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SUMMARY

An analytical study has been conducted to examine the effects of applying thrust along with optimum aerodynamic-control-surface deflections on the spin-recovery characteristics from both incipient and developed spins for four configurations considered as generally representative of modern airplanes.

The results of this investigation indicate that the effects of thrust on spin recovery, either favorable or unfavorable, are generally small; however, they do indicate that applying thrust during a relatively nonoscillatory spin has a favorable effect on the number of spinning turns required for recovery. The magnitude of the improvement is not large but may be such that the use of a turbojet propulsion engine may aid recoveries, especially during the incipient phase of the spin. The use of thrust during attempted recoveries from fairly oscillatory spins indicates no consistent effects – that is, both favorable and unfavorable results have been obtained. Since the number of configurations investigated herein is too small to provide conclusive evidence and since there is a possibility of serious damage to jet engines due to inlet flow distortions caused by the high angles of attack involved in a spin, the use of engine thrust as part of a spin-recovery technique should be carefully investigated for any airplane configuration in question before its use is recommended for that particular configuration.

INTRODUCTION

Airplane spin recoveries are generally attempted by deflecting aerodynamic control surfaces in an optimum manner for the particular airplane, and power is usually cut to idle as soon as a fairly high spin angle of attack is reached and before the control deflections are made. The following question has often been asked: What, in general, are the effects of applying thrust along with aerodynamic-control-surface deflections when attempting recovery from incipient spins and from fully developed spins? To investigate this problem, an analytical study has been made to help determine the effects of thrust on spin recovery for four configurations which are considered as being generally representative of modern airplanes. The configurations represented were a stub-wing research vehicle, a delta-wing fighter, a swept-wing fighter, and a delta-wing bomber. These four configurations were selected to conduct this generalized study because they were configurations for which suitable aerodynamic data were available for input to the computer calculations. The results obtained from this investigation, however, are not intended to be directly applicable to these or any other particular airplane configurations because of certain inadequacies in the aerodynamic data, because of various assumptions that had to be made in the analysis, and because of the statistically small sample. Nevertheless, the investigation is intended to show whether thrust can have any significant effect and, perhaps, to indicate some general trends.

A range of values of thrust was covered for each configuration. These thrusts were constant symmetrical forces directed forward along the X body axis through the center of gravity and were applied instantaneously along with optimum deflections of aerodynamic control surfaces for recovery. Recoveries (or attempted recoveries) were calculated starting at 1, 3, and 5 turns after the initiation of spin entries. For some of the spin-entry and spin motions that were fairly oscillatory in nature, calculations were also made to investigate the effects of thrust on recoveries initiated during various phases of the oscillatory cycle. The calculations included maximum and minimum angle-of-attack conditions.

SYMBOLS

The body system of axes is used. This system of axes, related Euler angles, and positive directions of corresponding forces and moments are illustrated in figure 1. The units used for the physical quantities in this paper are given both in the U.S. Customary Units and in the International System of Units (SI). Factors relating the two systems are given in reference 1.

b wing span, ft (cm)

C_l rolling-moment coefficient, $\dfrac{M_X}{\frac{1}{2}\rho V_R^2 Sb}$

C_m pitching-moment coefficient, $\dfrac{M_Y}{\frac{1}{2}\rho V_R^2 S\bar{c}}$

C_n yawing-moment coefficient, $\dfrac{M_Z}{\frac{1}{2}\rho V_R^{\,2} Sb}$

C_X longitudinal-force coefficient, $\dfrac{F_X}{\frac{1}{2}\rho V_R^{\,2} S}$

C_Y side-force coefficient, $\dfrac{F_Y}{\frac{1}{2}\rho V_R^{\,2} S}$

C_Z vertical-force coefficient, $\dfrac{F_Z}{\frac{1}{2}\rho V_R^{\,2} S}$

$\bar{c}$ mean aerodynamic chord, ft (m)

F_X longitudinal force acting along X body axis, lb (N)

F_Y side force acting along Y body axis, lb (N)

F_Z vertical force acting along Z body axis, lb (N)

g acceleration due to gravity, ft/sec^2 (m/s^2)

g_o acceleration due to gravity at sea level, 32.17 ft/sec^2 (9.8054 m/s^2)

h_o altitude at beginning of time increment, ft (m)

h_1 altitude at end of time increment, ft (m)

I_X, I_Y, I_Z moments of inertia about X, Y, and Z body axes, slug-ft^2 (kg-m^2)

$I_{X,eng}$ moment of inertia of engine rotating parts, slug-ft^2 (kg-m^2)

M_X rolling moment acting about X body axis, ft-lb (m-N)

M_Y pitching moment acting about Y body axis, ft-lb (m-N)

M_Z yawing moment acting about Z body axis, ft-lb (m-N)

m mass of airplane, W/g, slugs (kg)

N	number of spinning turns made during spin-entry attempt
p,q,r	components of resultant angular velocity about X, Y, and Z body axes, radians/sec
T	thrust, lb (N)
R	radius of earth, ft (m)
S	wing surface area, sq ft (m^2)
t	time, sec
u,v,w	components of resultant velocity V_R along X, Y, and Z body axes, ft/sec (m/s)
V	vertical component of velocity of airplane center of gravity (rate of descent), ft/sec (m/s)
V_R	resultant linear velocity, ft/sec (m/s)
W	weight, lb (N)
X,Y,Z	longitudinal, lateral, and vertical axes of airplane
α	angle of attack, angle between relative wind V_R projected into XZ-plane of symmetry and X body axis, positive when relative wind comes from below XY body plane, deg
β	angle of sideslip, angle between relative wind V_R and projection of relative wind on XZ-plane, positive when relative wind comes from right of plane of symmetry, deg
δ_a	aileron deflection with respect to chord line of wing, positive when trailing edge of right aileron down (left stick), deg
δ_e	elevator deflection with respect to fuselage reference line, positive with trailing edge down, deg
δ_r	rudder deflection with respect to fin, positive with trailing edge to left, deg

θ_E total angular movement of X body axis from horizontal plane measured in vertical plane, positive when airplane nose is above horizontal plane, deg

ρ air density, slugs/cu ft (kg/m^3)

ϕ angle between Y body axis and horizontal measured in vertical plane, positive for erect spins when right wing is downward and for inverted spins when left wing is downward, deg

ϕ_E total angular movement of Y body axis from horizontal plane measured in YZ body plane, positive when clockwise as viewed from rear of airplane (if X body axis is vertical, ϕ_E is measured from a reference position in horizontal plane), deg

ψ_E horizontal component of total angular deflection of X body axis from reference position in horizontal plane, positive when clockwise as viewed from vertically above airplane, deg

ω_{eng} rotational rate of engine moving parts about X body axis, radians/sec

$$C_{l_p} = \frac{\partial C_l}{\partial\left(\frac{pb}{2V_R}\right)}; \quad C_{n_p} = \frac{\partial C_n}{\partial\left(\frac{pb}{2V_R}\right)}$$

$$C_{l_r} = \frac{\partial C_l}{\partial\left(\frac{rb}{2V_R}\right)}; \quad C_{n_r} = \frac{\partial C_n}{\partial\left(\frac{rb}{2V_R}\right)}$$

$$C_{l_{\dot\beta}} = \frac{\partial C_l}{\partial\left(\frac{\dot\beta b}{2V_R}\right)}; \quad C_{n_{\dot\beta}} = \frac{\partial C_n}{\partial\left(\frac{\dot\beta b}{2V_R}\right)}$$

$$C_{m_q} = \frac{\partial C_m}{\partial\left(\frac{q\bar{c}}{2V_R}\right)}$$

$$C_{l_\beta} = \frac{\partial C_l}{\partial\beta}$$

$C_{n_\beta} = \frac{\partial C_n}{\partial \beta}$

$C_{Y_\beta} = \frac{\partial C_Y}{\partial \beta}$

$C_{l_{\delta_a}}$ incremental rolling-moment coefficient due to aileron deflection, per deg

$C_{l_{\delta_r}}$ incremental rolling-moment coefficient due to rudder deflection, per deg

$C_{n_{\delta_a}}$ incremental yawing-moment coefficient due to aileron deflection, per deg

$C_{n_{\delta_r}}$ incremental yawing-moment coefficient due to rudder deflection, per deg

$C_{Y_{\delta_a}}$ incremental side-force coefficient due to aileron deflection, per deg

$C_{Y_{\delta_r}}$ incremental side-force coefficient due to rudder deflection, per deg

A dot over a symbol represents a derivative with respect to time.

PROCEDURES AND CALCULATIONS

Spin entries and recoveries from spinning motions were calculated by a high-speed digital computer which solved the equations of motion and associated formulas presented in the appendix. The equations of motion are Euler's equations representing six degrees of freedom along and about the airplane body system of axes. (See fig. 1 for illustration of body axes.) The mass and dimensional characteristics used in the calculations are listed in table I. The configurations studied are referred to as configuration A (a stub-wing research vehicle), configuration B (a tailless delta-wing fighter), configuration C (a tailless delta-wing bomber), and configuration D (a swept-wing fighter with a conventional horizontal tail).

In general, all the aerodynamic data used were nonlinear with angle of attack. (See figs. 2 to 7.) These data, for the most part, were taken from static and dynamic force tests of small-scale models of the configurations. However, since for some configurations test data were not available, certain aerodynamic characteristics had to be estimated. Figure 8 presents some arbitrary values of C_m and C_{l_β} that were used for some additional calculations for configuration D. The oscillation-type rotary derivatives presented in figures 6 and 7 were obtained as combination derivatives which include the effects of $\dot{\beta}$ – that is, C_{l_p} is actually $\left(C_{l_p} + C_{l_{\dot{\beta}}} \sin \alpha\right)$, C_{n_p} is actually $\left(C_{n_p} + C_{n_{\dot{\beta}}} \sin \alpha\right)$, C_{l_r} is actually $\left(C_{l_r} - C_{l_{\dot{\beta}}} \cos \alpha\right)$, and C_{n_r} is actually $\left(C_{n_r} - C_{n_{\dot{\beta}}} \cos \alpha\right)$. However, inasmuch as the full derivatives could not be separated into their component parts, it was arbitrarily decided for this study to treat the derivatives as though they were due solely to angular velocities about body axes. In addition, constant values of C_{m_q} were used for each configuration as follows: For configuration A, $C_{m_q} = -10$; for configuration B, $C_{m_q} = -1$; and for configurations C and D, $C_{m_q} = -2$. The values of C_{m_q} for configurations A and C are average values taken from measured data. The values of $C_{m_q} = -1$ for configuration B and $C_{m_q} = -2$ for configuration D were selected because preliminary time-history calculations determined that these values allowed good simulations of experimental spin motions.

The approach used in the investigation was to calculate an attempted spin entry for each configuration by starting at or near trimmed gliding flight and flying the airplane up through the stall angle of attack (1-g stall maneuver). Initial flight conditions used are shown in table II. In all calculations, the elevators were up at the start and right rudder was applied at or just after the stall to obtain a yawing motion to the right, and left stick was applied, variously timed, to attempt to promote spin entries to the right. Thrust was kept at zero during the spin-entry attempts. After it was determined that spins could be entered, a group of zero-thrust (or reference) recovery attempts were made by deflecting the rudder against the direction of yaw and the ailerons with the direction of yaw (left rudder and right stick when spinning to the pilot's right). These no-thrust recovery attempts were made after 1-, 3-, and 5-turn spins were obtained for the various configurations. The control movements used for recovery are optimum for recovery from spins for airplanes such as the subject configurations, which are loaded heavily along the fuselage. (See ref. 2.) The elevators remained in the initial up position throughout all recovery calculations. After the zero-thrust recovery results were obtained, thrusts of 8000 pounds (35 586 N), 16 000 pounds (71 172 N), or 24 000 pounds (106 757 N) were applied during the subsequent recovery attempts, simultaneously with the movement of the aerodynamic controls for recovery, in order to determine the incremental effects of these thrusts. As previously mentioned, the full amount of thrust was applied instantaneously during the investigation. A few recovery-attempt calculations were also made in which the thrust was applied on a gradual basis in order to determine its effect. Once thrust was applied during a given recovery attempt, it was maintained along with recovery control-surface deflection until a recovery was achieved or the calculation was stopped because it was obvious that no recovery would be achieved.

A recovery was considered to have been achieved when either the spin-rotation ceased or the angle of attack became and remained less than the stall angle. In general, when the angle of attack of a spinning airplane becomes and remains less than the stall angle, the airplane enters a steep dive without significant rotation ($r \approx 0$). In some cases, however, the airplane may be turning or rolling in a spiral glide or an aileron roll. Also, sometimes the airplane may roll or pitch to an inverted attitude from the erect spin and may still have some rotation; but, in this situation, the airplane is out of the original erect spin and has gone through a recovery condition during which time the pilot could move the controls to stay in the recovered condition.

In most of the calculations, no gyroscopic-moment effects due to engine rotating parts were included. However, for two configurations in which the application of thrust was found to be beneficial, the possible further effects of including gyroscopic moments were investigated briefly for both right and left spins. No mass decrease accompanied the application of thrust in the calculations.

RESULTS AND DISCUSSION

The calculated results are presented in figures 9 to 13 as time histories of the spin entry and attempted recovery motions. In these figures, all spin entries and spins are indicated by solid lines and all attempted recoveries are indicated by dashed lines. These time histories show that developed spins were obtained for all four configurations. The number of turns required for recovery and the altitude loss for the various conditions are presented in table III. The altitude loss represents the amount lost up to the point that the airplane stopped spinning and not to that required to regain straight and level flight. All the results presented in this paper are for the calculations in which thrust was applied instantaneously because the results from the calculation in which thrust was applied gradually were similar. These results should not be applied directly to any particular airplane of the types represented by the configurations investigated because of considerable differences between various airplane configurations of the same general type and because the aerodynamic inputs are not sufficiently accurate in detail even for the particular configurations for which the calculations were made.

Configurations A and B

The results presented in figures 9 and 10 and table III for configurations A and B (a stub-wing fighter and a delta-wing fighter, respectively) show similar trends. Both configurations displayed relatively nonoscillatory spin characteristics and both could achieve recoveries for the zero-thrust conditions. Also, for both configurations, the use of thrust improved the recovery characteristics. The two configurations were significantly different, however, with regard to zero-thrust recoveries. The recoveries for configuration B were rapidly acquired with a small altitude loss, whereas those for configuration A were slower with a greater loss of altitude.

In interpreting these data it might be observed that the use of 24 000 pounds (106 757 N) of thrust, which is a very high level of thrust for these 15 000- to 24 000-pound (66 723 to 106 757 N) configurations, reduced the number of turns required for recovery to about one-half that for the zero-thrust condition. This level of thrust would be required for 10 to 15 seconds, and the weight of fuel consumed in this length of time would be far too high to make the use of an auxiliary rocket for producing this thrust practical for spin recovery. The results shown in table III indicate that the use of the 8000-pound (35 586 N) level of thrust, which is a more appropriate value for a turbojet propulsion engine that might be installed in an airplane of this size, would reduce the number of turns required for recovery. The effect of thrust appears to be more significant during the incipient phase of the spin than during the developed spins. It should be realized that it is questionable whether the engine of any particular high-performance airplane can be operated at high thrust levels in the spinning attitude because of the danger of compressor stall and consequent serious damage to the engine due to high inlet flow distortion caused by the high angle of attack.

When the use of a turbojet engine is considered for recovery, the effects of the gyroscopic moments due to the engine should be considered. Table IV presents the results of some supplementary calculations made to indicate the effect that might be expected from engine gyroscopic moments. The calculations were made for an angular momentum of the engine rotating parts of 16 000 slug-ft^2/sec (21 693 kg-m^2/sec), which was considered to be an appropriate value for an engine which could produce 8000 pounds (35 586 N) of thrust at a spin altitude of about 30 000 feet (9144 m). The results in table IV show that the effect of the gyroscopic moments was not consistent in that sometimes it was detrimental for recovery from spins in a given direction as compared with the case of using thrust with no gyroscopic moments. However, the use of thrust, with or without engine gyroscopic moment, gave improvement in the number of turns required for recovery over that required for the zero-thrust condition; although, in some cases, the improvement was small.

Configuration C

The time histories for configuration C (a delta-wing bomber) are presented in figure 11 and show that a very oscillatory spin was entered. In fact, the configuration oscillated below the stall angle of attack and out of the spin before 5 spinning turns were reached without recovery controls being applied. When recovery controls were applied after 1 and 3 spinning turns, it took approximately $2\frac{1}{2}$ and $3\frac{1}{2}$ additional turns, respectively, to achieve a recovery. When thrust was included during each recovery attempt, the results (fig. 11 and table III) indicated that thrust had little or no effect on recoveries for this configuration. An additional calculation was made during which a thrust of 64 000 pounds (284 686 N) was used at the same time recovery controls were applied; however, even this large thrust had no appreciable effect on the number of turns required for spin recovery.

