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ROLL UTILIZATION OF AN F-100A AIRPLANE DURING

SERVICE OPERATIONAL FLYING

By Gene J. Matranga

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NATIONAL AERONAUTICS AND
SPACE ADMINISTRATION
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SUMMARY

As a means of evaluating the roll utilization of a fighter airplane capable of supersonic speeds, an instrumented North American F-100A fighter airplane was flown by U. S. Air Force pilots at Nellis Air Force Base, Nev., during 20 hours of service operational flying. Mach numbers up to 1.22 and altitudes up to 50,000 feet were realized in this investigation.

Results of the study showed that except for high g barrel rolls performed as evasive maneuvers and rolls performed in acrobatic flying, rolling was utilized primarily as a means of changing heading. Acrobatic and air combat maneuvering produced the largest bank angles ($1,200^\circ$), roll velocities (3.3 radians/sec), rolling accelerations (8 radians/sec^2), and sideslip angles (10.8°). Full aileron deflections were utilized on numerous occasions. Although high rolling velocities and accelerations also were experienced during several air-to-air gunnery missions, generally, air-to-air gunnery and air-to-ground gunnery and bombing required only two-thirds of maximum aileron deflection. The air-to-air gunnery and air combat maneuvers initiated from supersonic speeds utilized up to two-thirds aileron deflection and bank angles of less than 180° and resulted in rolling velocities and accelerations of 2 radians per second and 4.6 radians per second^2, respectively. Rolling maneuvers were often initiated from high levels of normal acceleration, but from levels of negative normal acceleration only once.

INTRODUCTION

To aid in the development of more realistic design criteria for future aircraft the National Aeronautics and Space Administration, in cooperation with the U. S. Air Force and the Bureau of Aeronautics (Department

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[*]Title, Unclassified.

of the Navy), has conducted a series of flight programs wherein completely instrumented airplanes were placed in service squadron operation and the utilization of the airplanes was evaluated. The results of a program of this type are published in reference 1.

To obtain comparable data for an airplane capable of sustained supersonic speeds, an F-100A airplane was completely instrumented by the NASA High-Speed Flight Station, at Edwards, Calif., and was stationed at Nellis Air Force Base, Nev., where it was flown by Air Force pilots during several phases of combat fighter training. Some results of this investigation, including a summary of roll characteristics, are presented in reference 2.

In this paper the detailed effects of flight missions such as air combat maneuvering, air-to-air gunnery, air-to-ground gunnery and bombing, and acrobatic flights on the rolling characteristics of the F-100A are discussed to furnish data for the continuing study of roll requirements. Also, the rolling characteristics of the airplane at subsonic speeds and at supersonic speeds are compared.

SYMBOLS

a_l	longitudinal acceleration, g units
a_n	normal acceleration, g units
a_t	transverse acceleration, g units
g	acceleration due to gravity, ft/sec^2
h_p	pressure altitude, ft
i_t	stabilizer deflection, deg
M	Mach number
p	rolling velocity, radians/sec
$\dot{p}$	rolling acceleration, radians/sec^2
q	pitching velocity, radians/sec
$\dot{q}$	pitching acceleration, radians/sec^2
r	yawing velocity, radians/sec

$\dot{r}$ yawing acceleration, radians/sec^2

t time, sec

V_e equivalent airspeed, knots

α angle of attack, deg

β angle of sideslip, deg

δ_a total aileron deflection, deg

δ_r rudder deflection, deg

δ_s slat deflection, percent full open deflection

$\Delta\varphi$ change in angle of bank, deg

AIRPLANE

The F-100A is a single-place, single-engine, fighter-type airplane having a low, swept wing and low, swept horizontal tail. The 45° swept wing is characterized by midsemispan ailerons and free-floating leading-edge slats. A J57-P21 turbojet engine with afterburner powers the airplane. All control surfaces are actuated by an irreversible hydraulic system.

A three-view drawing and a photograph of the airplane are shown in figures 1 and 2, respectively. The physical characteristics are presented in table I.

The airplane is equipped with a yaw damper; however, the damper was inoperative during most of the tests because of repeated malfunctions.

INSTRUMENTATION

The following quantities pertinent to this investigation were recorded on NACA internal recording instruments synchronized by means of a common timer:

     Airspeed and altitude
     Aileron, rudder, and stabilizer position
     Slat position

Transverse, normal, and longitudinal acceleration
Roll, yaw, and pitch velocity and acceleration
Angle of attack and sideslip

The airspeed and altitude were measured with an NACA pitot-static tube mounted on the airplane nose boom. The airspeed system was calibrated in flight and is considered accurate to $M = \pm 0.01$ subsonically and supersonically, and to $M = \pm 0.02$ transonically. Also on the nose boom were free-floating vanes used to measure angle of attack and angle of sideslip. The angular velocities and accelerations were referenced to the body axis of the airplane. Change in bank angle was obtained by integrating the roll-velocity data and is accurate to $\pm 10^\circ$. The accelerometer for measuring normal, longitudinal, and transverse accelerations was mounted in the plane of symmetry forward and above the airplane center of gravity.

To relieve the pilot of any recording-instrument-switching procedure, a microswitch attached to the nosegear scissors initiated data recording as the nosewheel lifted off. Recording was terminated by actuation of the microswitch at nosegear touchdown. Several flights were of longer time duration than film time available, so the latter portions of these flights could not be recorded.

TESTS

A total of 32 flights (approximately 20 hours of flight time) were performed with the airplane by Air Force pilots at Nellis Air Force Base, Nev., during the combat training programs of the 3595th Combat Crew Training Group (Fighter) and the USAF Fighter Weapons School. The missions flown encompassed air combat maneuvering (which simulated the mission of an air-superiority fighter); air-to-air gunnery (which simulated an interceptor); air-to-ground gunnery and bombing, including toss bombing, dive bombing, and rocket deliveries (which simulated a fighter bomber); and acrobatic-type maneuvering. The air-to-ground bombing and rocket deliveries were feigned because of the limited weapons system capability of the F-100A airplane. Altitudes up to 50,000 feet and Mach numbers up to 1.22 were recorded during the course of this investigation. The only deviations from the Nellis AFB training syllabus were the maneuvers performed at, or initiated from, supersonic speeds. To conserve fuel and thereby prolong flight duration, the training syllabus did not include supersonic maneuvering. However, to provide maneuvering information throughout the flight envelope, maneuvers at supersonic speeds were requested and were obtained in air combat maneuvering and air-to-air gunnery flights.

During the course of this investigation the airplane was flown by 18 pilots; two pilots had as many as four flights in the airplane. Normally, all pilots were equipped with g-suits, so motions were readily performed at all usable g levels.

RESULTS AND DISCUSSION

The presentation of data is divided into three sections. The data are discussed first by type of mission and include data at all speeds. An examination of the maneuvers performed at supersonic speeds follows. Finally, a comparison is made of the types of missions flown.

When examining the data, it should be realized that the values presented on the plots are the peak values occurring during any given maneuver, and all the peak values do not necessarily occur simultaneously. The exceptions to this statement are the values of normal acceleration presented; these data are the values at the initiation of each maneuver.

Types of Missions

Air combat maneuvers.- Plots of pertinent airplane characteristics in roll for air combat maneuvers are presented as a function of equivalent airspeed in figure 3, as a function of rolling velocity in figure 4, and as a function of total aileron deflection in figure 5.

From these plots several observations can be made. Full aileron deflections were used occasionally at all speeds for the air combat maneuvers. The large bank angles attained in some flights increased as speed and rolling velocity increased. Several relatively large sideslip angles were attained with correspondingly low values of rolling velocity (fig. 4(c)) as a result of combined maneuvers and, therefore, were not induced solely by roll. Peak values of rolling velocity, rolling acceleration, and angle of sideslip generally increased with increasing aileron deflection. Also showing the effects of combined maneuvers were the appreciable values of rolling accelerations which accompanied the use of little or no aileron deflection. The use of the rudder to supplement or supplant the aileron for rolling power accounts for many of these points. A time history of an extreme evasive maneuver is shown in figure 6. At about 9 seconds the wing was in the stall region and a roll-off to the left was experienced, despite the accompanying left sideslip and the application of rudder and aileron against the roll. The pilots used such maneuvers occasionally in an attempt to evade a pursuer, and these maneuvers were generally successful.

The rolling maneuvers at times were initiated from appreciable values of normal acceleration $(a_n > 4)$; however, one instance was recorded where the roll was initiated from a negative g condition.

Air-to-air gunnery.- The pertinent airplane characteristics in roll for air-to-air gunnery as functions of equivalent airspeed, rolling velocity, and total aileron deflection are illustrated in figures 7, 8, and 9, respectively.

During these maneuvers full aileron deflections were never used, and the maximum change of bank angle was in the neighborhood of 200°. The maximum recorded rolling acceleration of 6.7 radians/sec² was attained with a corresponding rolling velocity of 1.1 radians/sec in attempting to avoid collision with the tow target immediately after gun firing at close range. The most important observation from these data is that generally maximum or near maximum values of available rolling velocities were used for any aileron input (fig. 9(b)).

