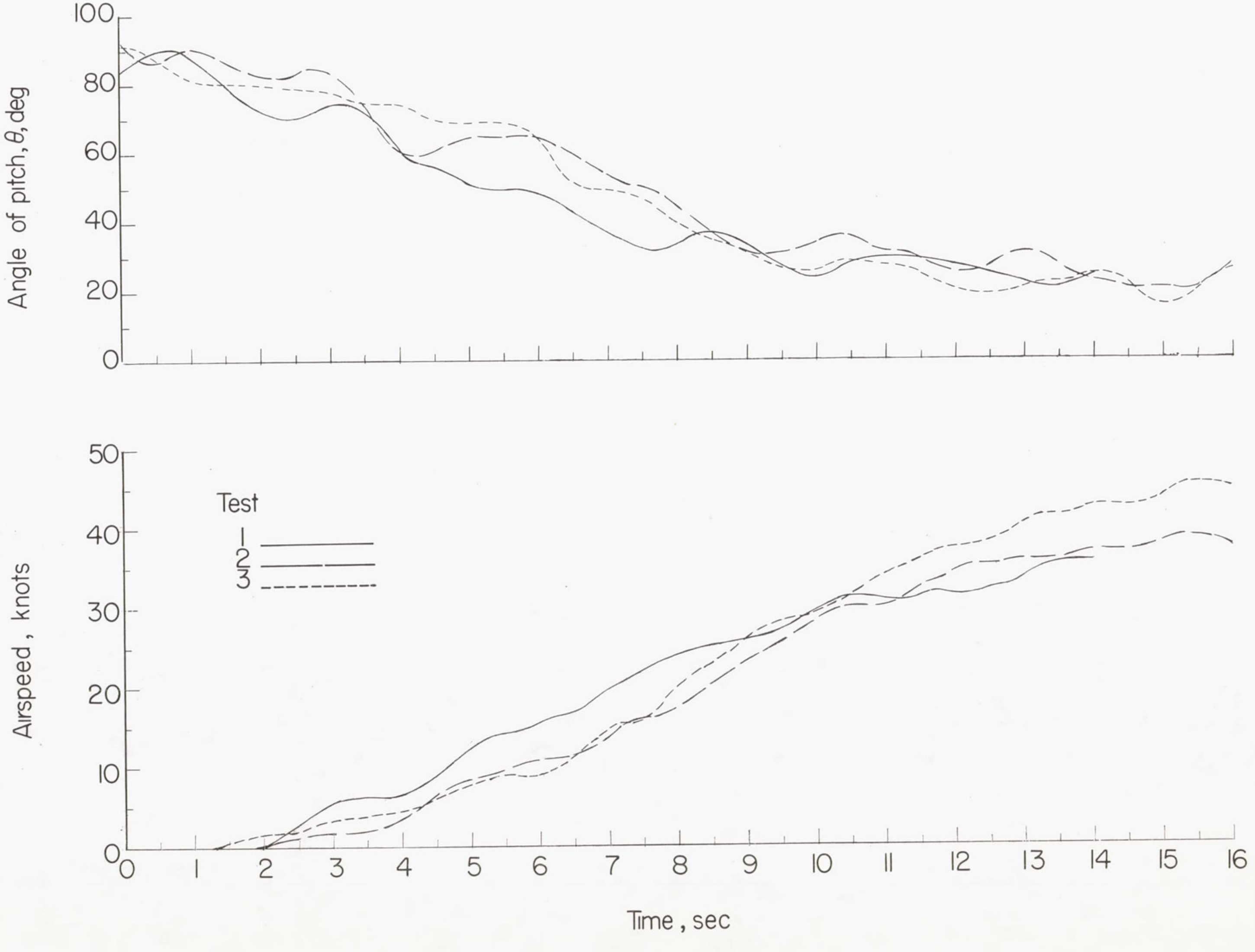

Figure 4.- Rapid transitions from hovering flight to forward flight.