Configuration D

The time histories for configuration D (a swept-wing fighter) are presented as figures 12 and 13. This configuration had a very oscillatory spin. When recovery controls were applied for the zero-thrust condition after 1, 3, and 5 spinning turns had been completed, results indicate that more than 10 additional turns would be required for recoveries. These are, of course, very poor basic recovery characteristics. Thrusts applied as recoveries were attempted from a 1-turn or a 5-turn spin (table III) were found to have a favorable effect, although the recoveries were still slow. However, thrust was not favorable when recovery was attempted from a 3-turn spin; rather a new developed spin condition ensued. Because it appeared that the inconsistent results noted might be associated with the fact that the spin-entry and spin motions for this configuration were very oscillatory, additional calculations were made to determine the effect of initiating recoveries at various angles of attack – including the approximate maximum and minimum values noted during the oscillations. These results were not particularly conclusive insofar as indicating trends is concerned. Some of these results are included in table III and indicate the following: Thrust was favorable when attempting recovery from a 3.12-turn spin compared with results obtained from a 3-turn spin; and for the former condition the angle of attack at which recovery was initiated was 18° lower than it was for the latter condition. However, thrust was harmful when recovery was attempted from a 1.2-turn spin compared with results obtained after a 1-turn spin, even though for the 1.2-turn spin, the angle of attack at which recovery was initiated was 29° lower than it was for the 1-turn spin.

In order to investigate the results obtained for this configuration more extensively, the arbitrary aerodynamic data shown in figure 8 were used in an attempt to obtain a less oscillatory spin. A spin entry and a spin were calculated by using these data, and the results are shown in figure 13 and included in table III. A comparison of the calculated spin-entry and spin motions for this additional calculation with those calculated by using the original data (see fig. 12) indicates that the spin-entry oscillations were somewhat lower in frequency and that the spin achieved had a lower rate of rotation than did the original spin. As may be seen in figure 13 and in table III, the recovery results indicate that thrust was favorable for all conditions investigated. This situation was not true before the arbitrary aerodynamic data were used.

Summation and Significance of Results of Spin-Recovery Calculations

The results of this limited investigation indicate that the effects of thrust on spin recovery, either favorable or unfavorable, are generally small. They do indicate that while attempting recovery from a relatively nonoscillatory spin – that is, one with fairly low oscillation frequencies and amplitudes – applying thrust along with optimum deflections of the aerodynamic control surfaces is favorable to recovery. For a fairly oscillatory spin, however, the effects noted in this study are not clear cut. The effects may be favorable or unfavorable, and it is possible that during oscillatory spin motions the effects of thrust application become quite subordinate to, and are overridden by the varying nature of, the aerodynamic and inertia cross-couple moment influences which are inherent within and have large effects on spin and recovery motions.

The magnitude of the favorable effect of thrust on recovery of the less oscillatory spins studied was large enough to indicate that for some configurations the spin-recovery characteristics could be improved, especially during the incipient phase of the spin. As pointed out previously, however, there is some question as to whether the turbojet engine of any particular high-performance airplane could actually be operated at the high angles of attack involved in a spin. For this reason, and because the present investigation was very limited in scope, a careful investigation of the use of thrust should be made for any particular configuration before it is recommended as part of the recovery technique.

CONCLUSIONS

The results of this analytical investigation of the effects of thrust on recovery characteristics of four configurations representative of modern airplanes indicate the following conclusions:

1. The effects of thrust on spin recovery, either favorable or unfavorable, are generally small.

2. For the configurations which displayed relatively nonoscillatory spins, the use of thrust appears to aid spin recovery. The magnitude of the improvement is not large but may be such that the use of the thrust of a turbojet propulsion engine may give significant improvements for configurations which have borderline recovery characteristics with zero thrust.

3. For the configurations which displayed fairly oscillatory spins, the effect of application of thrust during recovery is inconsistent – with the effect on recovery being favorable for some configurations and unfavorable for others.

4. Since the number of configurations investigated in the present paper is too small to provide conclusive evidence and since there is a possibility of serious damage to jet

engines due to inlet flow distortions caused by the high angles of attack involved in a spin, the use of engine thrust as part of a spin-recovery technique should be carefully investigated for any airplane configuration in question before the use of thrust is recommended for that particular configuration.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., November 17, 1965.

APPENDIX

EQUATIONS OF MOTION AND ASSOCIATED FORMULAS

The equations of motion used in the calculations were:

$$\dot{p} = \frac{I_Y - I_Z}{I_X} qr + \frac{\rho V_R{}^2 Sb}{2I_X}\left(C_{l_\beta}\beta + C_{l_{\delta_r}}\delta_r + C_{l_{\delta_a}}\delta_a\right) + \frac{\rho V_R Sb^2}{4I_X}\left(C_{l_p}p + C_{l_r}r\right)$$

$$\dot{q} = \frac{I_Z - I_X}{I_Y} pr + \frac{\rho V_R{}^2 S\bar{c}}{2I_Y} C_m + \frac{\rho V_R S\bar{c}^2}{4I_Y} C_{m_q}q - \frac{I_{X,eng}\omega_{eng}}{I_Y} r$$

$$\dot{r} = \frac{I_X - I_Y}{I_Z} pq + \frac{\rho V_R{}^2 Sb}{2I_Z}\left(C_{n_\beta}\beta + C_{n_{\delta_r}}\delta_r + C_{n_{\delta_a}}\delta_a\right) + \frac{\rho V_R Sb^2}{4I_Z}\left(C_{n_p}p + C_{n_r}r\right) + \frac{I_{X,eng}\omega_{eng}}{I_Z} q$$

$$\dot{u} = -g \sin \theta_E + vr - wq + \frac{\rho V_R{}^2 S}{2m} C_X + \frac{T}{m}$$

$$\dot{v} = g \cos \theta_E \sin \phi_E + wp - ur + \frac{\rho V_R{}^2 S}{2m}\left(C_{Y_\beta}\beta + C_{Y_{\delta_r}}\delta_r + C_{Y_{\delta_a}}\delta_a\right)$$

$$\dot{w} = g \cos \theta_E \cos \phi_E + uq - vp + \frac{\rho V_R{}^2 S}{2m} C_Z$$

In addition, the following associated formulas were used:

$$\alpha = \tan^{-1} \frac{w}{u}$$

$$\beta = \sin^{-1} \frac{v}{V_R}$$

$$V_R = \sqrt{u^2 + v^2 + w^2}$$

$$V = -u \sin \theta_E + v \cos \theta_E \sin \phi_E + w \cos \theta_E \cos \phi_E$$

$$h_1 = h_o - \Delta t\, V$$

$$\dot{\theta}_E = q \cos \phi_E - r \sin \phi_E$$

$$\dot{\phi}_E = p + r \tan \theta_E \cos \phi_E + q \tan \theta_E \sin \phi_E$$

APPENDIX

$$\dot{\psi}_E = \frac{r \cos \phi_E + q \sin \phi_E}{\cos \theta_E}$$

$$g = g_o\left(\frac{R}{R + h_1}\right)^2$$

$$\text{Turns in spin} = \frac{\int \dot{\psi}_E \, dt}{2\pi}$$

$$\phi_E = \sin^{-1} \frac{\sin \phi}{\cos \theta_E}$$

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TABLE I.- MASS AND DIMENSIONAL CHARACTERISTICS

Parameter	Configuration			
	A	B	C	D
$\bar{c}$,				
ft	10.27	23.76	36.17	11.83
m	3.13	7.24	11.02	3.61
b,				
ft	22.36	38.12	56.89	35.67
m	6.82	11.62	17.34	10.87
S,				
sq ft	200.00	695.05	1 542.53	385.33
m^2	18.58	64.57	143.31	35.80
W,				
lb	15 792	24 811	71 800	23 771
N	70 246	110 365	319 382	105 739
I_X,				
slug-ft^2	4 288	13 600	290 000	11 709
kg-m^2	5 814	18 439	393 187	15 875
I_Y,				
slug-ft^2	73 384	128 000	747 000	82 654
kg-m^2	99 495	173 545	1 012 786	112 064
I_Z,				
slug-ft^2	74 867	138 000	965 000	89 237
kg-m^2	101 506	187 103	1 308 364	120 989
Control deflections:				
δ_e, deg	-35.0	-25.0	-20.0	-30.0
δ_r, deg	±7.5	±25.0	±30.0	±6.0
δ_a, deg	±7.5	±7.5	±15.0	±15.0

TABLE II.- INITIAL CONDITIONS USED IN CALCULATIONS

[$\beta = \phi_E = \psi_E = v = p = r = q = T = 0$; Altitude = 30 000 ft (9.144 km)]

Configuration	α, deg	θ_E, deg	u, ft/sec	u, m/sec	w, ft/sec	w, m/sec	V_R, ft/sec	V_R, m/sec
A	25	25	269.0	82.0	125.5	38.3	297.0	90.5
B	18	18	314.7	95.9	102.3	31.18	330.9	100.9
C	20	0	341.4	104.1	124.3	37.9	363.3	110.7
D	10	10	587.0	178.9	103.5	31.5	596.1	181.7

TABLE III.- NUMBER OF TURNS AND ALTITUDE LOSS REQUIRED FOR RECOVERY

Thrust, lb (N)	Turns required			Altitude loss, ft (m)		
	N = 1	N = 3	N = 5	N = 1	N = 3	N = 5
			Configuration A			
0	2.23	6.49	6.95	3 289 (1 002)	6 353 (1 936)	5 596 (1 706)
8 000 (35 586)	1.36	4.41	6.34	2 287 (698)	4 710 (1 436)	5 599 (1 707)
16 000 (71 172)	.94	3.22	5.02	1 623 (495)	3 793 (1 156)	4 672 (1 424)
24 000 (106 757)	.81	2.46	4.03	1 431 (436)	3 018 (920)	3 912 (1 192)
			Configuration B			
0	0.25	1.60	2.37	1 161 (354)	3 559 (1 085)	4 297 (1 310)
8 000 (35 586)	.20	1.24	1.80	1 041 (317)	2 849 (868)	3 454 (1 053)
16 000 (71 172)	.17	1.01	1.48	633 (193)	2 424 (739)	2 854 (870)
24 000 (106 757)	.15	.86	1.25	608 (185)	2 076 (633)	2 549 (777)
			Configuration C			
0	2.35	3.20	---	4 686 (1 428)	5 295 (1 614)	-----------
8 000 (35 586)	2.36	3.24	---	4 637 (1 413)	5 305 (1 617)	-----------
16 000 (71 172)	2.36	3.28	---	4 705 (1 434)	5 395 (1 644)	-----------
24 000 (106 757)	2.37	3.31	---	4 648 (1 417)	5 505 (1 678)	-----------
			Configuration D			
0	16.40	10.40	10.13	12 971 (3 954)	8 534 (2 601)	8 215 (2 504)
8 000 (35 586)	6.55	No recovery	9.40	6 292 (1 918)	No recovery	8 974 (2 735)
16 000 (71 172)	4.90	No recovery	5.30	4 881 (1 488)	No recovery	5 296 (1 614)
24 000 (106 757)	4.32	No recovery	5.20	4 191 (1 277)	No recovery	5 021 (1 530)
	N = 1.20		N = 3.12	N = 1.20	N = 3.12	
0	10.00		6.40	7 761 (2 366)	6 264 (1 909)	
8 000 (35 586)	No recovery		5.13	No recovery	4 743 (1 446)	
16 000 (71 172)	No recovery		5.28	No recovery	5 494 (1 675)	
24 000 (106 757)	No recovery		8.04	No recovery	8 070 (2 460)	
			Results using arbitrary data as shown in figure 8			
	N = 1	N = 3	N = 5	N = 1	N = 3	N = 5
0	1.36	2.70	3.29	2 706 (825)	4 432 (1 351)	4 626 (1 410)
8 000 (35 586)	1.12	2.33	3.04	2 249 (685)	3 650 (1 113)	4 209 (1 283)
16 000 (71 172)	1.09	2.18	2.80	2 069 (631)	3 514 (1 071)	4 132 (1 259)
24 000 (106 757)	1.05	2.11	2.53	2 014 (614)	3 349 (1 021)	4 007 (1 221)

TABLE IV.- GYROSCOPIC-MOMENT EFFECTS ON NUMBER OF TURNS REQUIRED FOR RECOVERY

Thrust		$I_{X,eng}\omega_{eng}$		Turns required for right spin			Turns required for left spin		
lb	N	$\frac{\text{slug-ft}^2}{\text{sec}}$	$\frac{\text{kg-m}^2}{\text{sec}}$	N = 1	N = 3	N = 5	N = 1	N = 3	N = 5
Configuration A									
0	0	0	0	2.23	6.49	6.95	2.23	6.49	6.95
8000	35 586	0	0	1.36	4.41	6.34	1.36	4.41	6.34
8000	35 586	16 000	21 693	1.07	5.19	5.36	1.35	3.17	4.99
Configuration B									
0	0	0	0	0.25	1.60	2.37	0.25	1.60	2.37
8000	35 586	0	0	.20	1.24	1.80	.20	1.24	1.80
8000	35 586	16 000	21 693	.17	1.16	2.02	.23	1.12	1.58

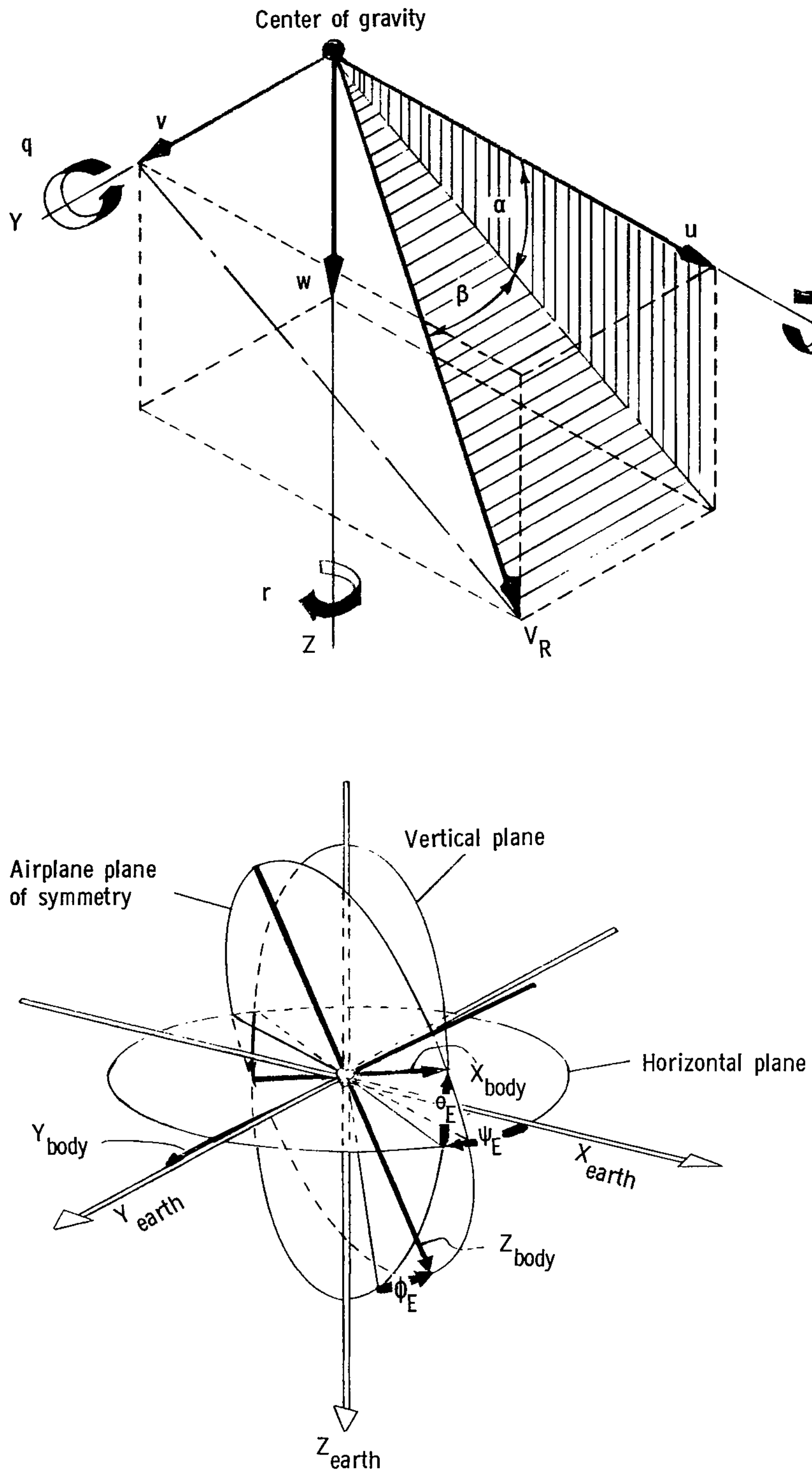


Figure 1.- Body system of axes and related angles. Arrows indicate positive directions.