Air-to-ground gunnery and bombing.- Variations of airplane characteristics in roll for air-to-ground gunnery and bombing as functions of equivalent airspeed as well as rolling velocity and total aileron deflection are plotted in figures 10 and 11, respectively.

It is readily evident that relatively little rolling motion was required to perform the air-to-ground gunnery and bombing. The peak values experienced during these maneuvers were recorded during the dive bomb and toss bomb phase of the air-to-ground bombing flights. Another notable fact is that although the peak values of rolling velocity and rolling acceleration are small, they remain nearly constant throughout the speed range.

Acrobatics.- The airplane characteristics in roll for acrobatic flights as a function of equivalent airspeed, rolling velocity, and total aileron deflection are presented in figures 12, 13, and 14, respectively.

Even though the number of maneuvers performed was limited, it is evident that the acrobatic type of flying at times called upon the full capabilities of the airplane, and that the parameter variations essentially followed the same trends as were experienced during the air combat maneuvers.

Supersonic Maneuvering

Plots of significant rolling parameters as a function of rolling velocity and total aileron deflection are presented in figure 15 for maneuvers performed at supersonic speeds.

As was indicated in the TESTS section, the limited supersonic maneuvers were performed in the air combat maneuvering and air-to-air gunnery only and were included in the data presentations of figures 3 to 5 and 7 to 9. Bank angles utilized never exceeded 180° and the peak rolling rates were about 2.0 radians/sec. Rolling accelerations of 4.5 radians/sec² were experienced for the relatively small rolling velocities and aileron deflections used, and in several instances the maneuvers were initated from high g flight conditions.

Comparison of Types of Missions

Comparisons of the envelopes of airplane roll characteristics for air combat maneuvering, air-to-air gunnery, air-to-ground gunnery and bombing, and acrobatic maneuvers are presented in figure 16 as a function of equivalent airspeed. Corresponding characteristics as a function of rolling velocity and total aileron deflection for these maneuvers as well as the supersonic maneuvers are presented in figures 17 and 18, respectively.

From figure 16 it is evident that the air combat maneuvering and acrobatic flying produced the largest rolling angles, velocities, and accelerations; however, the recorded velocities always fell below the recommended peak velocities set forth in reference 3. Large rolling accelerations were also encountered in air-to-air gunnery flights. Peak bank angles for both the air-to-air and air-to-ground gunnery and bombing never exceeded 300°, and slightly more than two-thirds of available total aileron deflection usually sufficed for these maneuvers. The air combat maneuvers experienced the largest angles of sideslip, none of which were considered objectionable by the pilots. The maximum and minimum values of normal acceleration at the initiation of a rolling maneuver also were recorded in air combat maneuvers, although air-to-air gunnery passes sometimes were initiated from high values of normal acceleration.

From figures 17 and 18 it is evident that for given rolling velocities and aileron deflections, air-to-ground gunnery and bombing required the least rolling acceleration. Supersonic maneuvering, air-to-air gunnery, air combat maneuvering, and acrobatic flights produced increasingly more rolling acceleration, in that order.

It is of interest to note that the values of angle of sideslip recorded in this investigation are below the maximum values experienced on the same airplane during the roll coupling investigation reported in reference 4.

Rolling velocity as a function of aileron deflection shows that for any given aileron deflection, large values of rolling velocity were occasionally utilized in all types of maneuvers. However, for both the

air-to-air gunnery and supersonic maneuvers, for any given aileron deflection, only maximum and near maximum available rolling velocity was realized; whereas, for the other maneuvers in many instances small velocities were obtained with large deflections.

An important general observation, which may not have been readily obvious from the data presented, should be noted. With the exception of high g barrel rolls performed as an evasive maneuver and rolls performed in acrobatics, aileron was seldom used for the purpose of pure rolling. Rather, it was used to accomplish a combined maneuver, such as effecting a change in heading to evade a pursuing aircraft or to get on target during a tracking maneuver.

CONCLUSIONS

From the results of 32 flights (20 flight hours) performed during various types of simulated combat and training missions with an F-100A airplane at Nellis Air Force Base, Nev., it can be concluded that:

1. Except for high g barrel rolls performed as evasive maneuvers and rolls performed in acrobatic flying, rolling was utilized primarily as a means of changing heading.

2. Acrobatic and air combat maneuvering utilized the largest bank angles $(1,200^\circ)$, rolling velocities (3.3 radians per second), rolling accelerations (8 radians per second^2), and sideslip angles (10.8°). Full aileron deflection was used on numerous occasions for these maneuvers. Although high rolling velocities and accelerations also were experienced during several air-to-air gunnery missions, generally, air-to-air gunnery and air-to-ground gunnery and bombing required a maximum of only two-thirds aileron deflection.

3. The air-to-air gunnery and air combat maneuvers initiated from supersonic speeds employed rolling velocities of 2 radians per second and accelerations of 4.6 radians per second^2 on occasion, but a peak of only two-thirds aileron deflection was employed, and bank angles of less than 180° were generated.

4. The normal acceleration level at the initiation of rolling maneuvers was at high positive values on numerous occasions, but was at a negative value only once.

High-Speed Flight Station,
    National Aeronautics and Space Administration,
        Edwards, Calif., Sept. 17, 1958.

REFERENCES

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2. Pembo, Chris, and Matranga, Gene J.: Control Deflections, Airplane Response, and Tail Loads Measured on an F-100A Airplane in Service Operational Flying. NACA RM H58C26, 1958.

3. Anon.: Military Specification - Flying Qualities of Piloted Airplanes. MIL-F-8785(ASG), Amendment -2, Oct. 17, 1955.

4. Finch, Thomas W., Peele, James R., and Day, Richard E.: Flight Investigation of the Effect of Vertical-Tail Size on the Rolling Behavior of a Swept-Wing Airplane Having Lateral-Longitudinal Coupling. NACA RM H55L28a, 1956.

TABLE I

PHYSICAL CHARACTERISTICS OF AIRPLANE

Wing:
    Airfoil section . . . . NACA 64A007
    Total area (including ailerons and 83.84 sq ft
      covered by fuselage), sq ft 385.21
    Span, ft 38.58
    Mean aerodynamic chord, ft 11.16
    Root chord, ft 15.86
    Tip chord, ft 4.15
    Taper ratio 0.262
    Aspect ratio 3.86
    Sweep at 0.25 chord line, deg 45
    Incidence, deg 0
    Dihedral, deg 0
    Geometric twist, deg 0
    Aileron -
      Area rearward of hinge line (each), sq ft 19.32
      Span at hinge line (each), ft 7.81
      Chord rearward of hinge line, percent wing chord 25
      Travel (each), deg . . . . ±15
    Leading-edge slat -
      Span, equivalent, ft 12.71
      Segments 5
      Spanwise location, inboard end, percent
        wing semispan 23.3
      Spanwise location, outboard end, percent
        wing semispan 89.2
      Ratio of slat chord to wing chord (parallel to
        fuselage reference line), percent 20
      Rotation, maximum, deg 15

Horizontal tail:
    Airfoil section . . . . NACA 65A003.5
    Total area (including 31.65 sq ft covered by fuselage),
      sq ft 98.86
    Span, ft 18.72
    Mean aerodynamic chord, ft 5.83
    Root chord, ft 8.14
    Tip chord, ft 2.46
    Taper ratio 0.30
    Aspect ratio 3.54
    Sweep at 0.25 chord line, deg 45
    Dihedral, deg 0
    Travel, leading edge up, deg 5
    Travel, leading edge down, deg 25
    Control system . . . . Irreversible hydraulic boost and artificial feel

TABLE I - Concluded

PHYSICAL CHARACTERISTICS OF AIRPLANE

Vertical tail:
  Airfoil section . . . . NACA 65A003.5
  Area (excluding dorsal fin and area blanketed by
    fuselage), sq ft 42.7
  Area blanketed by fuselage (area between fuselage contour
    line and line parallel to fuselage reference line through
    intersections of leading edge of vertical tail and
    fuselage contour line), sq ft 2.45
  Span (unblanketed), ft 7.93
  Mean aerodynamic chord, ft 5.90
  Root chord, ft 8.28
  Tip chord, ft 2.49
  Taper ratio 0.301
  Aspect ratio 1.49
  Sweep at 0.25 chord line, deg 45
  Rudder -
    Area, rearward of hinge line, sq ft 6.3
    Span at hinge line, ft 3.33
    Root chord, ft 2.27
    Tip chord, ft 1.50
    Travel, deg . . . . ±20
    Spanwise location, inboard end, percent vertical-tail
      span 3.1
    Spanwise location, outboard end, percent vertical-tail
      span 44.8
    Chord, percent vertical-tail chord 28.4
    Balance . . . . Aerodynamic

