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TECHNICAL NOTE

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FLIGHT-TEST INVESTIGATION OF AILERONS AS A SOURCE OF YAW CONTROL ON THE VZ-2 TILT-WING AIRCRAFT

By Robert J. Pegg

Langley Research Center
Langley Station, Hampton, Va.

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SUMMARY

The directional control characteristics of the VZ-2 tilt-wing aircraft have been measured wherein the original, partial-span ailerons were connected into the aircraft's directional control system to augment existing yaw control in the hovering configuration. Tests were made to determine the directional control response and effectiveness of the combined system in various flight conditions.

The results of this work showed that, if the control surfaces (flaps or ailerons or a combination of both) are of reasonably appropriate size and location, they can be useful as a supplementary source of yaw control, and thus permit adequate total yawing moments without prohibitive weight or power penalties. The tests suggest need for caution, however, in regard to roll coupling and control surface effectiveness at high sideslip angles when a large portion of the yaw control is obtained from such surfaces.

INTRODUCTION

A need for additional directional control in VTOL test aircraft was shown in reference 1, where the simplest yaw maneuvers in hovering flight were reported to be difficult to perform. It became apparent, during the course of a tilt-wing flight program at Langley Research Center (ref. 2) that there was a need for increased yaw control that would impose no undue weight or power penalty to the aircraft. The aircraft's partial-span ailerons, being the only control surfaces available, conveniently satisfied the immediate need of augmenting existing sources of yaw control, when the tilt-wing aircraft was in the hovering configuration.

Early theoretical work with other methods of VTOL yaw control systems may be found in references 3 and 4. Model force tests and free-flight data of the stability and control for three tilt-wing models involving the ailerons as a source of yaw control are reported in references 5 to 7.

In this report, flight-test results are compared with predicted yaw control values and flight characteristics are discussed in light of future design considerations. A brief analytical presentation (see appendix) shows how full-span trailing-edge control surfaces can increase the yaw control moment.

SYMBOLS

C_{L_A}	lift coefficient for wing with aileron deflected
D	rotor diameter, ft
W	aircraft weight, lb
w	disk loading, lb/sq ft (psf)
I_Z	yaw moment of inertia, slug-ft^2
i_w	wing angle, deg
L_A	lift of wing perpendicular to rotor slipstream due to deflected aileron, lb
L_S	lift of wing perpendicular to rotor slipstream due to deflected trailing-edge control surface, lb
M_c	control moment, ft-lb
P	power, horsepower
S	wetted wing area, sq ft
V	velocity, knots
v_i	downwash velocity, ft/sec
δ	rudder pedal displacement, in.
Ω	rotor rotational speed, radians/sec
ρ	sea-level density, slug/cu ft

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APPARATUS AND TEST PROCEDURE

Aircraft

Aircraft characteristics.- The VZ-2 test aircraft is a VTOL tilt-wing, twin rotor machine. A three-view drawing of the aircraft is shown in figure 1 and its physical characteristics are listed in table I. Figure 2 is a photograph of the aircraft in transition flight. The aircraft was flown during all tests with drooped leading edges on the wing as described in reference 2. Power is supplied by an 850-horsepower gas turbine engine and is controlled by the pilot through the collective pitch lever. Maximum usable horsepower has been limited by shafting and gearing to 650 horsepower. Instrumentation is the same as that described in reference 2.

Control system characteristics.- The aircraft, as tested in this investigation, utilizes separate combinations of control in the hovering, transition, and cruise regions of flight: (1) Yaw control, which is of primary interest, is obtained in hovering and transition through the use of a fan located vertically in the aft end of the aircraft and the ailerons which are connected into the directional control system. As forward speed is increased, the aileron deflections used for directional control are phased out, and yawing moments are obtained solely from the rudder and tail fan. Provisions were made for the pilot to vary the blade pitch of the yaw tail fan; thus, he could regulate the total thrust. (2) Pitch control is obtained in hovering by varying the thrust of a fan located in the aft end of the aircraft in the plane of the horizontal tail. As airspeed is increased, the tail fan is phased out and the all-movable horizontal tail provides the only pitch control. (3) Roll control is obtained by differentially operating the collective pitch of the main rotors during hovering and transition. As the wing angle is decreased and airspeed is increased this control is phased out and roll control is provided by the aileron.

Figure 3(a) shows the programing of the aileron deflection for full lateral stick deflection as a function of wing angle, and figure 3(b) shows the aileron deflection for full rudder pedal deflection as a function of wing angle.

Figure 4 shows a sectional view of the wing and aileron. Maximum aileron positions are denoted by the dashed lines radiating from the hinge point.

Test Conditions

The flight investigation consisted of three test maneuvers: (1) step yaw control inputs made in the hovering configuration to obtain the directional control moment based on the resulting initial yawing accelerations; (2) step yaw inputs made in several transition flight configurations to evaluate possible coupling between roll and yaw; (3) steadily increasing sideslip angles performed in transition flight to determine the effectiveness of the ailerons in sideslip.

RESULTS AND DISCUSSION

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Flight-Test Results

Hovering step inputs.- Several step pedal inputs were made during hovering flight while the maximum available yaw tail-fan control was varied from 0 to 100 percent. Figure 5 shows a typical time history, in the hovering configuration, of a step pedal input and the resulting yawing angular velocity. A compilation of the initial accelerations taken from these time histories was used to obtain control power data which is shown in figure 6 as a function of the variation of total available tail-fan control. Figure 6 indicates that, when the tail fan is producing no thrust (0 percent fan control), the contribution of the ailerons is approximately equal to one-half the moment produced by full thrust from the yaw tail fan (100 percent fan control). Pilots' comments indicated that the VZ-2 tail fan alone gives inadequate yaw control in hovering. Combined with the ailerons, pilots commented that the yaw control was improved but still not satisfactory. The more favorable pilot opinion may have been based on the change in characteristics of the total modified yaw control system about the neutral point. This is due to the linear aileron yawing moments superimposed on the nonlinear tail-fan thrust (ref. 2; fig. 14).

It is of interest to note that this configuration, with maximum available yaw control, failed to achieve an angular displacement for 1 second of 6.7° for 1-inch pedal deflection laid down as minimum requirements in reference 8 (by using fig. 5 and assuming a linear relationship between pedal deflection and yaw displacement, the yaw angular displacement for 1-inch pedal deflection was 2.8° in 1 second).

The majority of hovering tests were conducted at heights of approximately 10 feet and therefore do not reflect the loss of control effectiveness which has been experienced in ground effect in various wind-tunnel tests. No specific tests were performed in ground effect but pilots report that they have felt no marked deterioration of yaw control while in ground effect.

Directional step inputs in a transition flight configuration.- Step yaw inputs have been documented at a wing angle of 55° and yaw tail-fan control of 0 percent and 42 percent. Figure 7 shows typical time-history traces of a directional step displacement and the resulting yaw and roll angular velocities for the two yaw fan control inputs. From figure 7(a), as is to be expected, a right pedal displacement is shown to produce a slight left roll. Coupling caused by the ailerons was readily overpowered by the strong dihedral effect approximately 0.5 second after the input was initiated and was barely noticeable to the pilots. Figure 7(b) shows the same type of maneuver with the tail-fan control reduced from 42 percent to 0 percent. As is expected, the decreased tail-fan control requires that larger pedal deflections be used to produce the same yawing velocity; therefore, for the given maneuver, coupling is increased.

Pilots report that the coupling of the rolling velocities due to a rudder pedal step input with this particular aileron configuration was negligible in most of the flight regions tested and it was not objectionable. Although coupling proved not to be a problem with this aircraft, this effect may be of considerable magnitude on future machines with different physical characteristics.

Static lateral directional stability characteristics in a transition configuration.- Figure 8 shows steady-state plots of the lateral stick and rudder pedal positions as a function of sideslip angle for a wing angle of 40° and an airspeed of 40 knots. The lateral directional characteristics for the aircraft as previously measured in reference 1 without the modified aileron system are also plotted in figure 8(a) for comparison. Figure 8(b) shows the sideslip angle as a function of pedal position with 42-percent tail-fan control. In figure 8(c), yawing moments obtained solely from the ailerons are no longer sufficient to overpower the aircraft's directional moments at sideslip angles greater than approximately 30°. The vertical slope shown in figure 8(c) at large sideslip angles suggests a need for caution when designing wing control surfaces to be used as the sole source of moment. It could represent a potential inability of the control surfaces to provide adequate control for the large sideslip angles which may be required at low speeds. Present tests did not permit the isolation of the source of this steep rise.