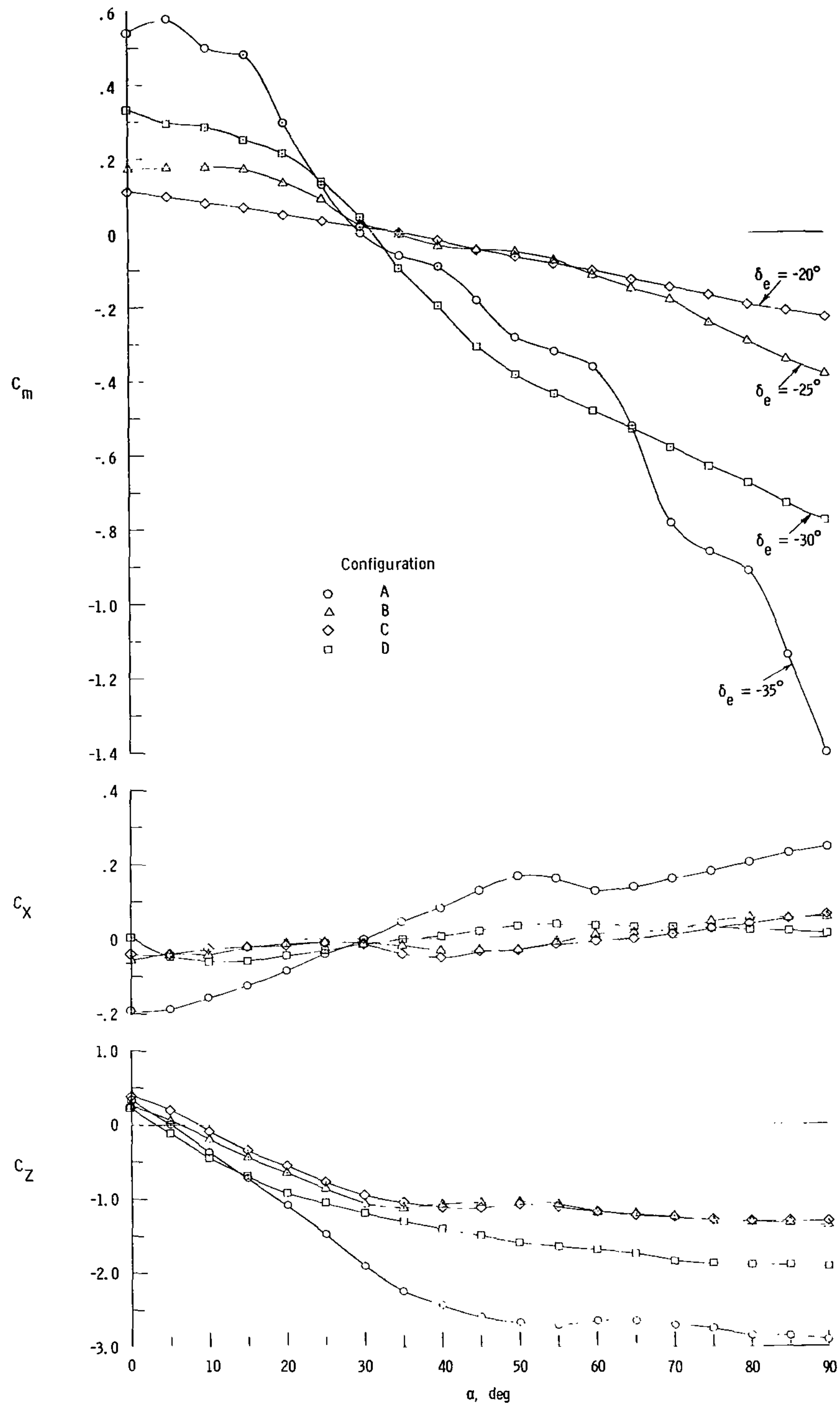


Figure 2.- Variations of pitching-moment, longitudinal-force, and vertical-force coefficients with angle of attack.

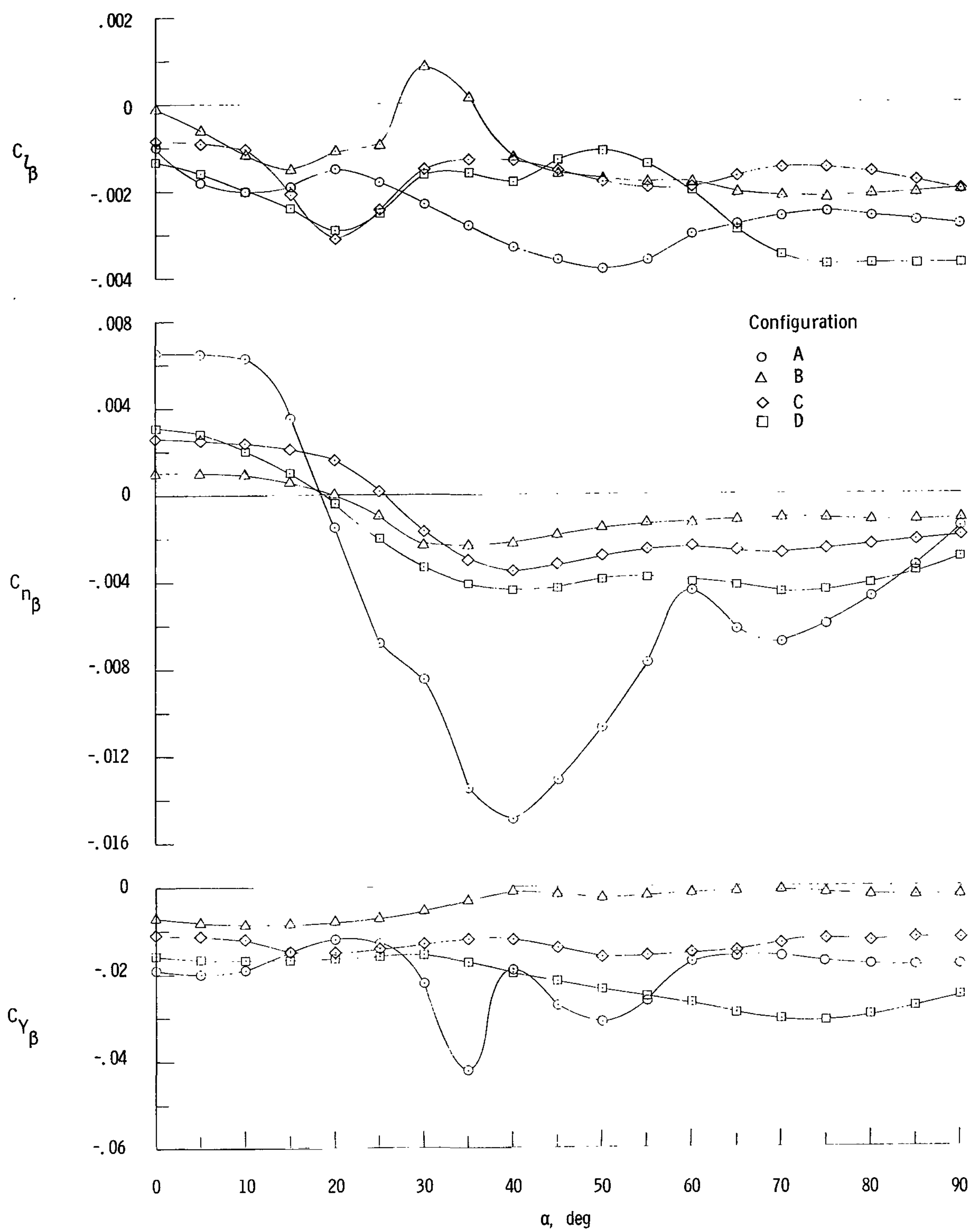


Figure 3.- Variations of sideslip derivatives with angle of attack.

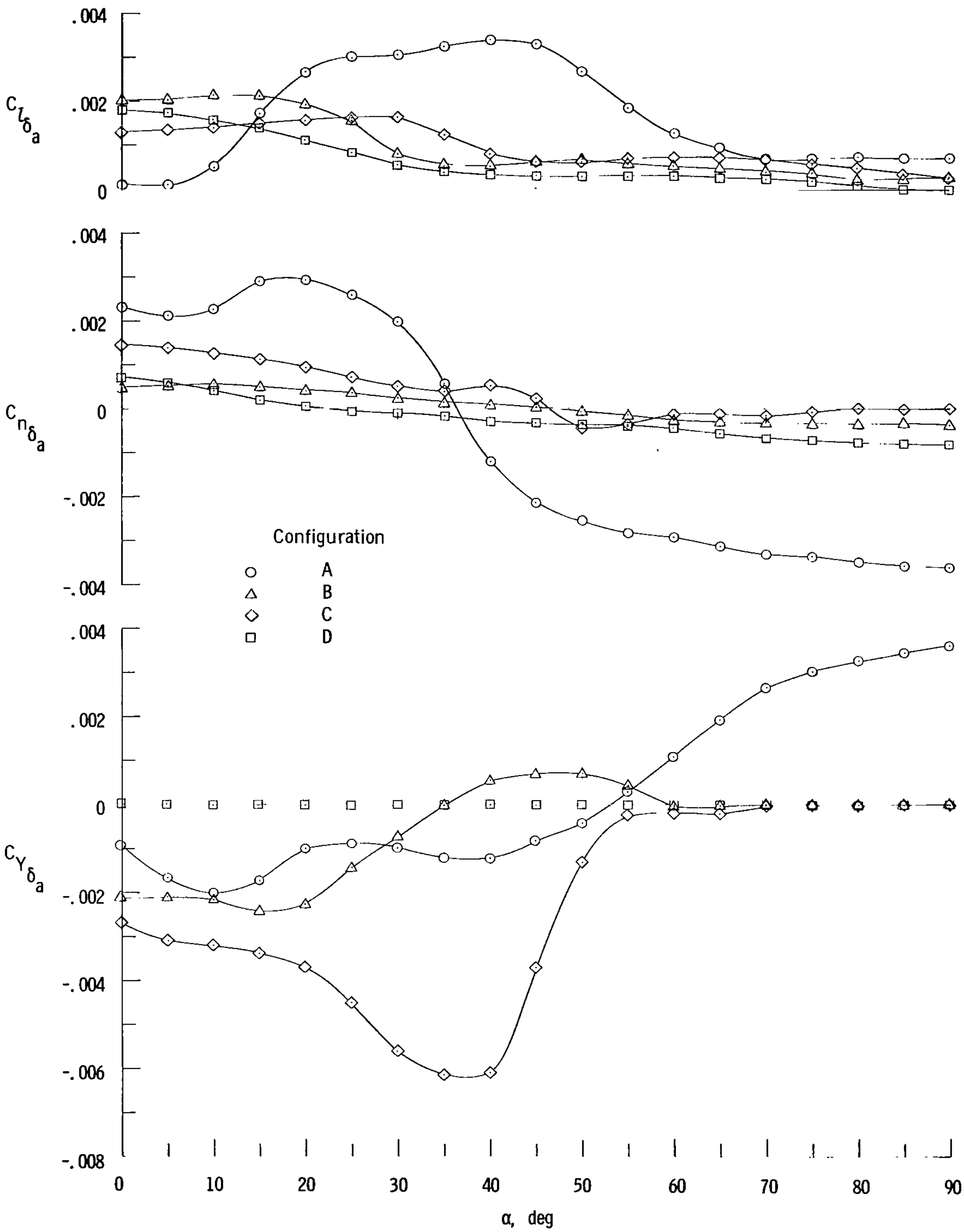


Figure 4.- Variation in increments in lateral-force and moment coefficients with angle of attack resulting from deflecting the ailerons.

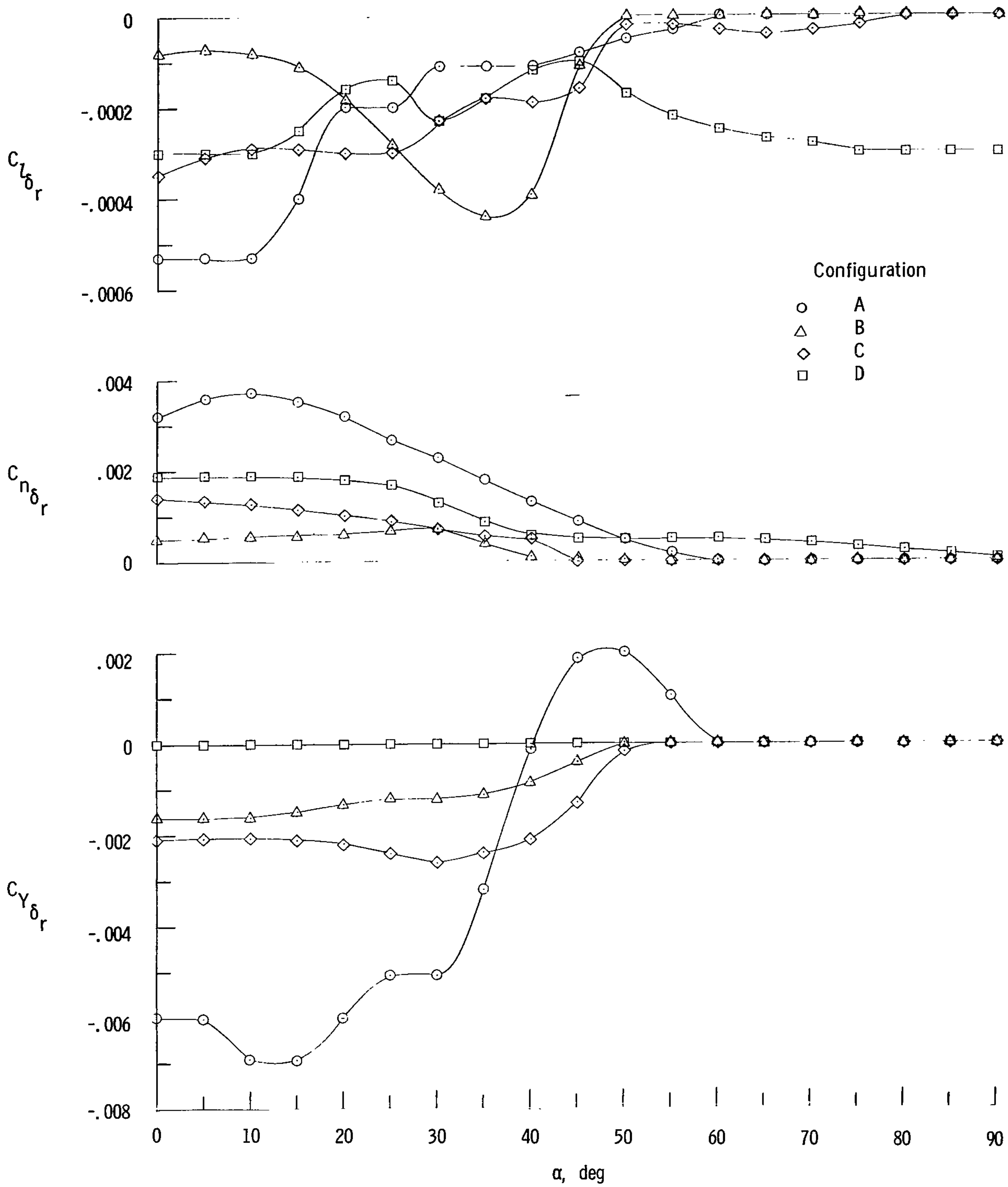


Figure 5.- Variation in increments in the lateral-force and moment coefficients with angle of attack resulting from a rudder deflection.

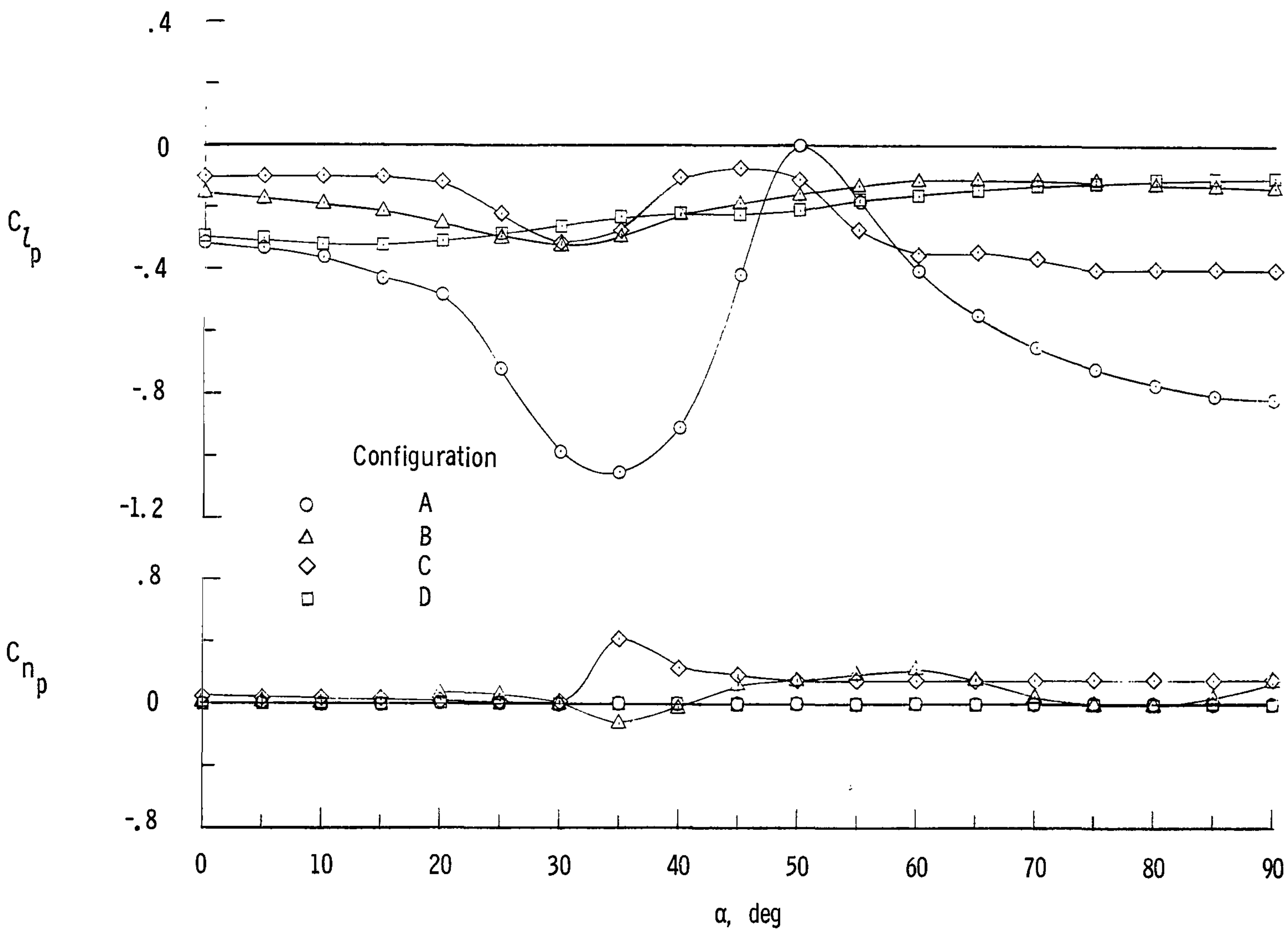


Figure 6.- Variation of out-of-phase rolling derivatives with angle of attack.