Fuselage:
  Length (afterburner nozzle closed), ft 45.64
  Maximum width, ft 5.58
  Maximum depth over canopy, ft 6.37
  Side area (total), sq ft 230.92
  Fineness ratio (afterburner nozzle closed) 7.86

Speed brake:
  Surface area, sq ft 14.14
  Maximum deflection, deg 50

Power plant:
  Turbojet engine . . . . One Pratt & Whitney J57 with afterburner
  Thrust (guarantee sea level), afterburner, lb 15,000
  Military, lb 9,000

Airplane weight, lb:
  Basic (without fuel, oil, water, pilot) 20,262
  Total (full fuel, oil, water, pilot) 25,400

Center-of-gravity location, percent mean aerodynamic chord:
  Total weight - gear down 30.2
  Total weight - gear up 30.2
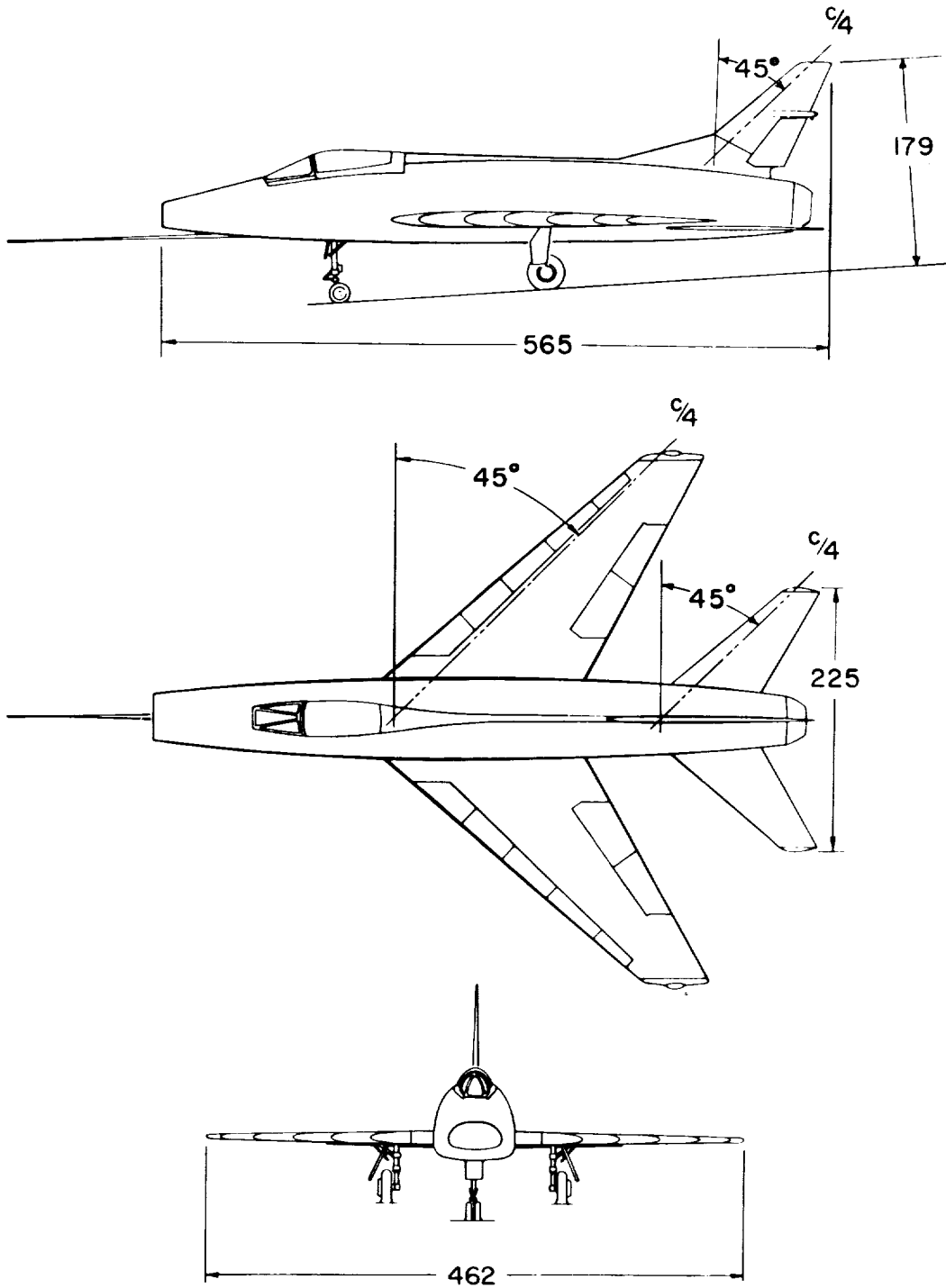
Figure 1.- Three-view drawing of the test airplane. All dimensions in inches.
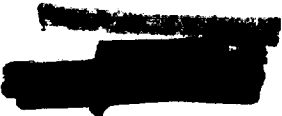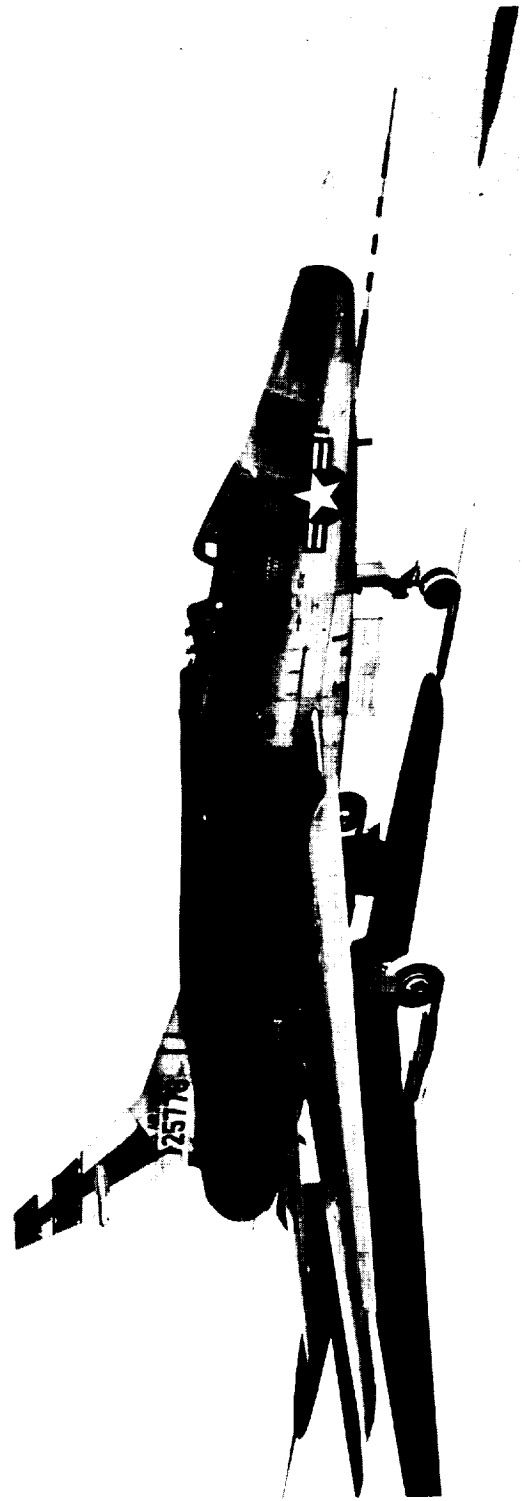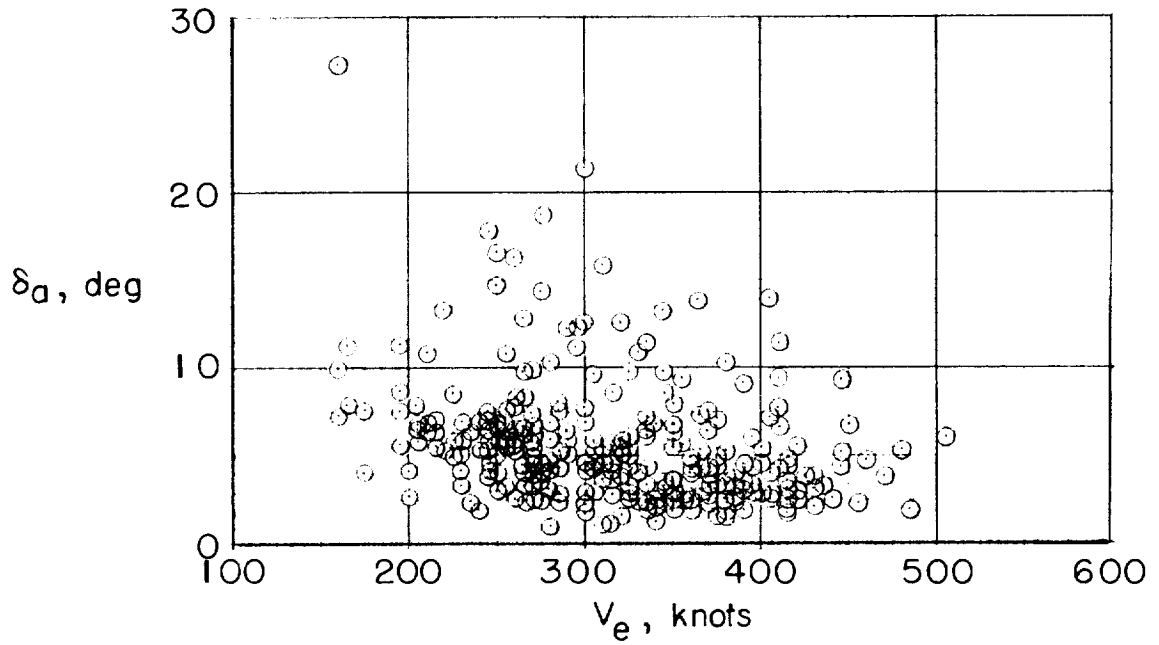
Figure 2.- Photograph of the airplane.   E-2097
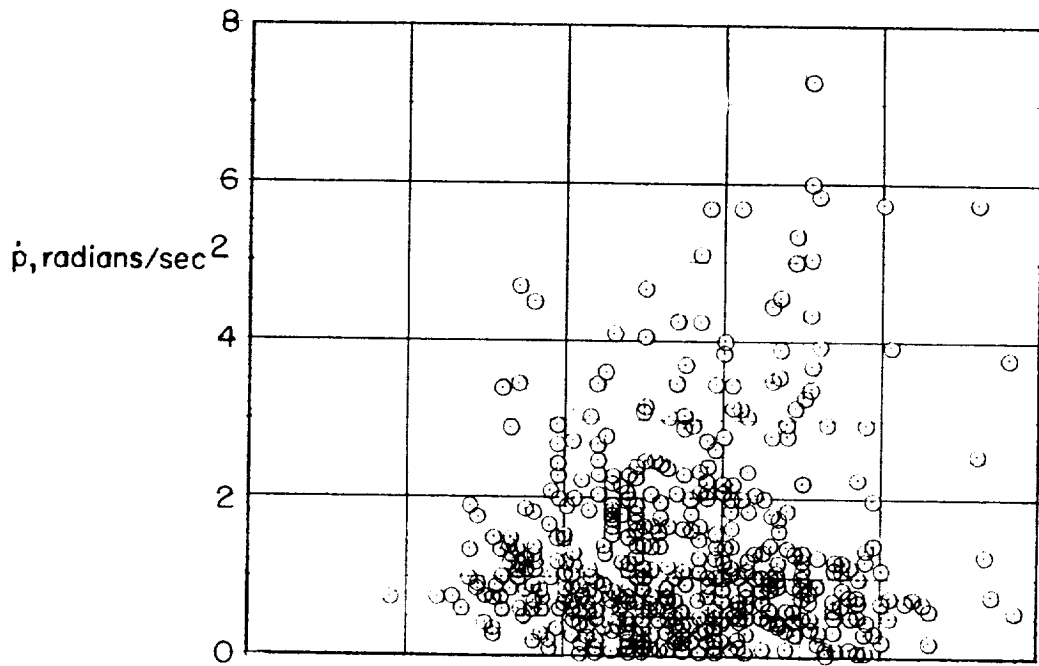
(a) Rolling acceleration.
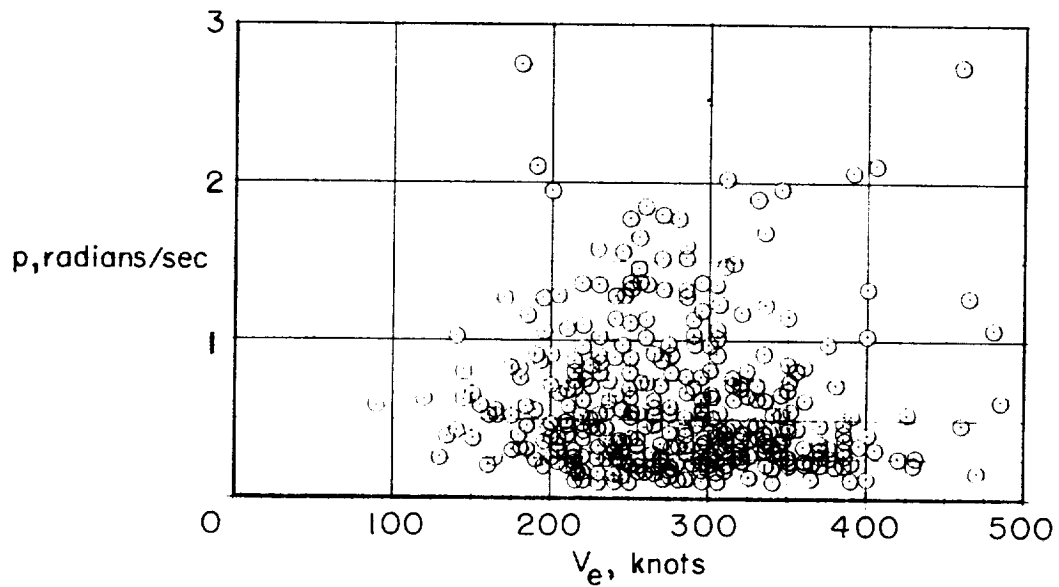
(b) Rolling velocity.