Pilot comments substantiate the data shown in figure 8 where the use of ailerons as a yaw control device did not cause appreciable changes in control with respect to the static directional stability characteristics or to lateral directional disturbances.

Discussion

Yaw control effectiveness provided by the ailerons has been reasonably well predicted by simple momentum considerations as is shown in the appendix of this report. Correlation was obtained between the flight data and the analysis shown in the appendix by estimating wing lift coefficients with and without ailerons deflected, and by assuming that each wing provided an equal share of the yawing couple and that the rotor slipstream was constant across the downwash cross section. Based on this correlation, an alternate configuration was analyzed. An enlarged full-span control surface was used in place of the partial span aileron. A 90-percent increase in yawing moment is noted for this case over the configuration with the partial-span ailerons used in the yaw control system. Although the simplified analysis showed good correlation in this case, substantiation for other combinations of design parameters will be required before the analysis can be used with confidence for accurate predictions rather than for preliminary estimates.

The application of control surfaces on the wing as a possible source of yawing moment depends on such things as the choice of the airfoil-control surface combination, size of control surfaces, and control surface moment arm. It appears that, if these design parameters are properly used, the wing control surfaces would be worthy of consideration in augmenting future VTOL aircraft yaw control systems.

SUMMARY OF RESULTS

The following statements summarize the results obtained with the aileron yaw control system in the configuration available on the VZ-2 tilt-wing aircraft:

1. Flight tests using partial-span ailerons as a means of providing yaw control moments in the hovering configuration showed that the ailerons provided approximately one-half the amount of control power as that provided by the yaw tail fan. Both devices combined produced a desirable increase in yawing moment but still not an acceptable amount.

2. Rolling motions of the aircraft due to directional inputs at the test flight conditions with the ailerons did not produce objectionable handling qualities. However, caution should be used when improved control surfaces are used because increased effectiveness might cause undesirable coupling.

3. The ailerons as the sole source of directional control did not produce enough yawing moment at high sideslip angles to overpower the aircraft's directional moments. High sideslip angles can be encountered at the lower speeds; hence, if this type of control were used as the sole source for yawing moments, unsatisfactory control characteristics at low speeds might result.

4. The hovering yaw control obtained through the use of ailerons is shown to be predictable in this case and of useful magnitude. It appears that properly designed control surfaces augmenting a yaw control system, such as a yaw tail fan, could be used to reduce the power required and size needed by such a system.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., May 10, 1962.

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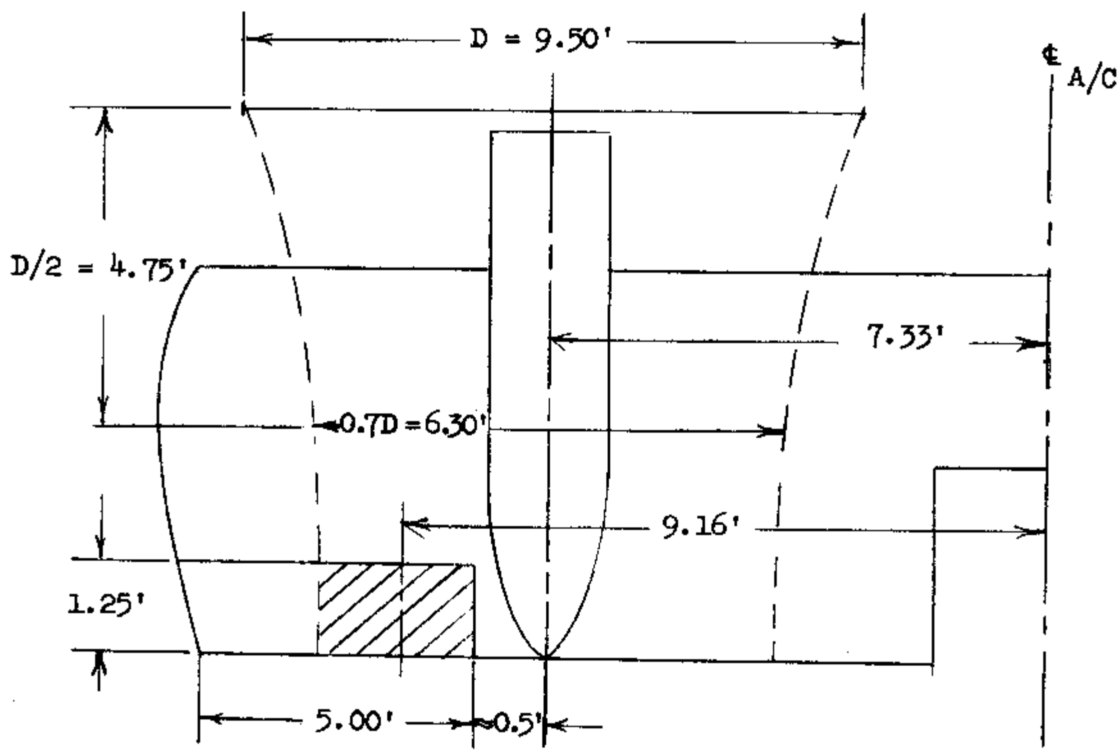
APPENDIX

CORRELATION OF FLIGHT DATA WITH THEORY AND EFFECT OF CONFIGURATION MODIFICATION

Theoretical calculations showing correlation with flight data and how a modification to the basic configuration can produce increased yawing control moments are presented in this appendix. The basic configuration is presented in the following sketch:



Sketch (a).- Basic configuration.

For the calculations for the basic configuration, the following values are assumed:

$$\Omega = 1{,}416 \text{ rpm}$$

$$D = 9.50 \text{ ft}$$

$$W = 3{,}200 \text{ lb}$$

$$C_{L_A} = 1.90$$

$$\delta = 6.0 \text{ in.}$$

The induced velocity is

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$$v_i = \sqrt{\frac{W}{2\rho}} = 69 \text{ ft/sec}$$

The lift produced by wing and aileron is

$$L_A = \frac{1}{2} \rho {v_i}^2 S C_{L_A}$$

$$= \frac{1}{2}(0.00238)(69)^2(4.75)(2.65)(1.90) = 135$$

Based on these values the control moment is

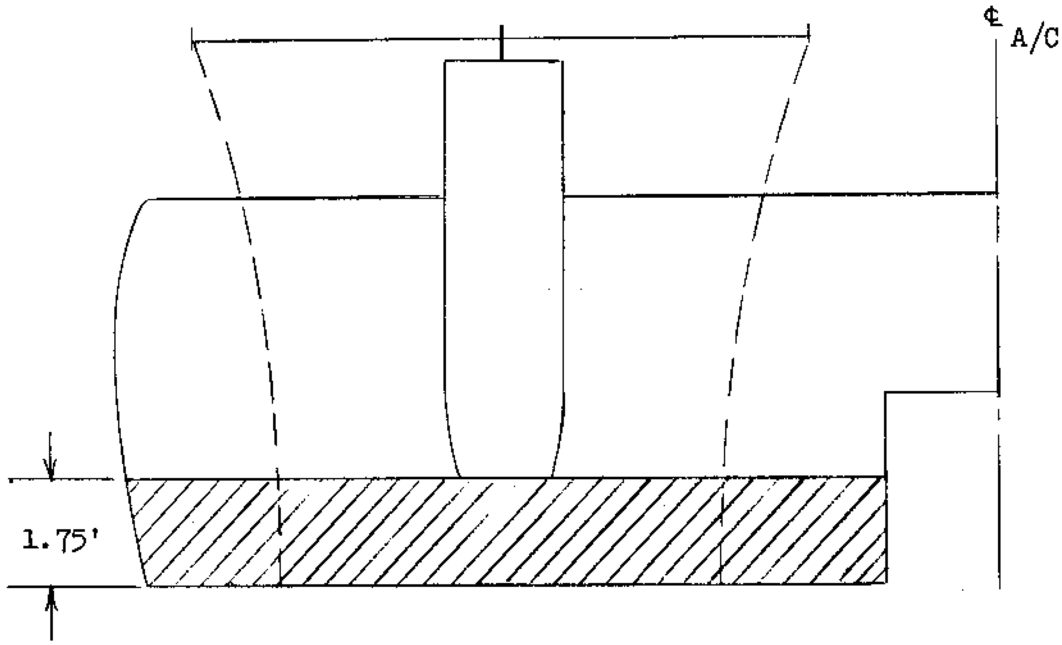
$$M_C = 2(9.16)(135) = 2{,}475 \text{ ft-lb}$$

$$\frac{M_C}{\delta I_Z} = \frac{2{,}475}{(6)(3{,}985)} = 0.103 \; \frac{\text{radian/sec}^2}{\text{in.}}$$

From flight data (fig. 6) the control moment is

$$\frac{M_C}{\delta I_Z} = \frac{450}{3{,}985} = 0.113 \; \frac{\text{radian/sec}^2}{\text{in.}}$$

Based on the good agreement in this case of the theoretical calculations and flight data, a variation of the basic configuration (see sketch (b)) is evaluated by the same theoretical analysis to find the increase that can be made in the ratios initial acceleration and pedal displacement.