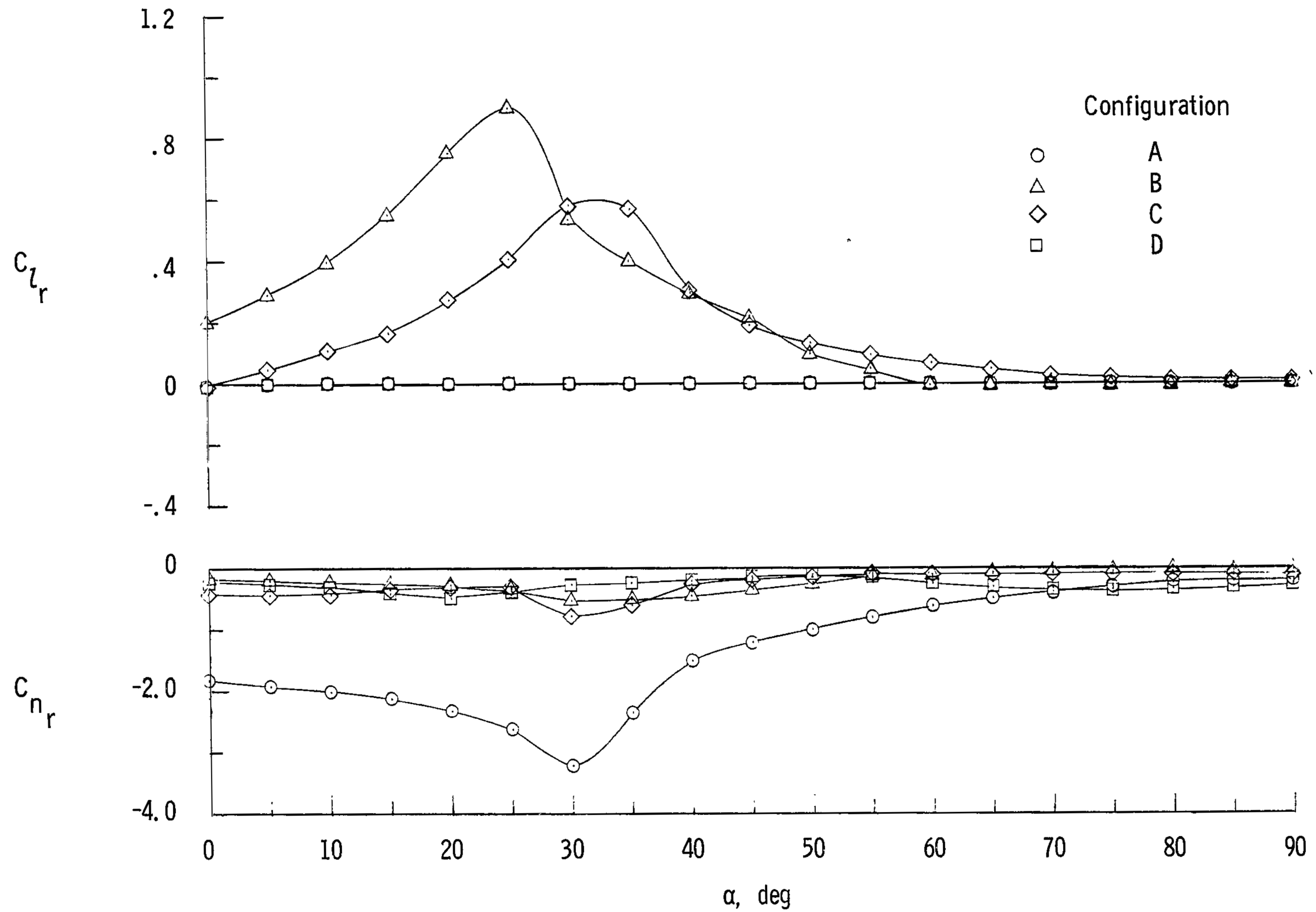


Figure 7.- Variation of out-of-phase yawing derivatives with angle of attack.

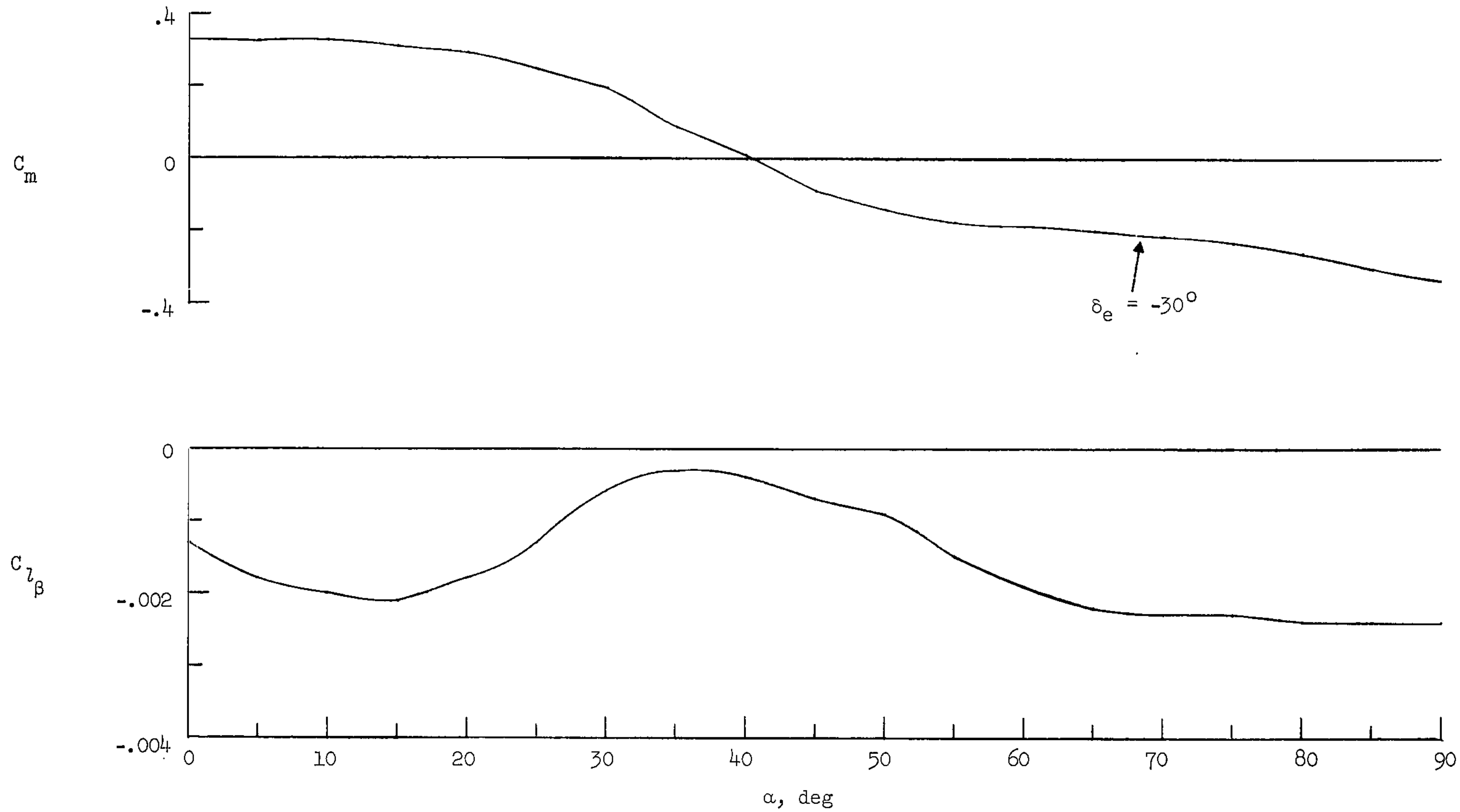
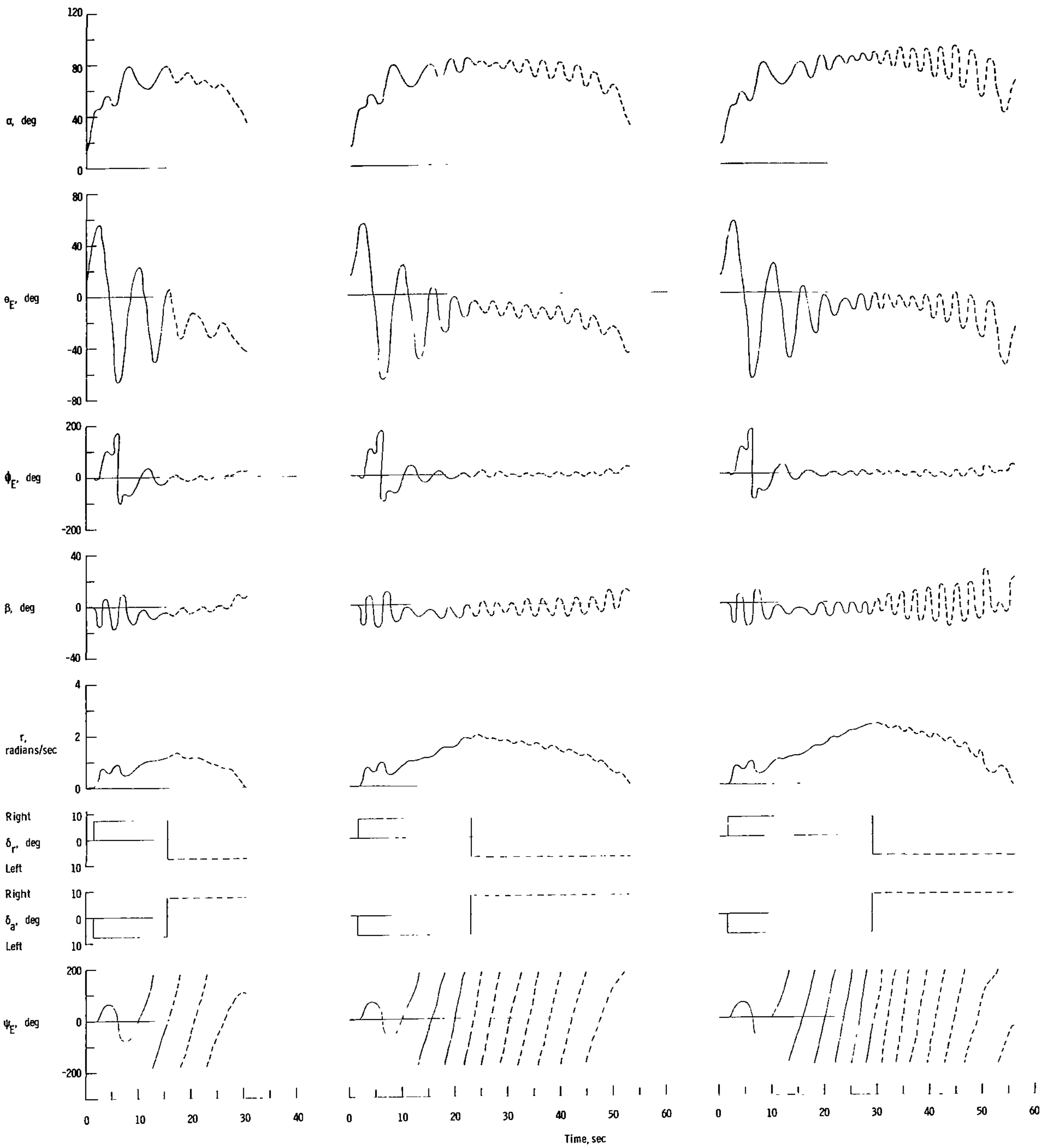
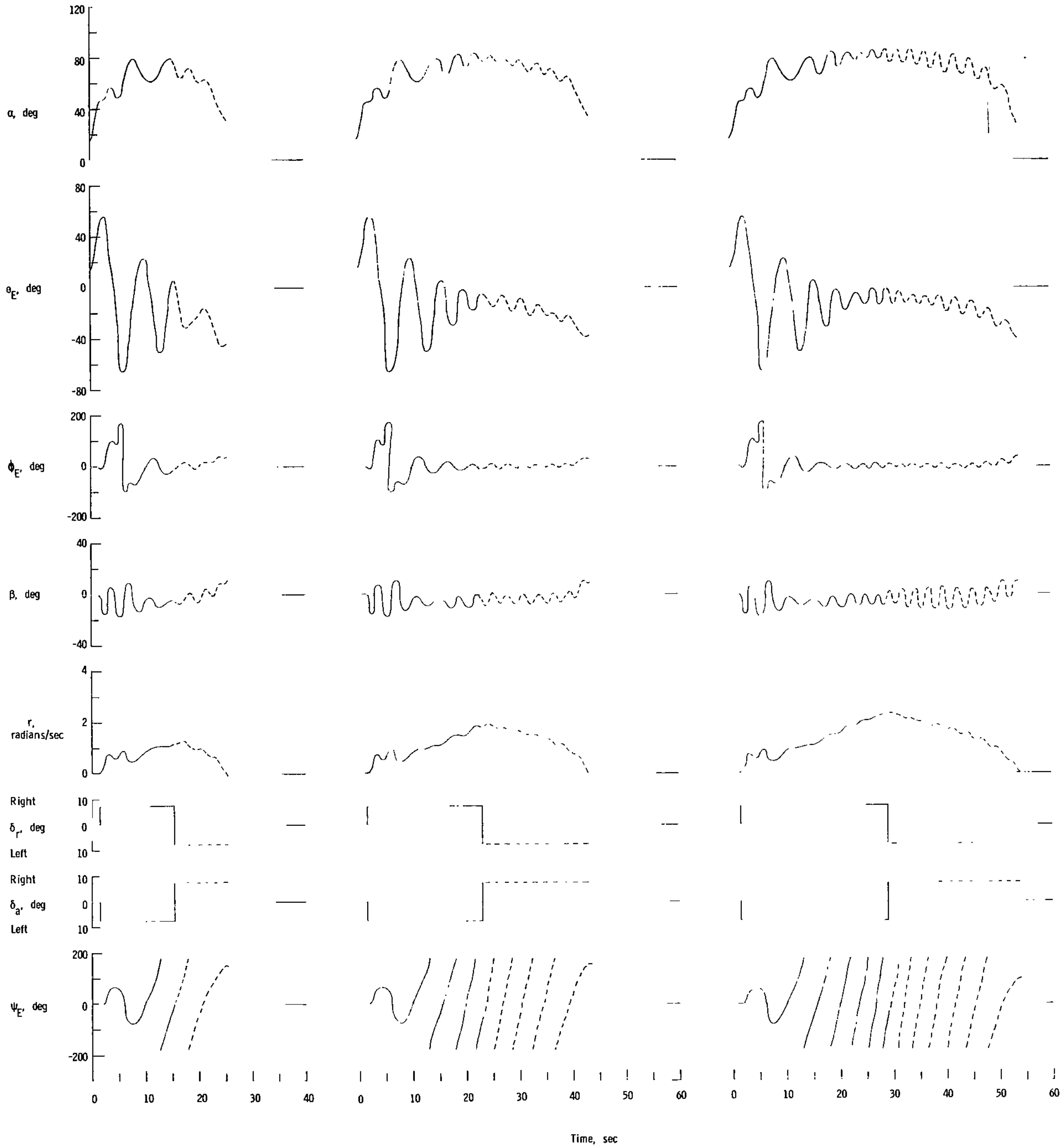


Figure 8.- Arbitrary data used for configuration D.