Figure 3.- Airplane characteristics in roll as a function of equivalent airspeed for air combat maneuvers.
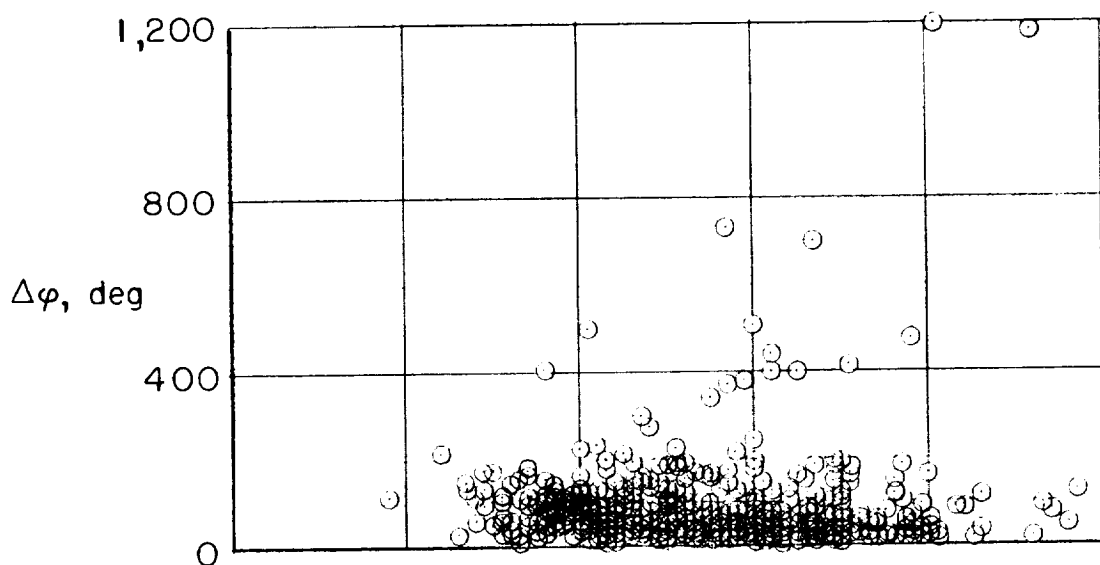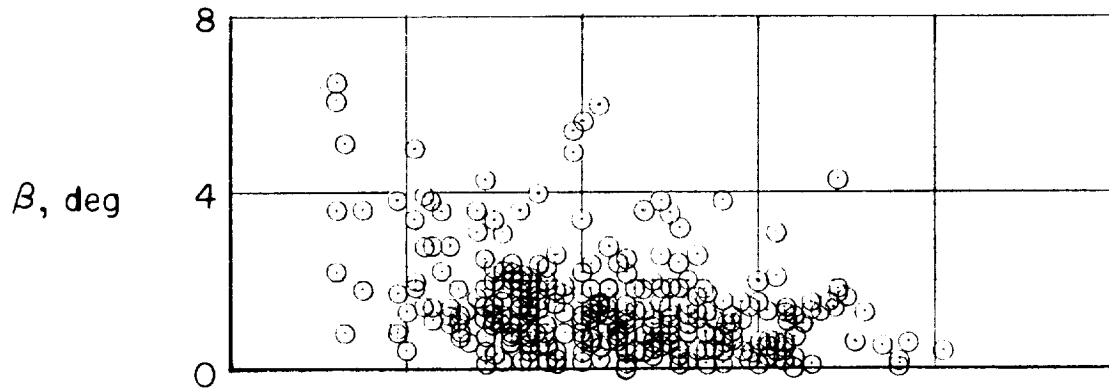
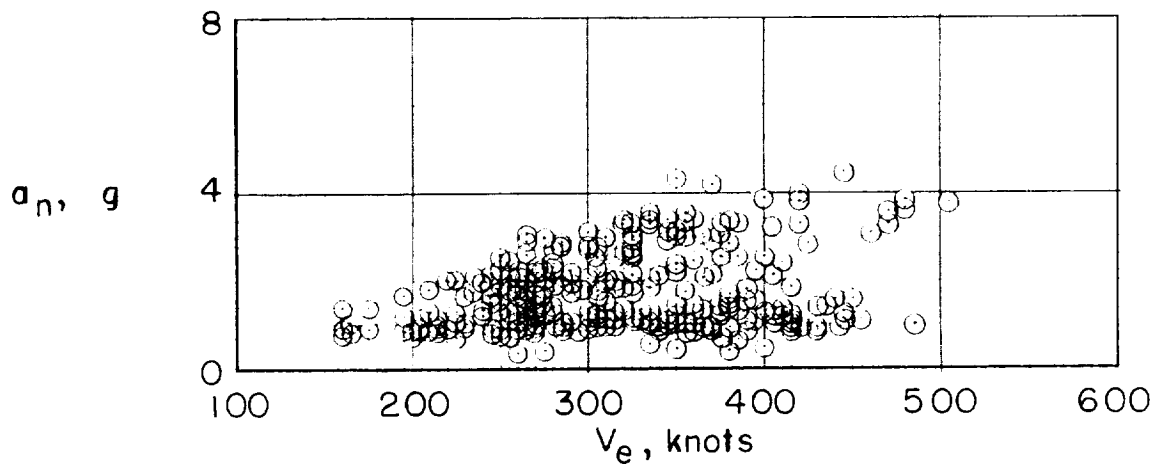(c) Change in angle of bank.
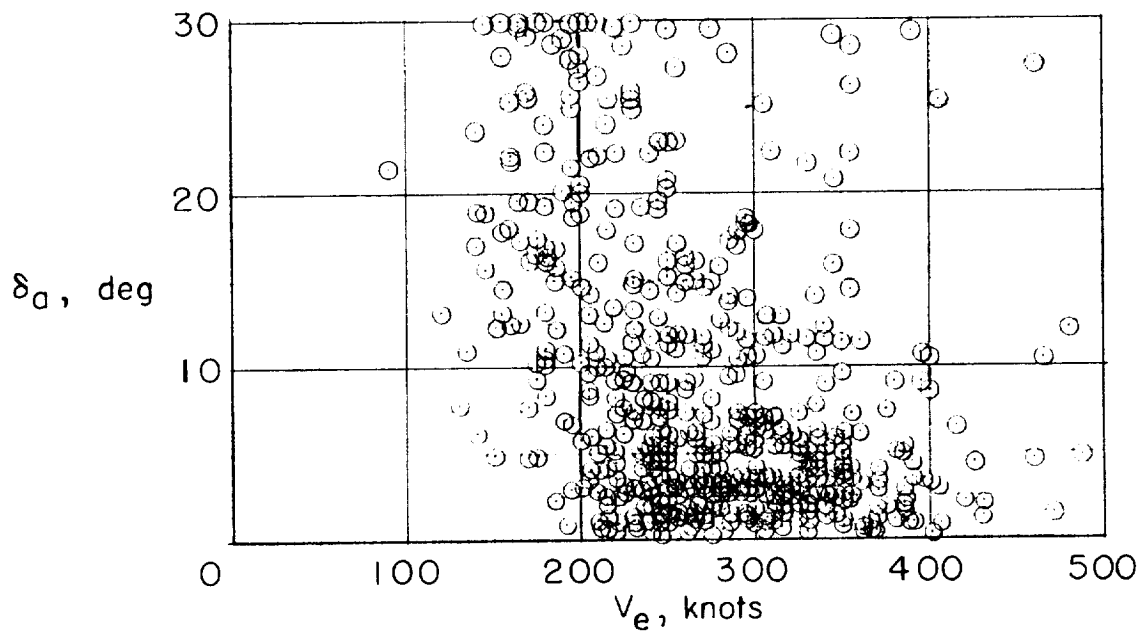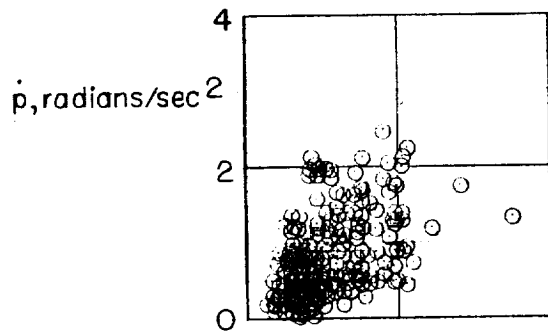