Sketch (b).- Full-span control surface.

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The lift produced by deflected surface is

$$L_s = \frac{1}{2}(0.00238)(69)^2(1.90)(4.75)(6.3) = 322$$

The control moment is

$$M_C = 2(322)(7.33) = 4,620 \text{ ft-lb}$$

$$\frac{M_C}{I_Z\delta} = \frac{4,620}{(6)(3,985)} = 0.197 \ \frac{\text{radian/sec}^2}{\text{in.}}$$

The percent increase over the basic configuration is

$$\frac{0.197 - 0.103}{0.103} = 0.913$$

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2. Pegg, Robert J.: Summary of Flight-Test Results of the VZ-2 Tilt-Wing Aircraft. NASA TN D-989, 1962.

3. Gevarter, W.: Propelloplane - Stability and Control Report. Rep. No. 141.7, Hiller Helicopters, Apr. 13, 1956.

4. Engineering Division: Summary Report - Jet Reaction Controls for VTO Aircraft. Rep. No. 3852-1 (Contract No. NOa(s)-10035), Ryan Aero. Co., Oct. 1, 1955.

5. Tosti, Louis P.: Force-Test Investigation of the Stability and Control Characteristics of a 1/8-Scale Model of a Tilt-Wing Vertical-Take-Off-and-Landing Airplane. NASA TN D-44, 1960.

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

8. Anon.: Helicopter Flying and Ground Handling Qualities; General Specification for. Military Specification MIL-H-8501A, Jan. 11, 1961.

TABLE I.- PHYSICAL CHARACTERISTICS OF THE VZ-2 AIRCRAFT

Rotors:		
Diameter, ft		9.5
Blade chord, in.		13
Blade twist (linear, root to tip), deg		19.2
Airfoil section		NACA 0009 with 0.5-inch cusp
Blade taper ratio		1
Solidity, $bc/\pi R$		0.218
Distance between propeller axes, ft		14.67
Differential pitch, deg		±2
Normal operating speed, rpm		1,416
Wing:		
Span (excluding tips), ft		24.88
Chord, ft		4.75
Airfoil section		NACA 4415
Taper ratio		1
Sweep, deg		0
Dihedral, deg		0
Pivot, percent chord		37.6
Ailerons:		
Chord, ft		1.25
Span, ft		6
Tilt range (referenced to upper longeron), deg		9 to 85
Vertical tail:		
Height, ft		5.43
Chord, mean geometric, ft		5.90
Sweep at leading edge, deg		28
Basic airfoil section		NACA 0012
Rudder:		
Chord, in.		21.5
Span, in.		58.0
Horizontal tail:		
Span (less tips), ft		9.90
Chord, ft		3.00
Sweep, deg		0
Taper ratio		1
Airfoil section		NACA 0012
Dihedral, deg		0
Length (distance from wing pivot to leading edge of tail), ft		10.475
Hinge point (distance from leading edge), in.		8.3
Control fans:		
Diameter (both fans), ft		2.00
Moment arm about wing pivot (both fans), ft		12.35
Number of blades		4
Speed, rpm		5,850
Fuselage length		26 feet 5 inches
Engine		Lycoming T 53
Weight as flown with ejection seat, lb		3,500
Center of gravity (for 9° wing incidence), percent mean aerodynamic chord		33.5
Center of gravity (for 85° wing incidence), feet forward of pivot point, measured along longitudinal axis		0.135
Aircraft weight, lb	3,432	3,204
Inertias:		
I_X	1,634	1,560
I_Y	2,937	2,899
I_Z	3,988	3,985
Total control travels:		
Lateral stick, in.		$9\frac{1}{8}$
Longitudinal stick, in.		$11\frac{1}{8}$
Pedal, in.		6

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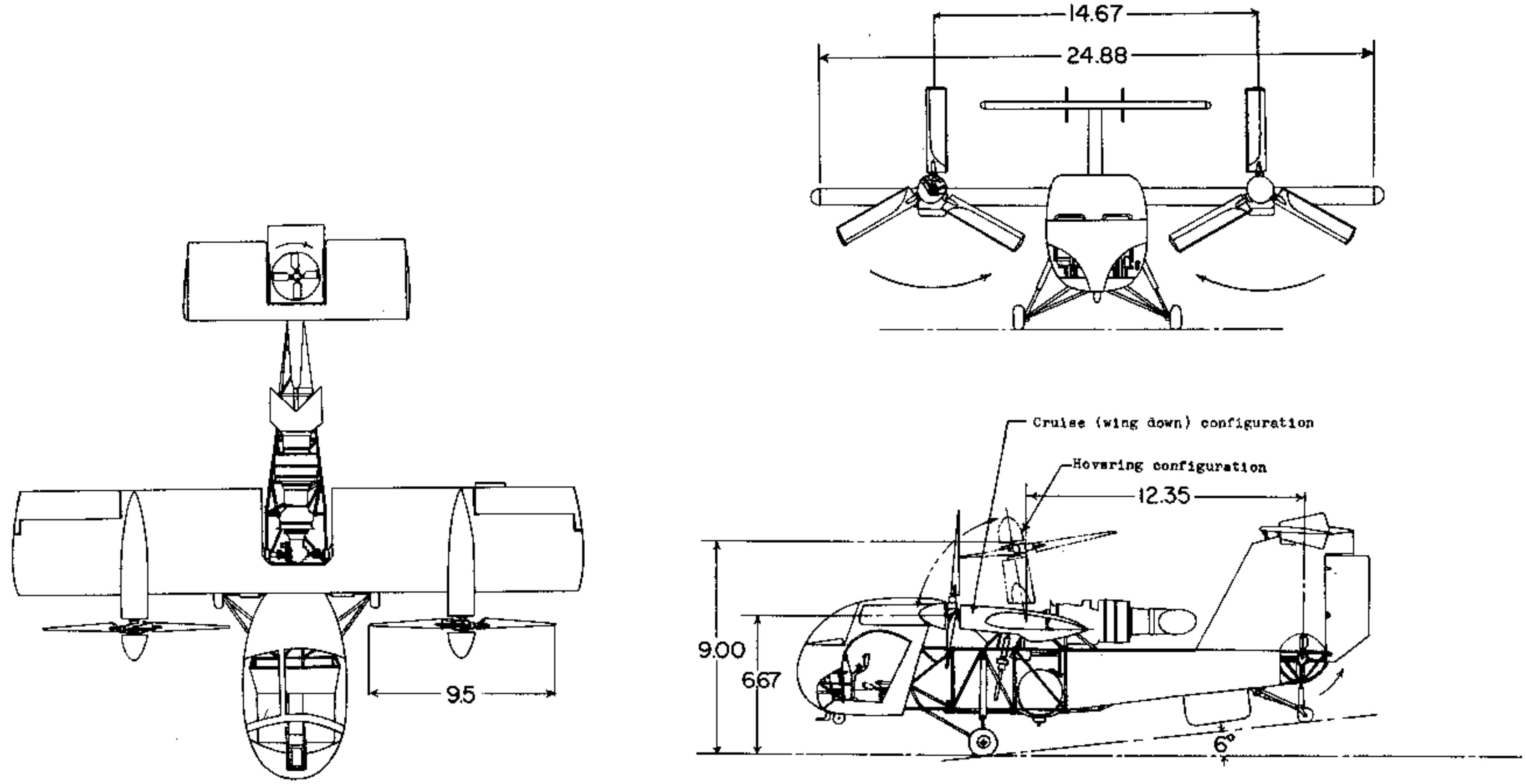

Figure 1.- Sketch of the tilt-wing VTOL aircraft. All dimensions are in feet, unless otherwise specified.

