

**NASA TECHNICAL
MEMORANDUM**

NASA TM X-73671

NASA TM X-73671

(NASA-TM-X-73671) EXPLORATORY INVESTIGATION
OF THE INCIPIENT SPINNING CHARACTERISTICS OF
A TYPICAL LIGHT GENERAL AVIATION AIRPLANE
(NASA) 43 p HC A03/MF A01 CSCL 01C

N77-26153

G3/08 31871
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EXPLORATORY INVESTIGATION OF THE INCIPIENT
SPINNING CHARACTERISTICS OF A TYPICAL
LIGHT GENERAL AVIATION AIRPLANE

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FOREWORD

This flight research program was jointly sponsored by the Department of Aeronautical and Astronautical Engineering and the Department of Aviation at Ohio State University, Columbus, Ohio. The author completed it in partial fulfillment of the requirements for a Master of Science Degree in Aeronautical and Astronautical Engineering.

The author wishes to express his sincere appreciation to the following persons for the contributions and support received from them: to Professor Gerald M. Gregorek, research advisor, Department of Aeronautical and Astronautical Engineering, for his guidance and inspiration; to Professor G. Stacy Weislogel, Department of Aviation, for supervising the operation of the research airplane and coordinating logistical support; to Mr. Ronald W. Ventola, Electronics Technician, Ohio State University, for configuring the analog computer; and to Mr. William A. Wildenhein, Aerospace Electronics Technician, NASA Lewis Research Center, for fabricating the Rate Measuring System.

EXPLORATORY INVESTIGATION OF THE INCIPIENT SPINNING

CHARACTERISTICS OF A TYPICAL LIGHT

GENERAL AVIATION AIRPLANE

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INTRODUCTION

The National Aeronautics and Space Administration and its predecessor, the National Advisory Committee for Aeronautics has conducted numerous stall/spin research programs in an effort to improve design criteria and enhance operational safety. The majority of these programs were developed in response to Defense Department priorities and consequently stall/spin technology as it pertains to general aviation airplanes today is still relatively sparse.

Recognizing this fact, the NASA Langley Research Center recently proposed a comprehensive program to develop existing stall/spin technology specifically for low speed general aviation airplanes.

Consistent with this effort and to supplement a much needed data base, this flight test program was conceived. It is exploratory in nature and seeks to examine flight characteristics in an area where the least amount of information exists.

After searching the literature, it appeared that the incipient spinning characteristics of general aviation airplanes were the least documented. Therefore, with this fact in mind and the necessity to remain within certain budgetary and time constraints, the following program objectives were established:

1. Measure angular rates in pitch, yaw, and roll through the stall during the incipient spin and throughout the recovery. Simultaneously, record control positions, angle of attack, and angle of sideslip.
2. Determine the characteristic incipient spinning motion from a given set of entry conditions.
3. Vary the sequence of recovery controls at two distinct points during the incipient spin and examine the effect on recovery characteristics.
4. Describe aerodynamic phenomena associated with flow over the aft portion of the fuselage, vertical stabilizer, and rudder.

RESEARCH AIRPLANE

The research airplane used in this program was a light, single engine, general aviation airplane with a fixed tricycle landing gear. The airplane was powered by a 180-horsepower engine, turning a fixed pitch propeller.

The basic airframe was modified with an Aerodynamic Fairings Installation consisting of nose strakes laterally fixed to either side of the engine compartment, anti-spin fillets secured to the leading edge of the stabilator, and a ventral fin attached to the underside of the fuselage directly below the vertical stabilizer and rudder. This Installation is an optional modification supplied by the airplane's manufacturer, and permits intentional spins within specified weight and balance limitations. Figure 1 shows the research airplane configured for flight. The small appendage on the right wingtip is a camera lens and mirror fairing that will be discussed later in this report.

Figure 2 shows the weight and balance status of the airplane before, during, and after each spin flight. Certificated weight and balance limitations for the utility and aerobatic category were observed for all spin test flights.

Mass distribution of the research airplane, in terms of its Inertial Yawing Moment Parameter, was approximately -20×10^{-4} . This figure was arrived at by referencing inertia values experimentally derived by the NASA Langley Research Center for the same type airplane in a similar configuration.

INSTRUMENTATION

Angle of Attack

A pitot static boom was mounted to the outer left wing rib of the test airplane as shown in Fig. 3. A small vane connected to a one-turn potentiometer was attached to the boom and referenced to the chord line of the rib. Movement of the vane was mechanically limited to $\pm 30^\circ$. This mechanical constraint proved to be an unfortunate oversight since α_L measurements above $+30^\circ$ in left spins were unobtainable.

Angle of Sideslip

Figure 3 shows the sideslip measuring vane which was also mounted on the left pitot static boom. This vane was connected to a one-turn potentiometer and referenced to the longitudinal axis of the boom. Mechanical constraints limited the sideslip vane to $\pm 30^\circ$ movement.

Control Position Transducers

Slidewire potentiometers linked to each moveable control surface were utilized to measure control surface displacements. Zero stabilator position was arbitrarily referenced at a location approximately half way between full up and full down. Zero rudder position was referenced to mechanical neutral. Sign convention for stabilator and rudder position is standard, that is, yoke aft and rudder right are positive.

Aileron position measuring did pose some difficulties and interpretation of aileron position data must proceed with the following considerations:

(1) Due to idiosyncracies of the aileron slidewire installation, right aileron deflection gave a negative voltage output. To facilitate data reduction chores, the signs of the ordinates for aileron control position were reversed to retain standard convention, that is, right aileron positive.

(2) Aileron and sideslip were multiplexed on the same recording channel. In order to record a zero voltage at an actual zero sideslip condition, a bias voltage had to be applied to the channel. This bias also offset aileron zero and is reflected in the data by what appears to be a 10° right aileron displacement when, in fact, the ailerons are in a true neutral position.

(3) Total aileron displacement of 30° is the sum of full up (20°) and full down (10°).

Rate Measuring System

Angular velocities about the X, Y, and Z body axes were obtained from a Rate Measuring System. This system was composed of a three-axis Rate Gyro Package, a 26-volt, single-phase, 400-cycle Static Inverter, a three-channel Phase Sensitive Demodulator, and a Remote Gyro Output Controller.

The three-axis Rate Gyro Package consisted of three rate gyros mounted to a 1/4-inch-thick rectangular aluminum plate as shown in Fig. 4. Maximum capability of the pitch and yaw gyros were $\pm 100^\circ$ per second, while the roll gyro was rated at $\pm 400^\circ$ per second. The gyro axes were oriented to form a right-handed orthogonal system parallel to the body axes of the airplane.

The 26-volt Static Inverter supplied power to the rate gyros and was connected to the airplane battery through a solenoid actuated relay. This relay was controlled by a switch on the instrument panel in the cockpit, and provided an expeditious means of disconnecting the Static Inverter from the battery in the event of a malfunction.

The three-channel Phase Sensitive Demodulator unit contained a ± 12 VDC power supply, three gyro terminal boards, and three-phase demodulator boards. The gyro terminal boards provided two-phase power to the gyro motors and single-phase power to each gyro transformer. Demodulator boards produced a $\pm$ DC output proportional to the phase difference between a 400-cycle reference signal and the respective output signal from each gyro transformer. Voltage followers were added to each channel to provide a low impedance drive to the tape recorder. The Static Inverter and three-channel Phase Sensitive Demodulator unit are shown in Fig. 5.

Before gyro output signals from the Phase Sensitive Demodulator unit were recorded on tape, they were fed through a Remote Gyro Output Controller as shown in Fig. 6. This device provided the pilot with a means of monitoring and adjusting gyro output voltages to insure they remained within the input limitations of the tape recorder.

The Remote Gyro Output Controller was composed of a high impedance $\pm 50 \mu\text{a}$ meter, a gyro channel selector switch, and three 1-k Ω , ten-turn potentiometers.

The Rate Measuring System was calibrated before flight on a precision rate table. Each gyro was paired with a selected demodulation channel, and gyro/channel continuity was maintained throughout the flight program. For each channel, a number of potentiometer settings were determined so as to give a maximum ± 1.0 VDC gyro output voltage at certain pre-selected rates, for example, $\pm 50^\circ$ per second, $\pm 100^\circ$ per second, $\pm 200^\circ$ per second, etc. A calibration of the pitch axis is displayed in Fig. 7 to demonstrate typical results.

The advantages of this system were twofold:

(a) It provided a means of more fully utilizing each recording channel without exceeding input limitations.

(b) It reduced the number of data system qualification flights.

Analog Computer

Output signals from α , β , and three control position transducers were processed by a small Analog Computer, shown in Fig. 8, before they were recorded on tape. Aileron position and angle of sideslip were multiplexed, and a bias voltage was applied to a "zero-out" sideslip. This bias voltage also offset aileron zero and appears in the data as a 10^0 right aileron displacement when the ailerons are at true zero. Rudder position and angle of attack were also multiplexed in the same manner, but no bias voltage was required.

Data Acquisition System

Data acquisition was accomplished with a Lockheed Model 417 FM Tape Recorder as shown in Fig. 9. This system provided seven recording channels, each with a maximum range of ± 1.4 volts, and a frequency response greater than 15 kHz. A voice track was also available but was not utilized. The tape recorder received its power from an 18 VDC power supply.

A Remote Tape Recorder Control Head was used to activate the recorder in flight. This apparatus, mounted to the floor of the airplane adjacent to the left pilot's seat, is shown in Fig. 6.

All inputs to the tape recorder were scaled to ± 1.0 VDC maximum. The purpose of the procedure was to obtain data compatible with a ground based A/D converter for future use in exploring computer methods of spin data reduction and analysis.

Wing Mounted Camera

In order to study the aerodynamic flow phenomena over the aft fuselage and empennage, a 16-mm gun camera was mounted in the right wingtip as shown in Fig. 10. The interior wingtip mounting was chosen to minimize flow disturbances over the right aileron.

A stainless-steel mirror bracket was mounted over the 17-mm camera lens, providing a simple "prism effect." A hole approximately $1\frac{3}{4}$ inch square was cut in the wingtip to accommodate the mirror and lens. A styrofoam fairing was then carved and secured to the wingtip to minimize mirror flutter.

The camera carried a 50-foot film magazine which proved adequate for as many as eight to nine spins, provided that film speed was limited to 16 frames per second. Realistically a film speed of 64 frames per second should have been used, but since the intent was to gather as much general information as possible, the lower speed was selected.

The camera system derived its power from a rechargeable 28-volt battery supply located in the cockpit. Power to the camera was controlled by a two-position toggle switch located on the instrument panel.

Data Reduction

Flight data was played back on a strip chart recorder. The resulting product provided a group of strip charts that displayed a time history of all voltages recorded on each channel of the recorder. By referring to previously recorded calibration values for each channel, the ordinates of each strip chart were converted to a representative value such as degrees per second, for angular rates, or degrees for α_L , β_L , and control positions. Individual data runs were readily identified by large voltage surges which marked the beginning and end of each spin data run.

Strip chart data was then traced, labeled, and photographically reduced to report format size.

CONDUCT OF FLIGHT TESTS

Airplane configuration, mass distribution, and center of gravity were held constant for all spin flights. In addition, all spins were entered from a wings level, level flight attitude with idle power.

The airplane was decelerated at approximately 1 mile per hour per second. At two to three miles per hour above computed stall speed, the yoke was rapidly advanced to the aft stop while full rudder in the intended direction of spinning was applied. For full-turn spins, pro-spin aileron (full aileron opposite the direction of spinning) was applied as the airplane rolled through 90° bank. For one-half turn spins, pro-spin aileron was not applied.

All spin recoveries were initiated at basically two points during the incipient spin phase, that is, at the one-half turn point and at the one turn point. All spins were terminated by returning the controls to neutral in a pre-determined se-

quence. This procedure was established to examine recovery control effectiveness at different stages of the incipient spin.

The pilot's flight data card incorporated a "Recovery Control Sequence Box" which was a slightly modified version of Stone's "Spin-Shorthand" (data obtained from R. R. Stone of Beech Aircraft Corp.). This method of depicting spin data points, minimized inflight notetaking, and provided a concise visual depiction of the recovery control sequence for each spin entered. The "Recovery Control Sequence Box" was retained for each spin data reproduction and appears in the lower left corner of each page. A brief explanation of the "Recovery Control Sequence Box" appears in Fig. 11.

RESULTS AND DISCUSSION

The following discussion is broken down into three basic areas: (1) incipient spinning characteristics, (2) control sequence effect on recovery, and (3) aerodynamic flow phenomena observed on the aft fuselage, vertical stabilizer, and rudder.

1. Incipient Spinning Characteristics

The incipient spin represents a transition from random post stall motion to a steady developed spin. Unlike post stall motion, the incipient spin displays a definite rotation pattern which is unsteady in nature. This situation is depicted by the angular rates recorded in pitch, yaw, and roll, and may be studied by referring to the Spin Data Section.

Spin entry began with a stall. Pitch and yaw then coupled to produce a rolling moment about the longitudinal axis of the airplane. This rolling moment was aerodynamically reinforced as C_{l_p} became positive and auto-rotation ensued.

In both one-half and one-turn spins, p , r , and q increased in somewhat of an oscillatory manner. The motion was definitely time dependent, reflecting an unbalanced condition between aerodynamic and inertia forces. Pitching oscillations were roughly 180° out of phase with rolling oscillations, that is, as pitch rate decreased, roll rate increased, and vice-versa. This "out-of-phase" condition reflected the tendency of the rotating airplane to conserve its angular momentum.