(d) Total aileron deflection.

Figure 3.- Continued.
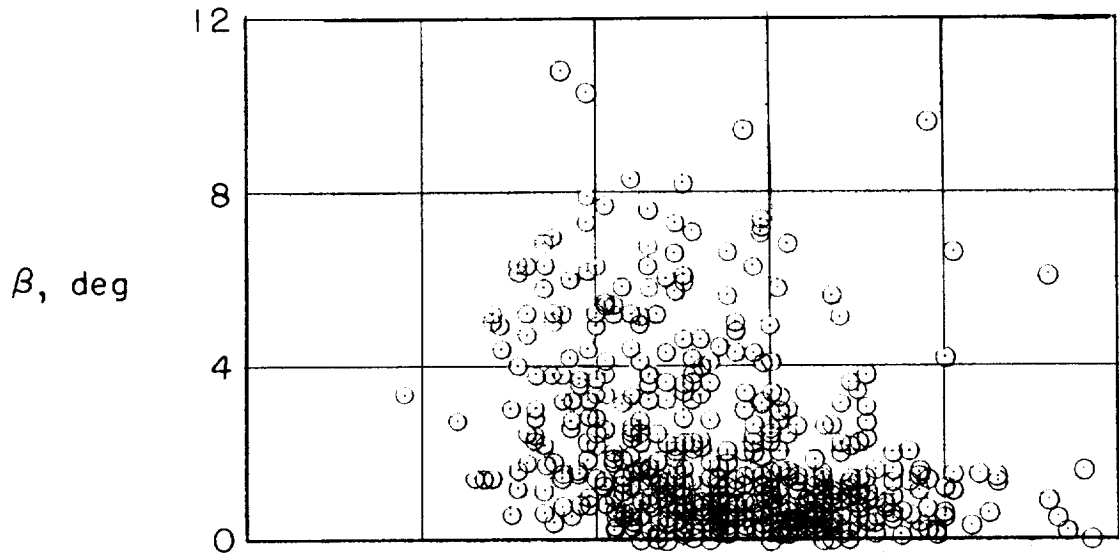
(e) Angle of sideslip.
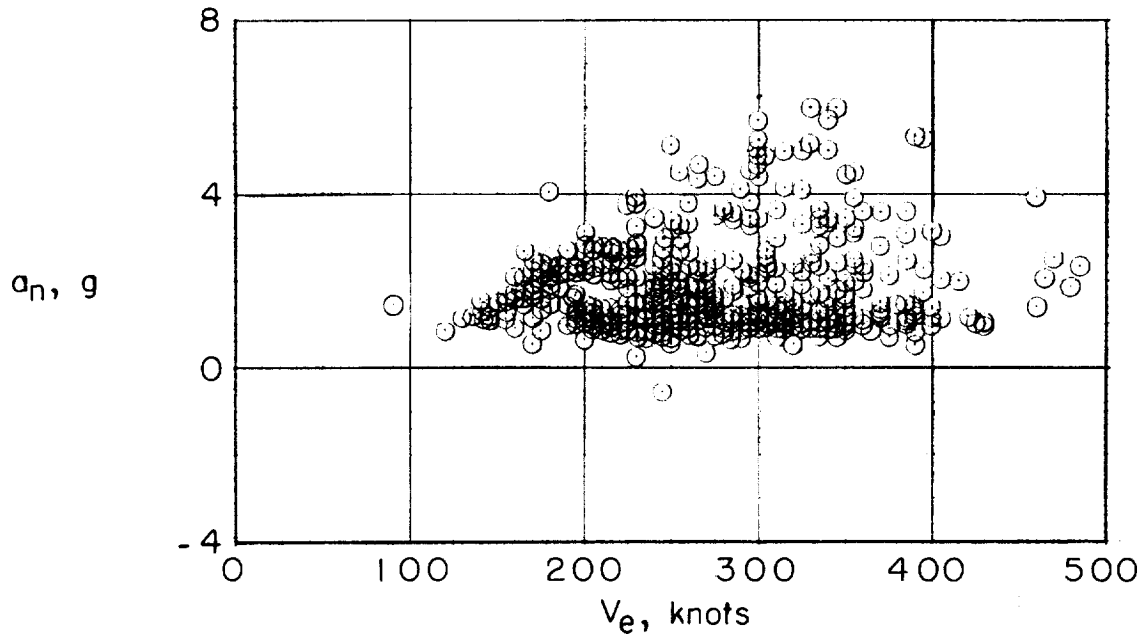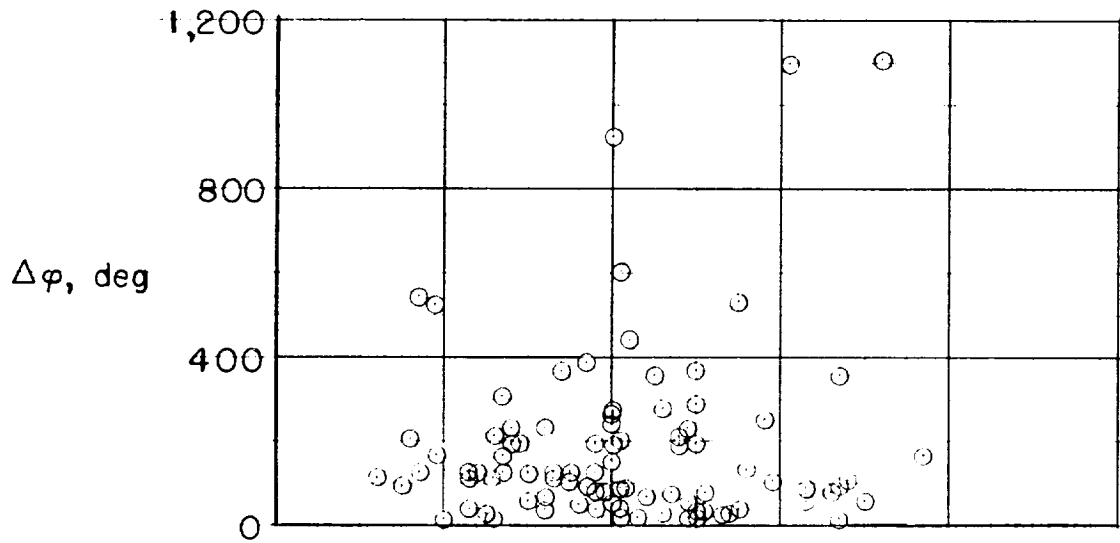