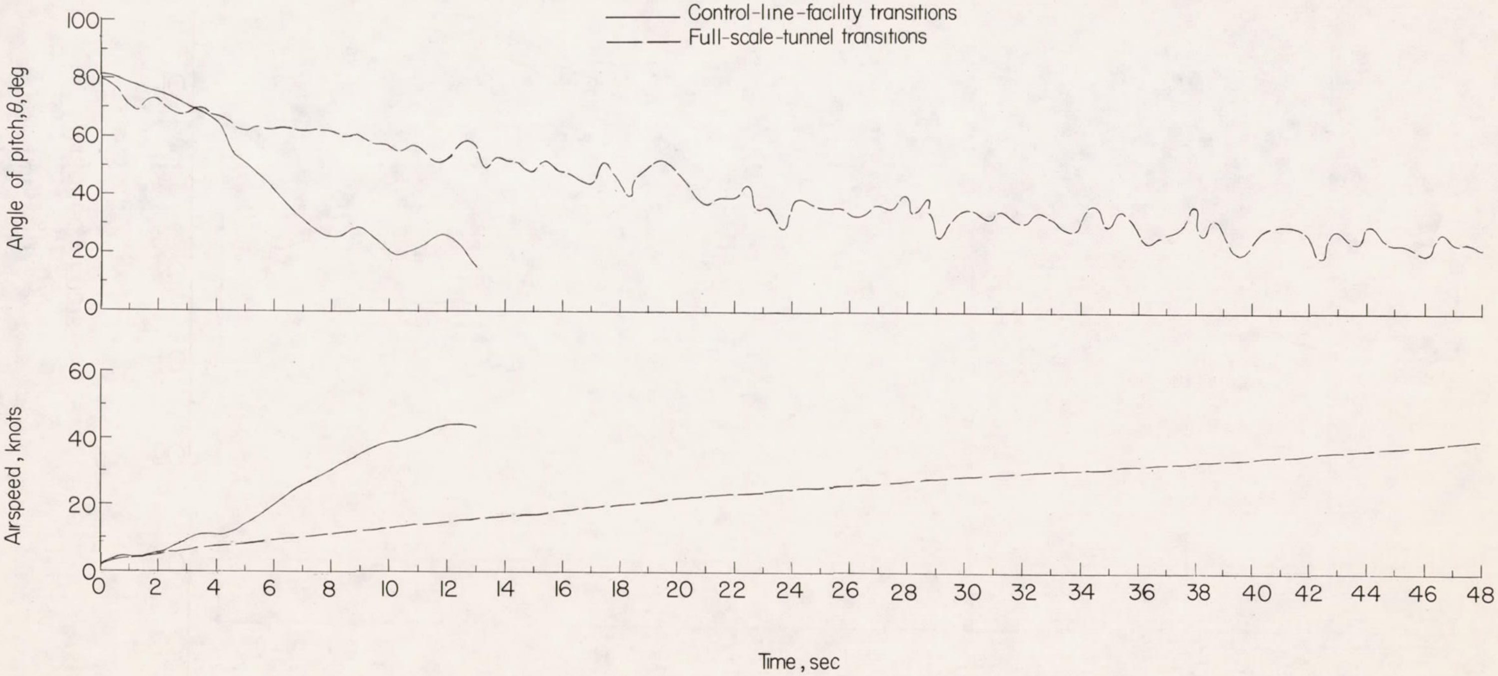

Figure 5.- Comparison of rapid and slow transitions from hovering flight to forward flight.