Level 1-g spin entries were characterized by a smooth roll-off as the nose of the airplane tracked in a helical path about a constant heading axis. The spin axis, which defines the trajectory of the rotating airplane, transitioned from horizontal to vertical in approximately two airplane revolutions.

The test airplane spun in a relatively steep attitude, about 50° to 55° nose down at the one-turn point, and exhibited a greater angular rate component in roll than in yaw. There was an absence of noticeable yawing oscillations, however, roll rate excursions were apparent especially during recovery.

2. Control Sequence Effect on Recovery From the Incipient Spin

Before one attempts to interpret the following remarks, it must be remembered that the weight and balance of the test airplane was held at the values given in Fig. 2 for all spin flights. If parameters such as mass distribution, center of gravity, or spin entry conditions were changed, the spinning and recovery characteristics of the test airplane may have been considerably different than those presented here.

For the mass distribution, center of gravity location, and entry conditions specified in this program, the stabilator proved to be the primary recovery control during the incipient spin. In all cases, as soon as the stabilator was neutralized, angle of attack would decrease and recovery would soon follow.

From the standpoint of the data acquired, variations in the sequence of recovery controls at the one-half turn point did not produce measurably different results, as long as all pro-spin controls were expeditiously returned to neutral. From a pilot's viewpoint, the stabilator was the only control which provided an immediate indication of impending recovery, regardless of where it was neutralized in the sequence. This indication was sensed by a reduction in "g", a decrease in pitch rate, and mild acceleration in roll rate.

Angular rate measurements verify that a relatively strong negative pitching moment occurred immediately after the stabilator was returned to neutral. It is interesting to note that neutral stabilator was quite adequate to effect recovery, and that the application of full or near-full down stabilator was not necessary. Because of the immediate recovery indications that resulted from neutralizing the stabilator, angular rate measurements in yaw gave little indication as to the effectiveness of the rudder as a recovery control.

Refer of Fig. S-1 in the Spin Data Section. In this run, the airplane became unstalled as rotation began and a spiral resulted. Note the measured

values of p and r as compared to Figs. S-2 through S-5 where spin entry did occur. This figure was included to show the dynamic similarity between a spin and a spiral for a steep spinning airplane, and to emphasize the difficulty that may be involved if one attempts to distinguish between the two visually. Without an angle of attack indicator, the only way a pilot can discern a steep spin from a spiral is by referencing his airspeed indicator.

Variations in the sequence of recovery controls at the one-turn point again indicated that the stabilator was the primary recovery control. Returning the stabilator to neutral produced an immediate decrease in pitch rate and angle of attack, while causing a very noticeable increase in roll rate.

In general the dynamic characteristics of the recovery seemed to have little dependence upon control sequence. It was noted, however that if aileron and stabilator were simultaneously neutralized either before or after the rudder was neutralized, a greater momentary acceleration in roll would be experienced. Figures S-14 and S-15 illustrate this observation.

Normally, the airplane would completely recover from the spin within 1 second after the last pro-spin control was returned to neutral. During this period of time, the airplane would continue to rotate approximately one-fourth turn, and then stop. Recovery from a steep upright dive would then be necessary to return to level flight.

3. Aerodynamic Flow Phenomena Observed on the Aft Fuselage, Vertical Stabilizer, and Rudder

Tufts attached to the right side of the fuselage, vertical stabilizer, and rudder were filmed by a 16-mm gun camera mounted in the right wingtip. The camera was activated approximately 5 mph above stall speed, and allowed to run until spin recovery was complete.

After the films were developed and reviewed, a group of frames displaying typical pre-stall, post-stall, and incipient spin flow patterns over the tufted areas, were selected and enlarged. These frames are referenced in the following discussion, and appear as Figs. F-1 through F-4 in the Film Data Section.

Since the gun camera ran at 16 frames per second, it was not possible to trace the exact motion of individual tufts. As a result, the term "flow disturbance" is loosely employed, and refers to tuft activity indicative of non-attached flow.

From a study of the films, three observations were made that characterized aerodynamic flow patterns over the tufted areas:

(a) The turbulent wing wake impinged upon the fuselage sides, creating flow disturbances that enveloped an area of the fuselage aft of the wing.

(b) The same general area of the fuselage was affected by flow disturbances, whether the spin was to the left or to the right.

(c) Flow over the vertical stabilizer and rudder remained essentially attached throughout the first turn.

As the airplane was slowed to stall speed and angle of attack increased, tuft activity on the fuselage in an area just above the trailing edge of the wing increased in intensity. Refer to Fig. F-1.

The films seemed to indicate that this disturbance was due to the combined effect of vortices shed from the trailing edge of the wing, and turbulence generated by fuselage/wing-flap mating irregularities.

As angle of attack was further increased, the area of the fuselage affected by these disturbances also increased. Figure F-2 shows a typical post stall flow pattern.

During the incipient spin, an even larger area of the fuselage aft of the wing came under the influence of these flow disturbances. Figures F-3 and F-4 show typical flow patterns for left and right spins, respectively. The general orientation of the disturbed area on the fuselage closely approximates the angle of attack of the spinning airplane.

The fact that flow patterns over the vertical stabilizer and rudder remained attached throughout the first turn, helped to explain from an aerodynamic standpoint, the low yaw rates encountered during the incipient spin.

SUMMARY AND CONCLUDING REMARKS

The incipient spinning and recovery characteristics of a light, general aviation airplane were examined in a brief flight test program jointly sponsored by the Department of Aeronautical and Astronautical Engineering, and the Department of Aviation at Ohio State University. Results of these tests may be summarized by the following remarks:

(a) Level 1-g spin entries produced an incipient spinning motion that was characterized by a mild, oscillatory buildup in pitch rate, yaw rate, and roll rate through the first turn. Dynamically the incipient spinning motion of the airplane was very similar from one spin to another.

(b) Airplane recovery characteristics were compared between left and right spins that employed the same recovery control sequence. In general, airplane response was nearly identical regardless of spinning direction.

(c) The stabilator proved to be the most effective recovery control throughout the first turn of the spin. The effectiveness of other controls was masked by the overwhelming power of the stabilator in terminating the incipient spin.

(d) Aerodynamic flow disturbances on the fuselage observed during each spin were primarily due to fuselage/turbulent wing wake interaction. Flow disturbance patterns were essentially the same during both left and right spins.

A quick survey of the Spin Data Section will verify that in nearly all cases, post stall motion of any significant magnitude was virtually non-existent. It must be emphasized, however, that all entries were made from a straight and level flight attitude with a slow deceleration into the stall. Had the entry profile been modified to include accelerated or inertially coupled entries, the post stall characteristics may have been measurable different.

One entry did produce somewhat of a post-stall motion, and it was significant in terms of the control input and resultant aerodynamic moments that produced the motion. Refer to Fig. S-11 in the Spin Data Section.

As the airplane stalled, it rolled off to the right. Full left rudder was applied at the stall, but right roll rate continued to build. Full right aileron was then applied and the resulting right sideslip that it helped generate, arrested the right roll.

As right roll rate decreased aileron was gradually neutralized and the airplane stopped rolling at approximately 20° to 30° of right bank. After a momentary pause, the airplane began rolling back to the left. As zero bank angle was approached, full right aileron was again applied and held. Left roll rate began decreasing, left yaw rate began increasing, and a slightly negative pitch rate developed. Another momentary pause in roll occurred as the airplane reached approximately 30° of left bank. Right sideslip began to build up again, the airplane continued rolling to the left, and a left spin ensued.

There was never any intention of producing this type of post-stall motion in the course of the flight tests, but its inadvertent occurrence did shed some light on the relative strength of rolling-moments due to sideslip. These rolling moments were apparently strong enough to oppose the rolling inertia of the airplane at rates greater than 25° per second.

This flight research program was developed only as a means of exploring the incipient spinning and recovery characteristics of a typical, light general aviation airplane. No attempt has been made to criticize or praise the characteristics of the research airplane selected for this study. It is hoped that the results of this program will provide pertinent information to future efforts in developing stall/spin technology for the general aviation industry.

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Figure 1. - Research airplane configured for flight.

N130SU (S/N MB485) WEIGHT AND BALANCE DETERMINATION

SPAN TEST 130SU WITH
CPT PARK, RECORDS, REMOTE CONTROLLER

	Weight (lbs)	Moment Arm (in)	Moment (lb in)
1. WEIGHED BASIC EMPTY WEIGHT (As of 8/14/76) (CONFIGURATION # 1)	1,727	112.4	194,140
2. EQUIPMENT			
(a) LESS: RIGHT FRONT SEAT	(16)	110	(1,760)
(b) LESS: FLIGHT DECK ANALOG CONTROLLER	—	—	—
(c) PLUS: REMOTE CONTROLLER	5	110	550
(d)	/	/	/
(e)	/	/	/
(f)	/	/	/
3. CREW			
(a) RANAUDO (incl. chute & helmet)	177	110	19,470
(b)	—	—	—
4. OBSERVERS			
(a)	—	—	—
(b)	—	—	—
5. Fuel (30 gal.) EACH TANK TO TAB	180	117	21,060
6. TAKEOFF GROSS WEIGHT	2073	112.6	233,460
7. LESS: FUEL USED TAKI, TAKEOFF, CLIMB TO 5000' (5 GAL) + CRUISE FOR 18 MIN (3 GAL) = 8 GAL	(48)	117	(5,616)
8. GROSS WEIGHT AT BEGINNING OF TEST	2025	112.5	227,844
9. LESS: FUEL USED DURING TEST: 10 GAL	(60)	117	(7,020)
10. LANDING GROSS WEIGHT	1965	112.4	220,824

NOTES:

- (1) BEW = included in Basic Empty Weight figure, Item 1.
- (2) Maximum weight: 2450 lb.
- (3) BEW includes 8 qts. oil, unusable fuel, all operating fluids.

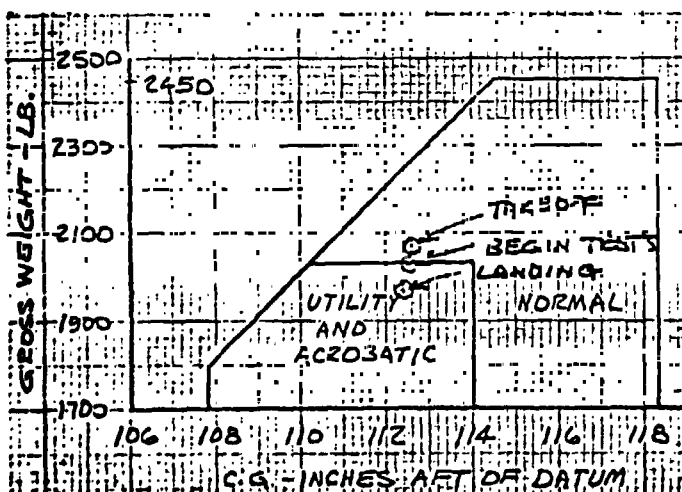


Figure 2

Prepared by: GSW

Date: 8/22/76

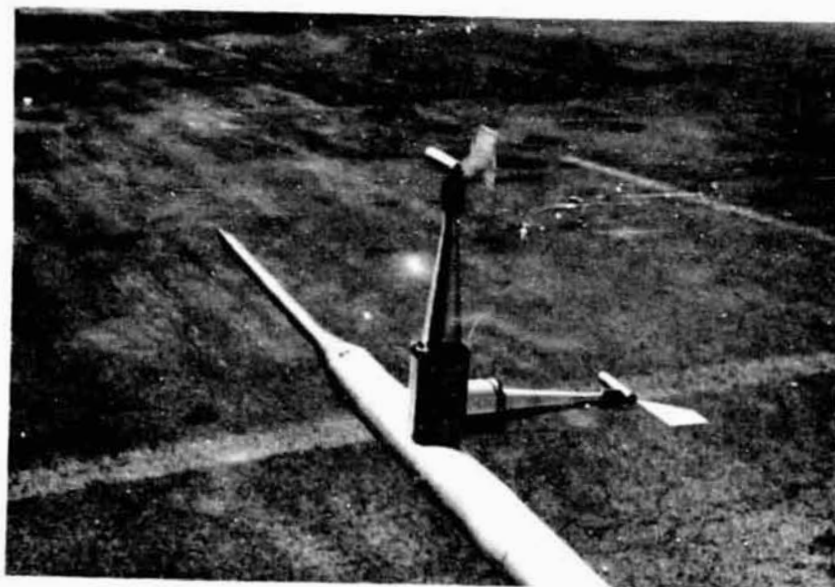


Figure 3. - Angle of attack and angle of sidedlip vanes mounted to a pitot static boom.