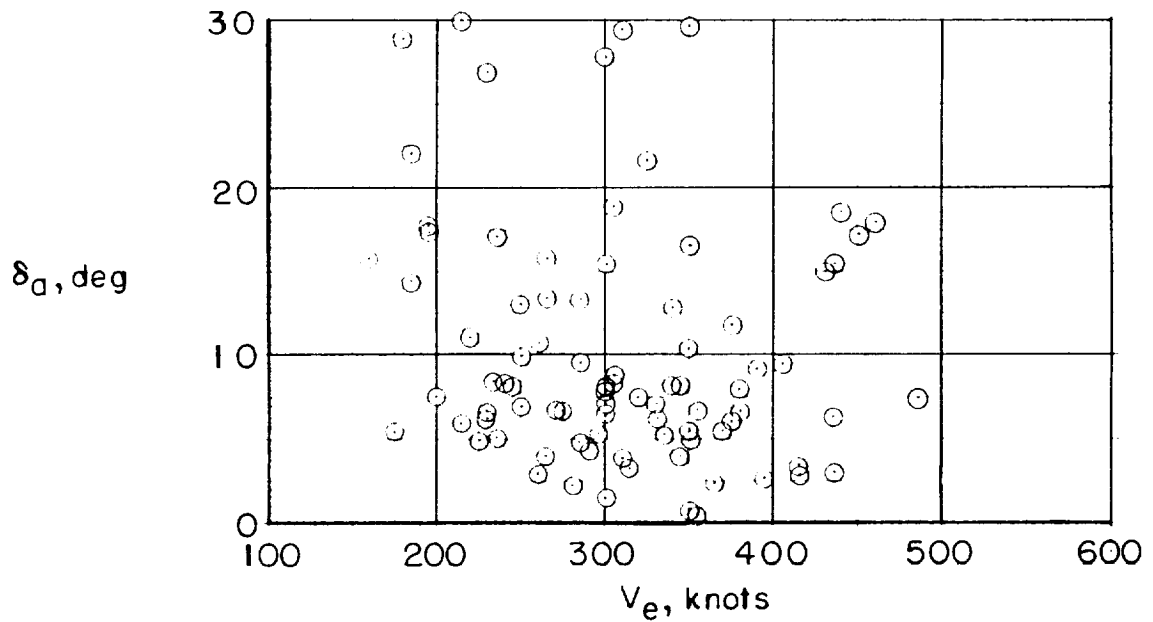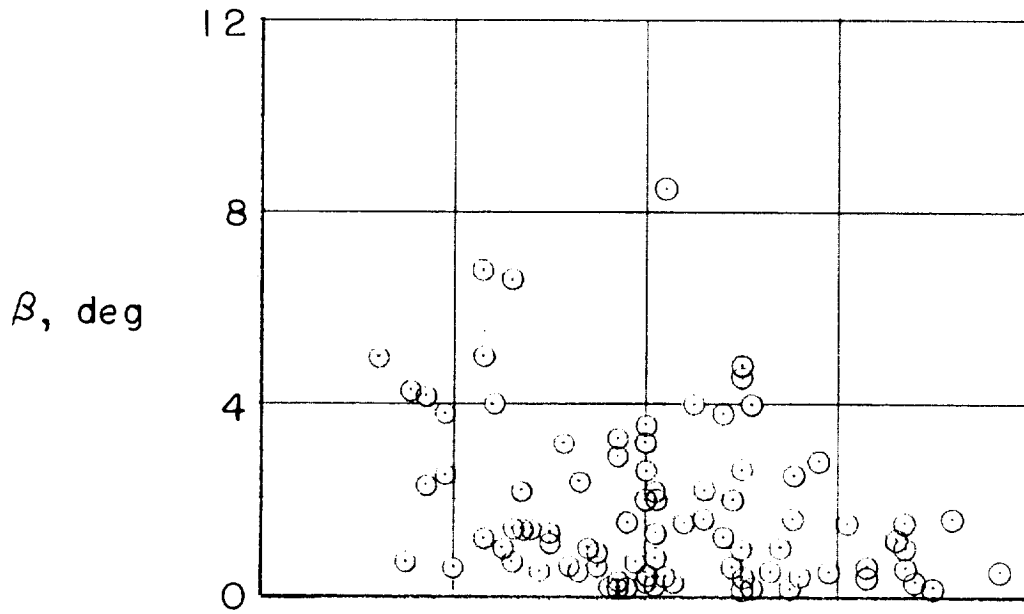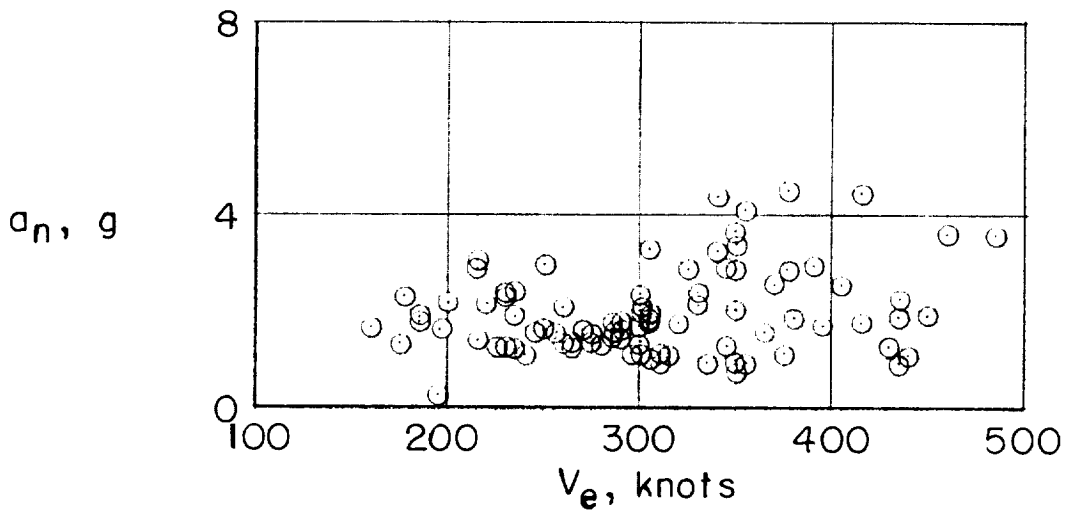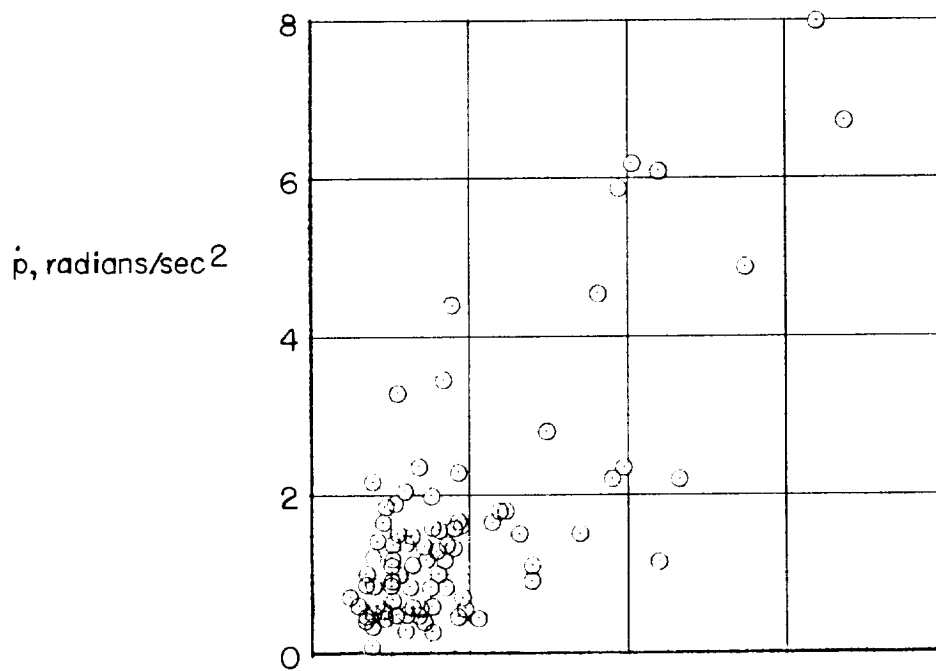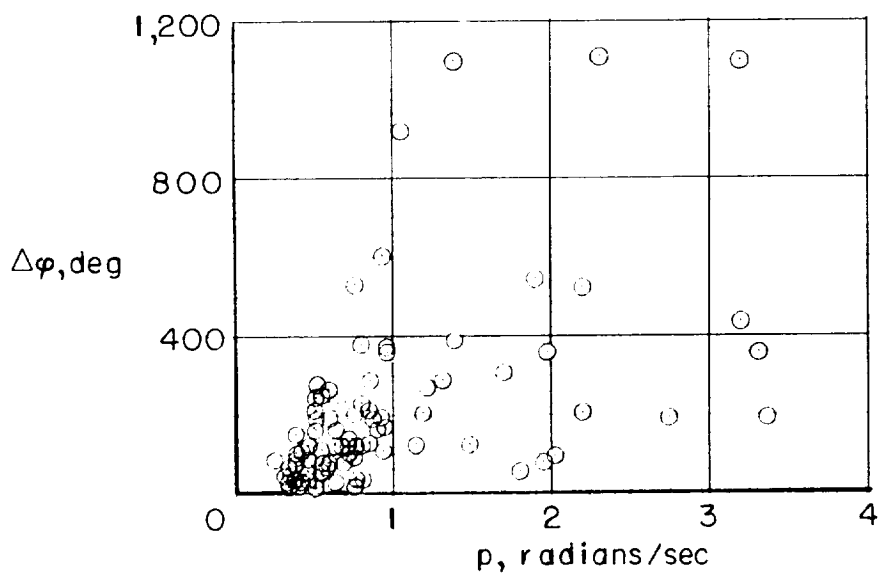