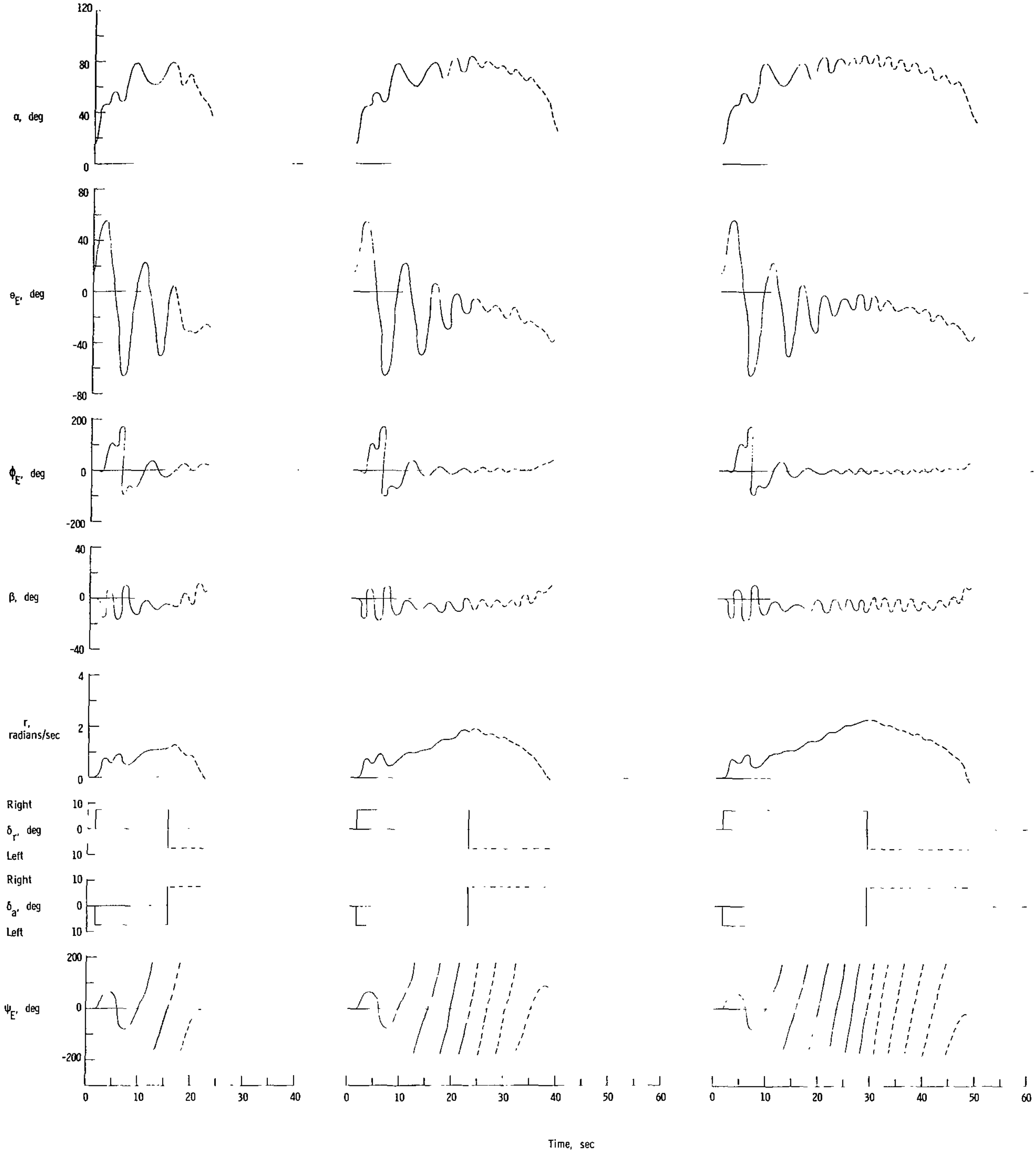
(a) Thrust = 0.

Figure 9.- Calculated spin entries and recovery attempts after 1, 3, and 5 spinning turns for configuration A.



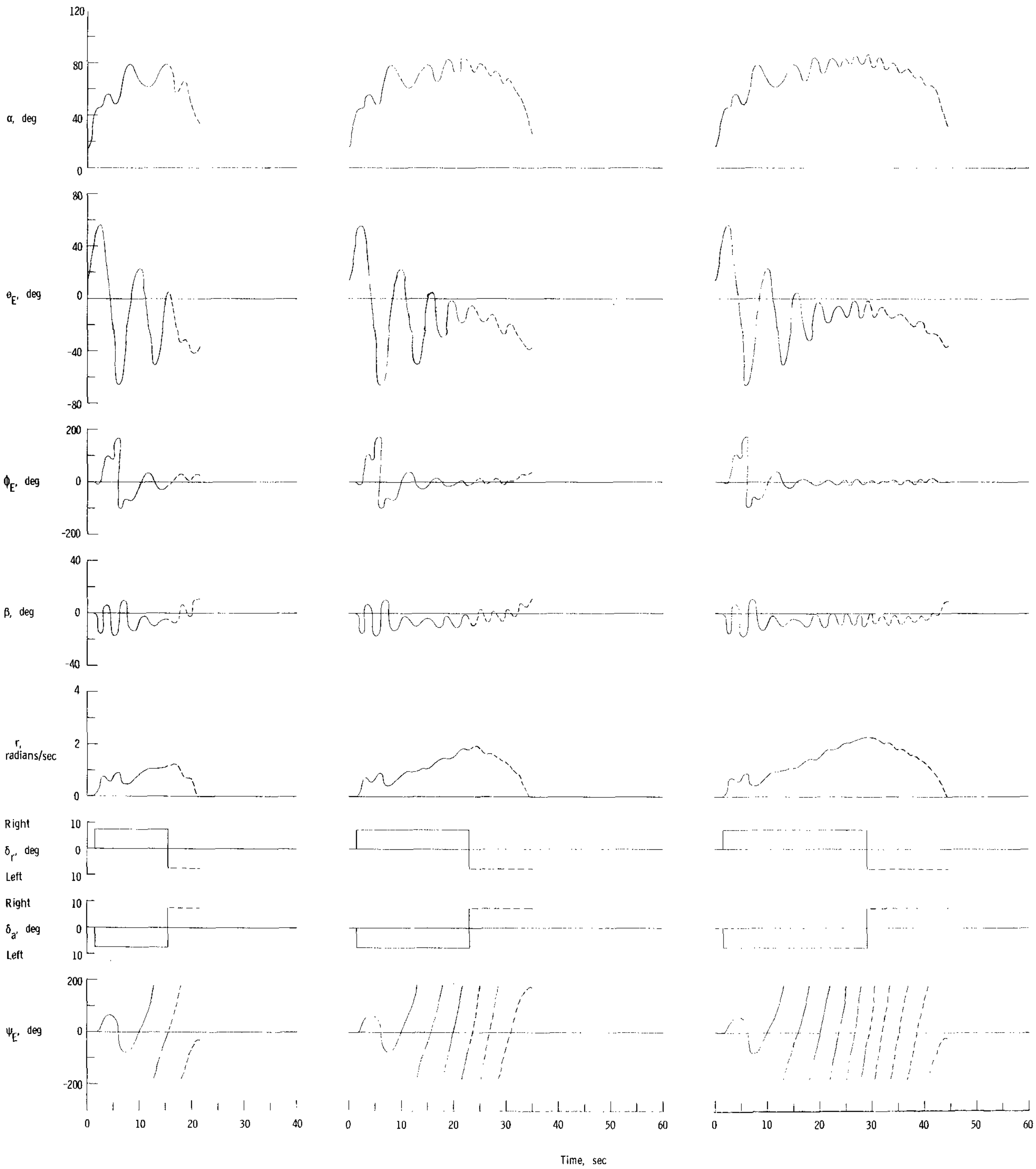
(b) Thrust = 8000 pounds (35 586 N).

Figure 9.- Continued.



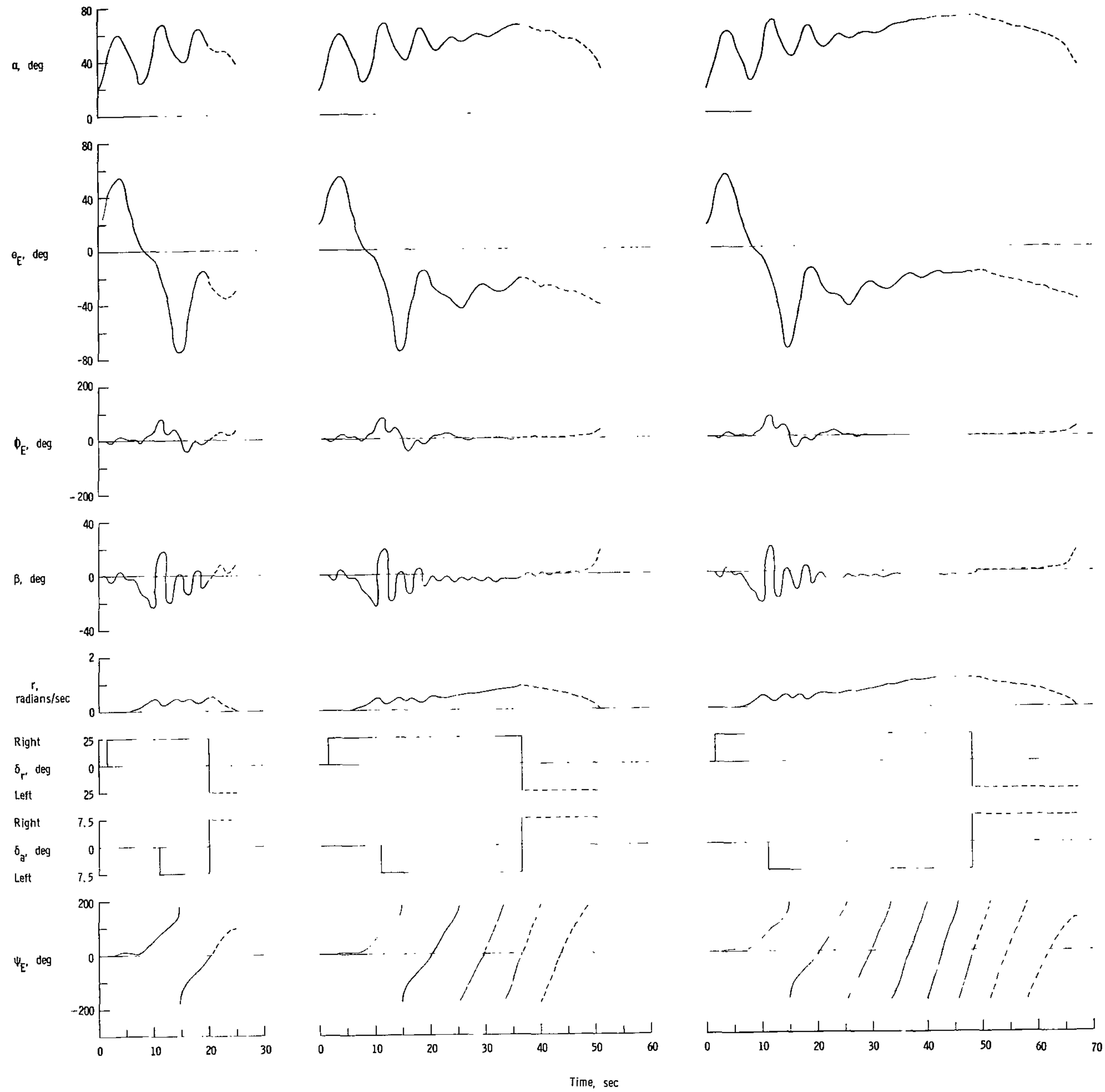
(c) Thrust = 16 000 pounds (71 172 N).

Figure 9.- Continued.



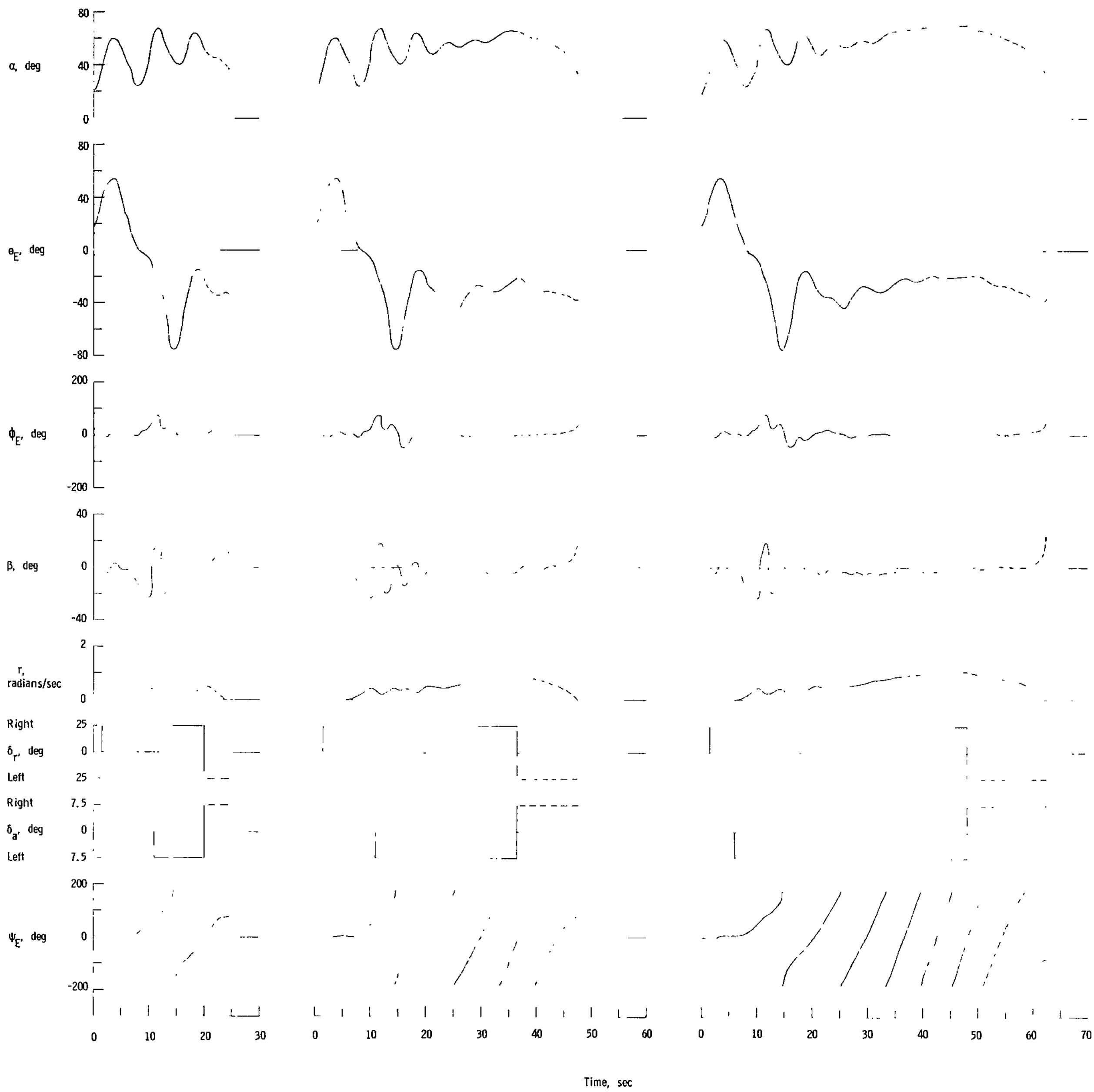
(d) Thrust = 24 000 pounds (106 757 N).

Figure 9.- Concluded.



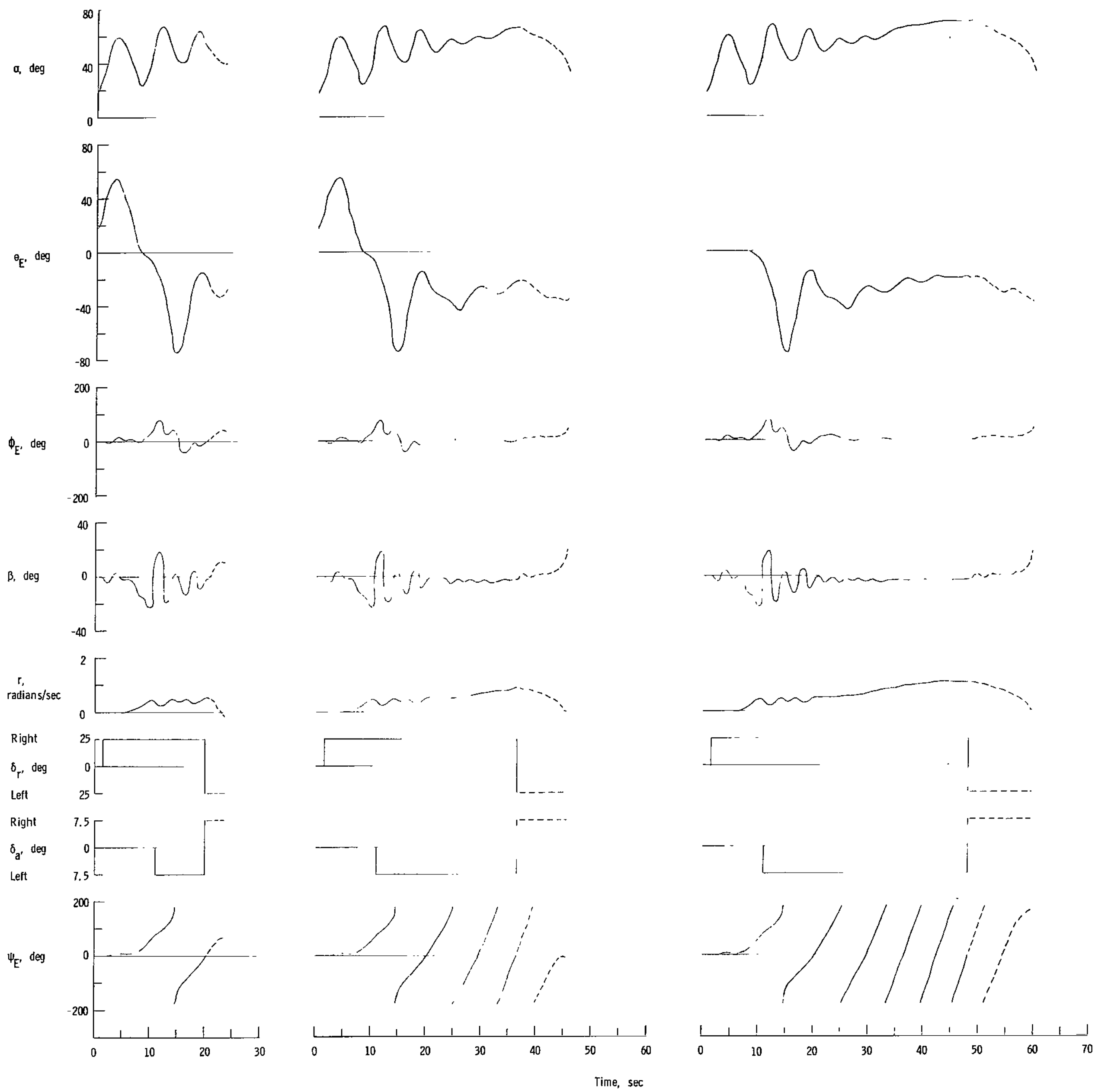
(a) Thrust = 0.