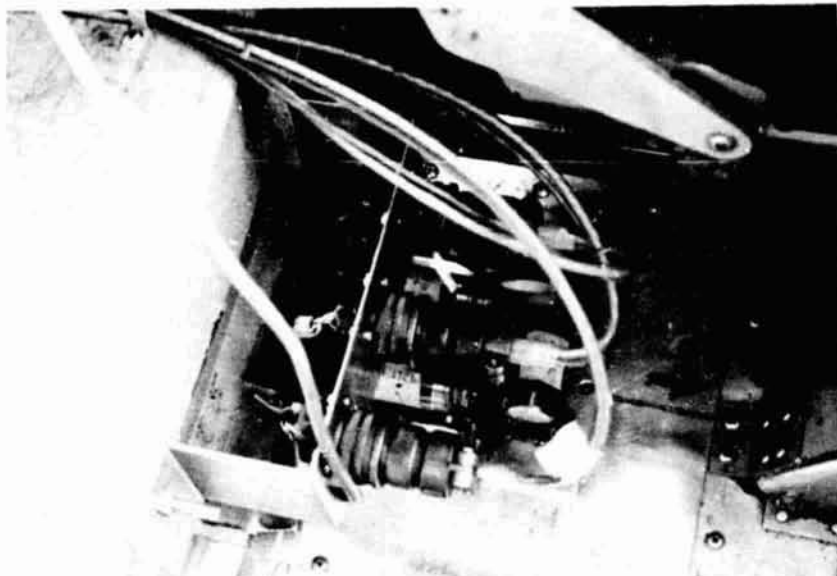


Figure 4. - Floor mounted three-axis rate gyro package.

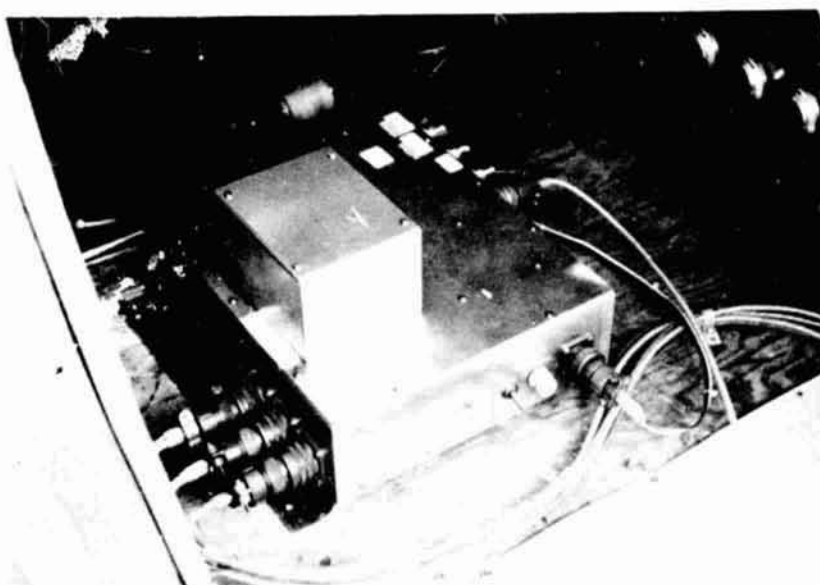


Figure 5. - Three channel phase sensitive demodulator and static inverter.

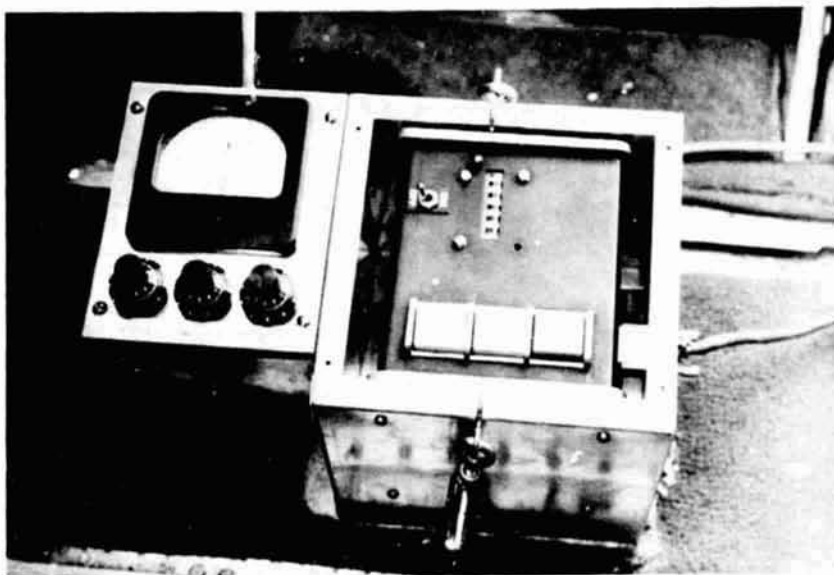


Figure 6. - Remote gyro output controller (left) and remote tape recorder control head (right).

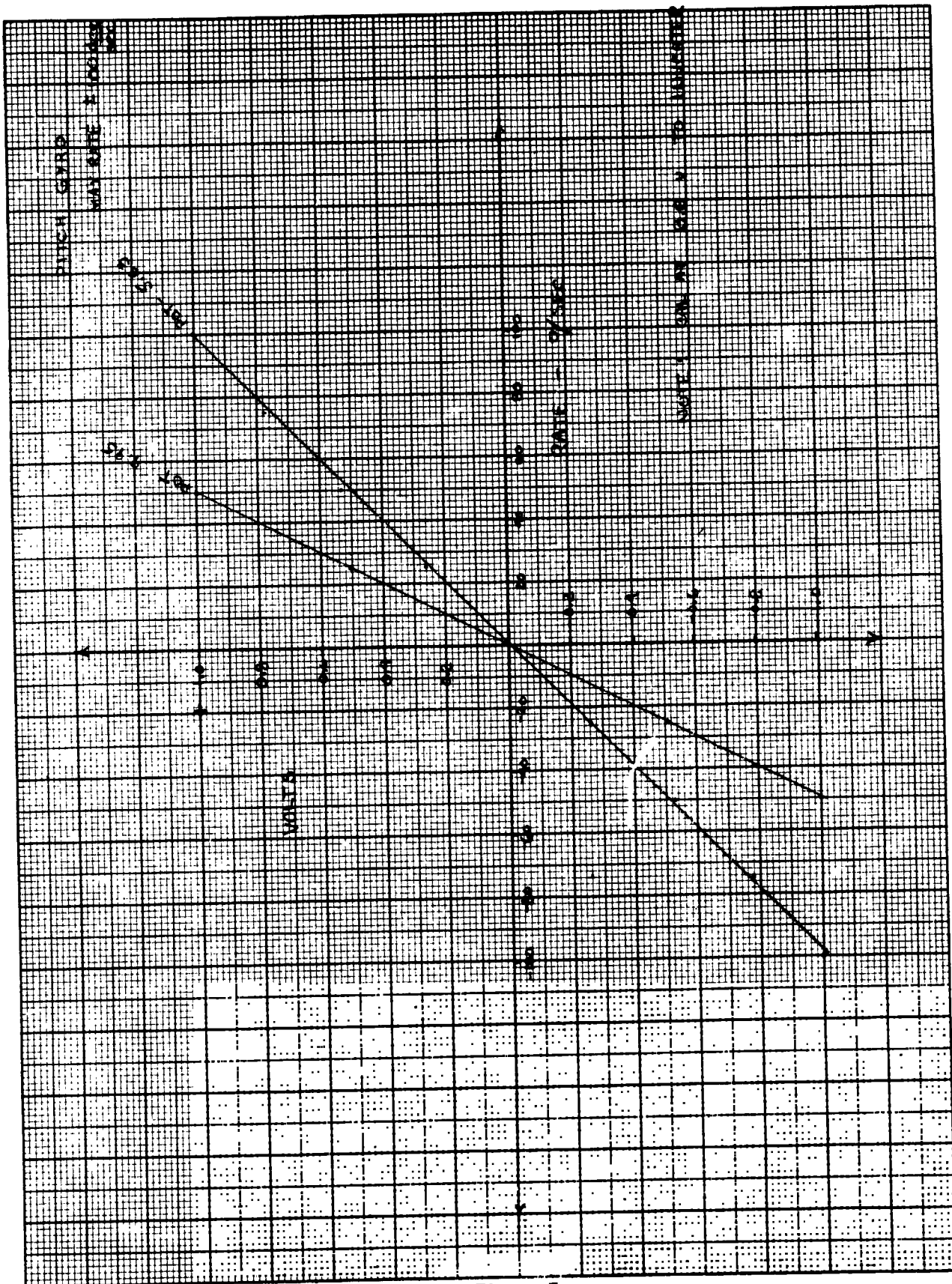


Figure 7

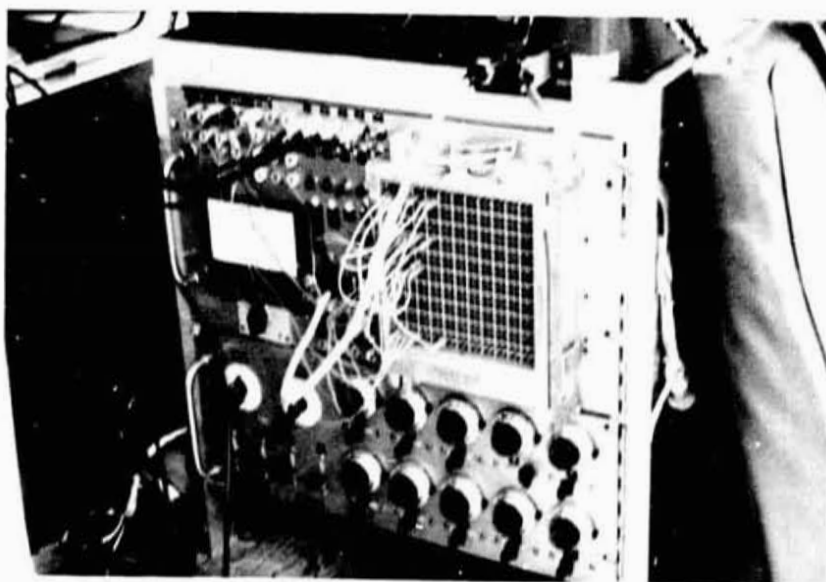


Figure 8. - Analog computer.

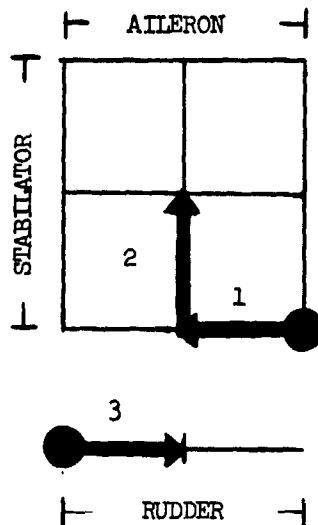
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ORIGINAL PAGE IS POOR



Figure 9. - Tape recorder installation.



Figure 10. - 16mm Gun camera installation.



Legend: The box indicates yoke position, i.e., stabilator and aileron.

The bar indicates rudder position.

The two large solid circles indicate pro-spin control position prior to recovery.

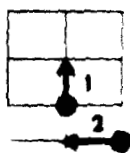
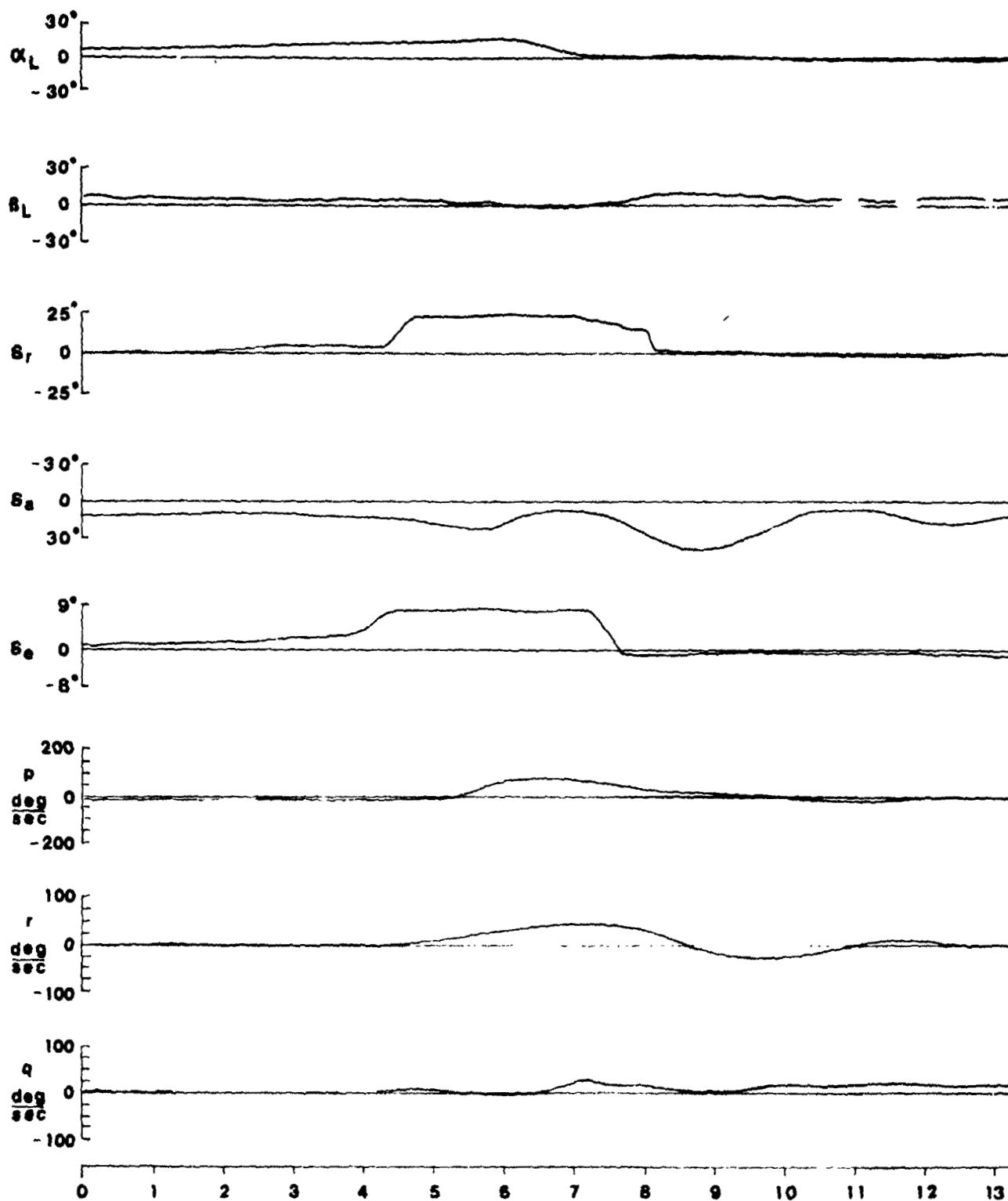
The arrows and corresponding numbers indicate the direction and sequence of recovery controls.