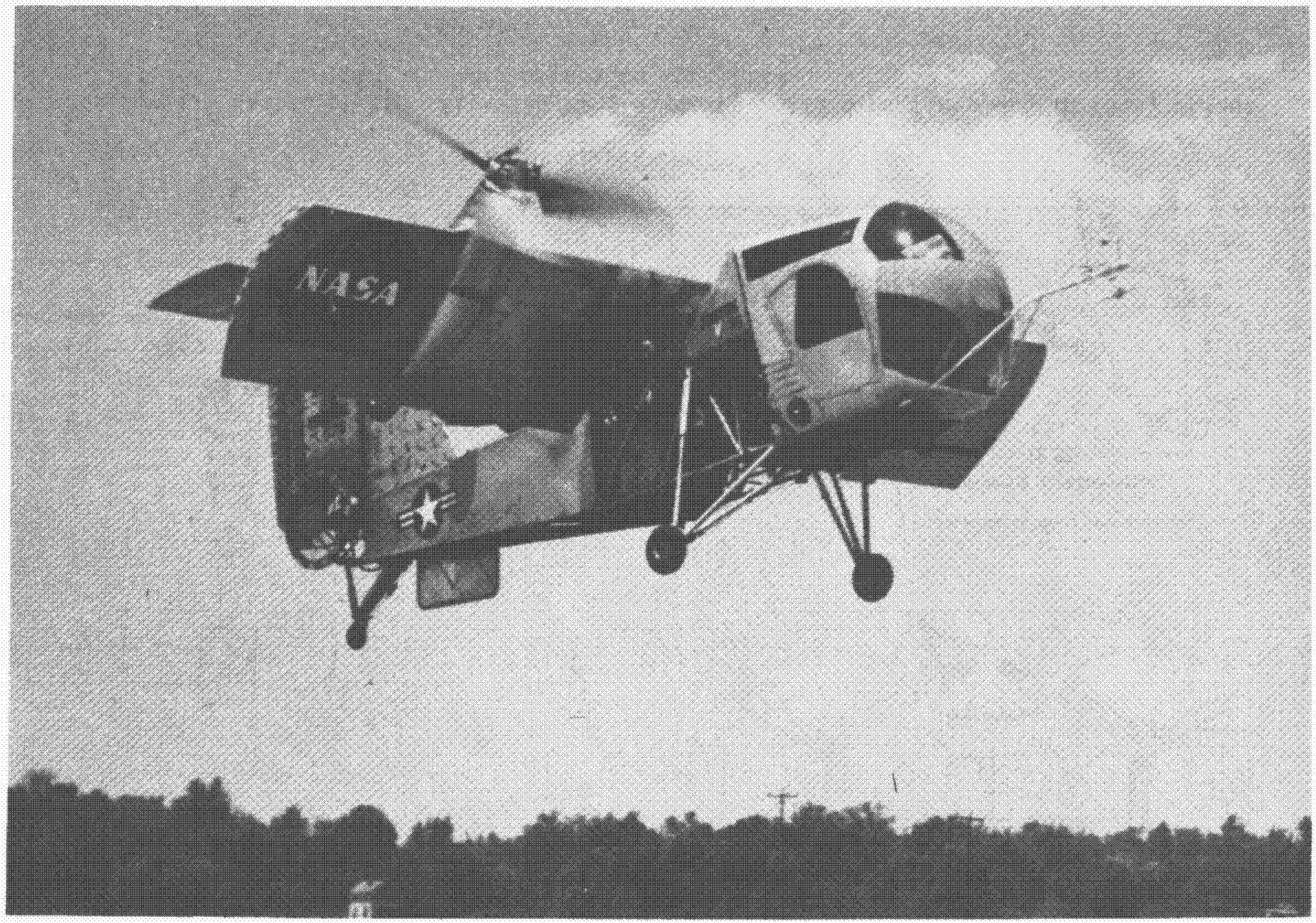

Figure 2.- Test aircraft in transition flight. L-60-4119

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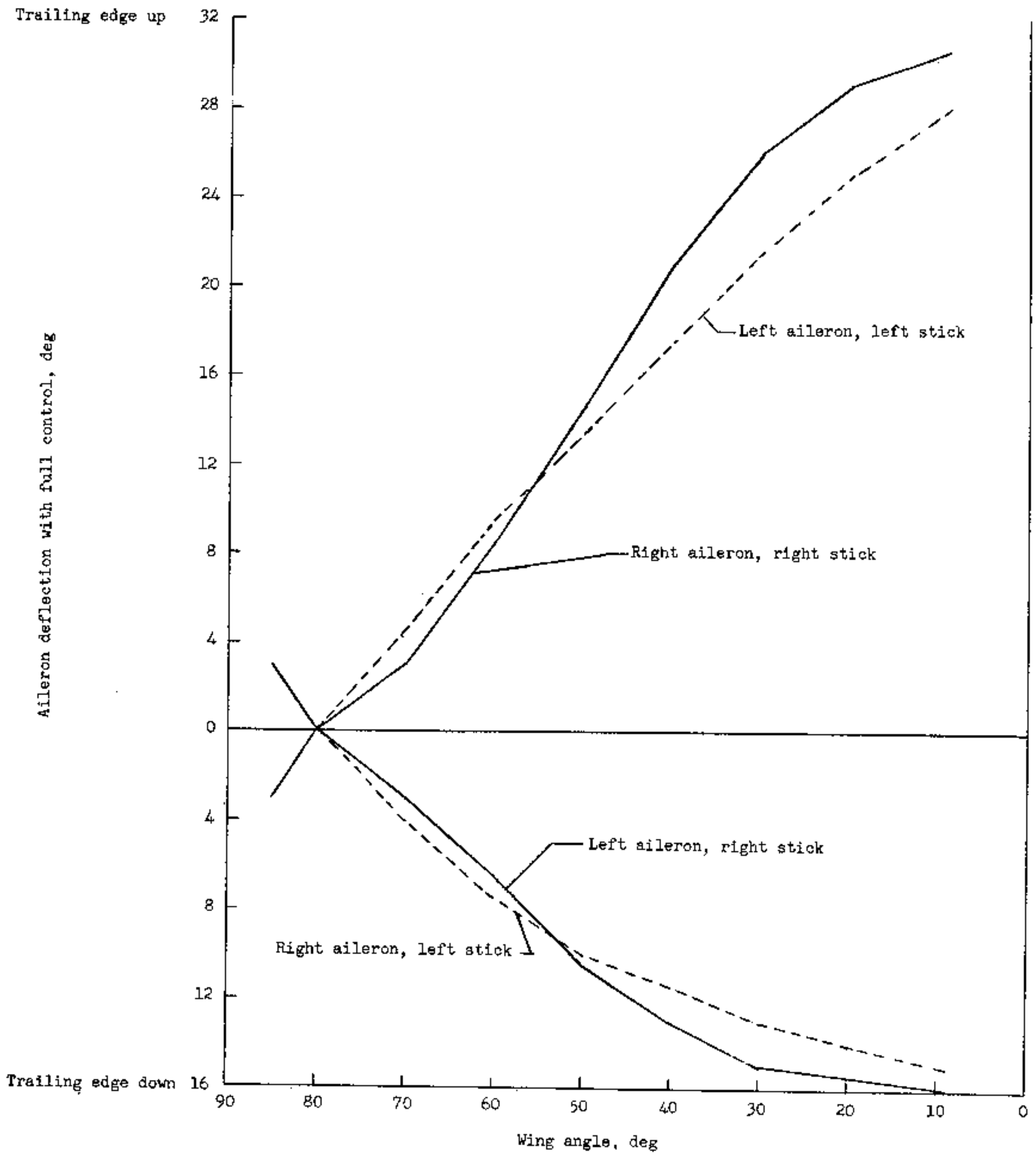
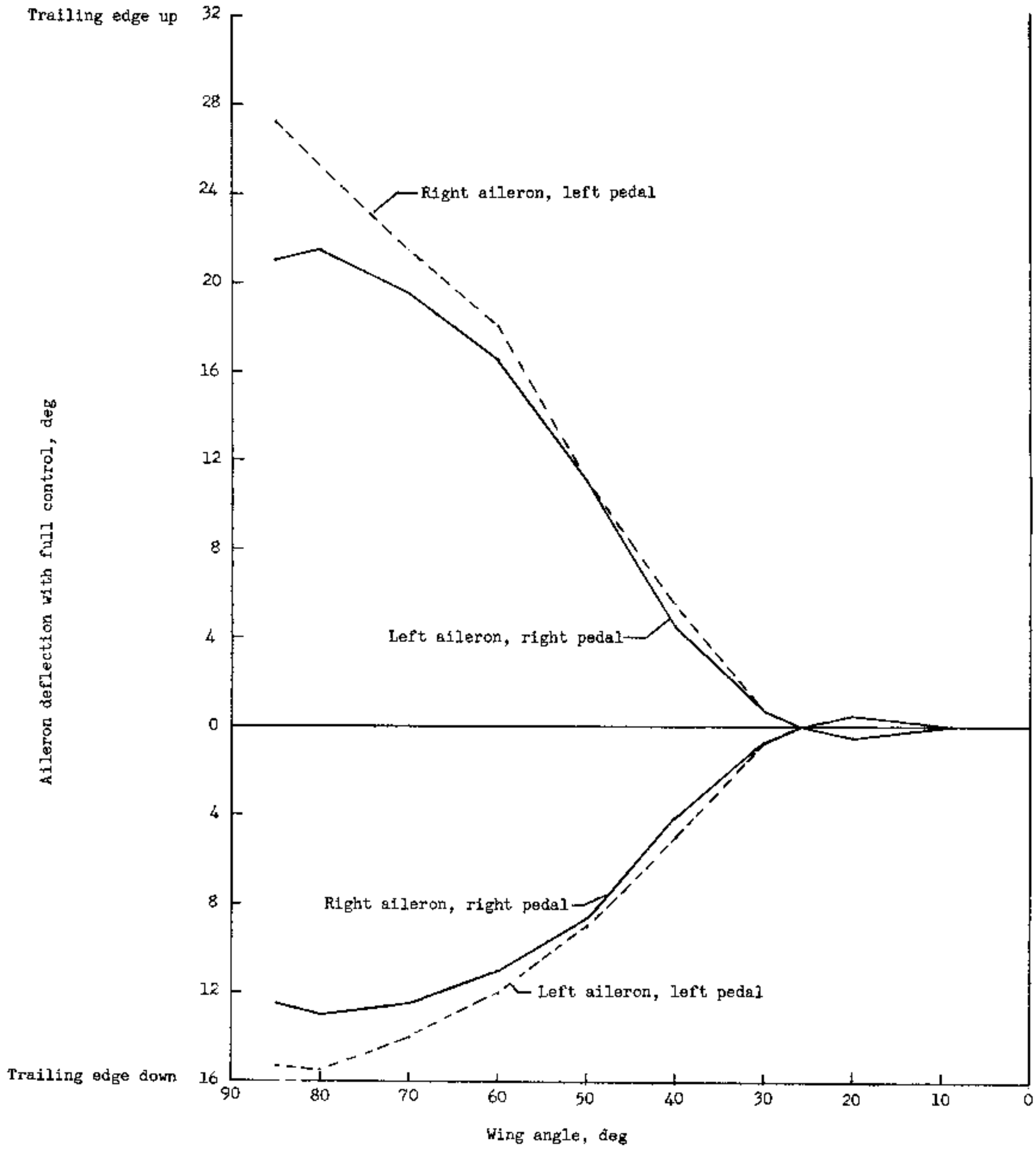