Figure 10.- Calculated spin entries and recovery attempts after 1, 3, and 5 spinning turns for configuration B.



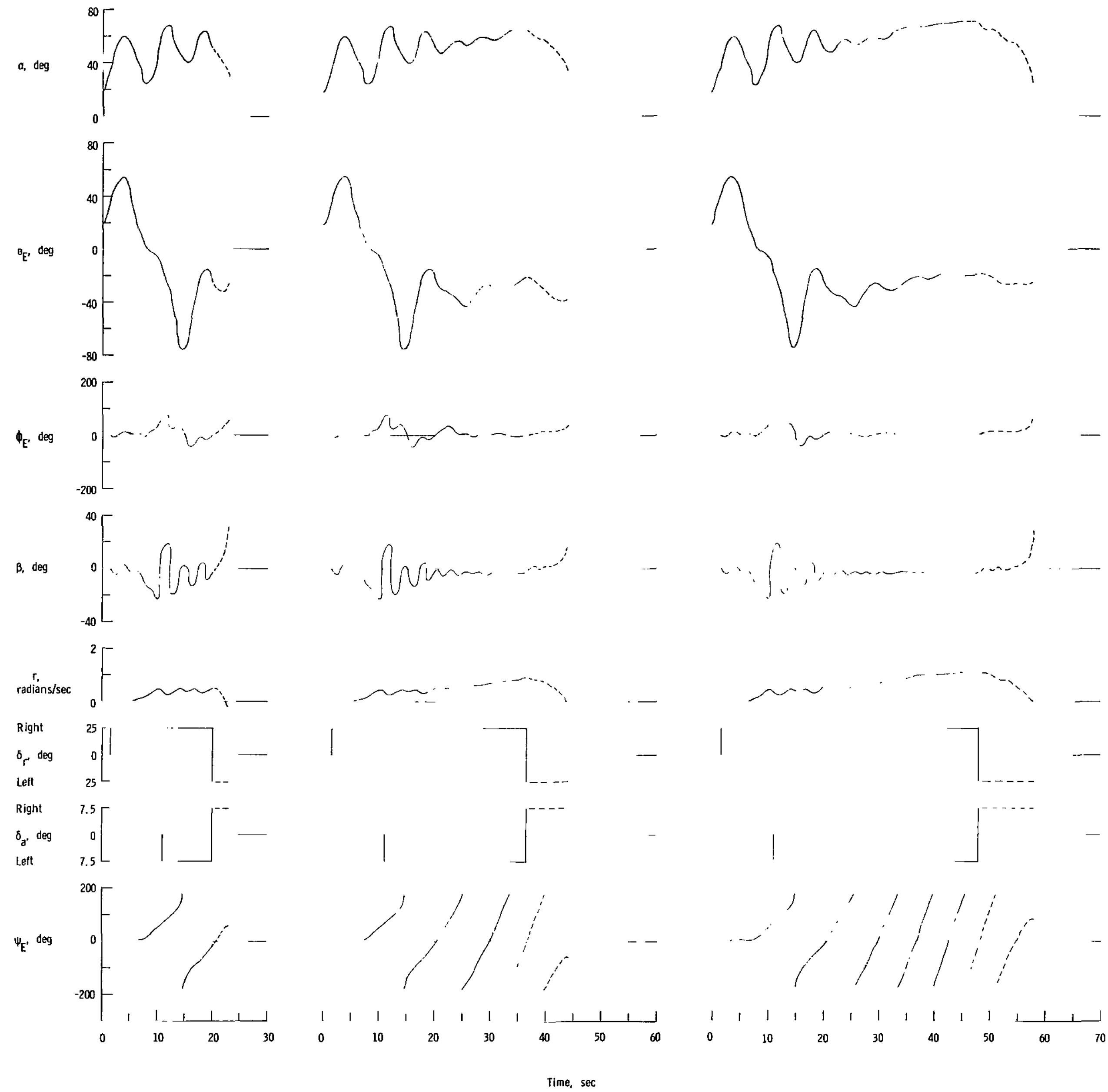
(b) Thrust = 8000 pounds (35 586 N).

Figure 10.- Continued.



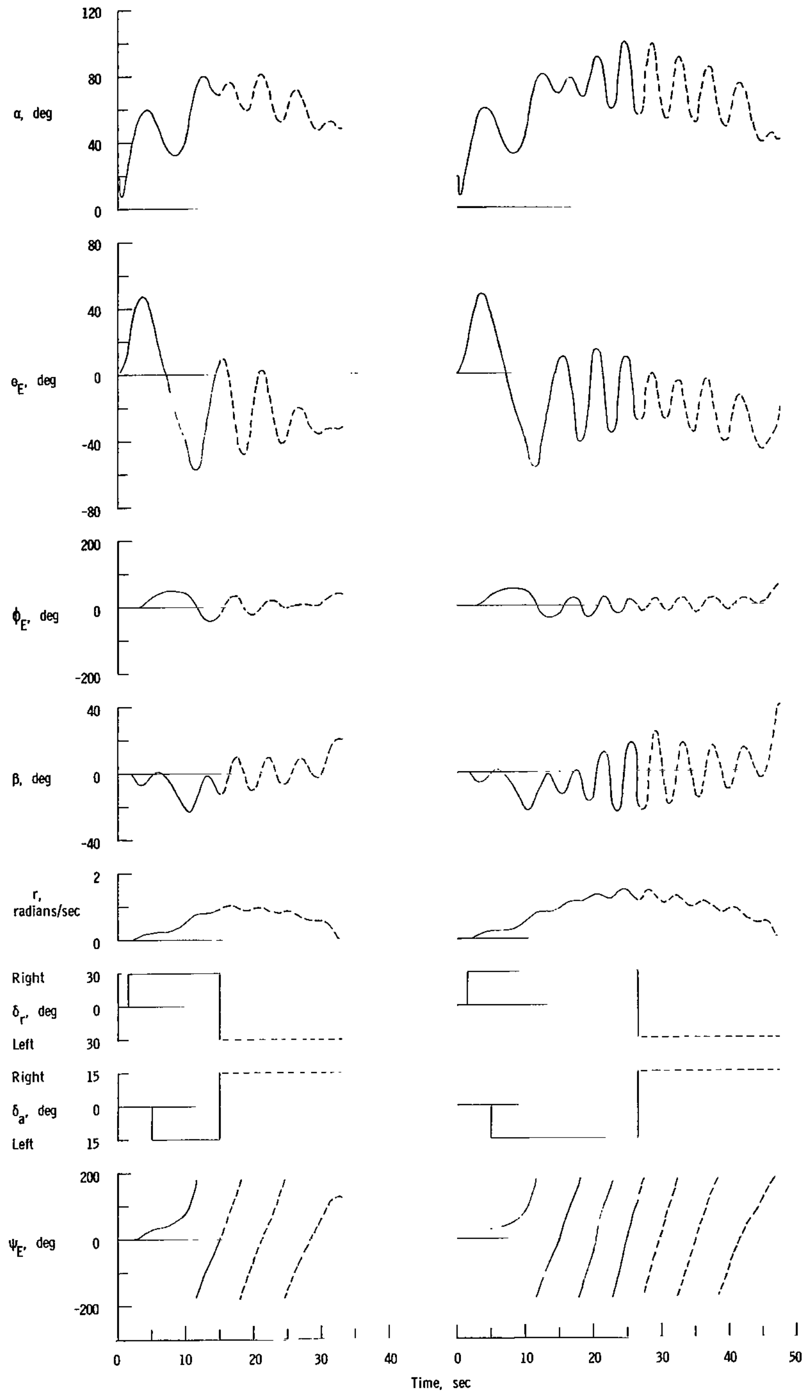
(c) Thrust = 16 000 pounds (71 172 N).

Figure 10.- Continued.



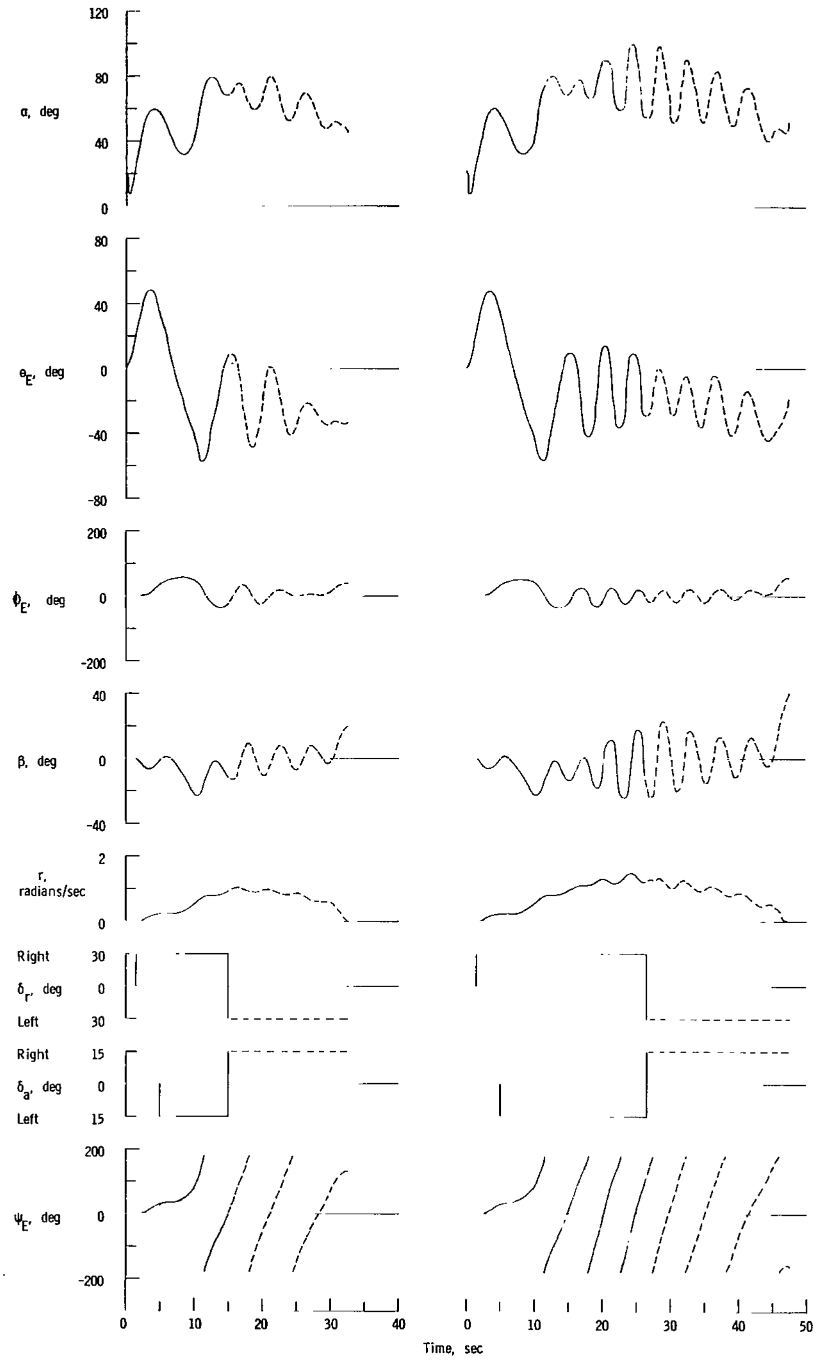
(d) Thrust = 24 000 pounds (106 757 N).

Figure 10.- Concluded.



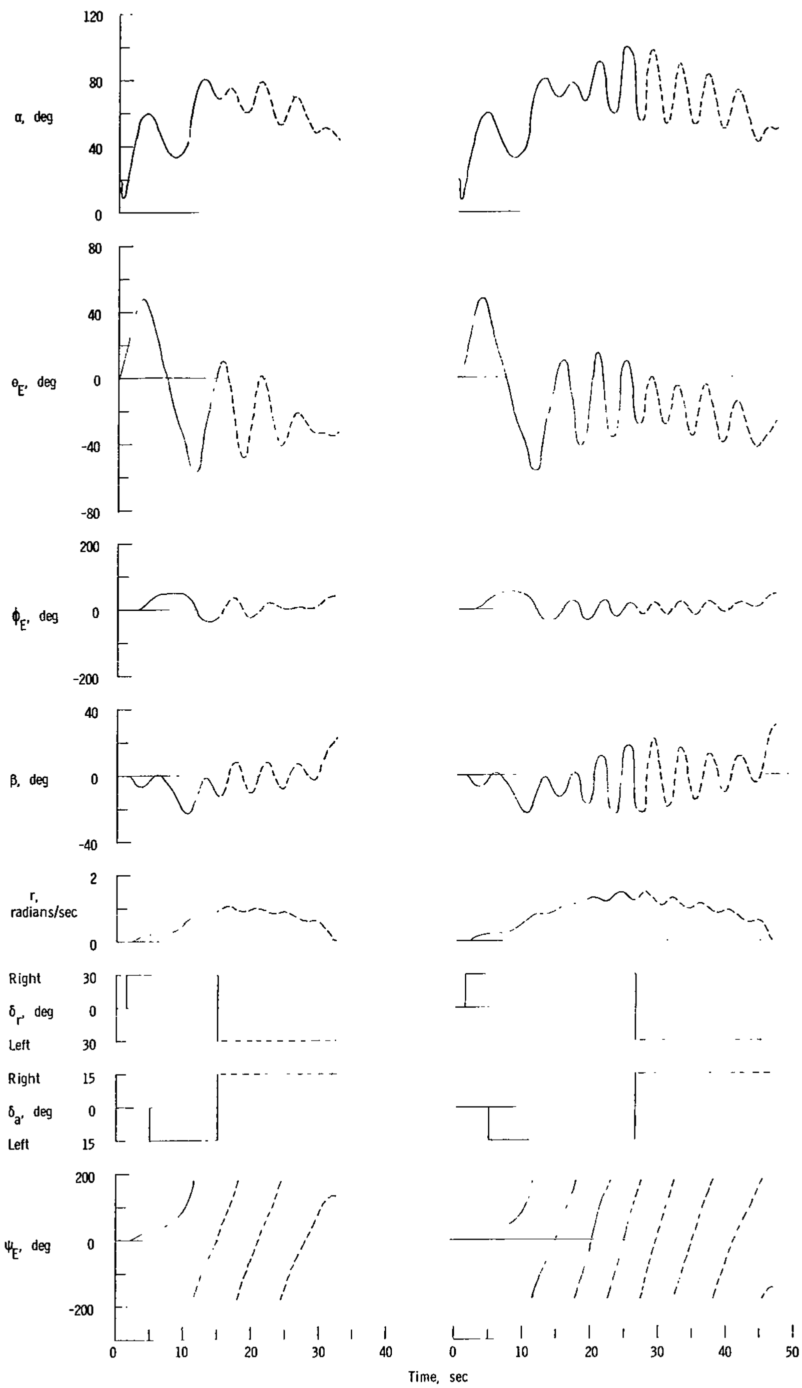
(a) Thrust = 0.

Figure 11.- Calculated spin entries and recovery attempts after 1 and 3 spinning turns for configuration C.