In the example shown, full aft stabilator, full right aileron, and full left rudder were maintained during the spin. For recovery, aileron, stabilator, and rudder were re-positioned to neutral in that sequence.

Recovery Control Sequence Box

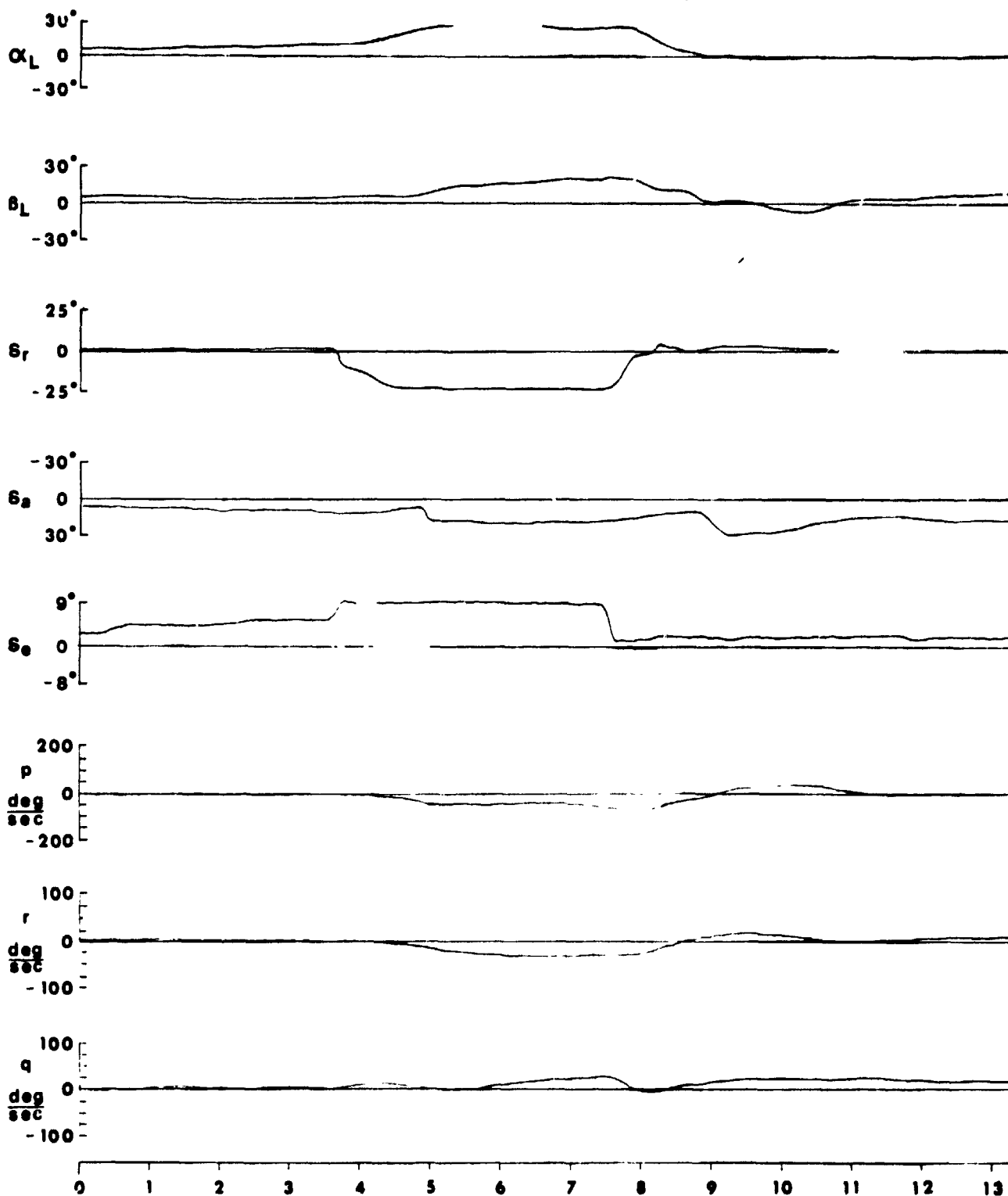
Figure 11

SPIN DATA SECTION



TIME-SECONDS
1, TURN RIGHT

Figure S-1



TIME - SECONDS
1/2 TURN LEFT

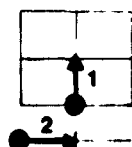
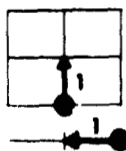
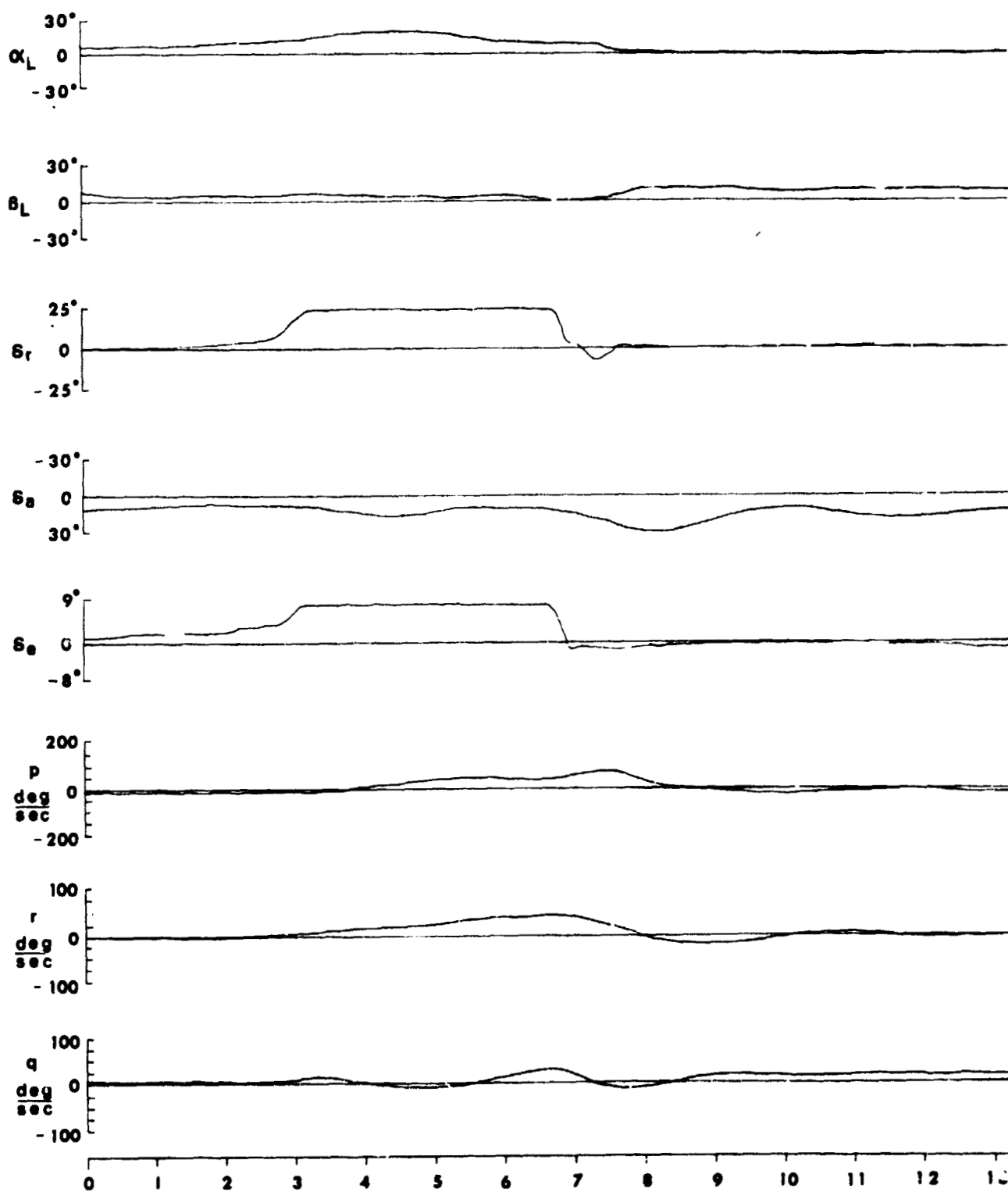
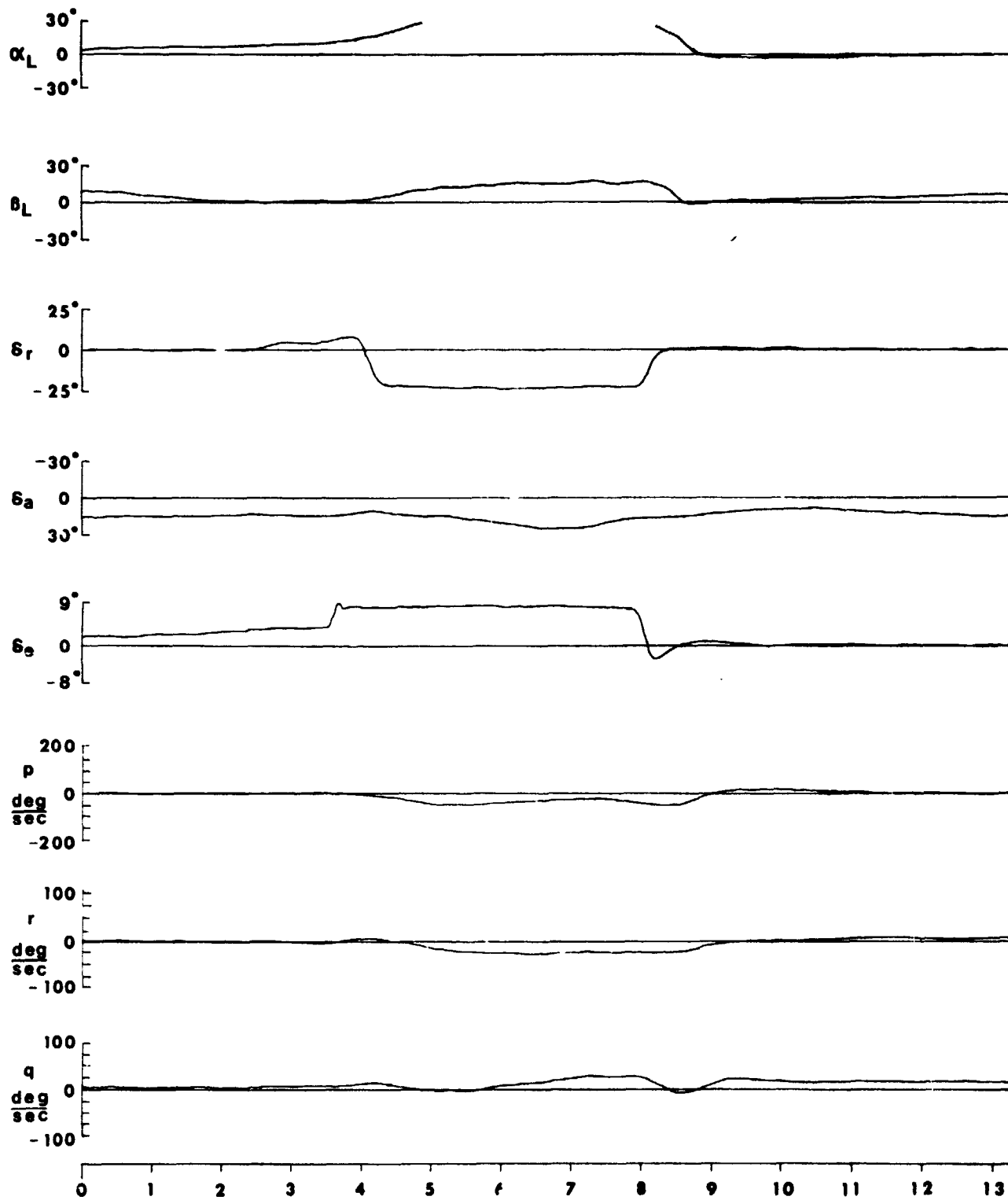