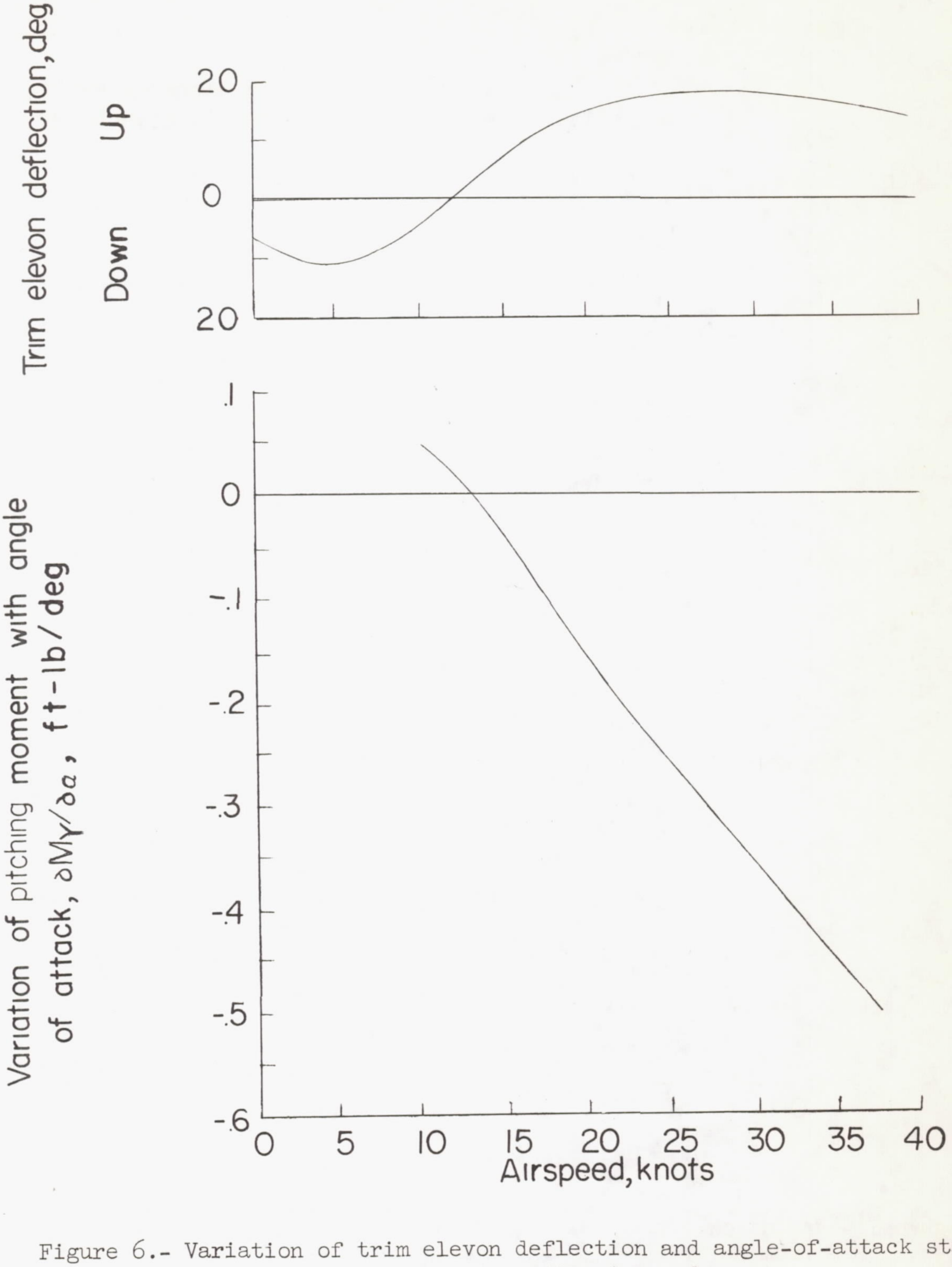

Figure 6.- Variation of trim elevon deflection and angle-of-attack stability parameter with airspeed.