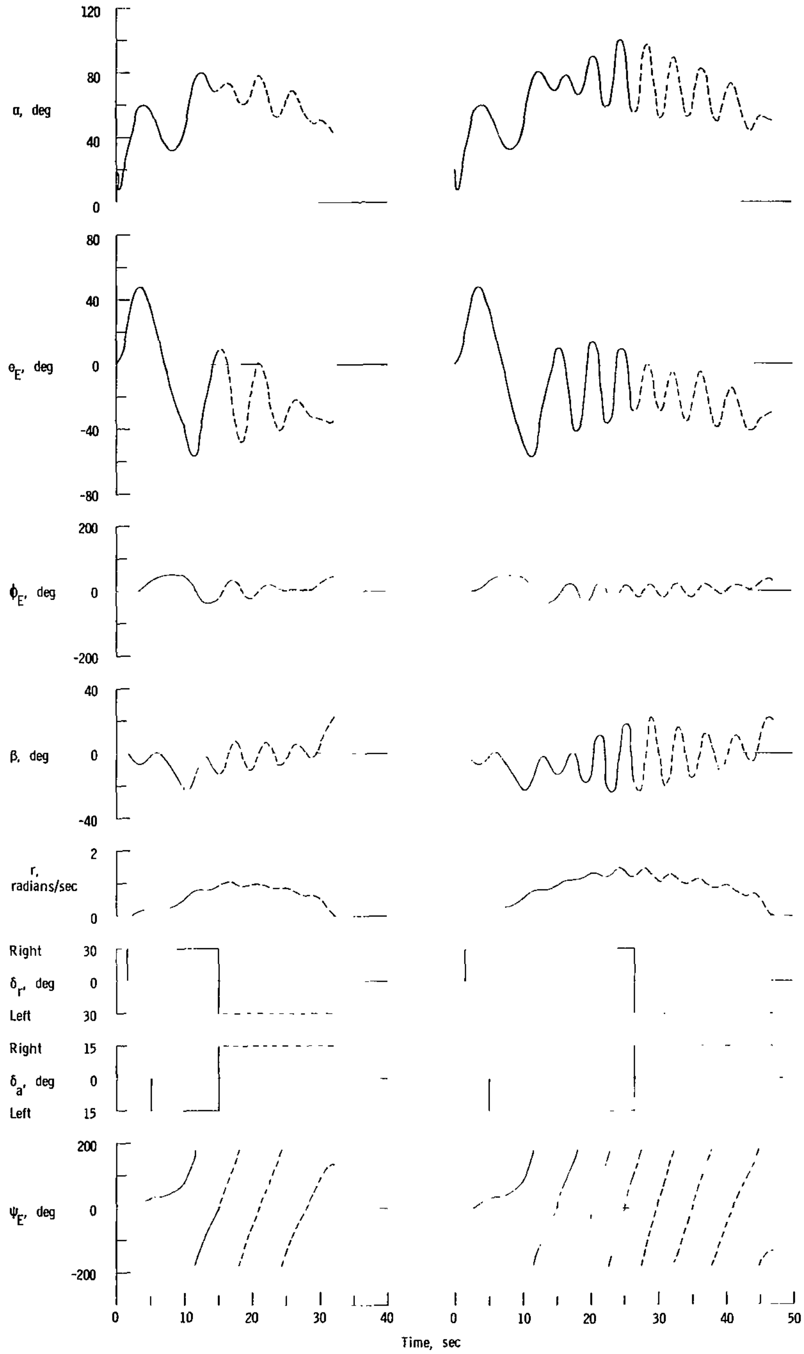
(b) Thrust = 8000 pounds (35 586 N).

Figure 11.- Continued.



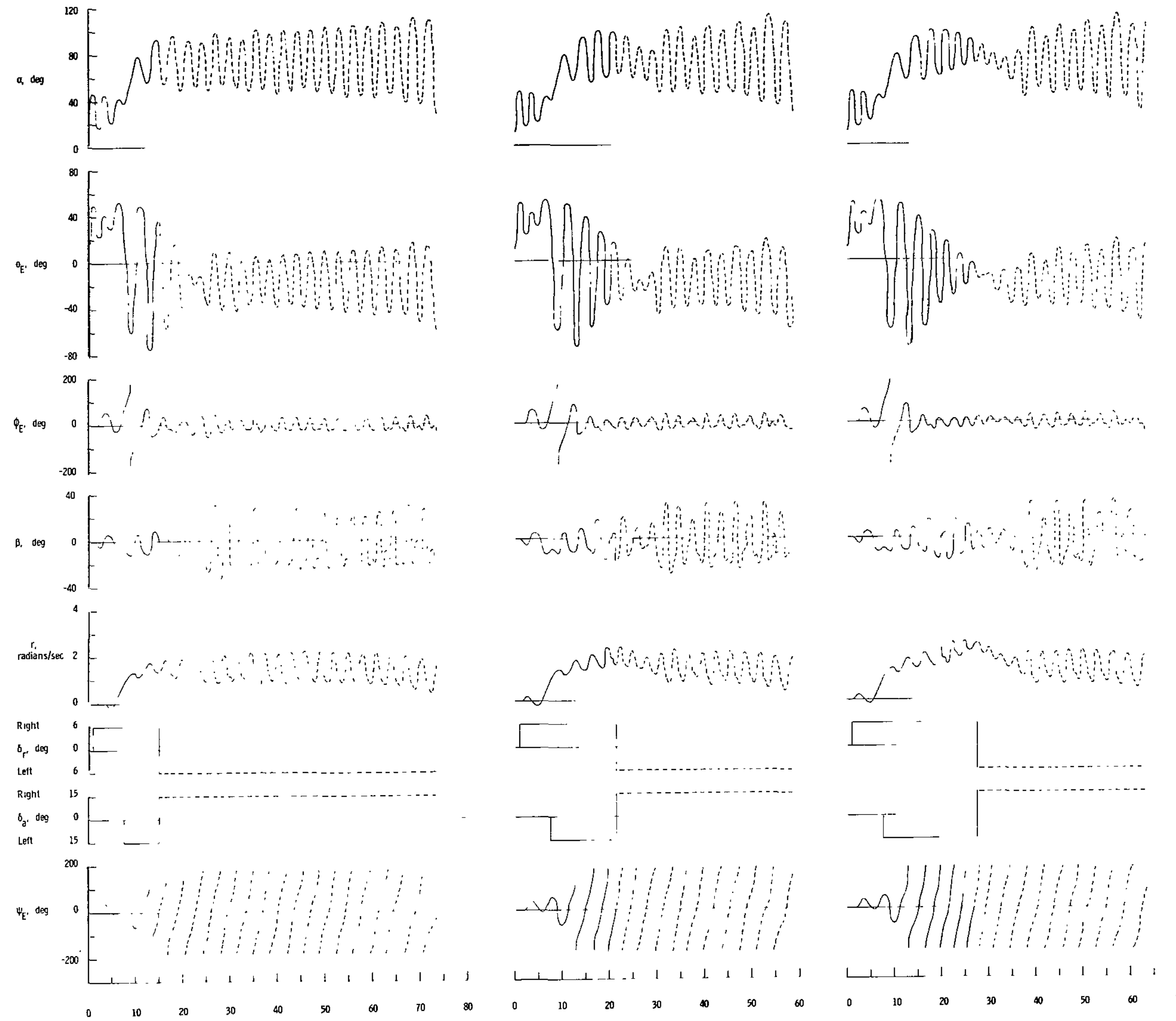
(c) Thrust = 16 000 pounds (71 172 N).

Figure 11.- Continued.



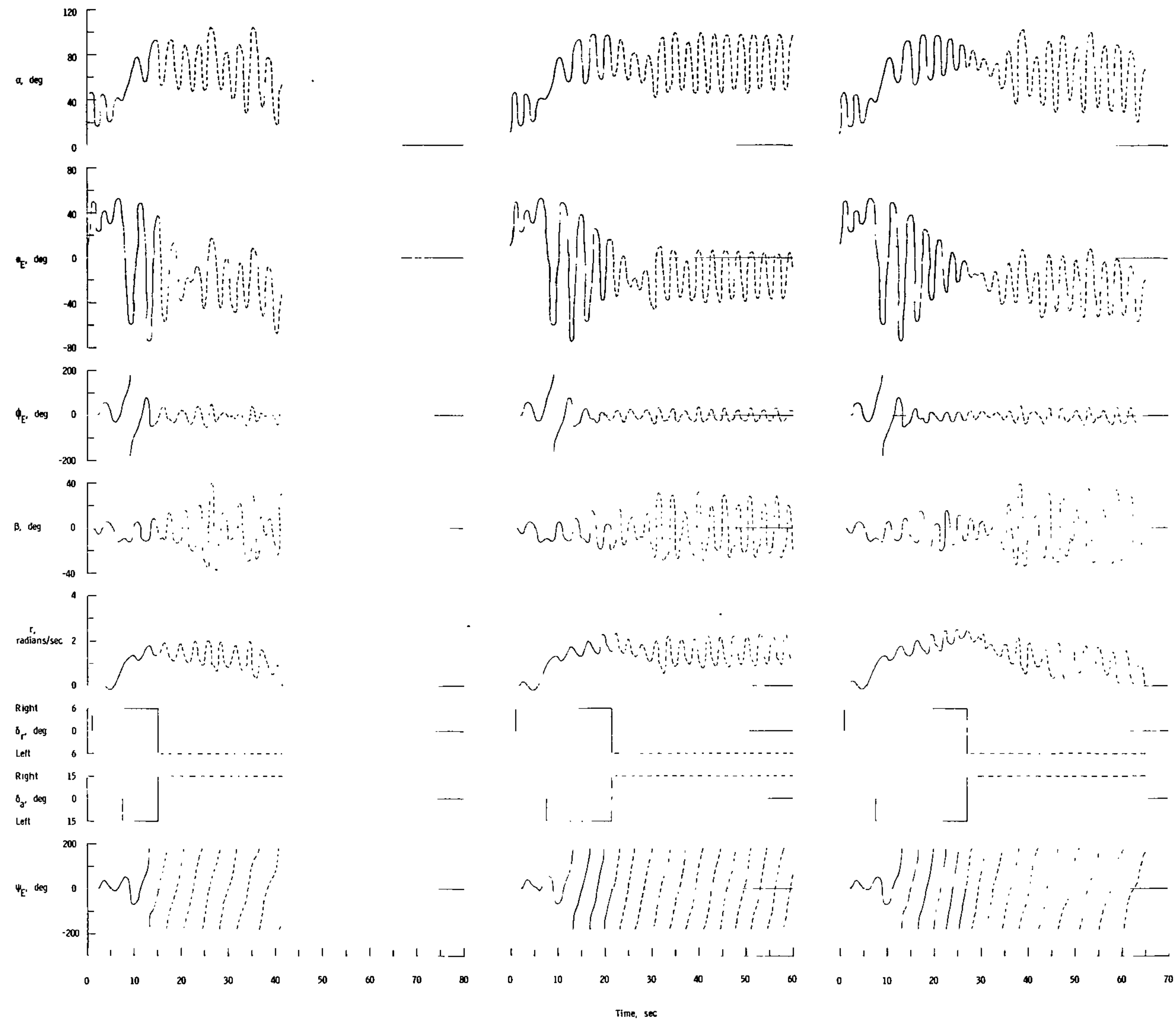
(d) Thrust = 24 000 pounds (106 757 N).

Figure 11.- Concluded.



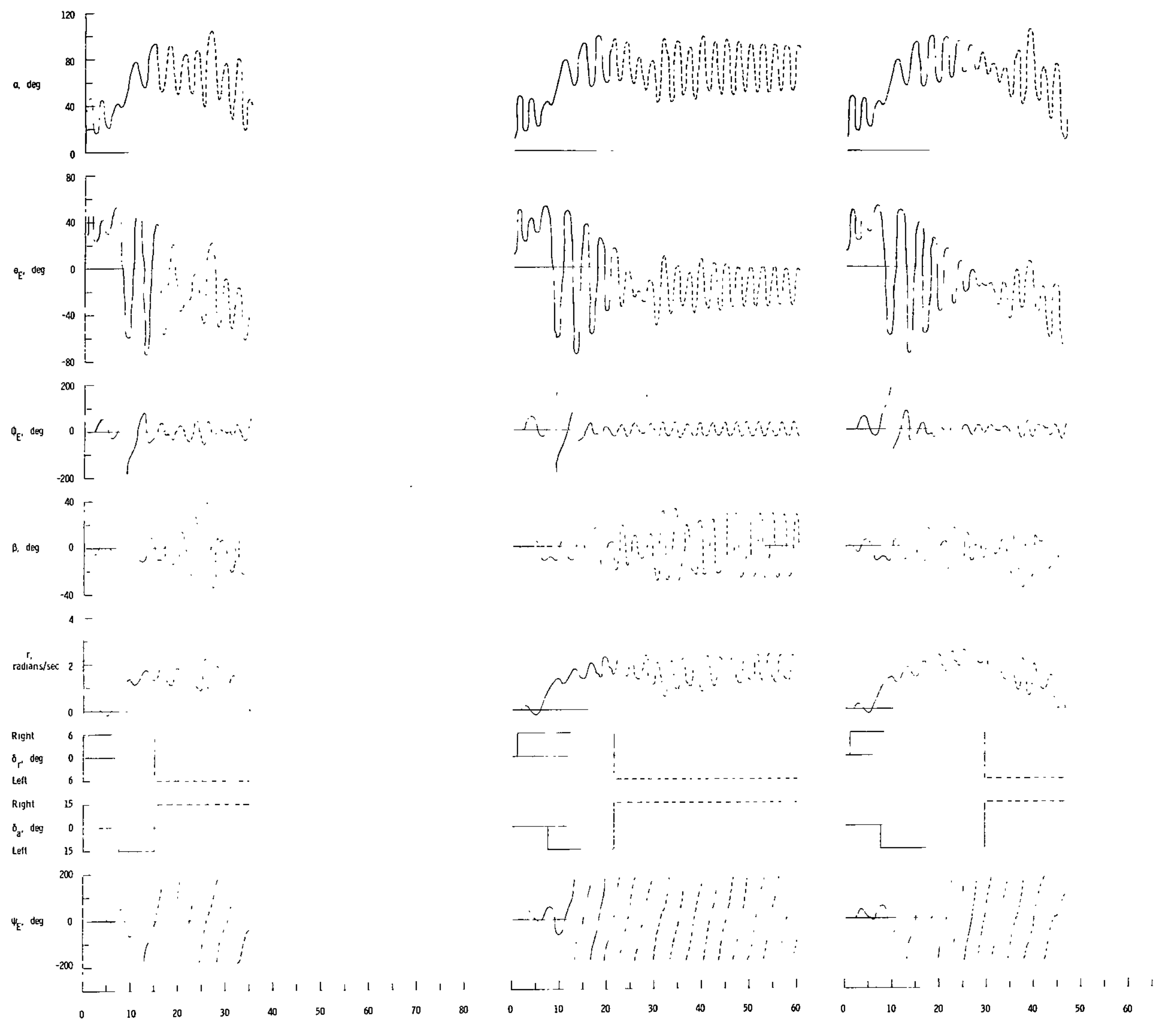
(a) Thrust = 0.

Figure 12.- Calculated spin entries and recovery attempts after 1, 3, and 5 spinning turns for configuration D.



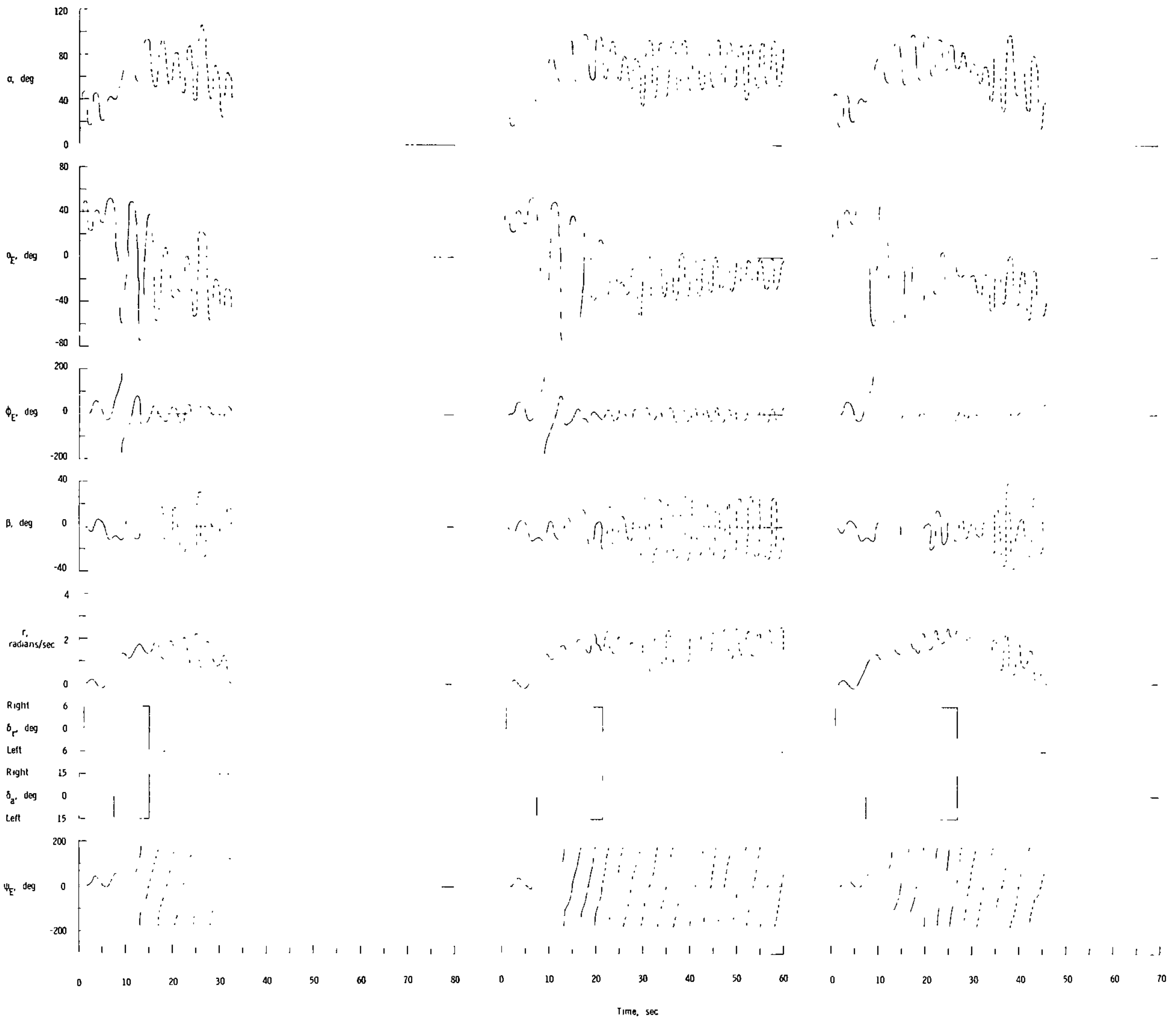
(b) Thrust = 8000 pounds (35 586 N).