Figure S-2



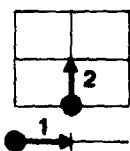
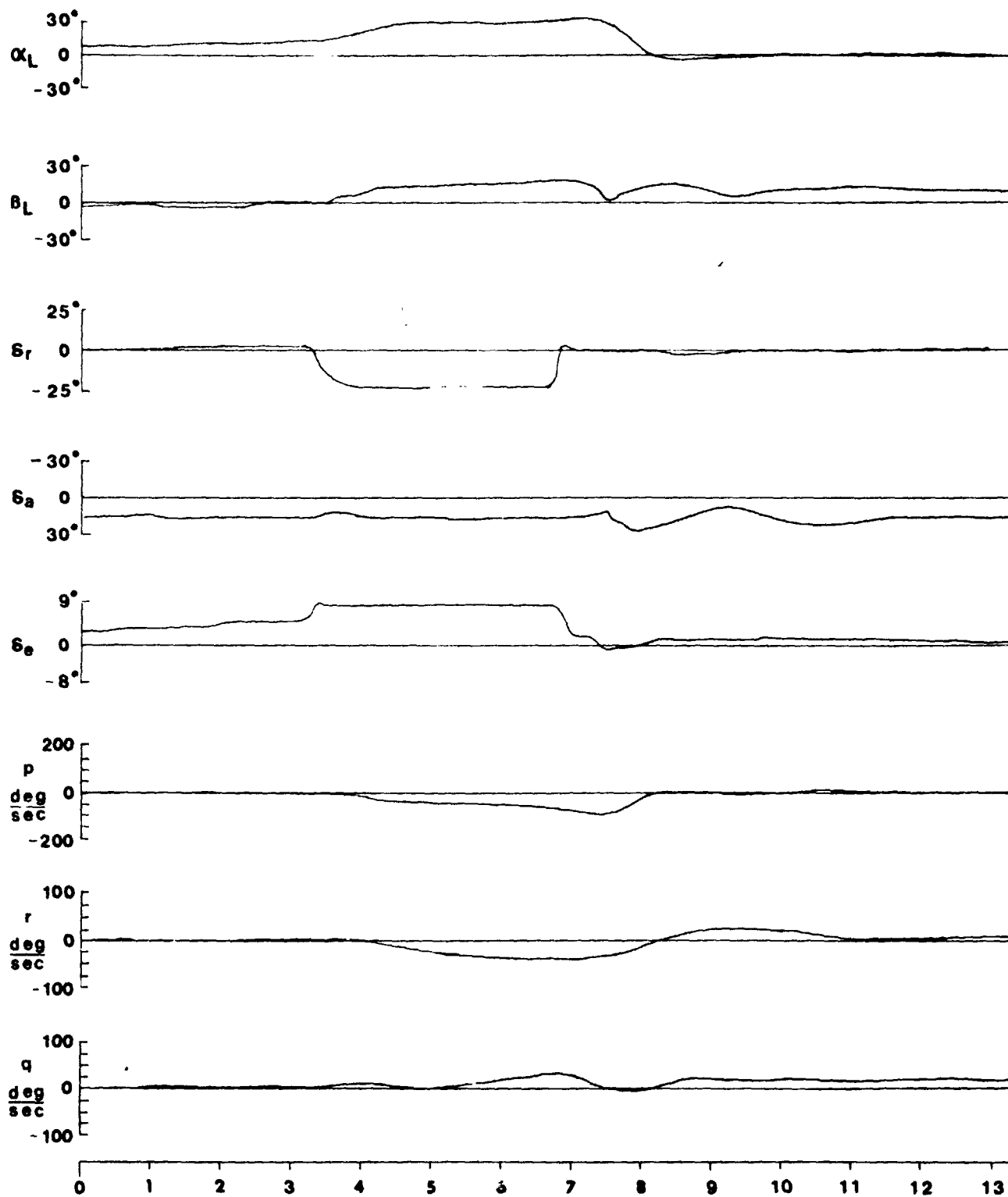
TIME-SECONDS
1/2 TURN RIGHT

Figure S-3



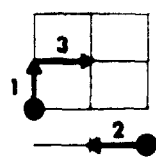
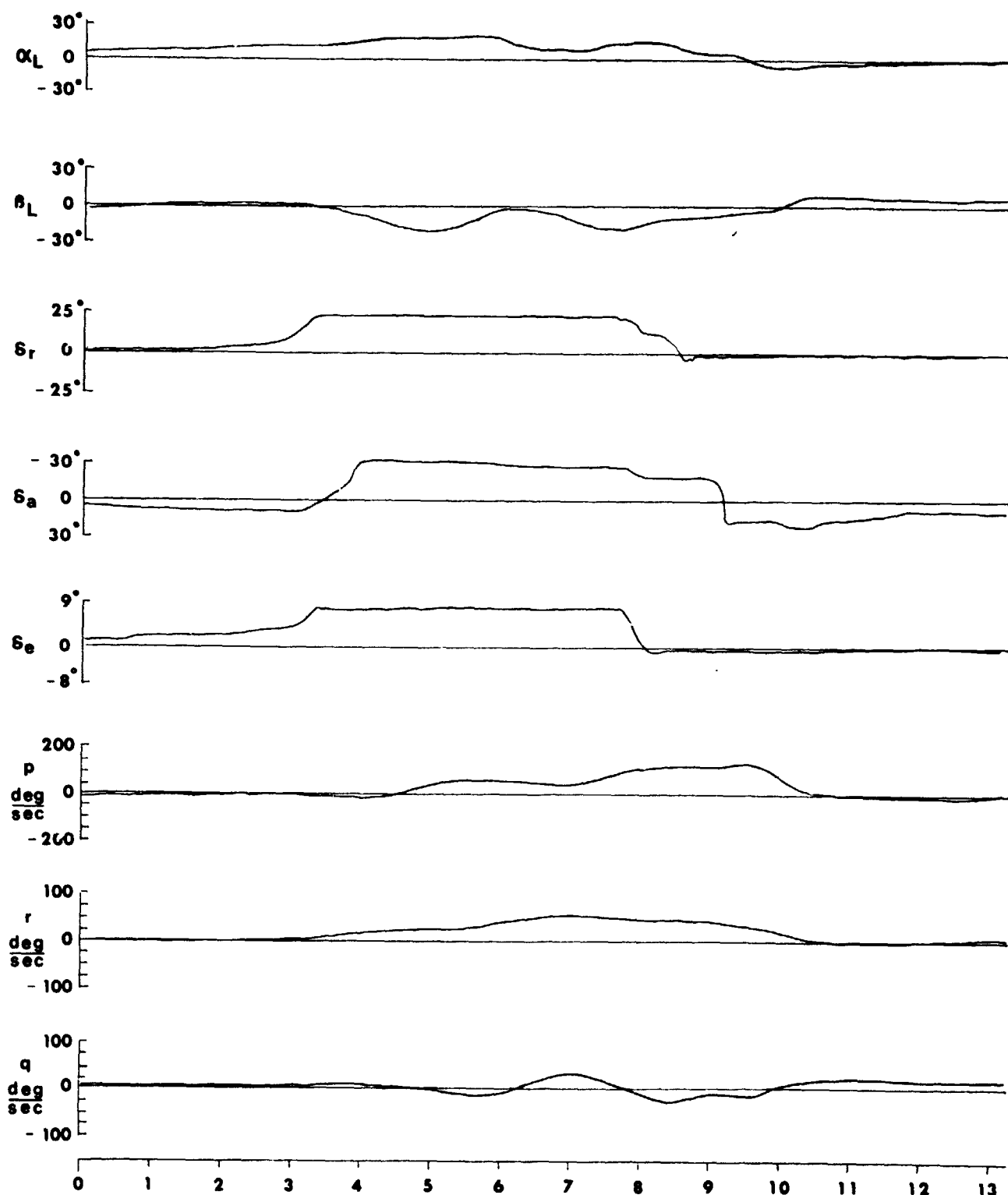
TIME - SECONDS
1/2 TURN LEFT

Figure S-4



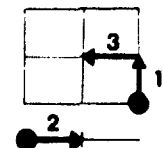
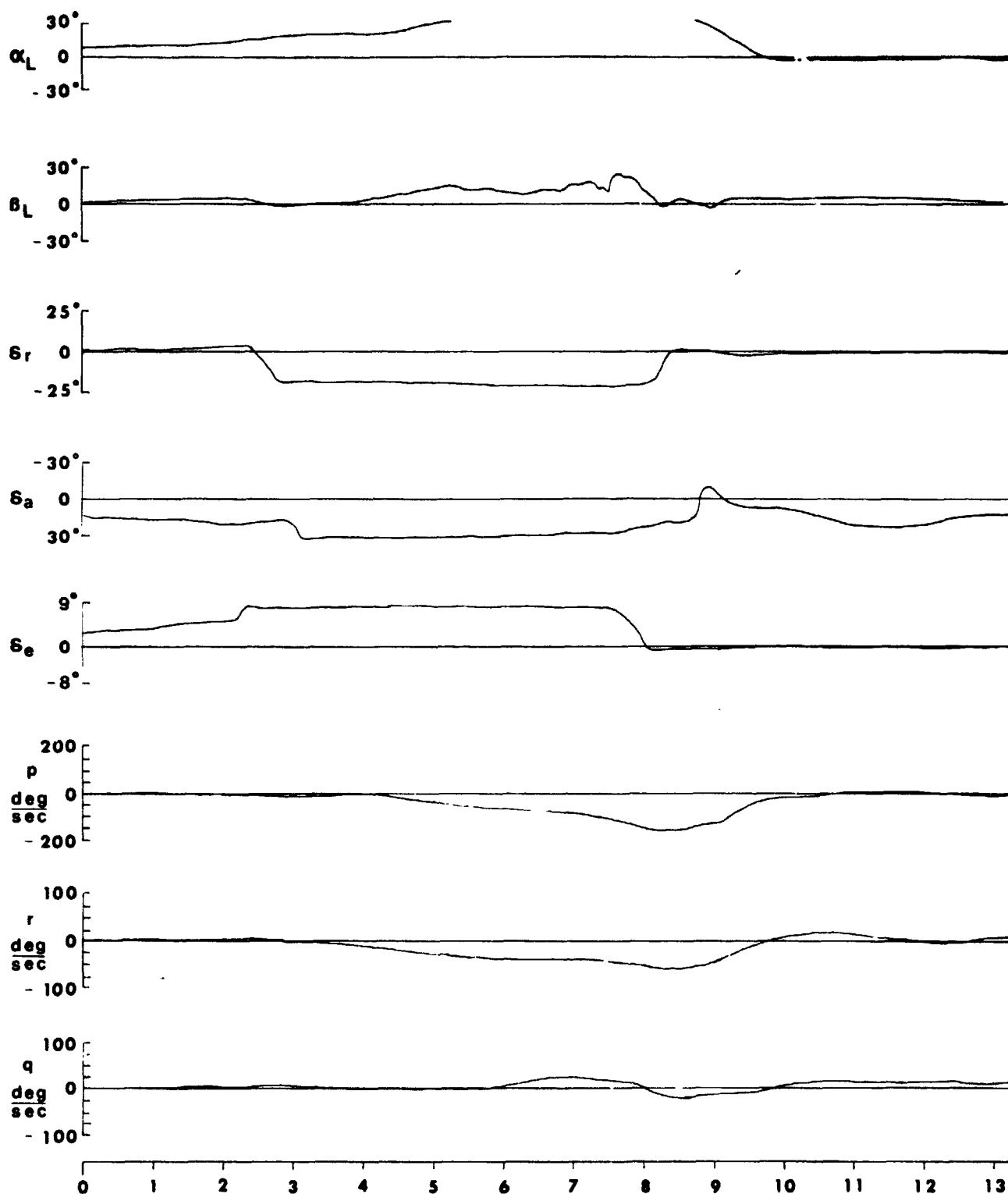
TIME - SECONDS
1/2 TURN LEFT