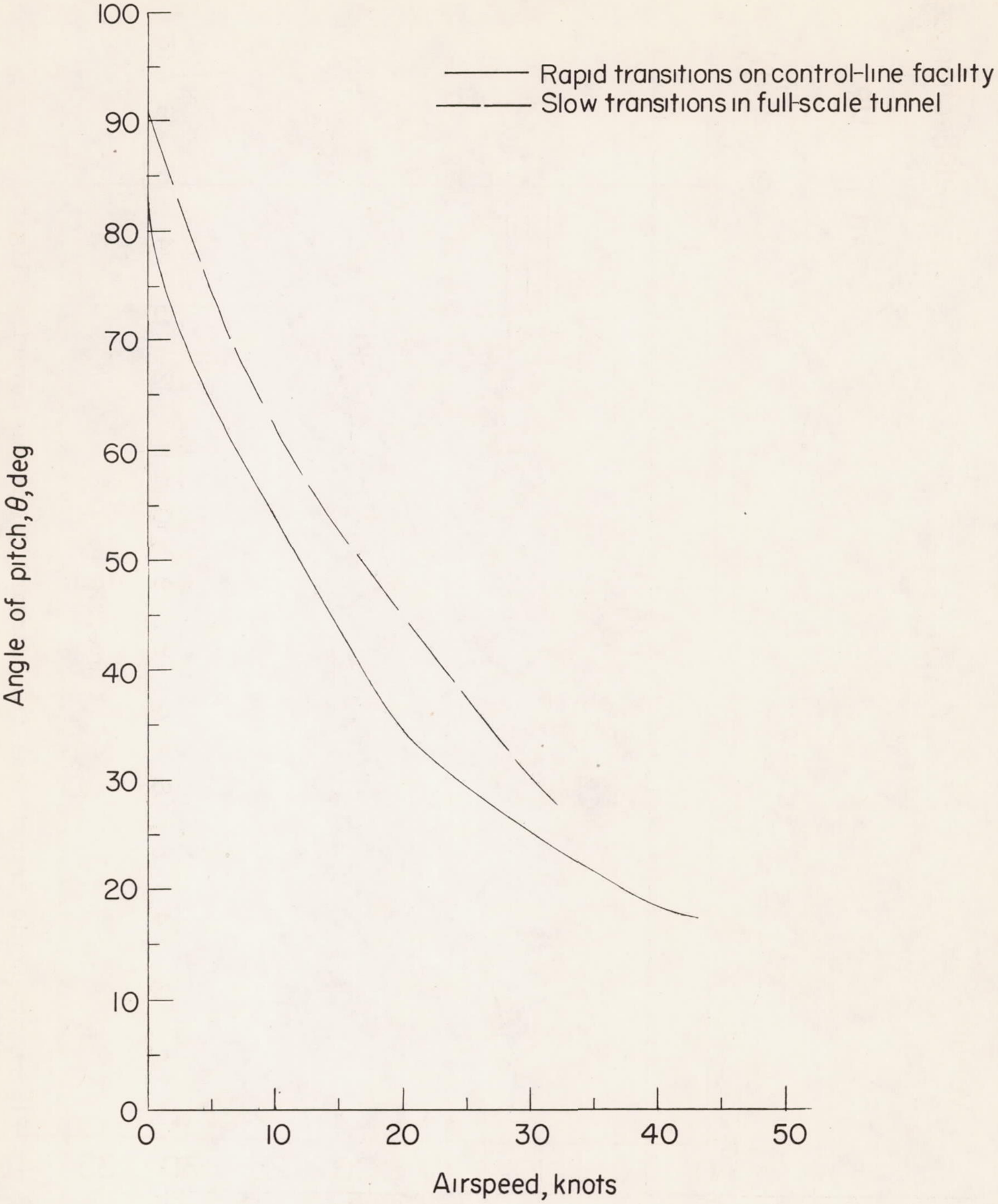

Figure 7.- Variation of angle of pitch with airspeed during transitions from hovering flight to forward flight.