Figure 12.- Continued.



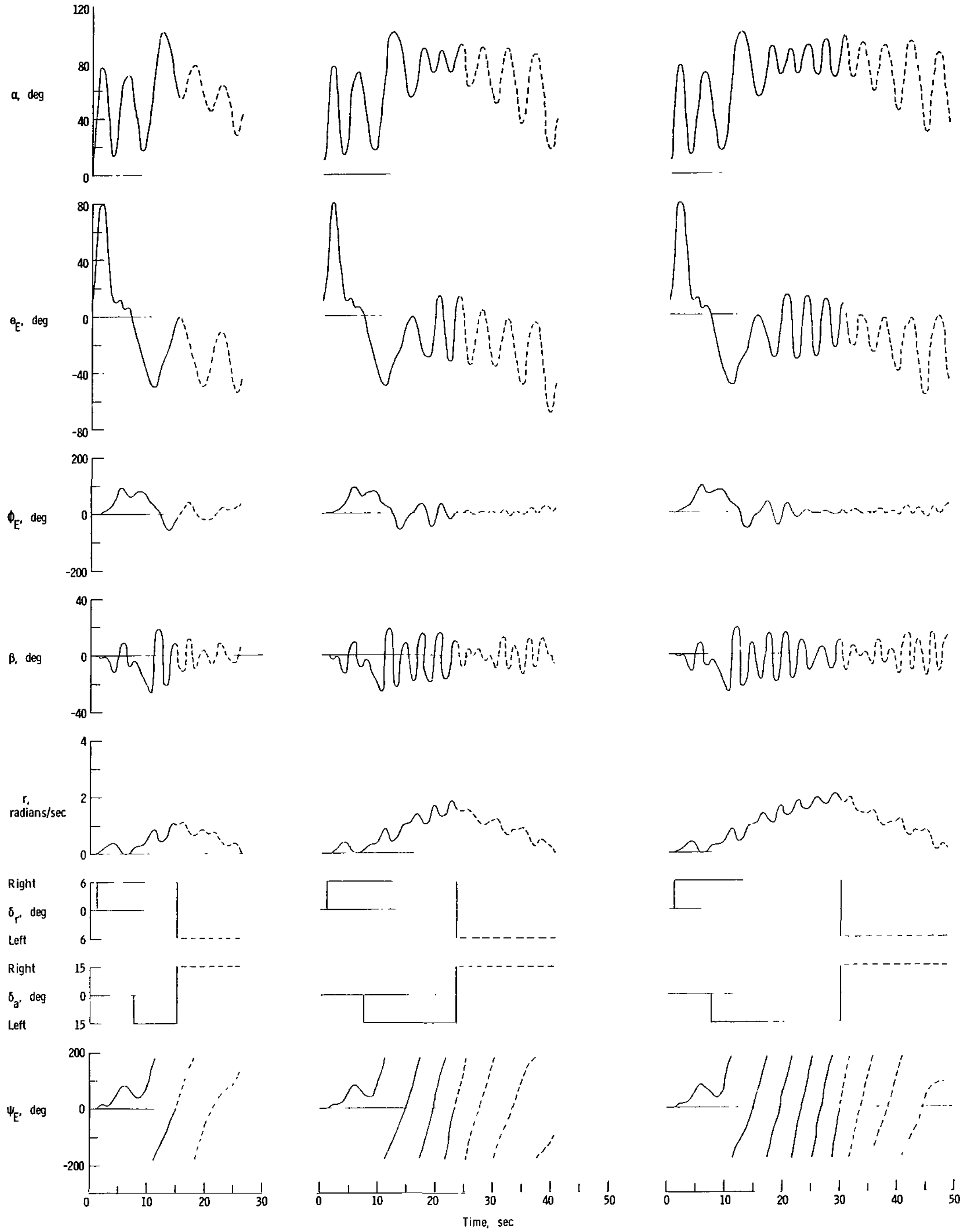
(c) Thrust = 16 000 pounds (71 172 N).

Figure 12.- Continued.



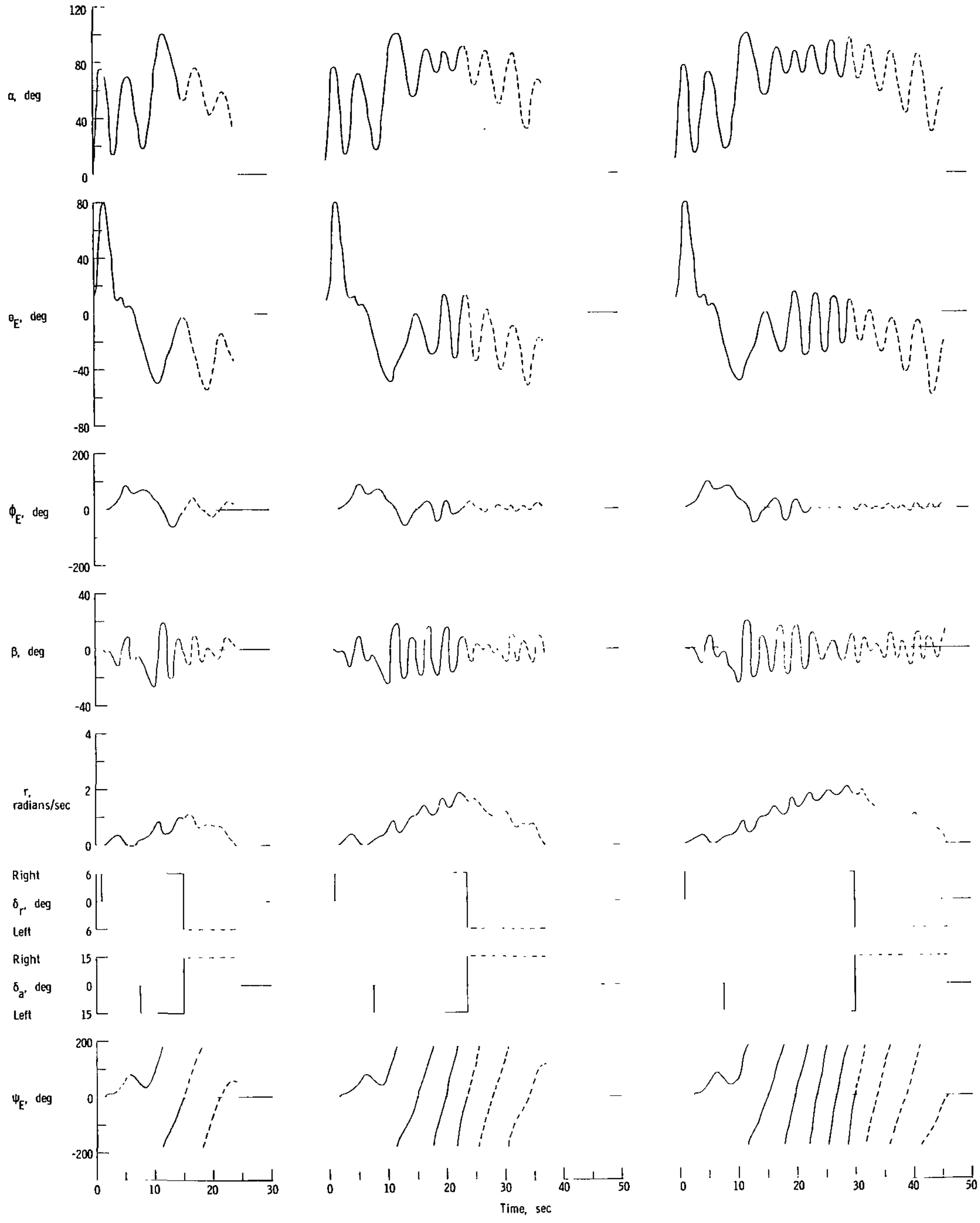
(d) Thrust = 24 000 pounds (106 757 N).

Figure 12.- Concluded.



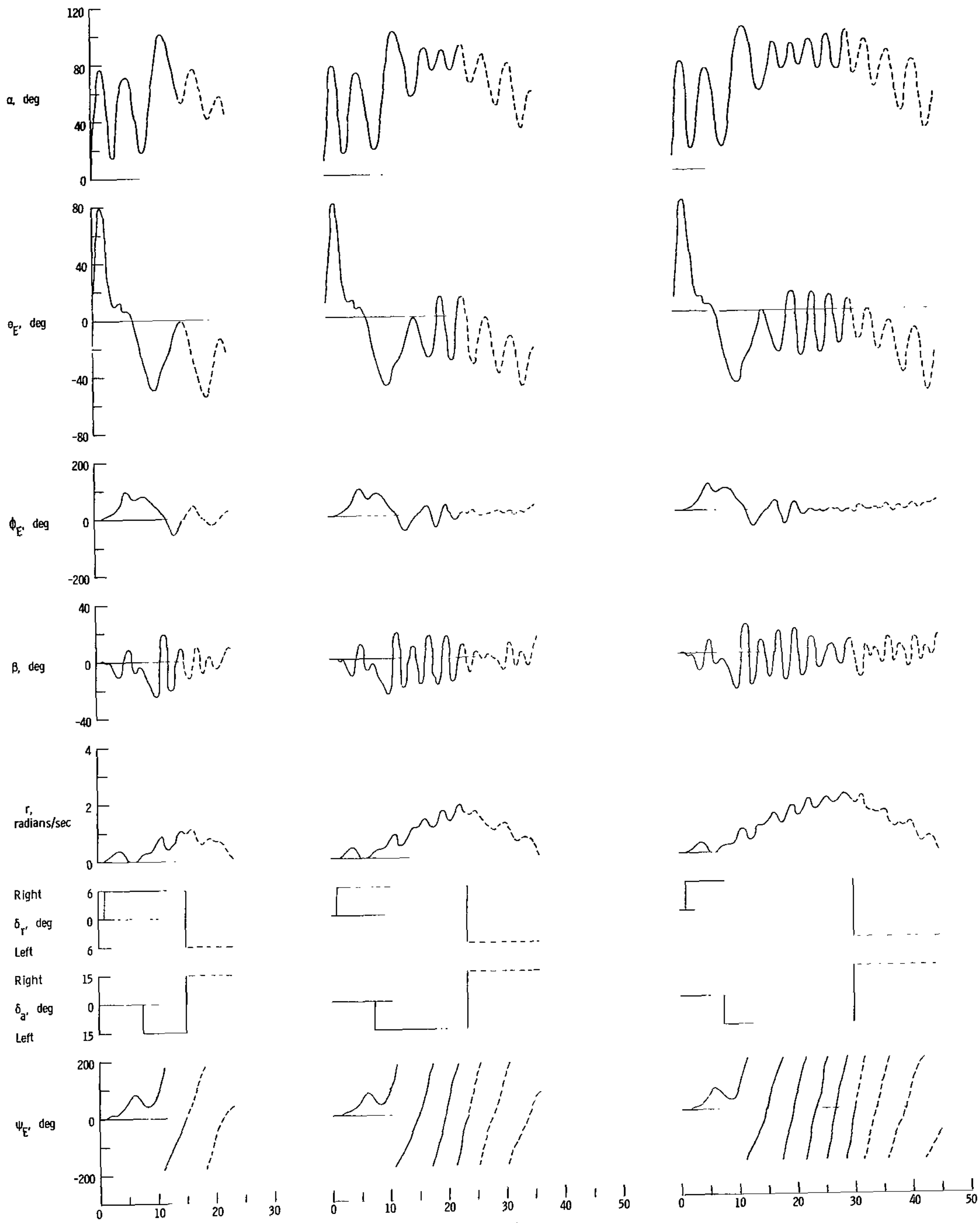
(a) Thrust = 0.

Figure 13.- Calculated spin entries and recovery attempts using arbitrary data presented as figure 8 after 1, 3, and 5 spinning turns for configuration D.



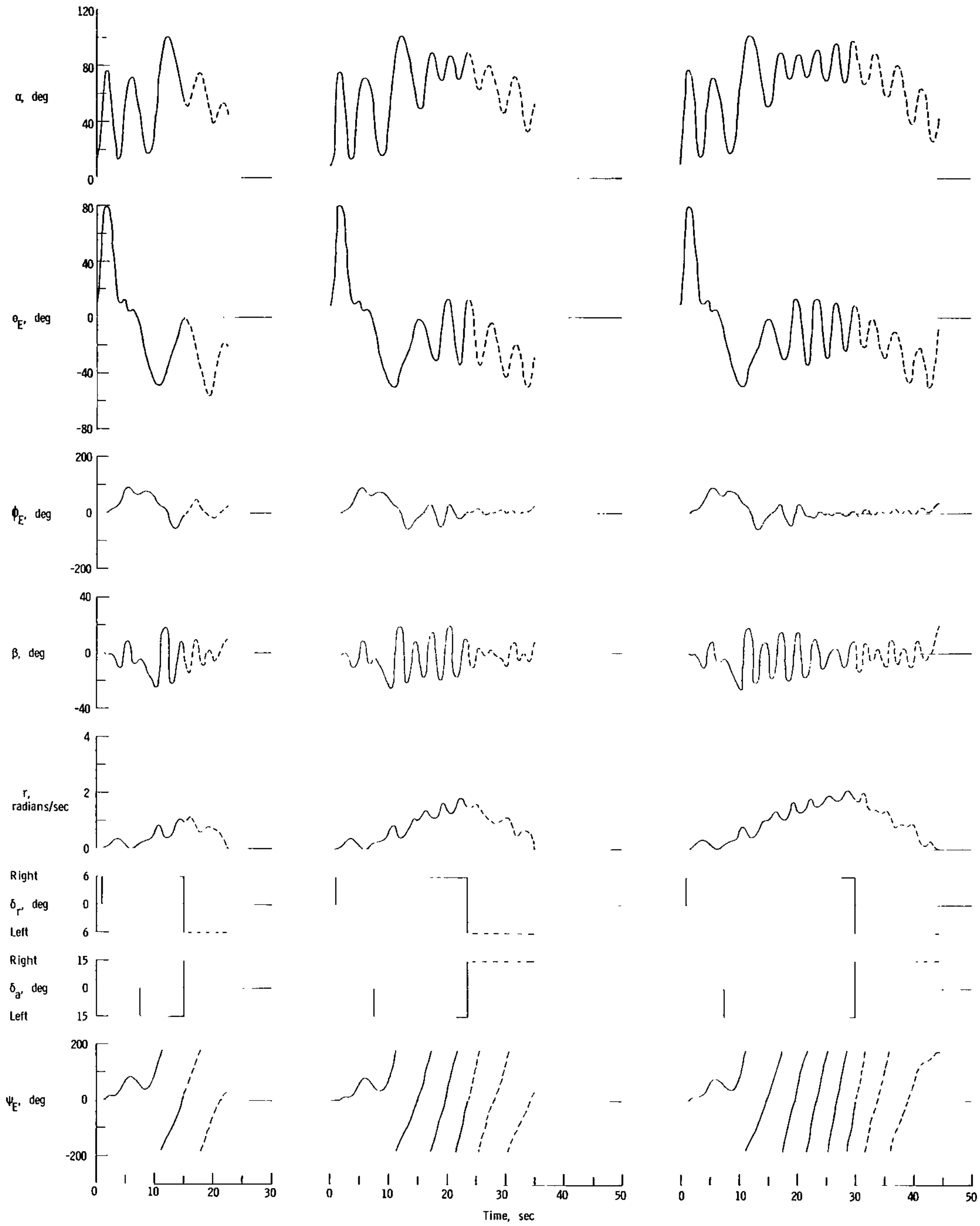
(b) Thrust = 8000 pounds (35 586 N).

Figure 13.- Continued.



(c) Thrust = 16 000 pounds (71 172 N).

Figure 13.- Continued.



(d) Thrust = 24 000 pounds (106 757 N).

Figure 13.- Concluded.

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