(a) Aileron travel for full lateral stick deflection.

Figure 3.- Aileron programing as a function of wing angle.



(b) Aileron travel for full pedal deflection.

Figure 3.- Concluded.

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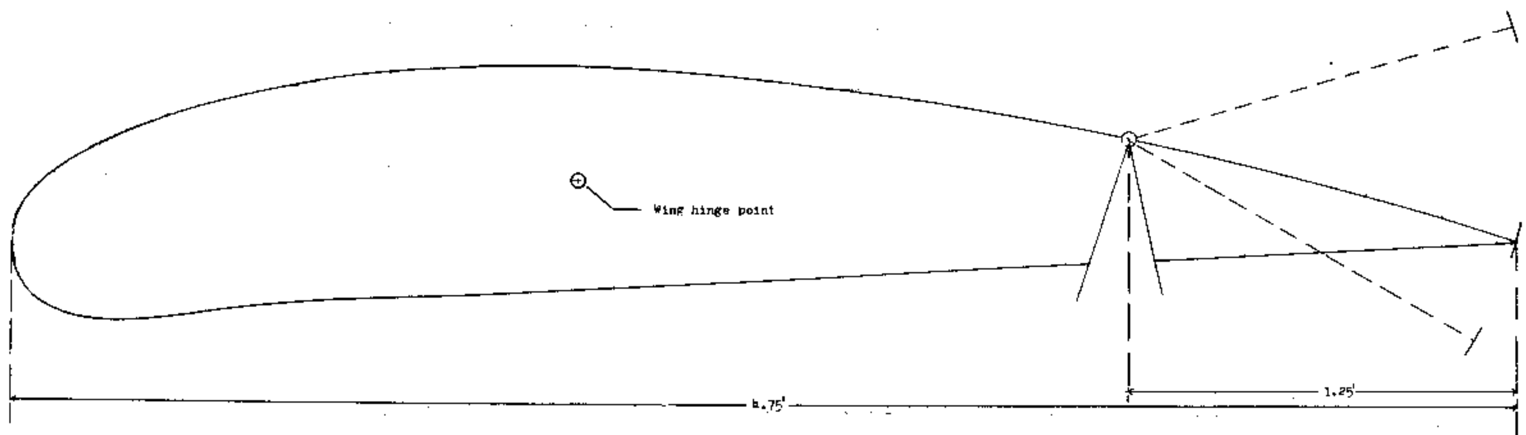


Figure 4.- Airfoil section showing aileron deflection.