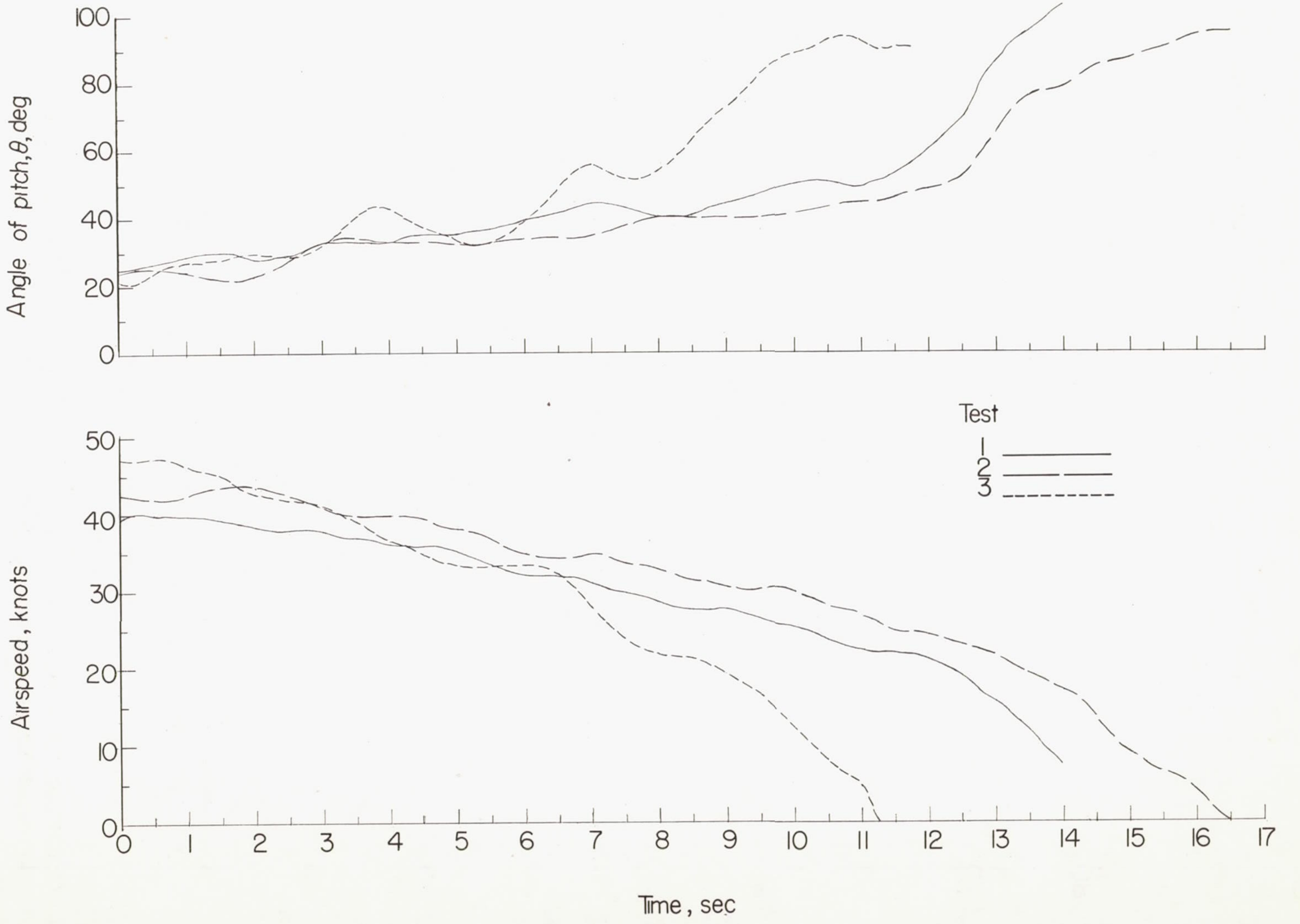

Figure 8.- Rapid transitions from forward flight to hovering flight.