(f) Initial normal acceleration.
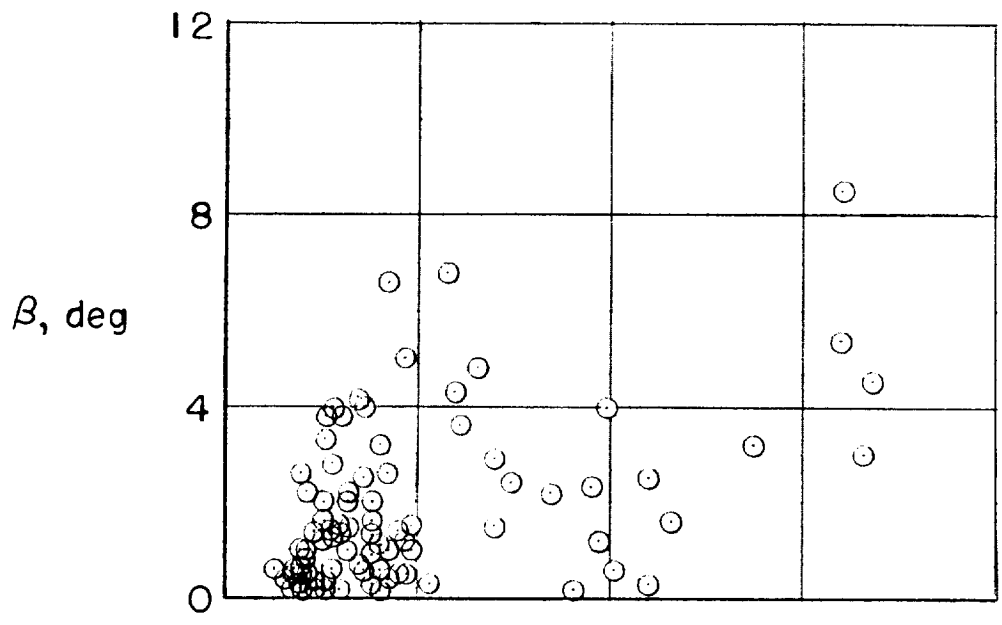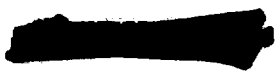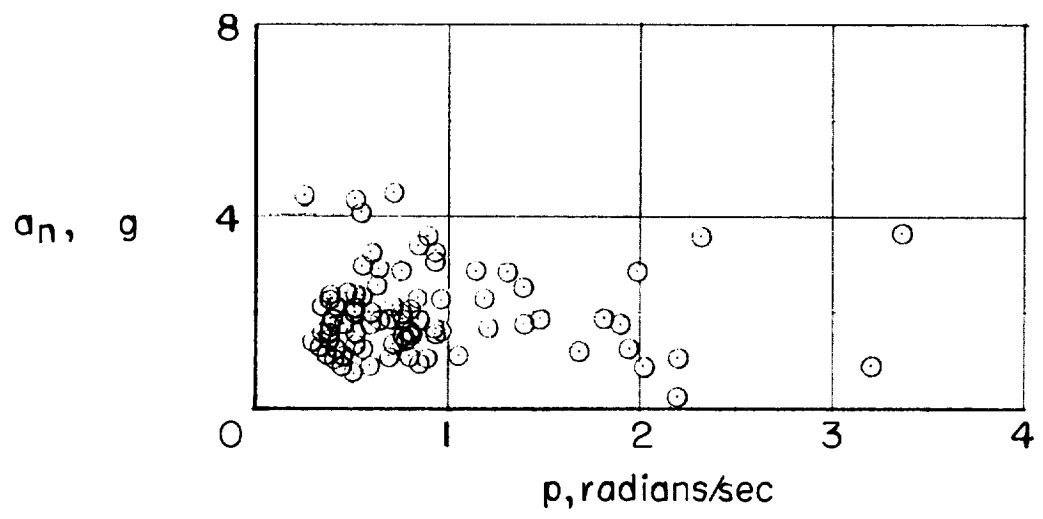
Figure 3.- Concluded.
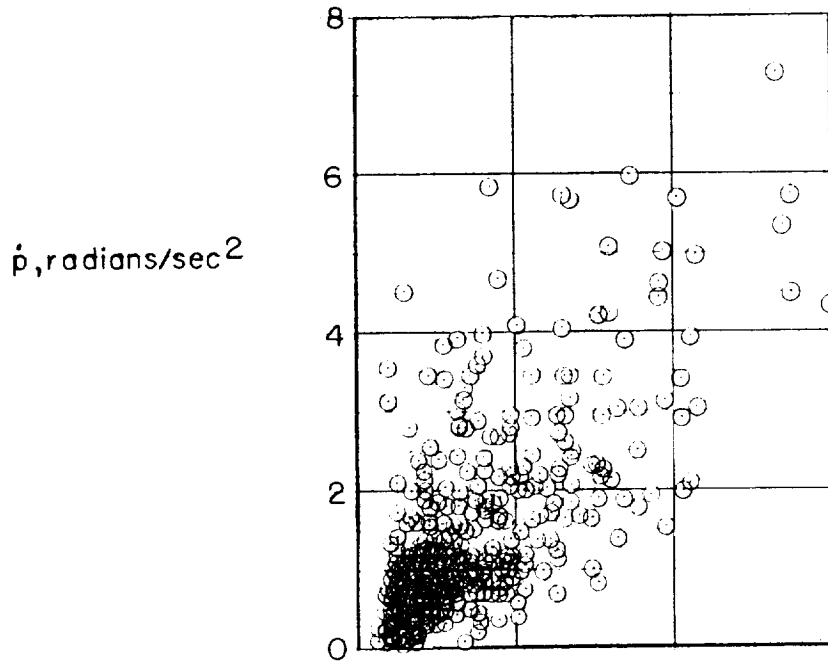
(a) Rolling acceleration.
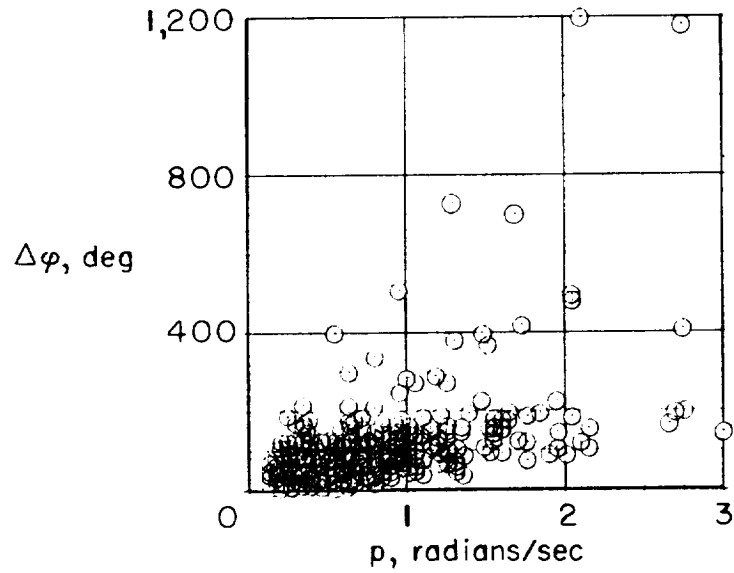
(b) Change in angle of bank.