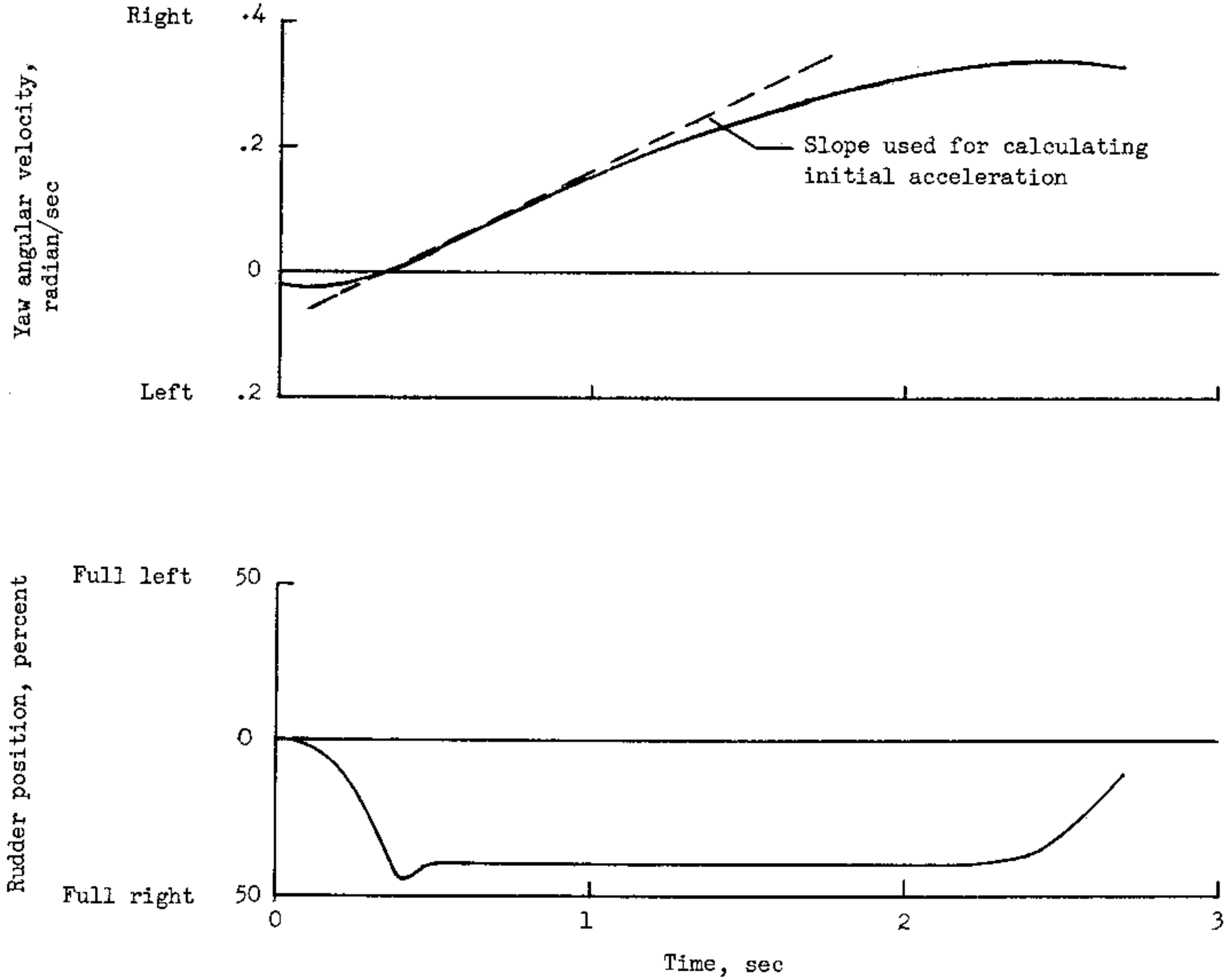


Figure 5.- Typical time history of a step pedal displacement and the resulting angular yawing velocity in the hovering configuration.

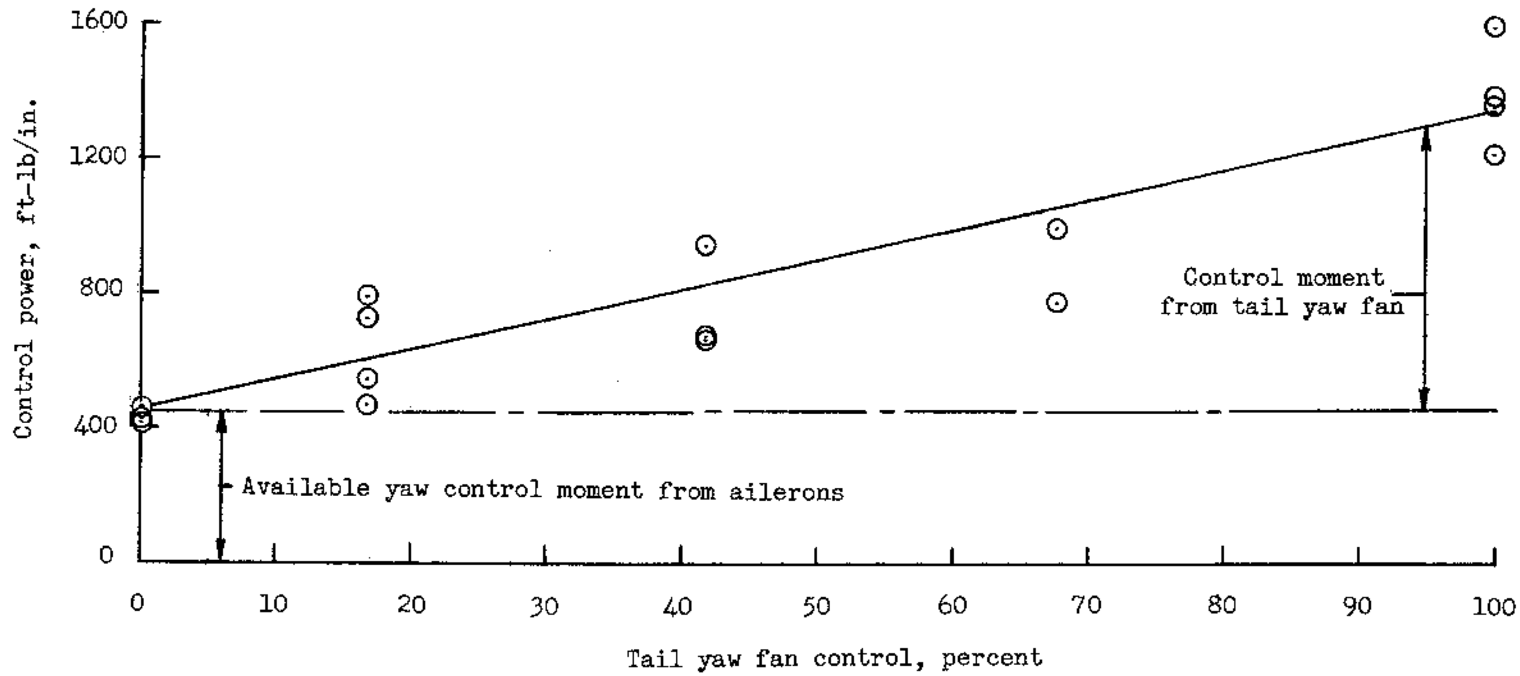
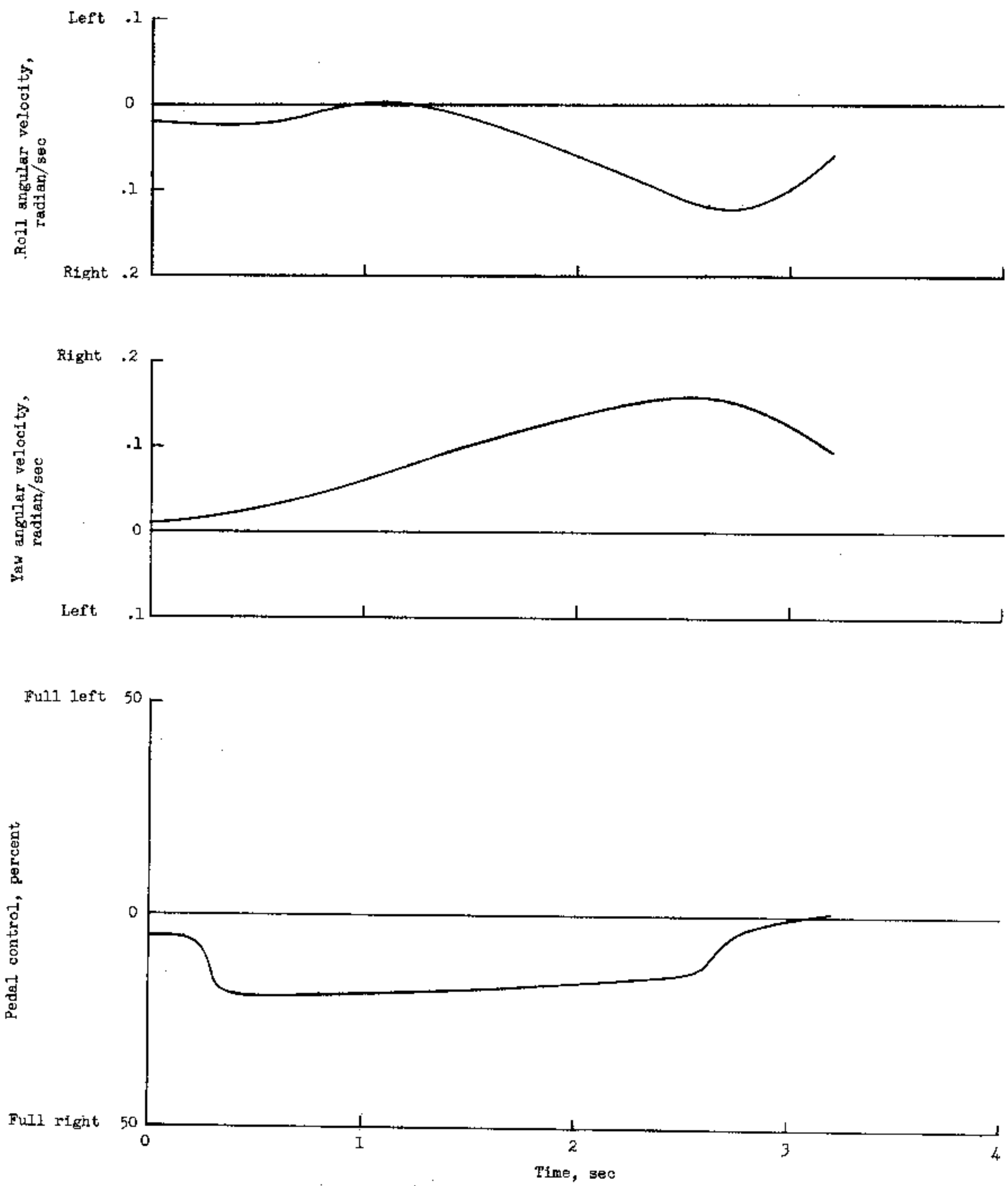


Figure 6.- Hovering yaw control moment per inch of pedal as a function of tail-fan control.