Figure S-5
27



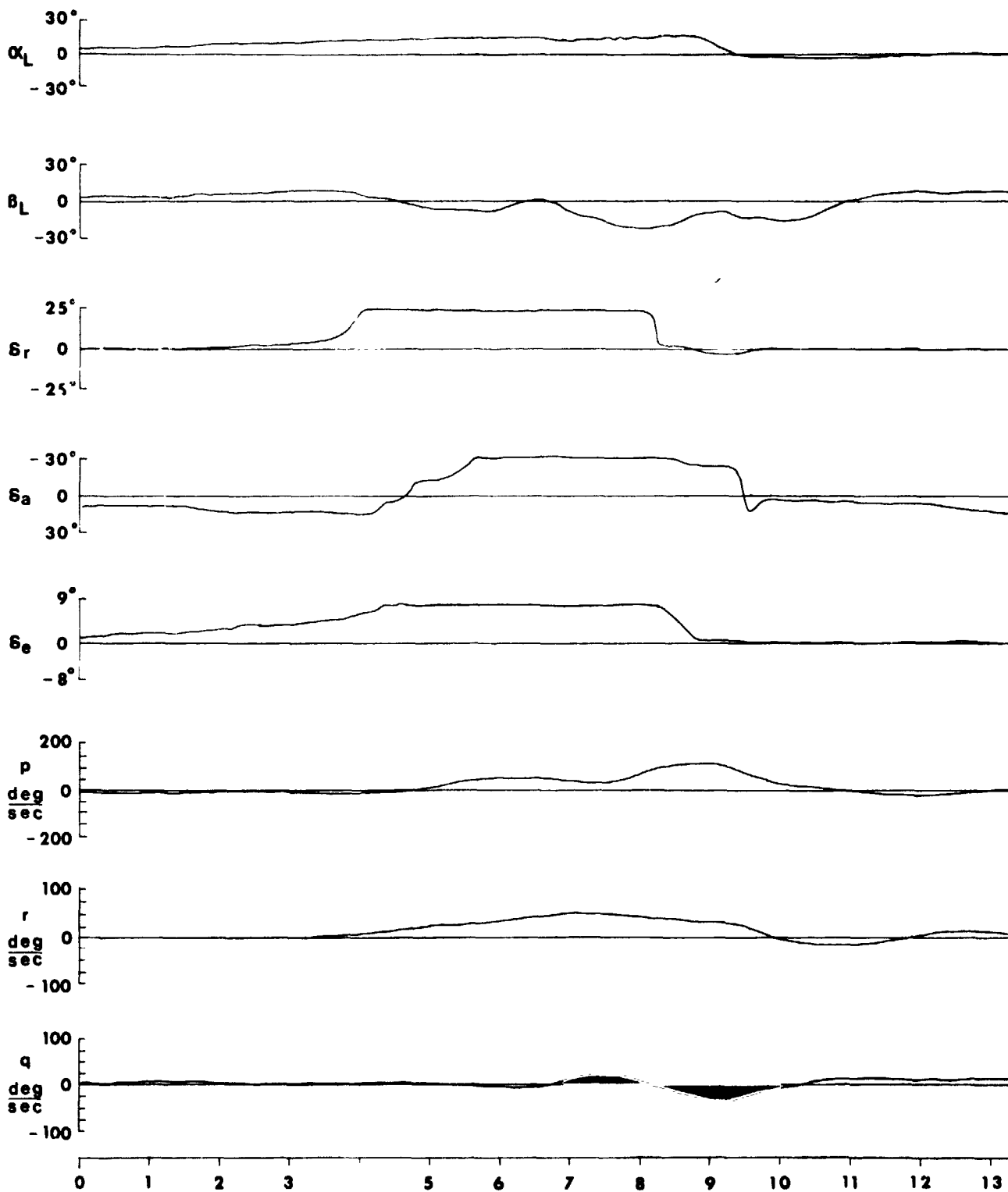
TIME - SECONDS
1 TURN RIGHT

Figure S-6
28



TIME - SECONDS
1 TURN LEFT

Figure S-7



TIME - SECONDS
1 TURN RIGHT

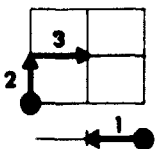
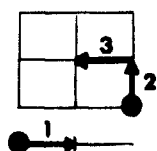
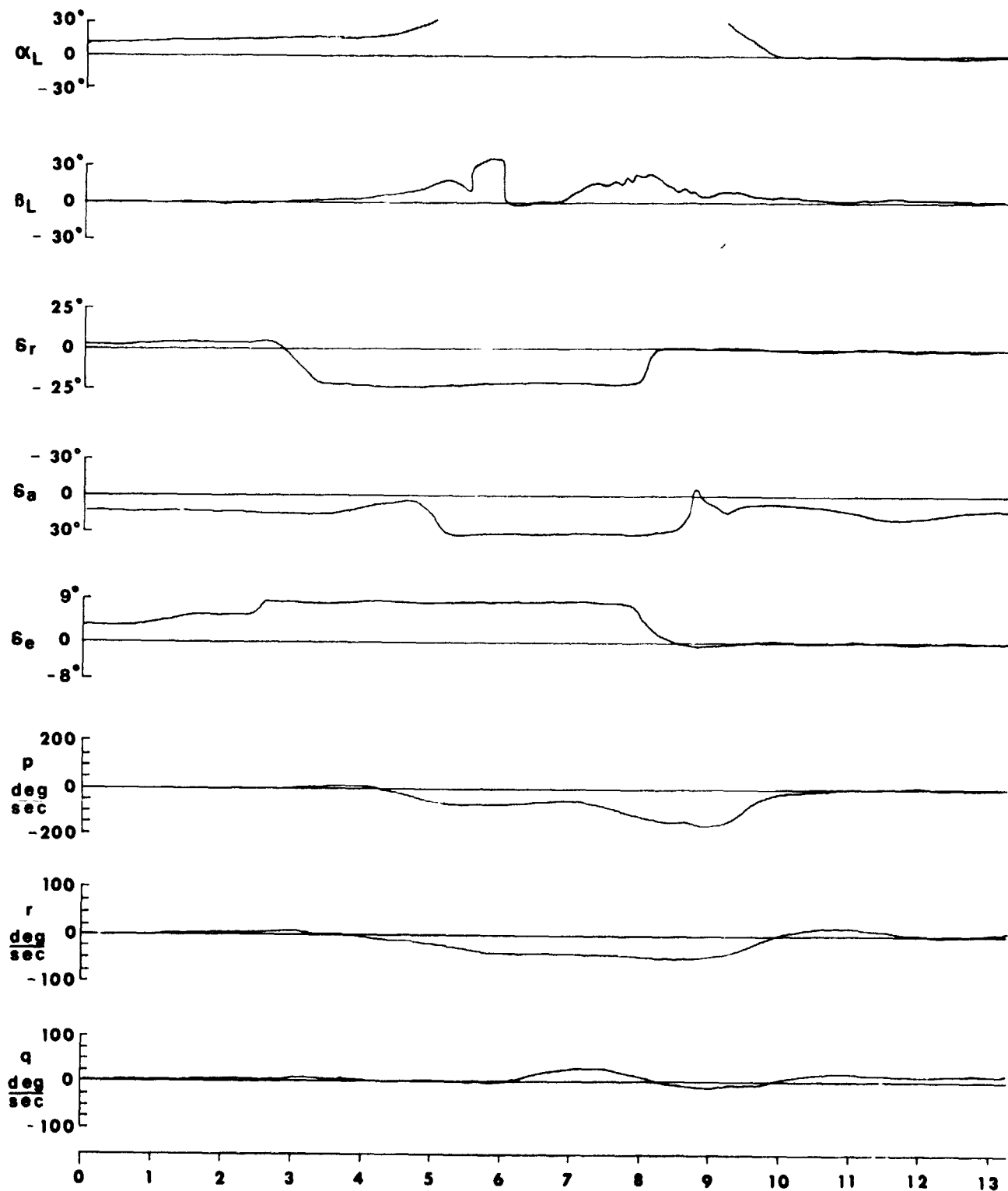
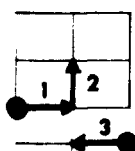
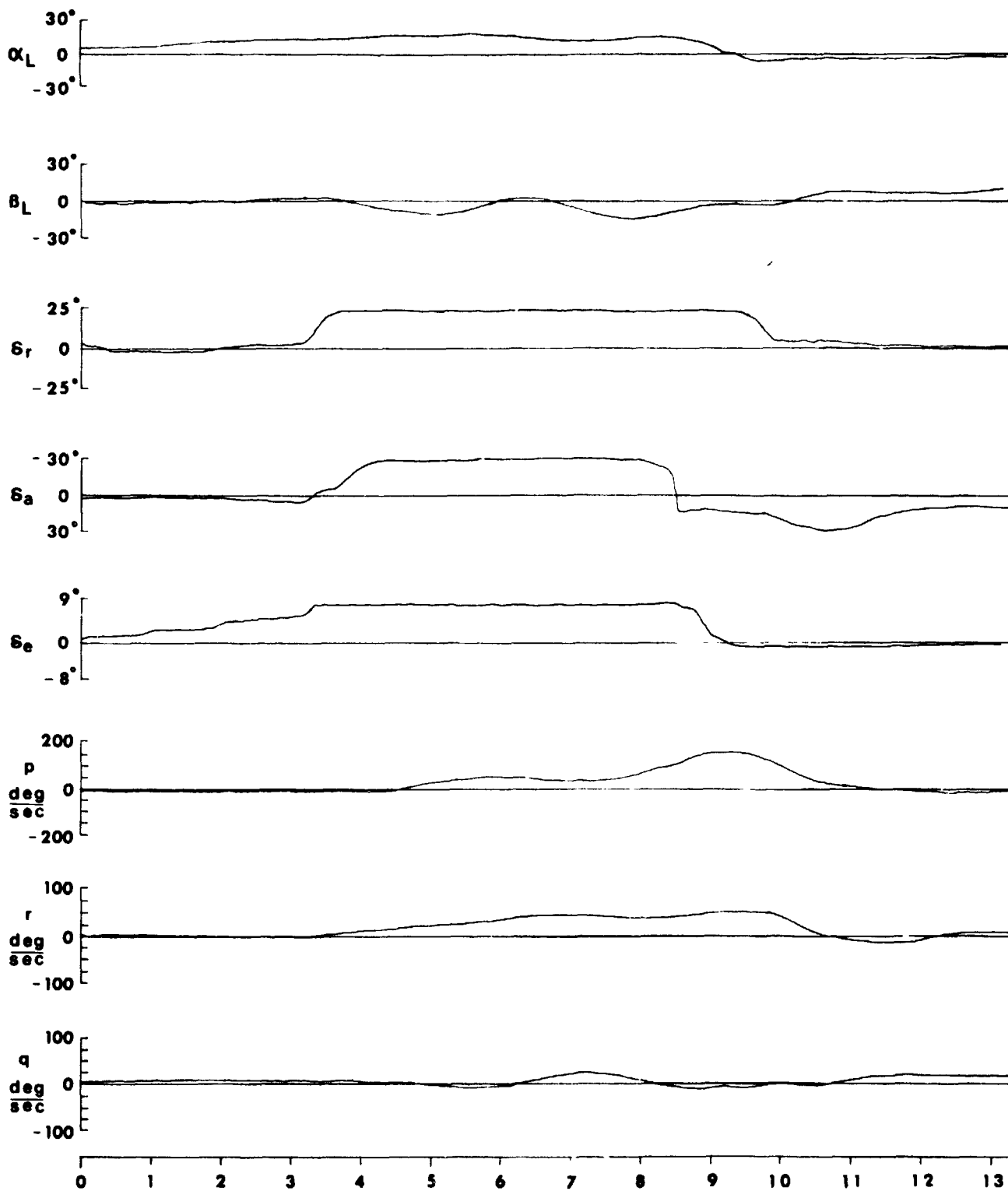


Figure S-8
30



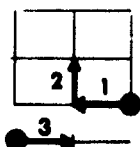
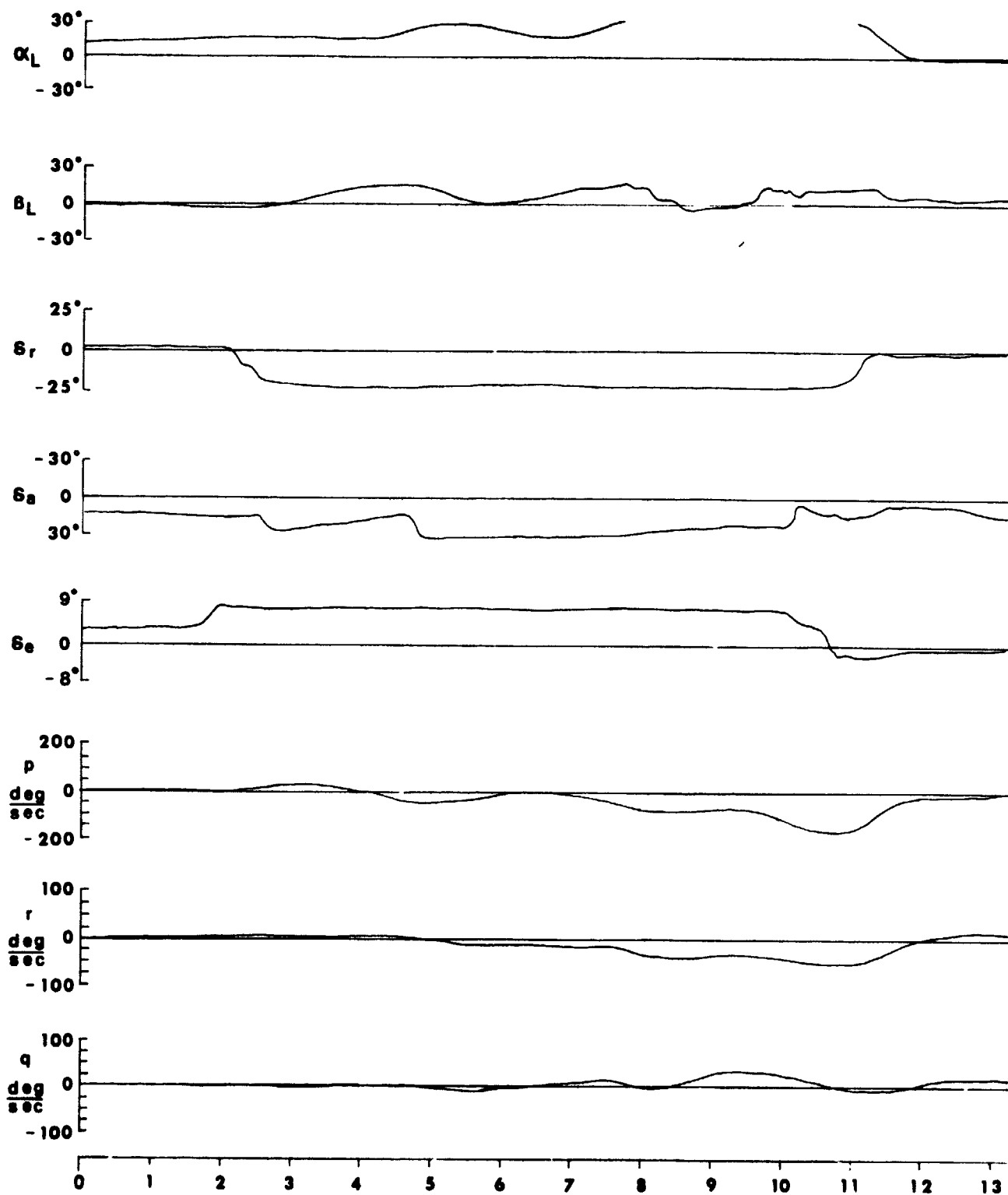
1 TURN LEFT