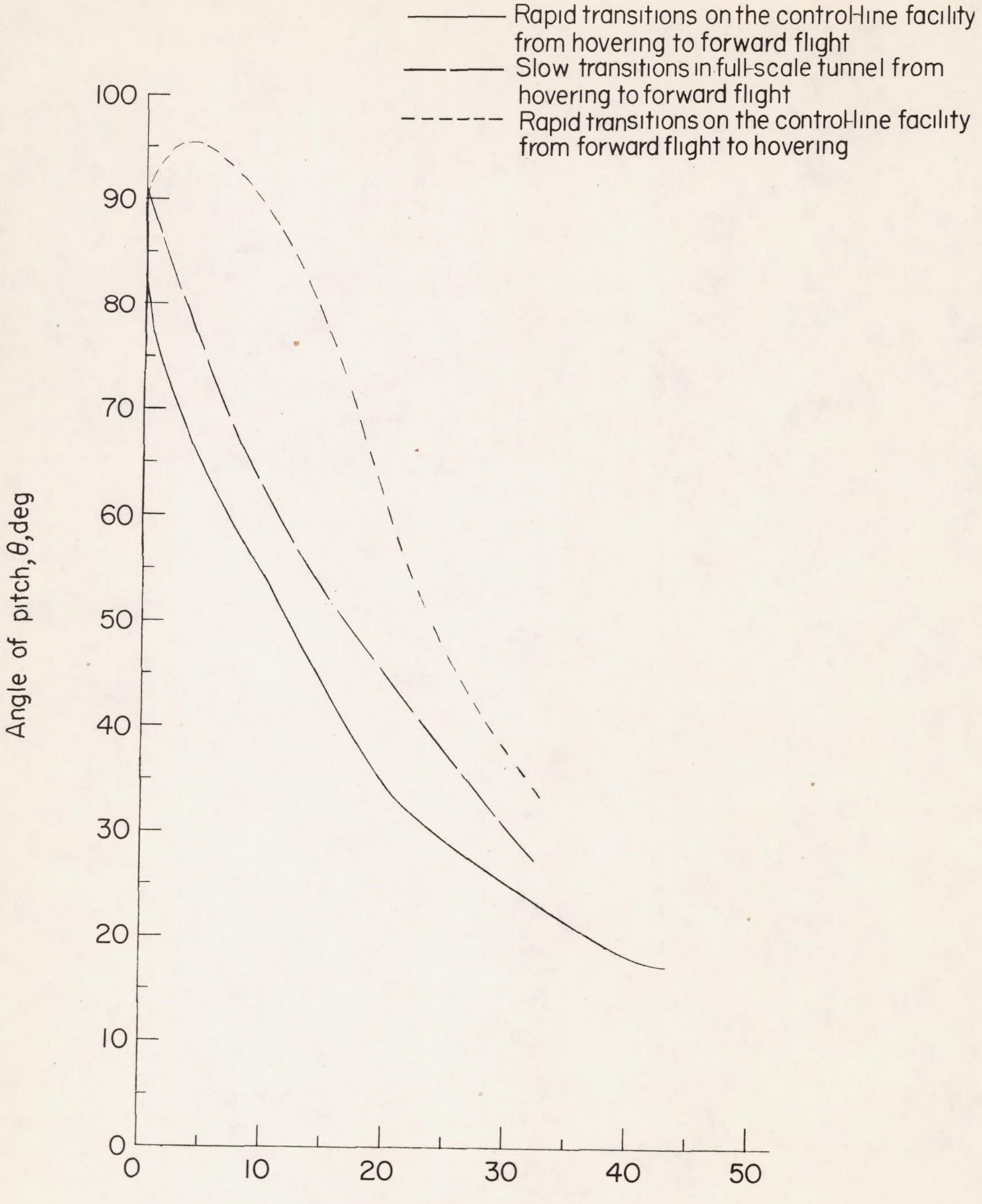

Figure 9.- Variation of angle of pitch with airspeed during transitions from hovering flight to forward flight and from forward flight to hovering flight.

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