(a) 42-percent tail-fan control.

Figure 7.- Time-history traces of pedal step displacements and the resulting angular yawing and rolling velocities. Flight conditions are: $i_w = 55^\circ$; V = 25 knots; and P = 600 horsepower.

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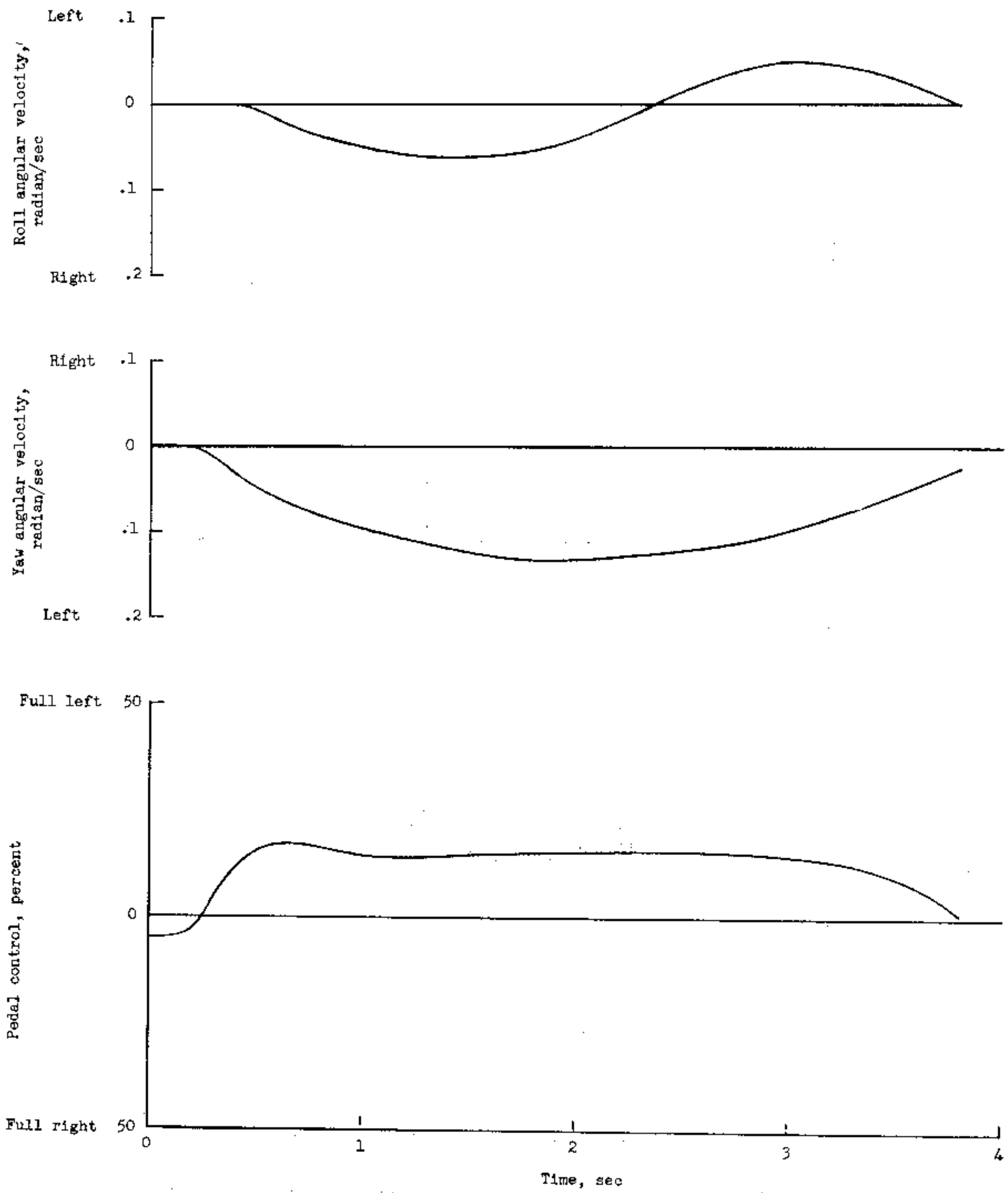

(b) 0-percent tail-fan control.

Figure 7.- Concluded.

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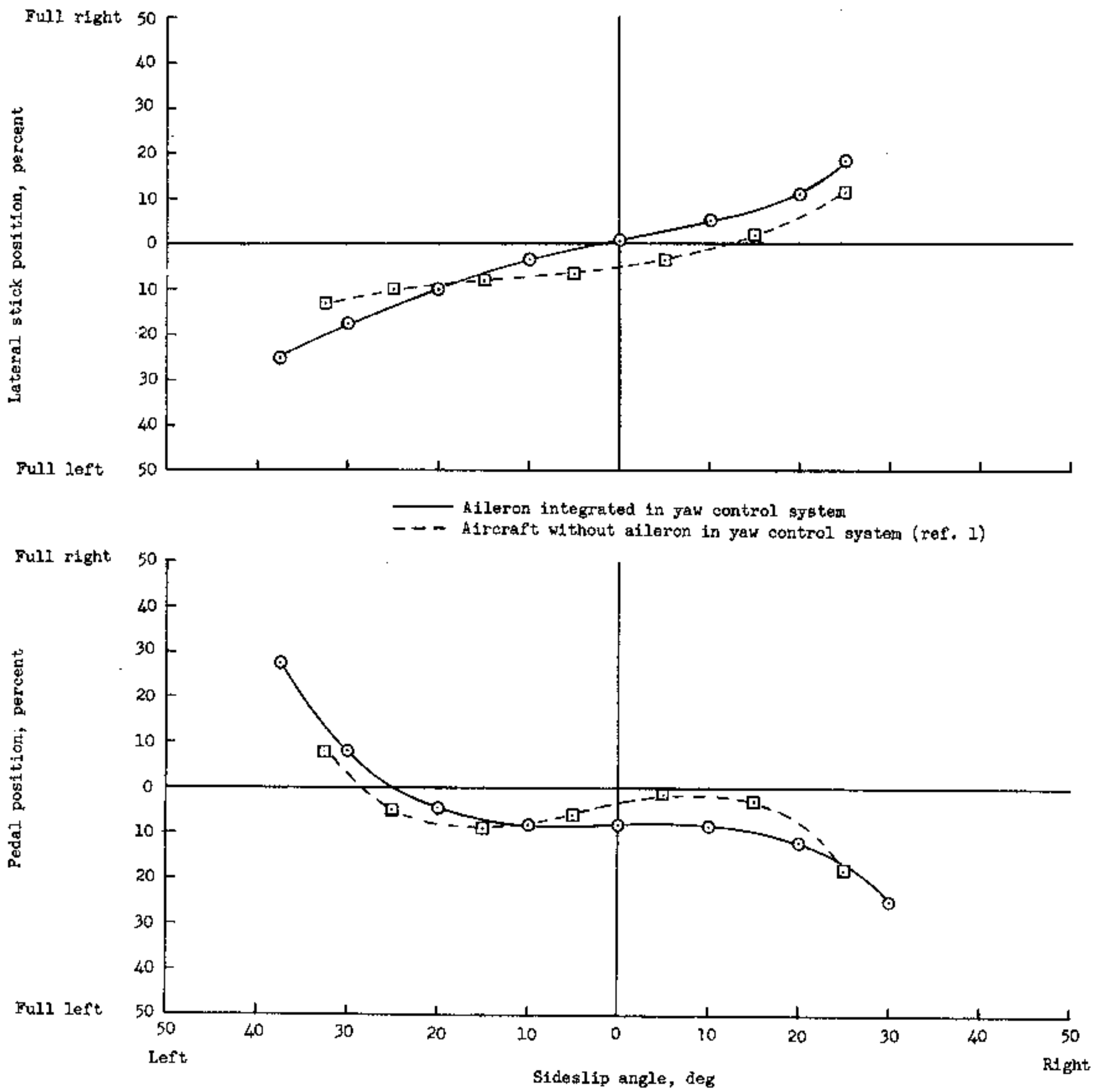

(a) 100-percent tail-fan control.