Figure S-9



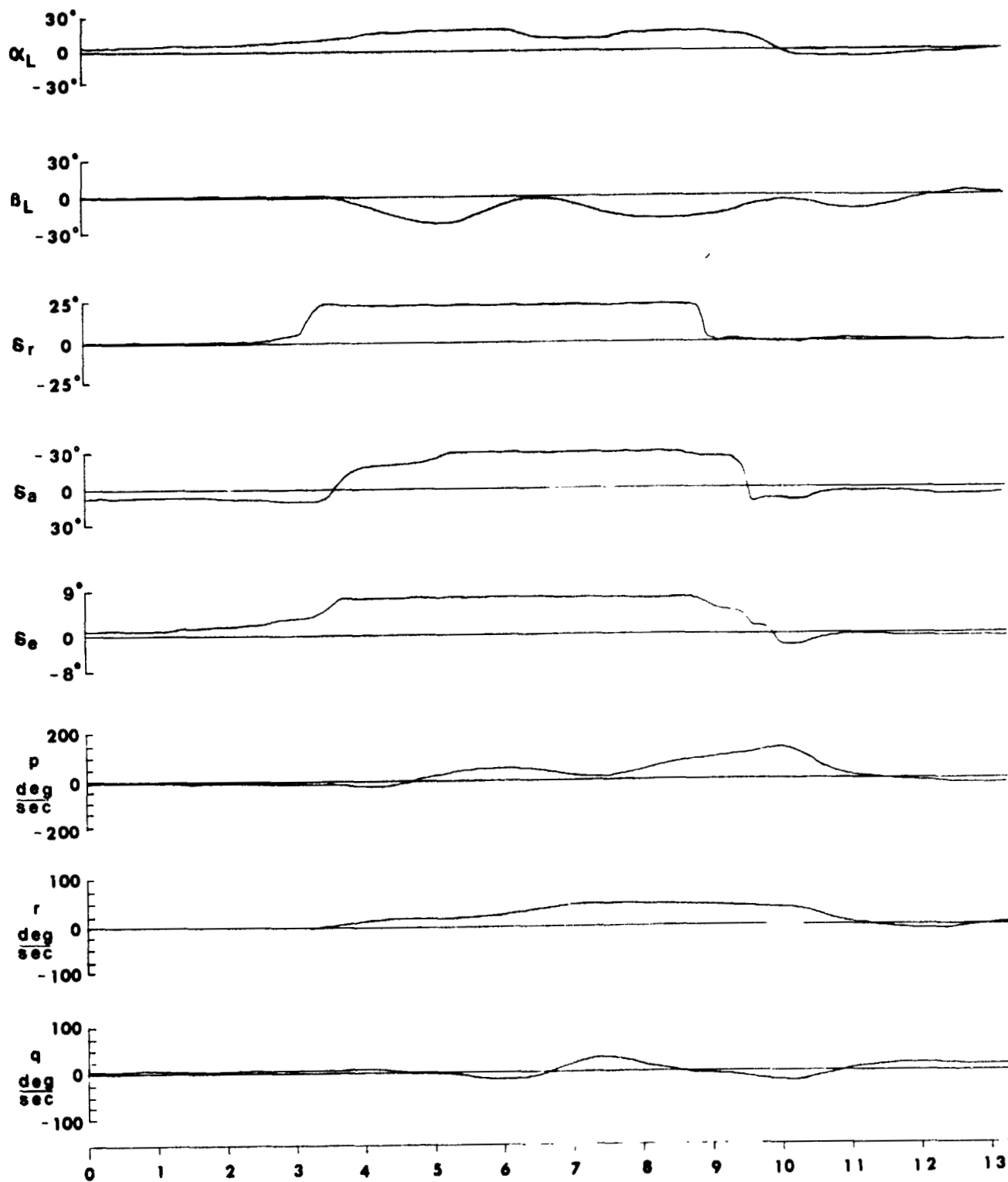
TIME-SECONDS
1 TURN RIGHT

Figure S-10



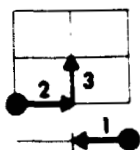
TIME - SECONDS
1 TURN LEFT

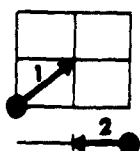
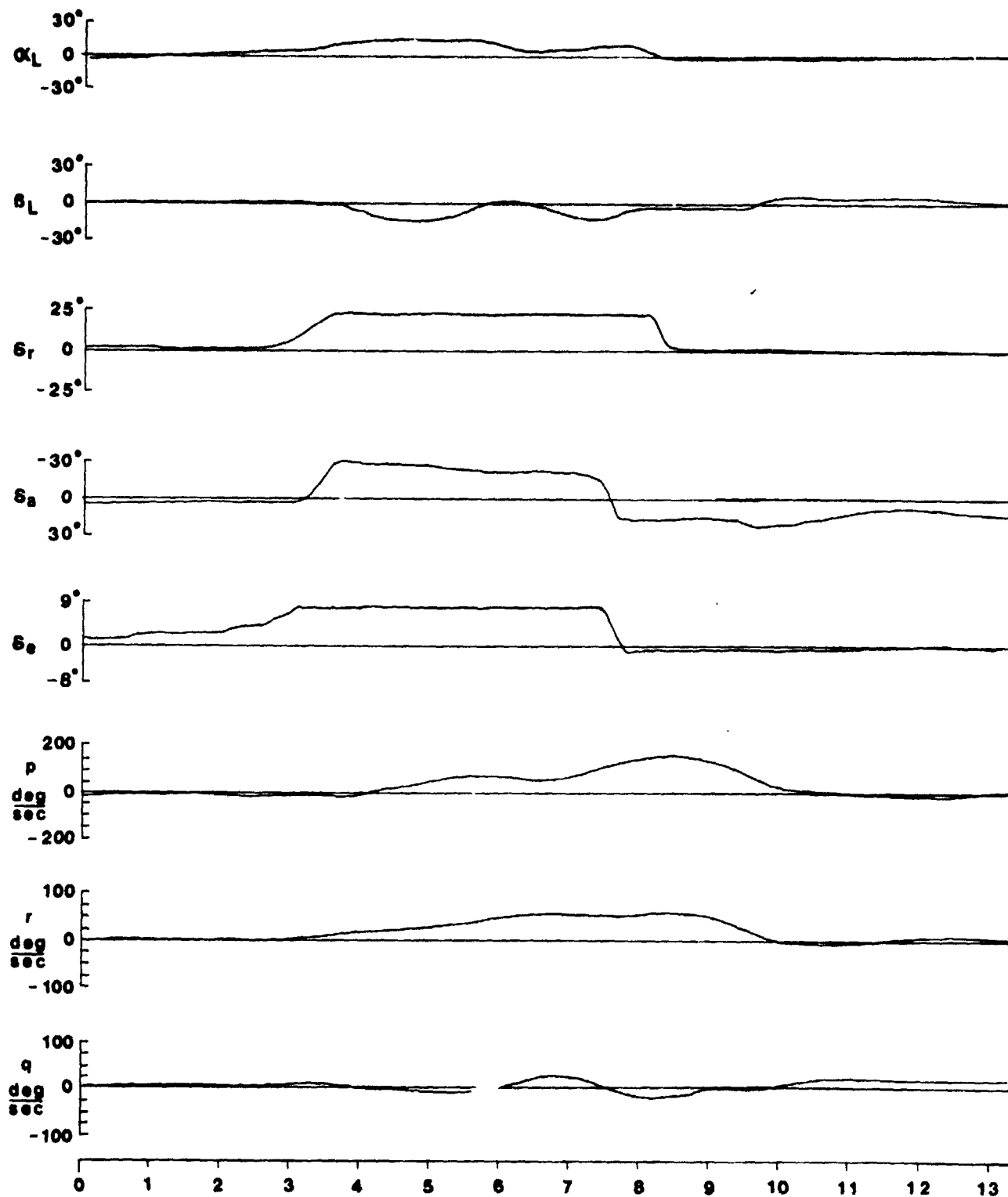
Figure S-11