Figure 8.- Static lateral directional stability characteristics. Flight conditions are: $i_w = 40^\circ$; V = 40 knots; and P = 550 horsepower.

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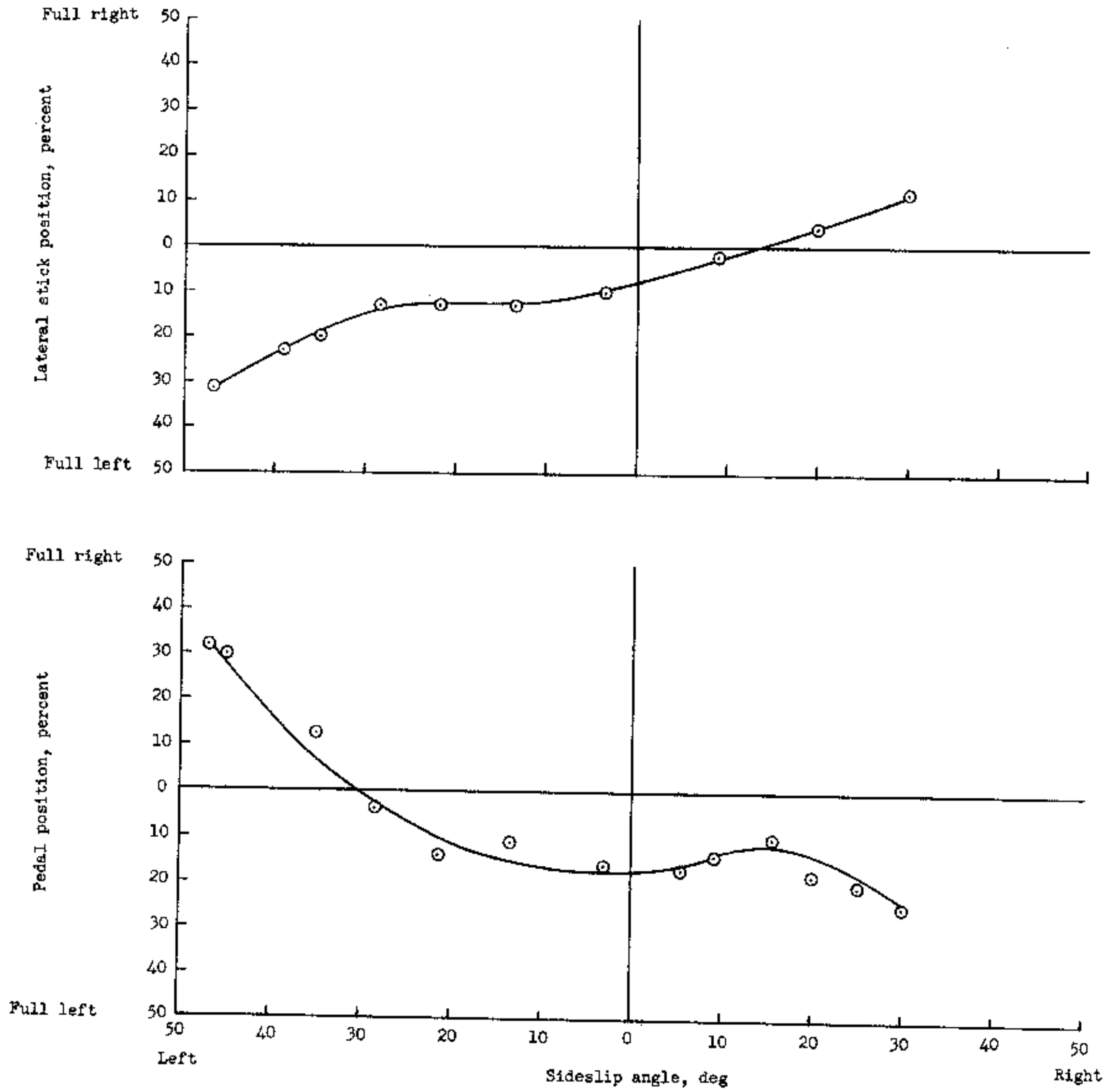
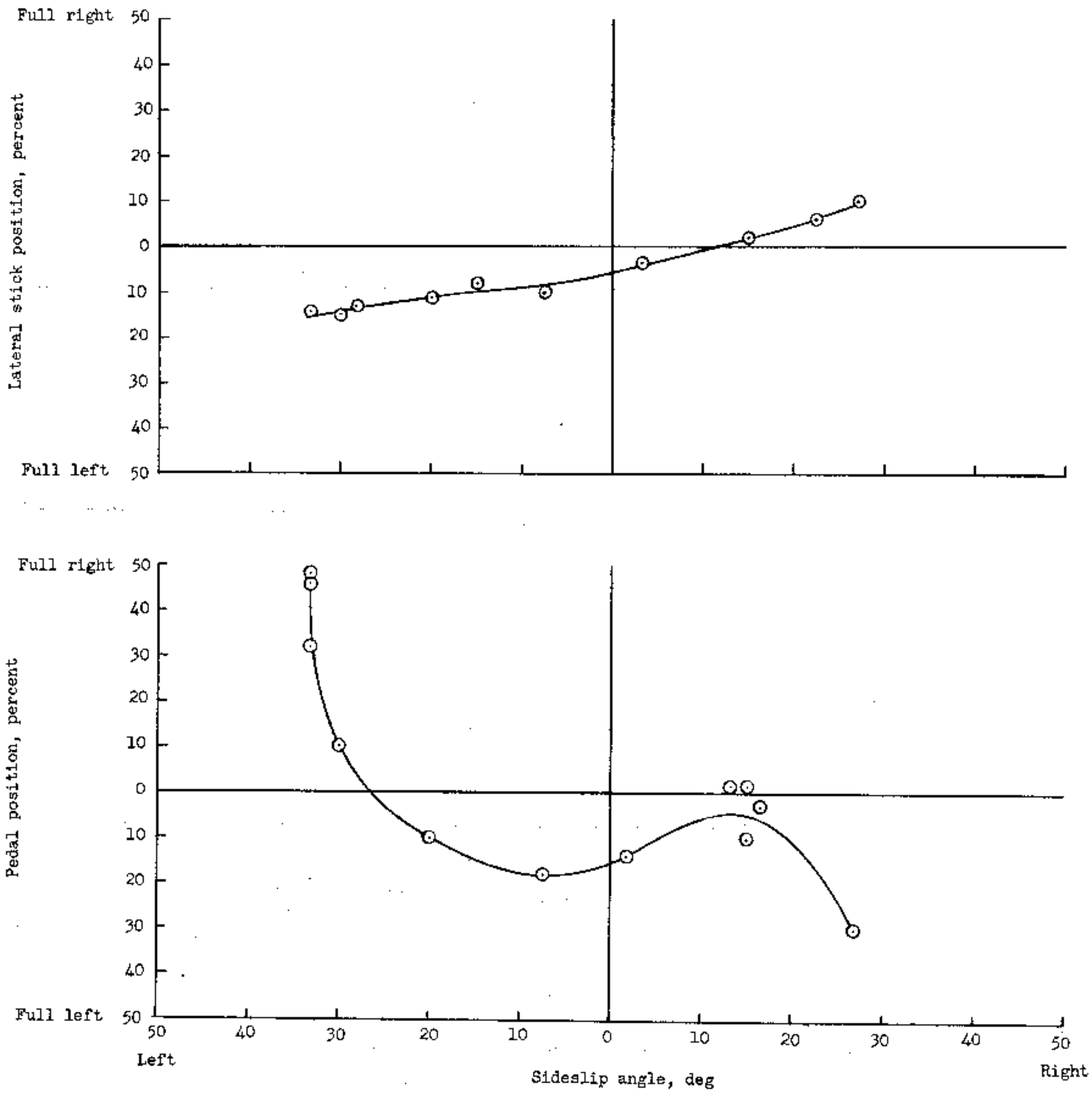


(b) 42-percent tail-fan control.

Figure 8.- Continued.



(c) 0-percent tail-fan control.

Figure 8.- Concluded.

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