TIME-SECONDS
 1 TURN RIGHT

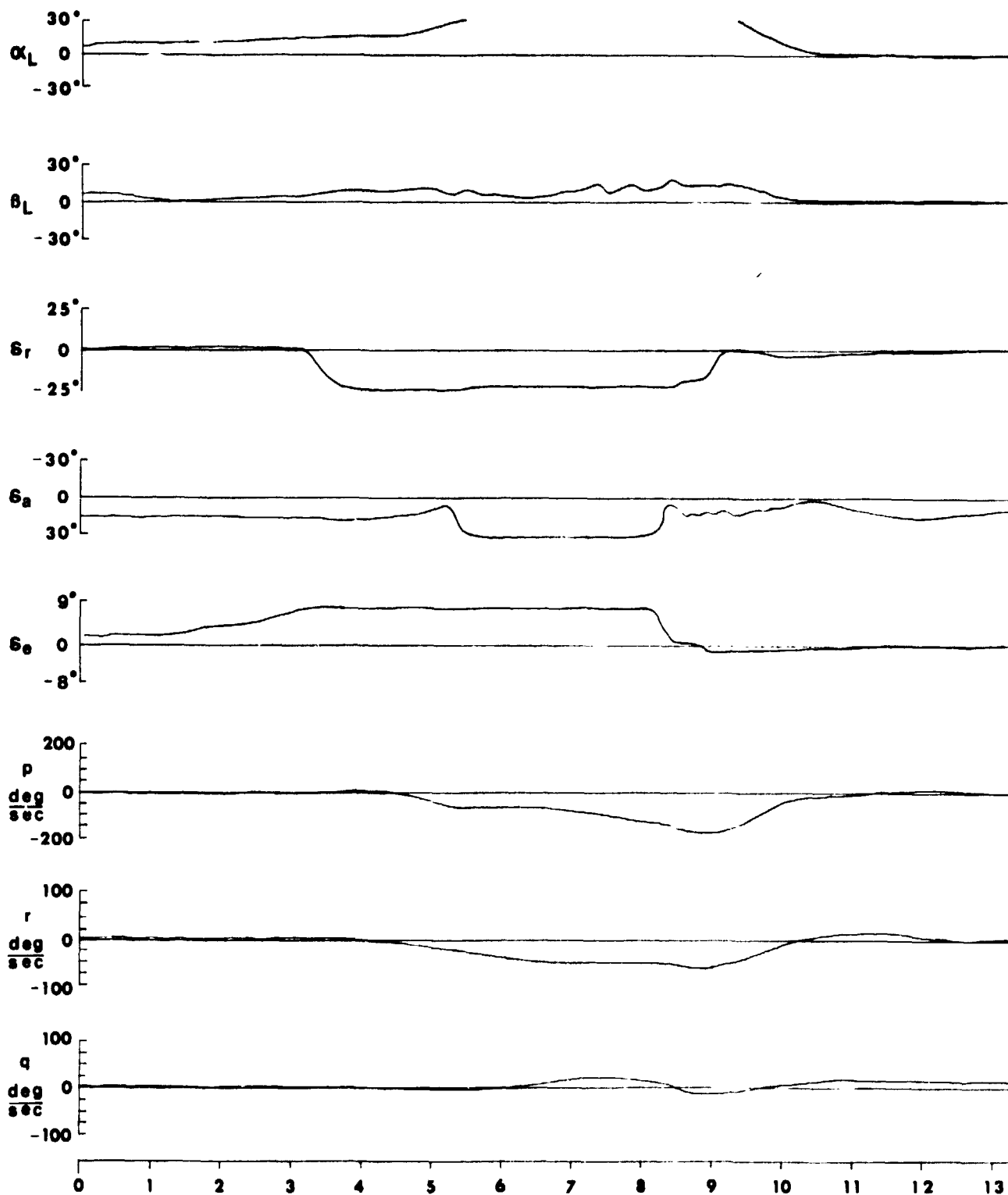
Figure S-12





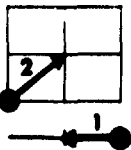
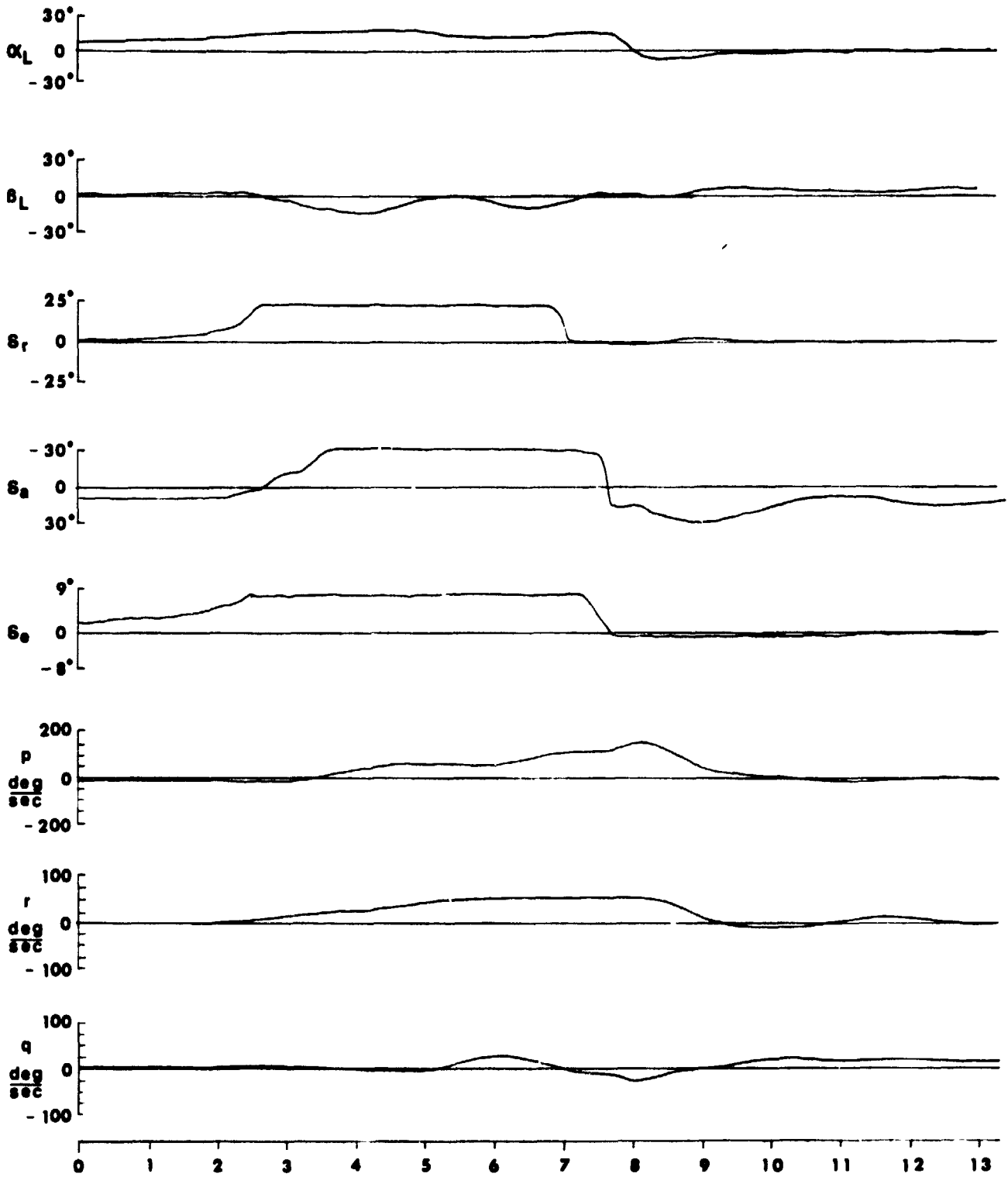
TIME - SECONDS
1 TURN RIGHT

Figure S-13



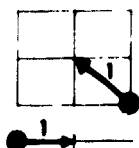
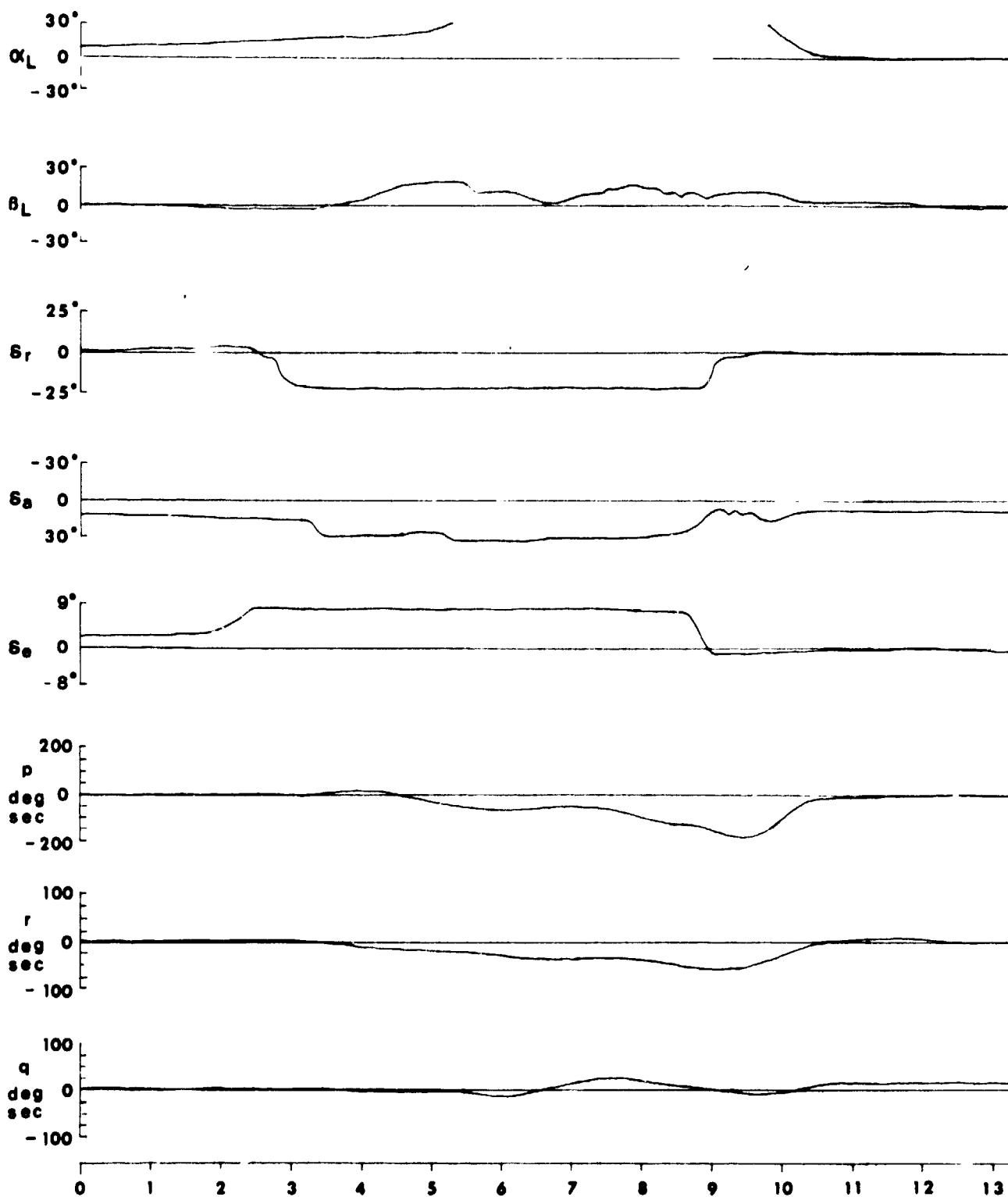
TIME-SECONDS
1 TURN LEFT

Figure S-14



TIME-SECONDS
1 TURN RIGHT

Figure S-15



TIME-SECONDS
1 TURN LEFT

Figure S-16

FILM DATA SECTION

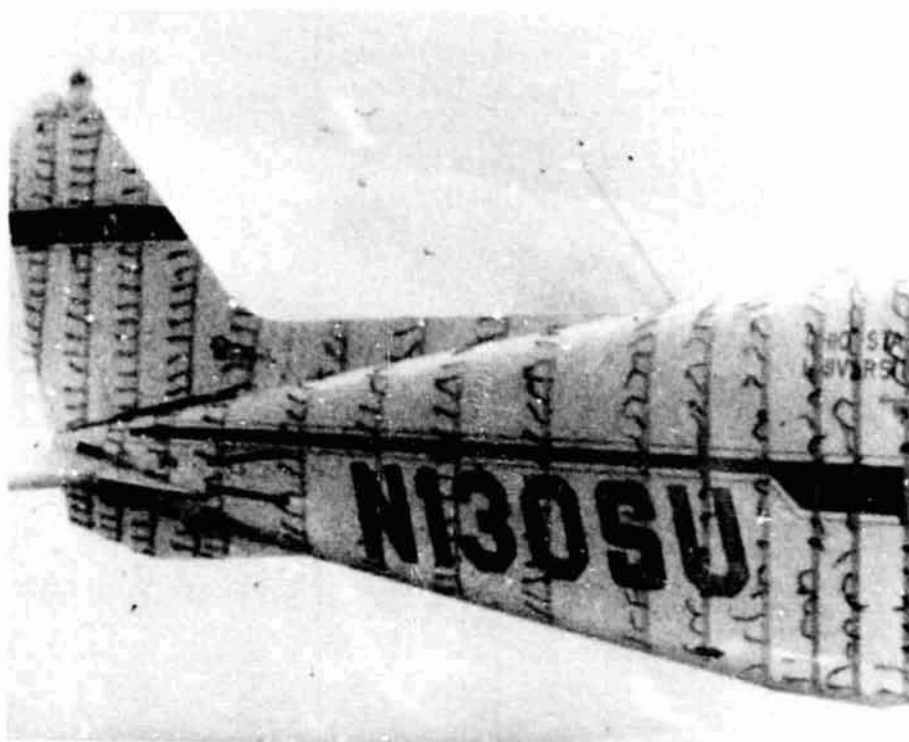


Figure F-1. - Pre stall.

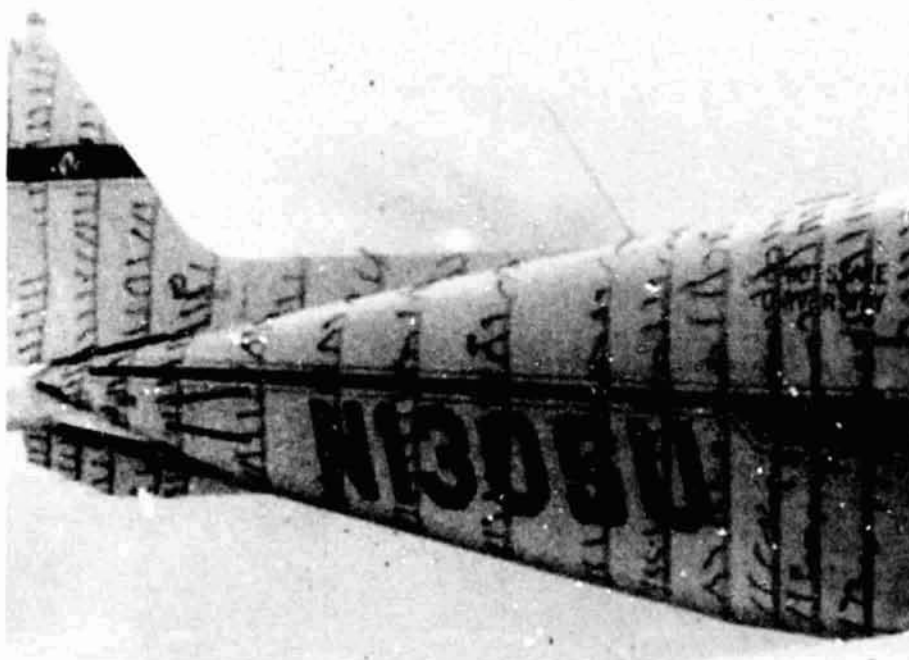


Figure F-2. - Post stall.

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR



Figure F-3. - Left spin.

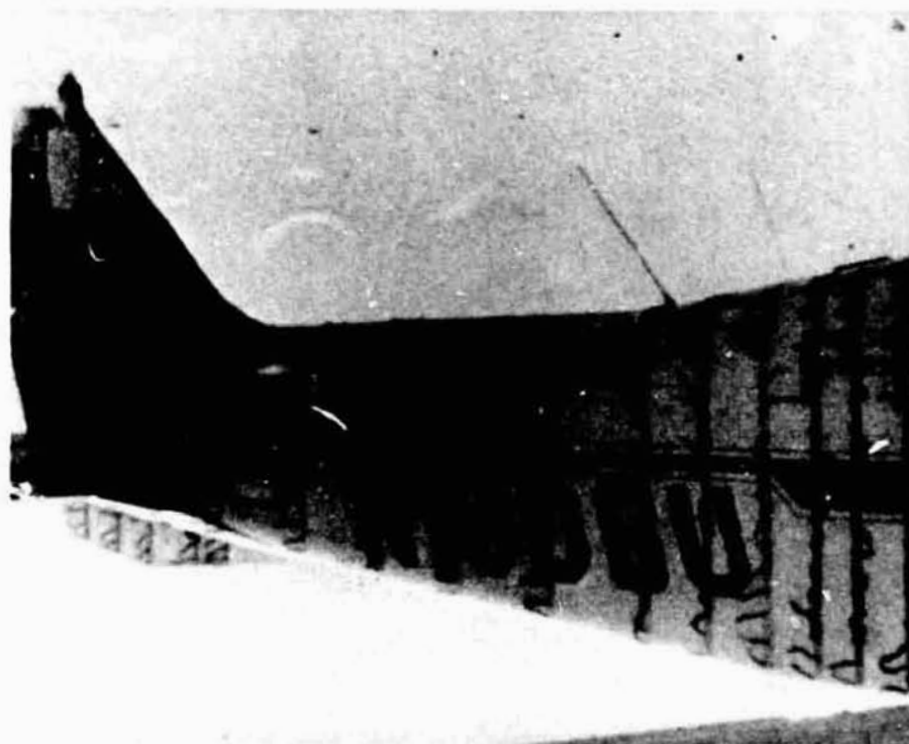


Figure F-4. - Right spin.