Figure 4.- Airplane characteristics in roll as a function of rolling
velocity for air combat maneuvers.
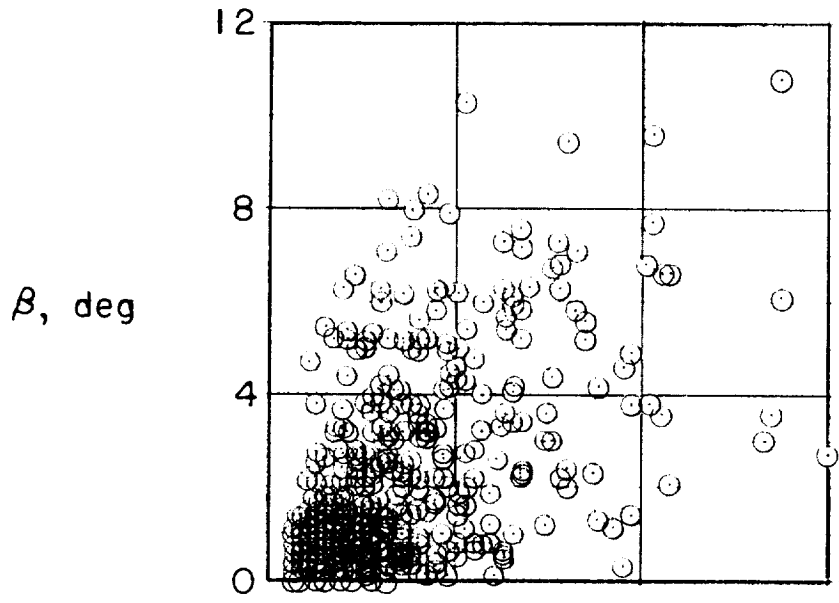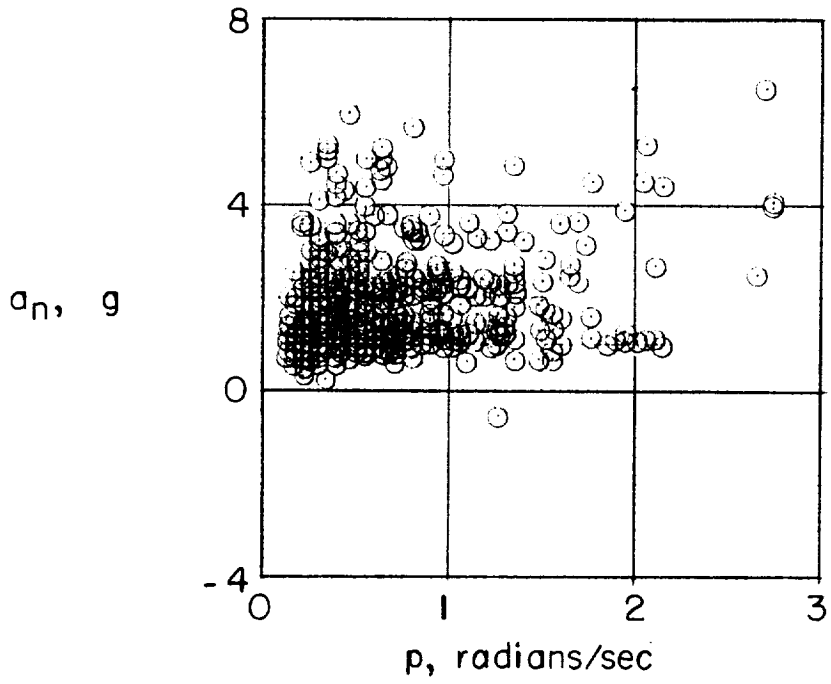
(c) Angle of sideslip.

(d) Initial normal acceleration.

Figure 4.- Concluded.

(a) Rolling acceleration.

$\dot{p}$, radians/sec^2 (y-axis of plot a)

p, radians/sec (y-axis of plot b)

δ_a, deg (x-axis)
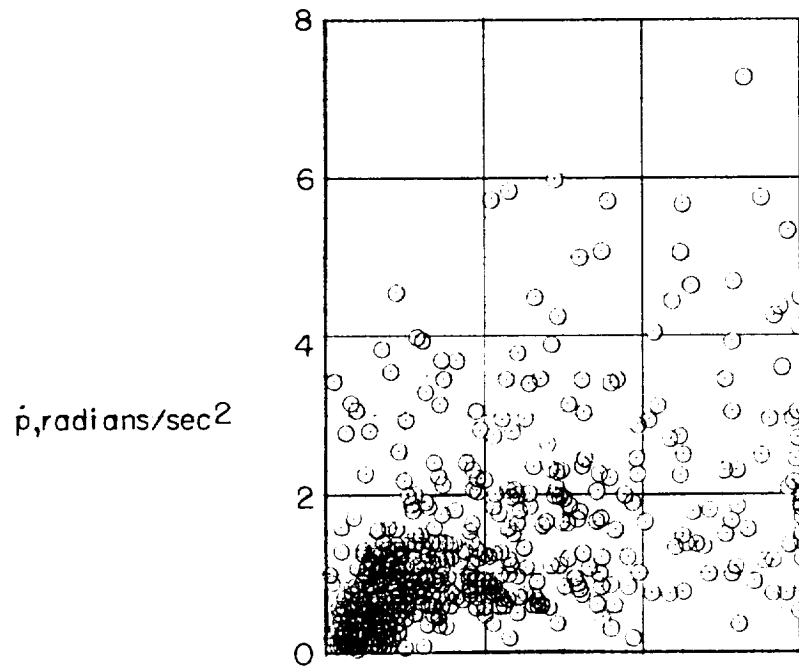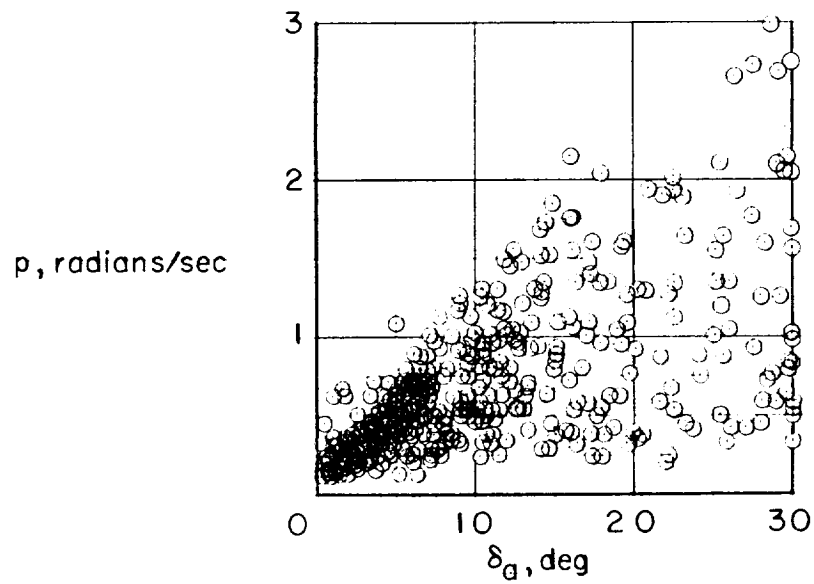
(b) Rolling velocity.

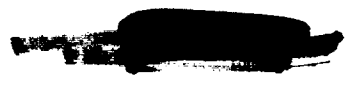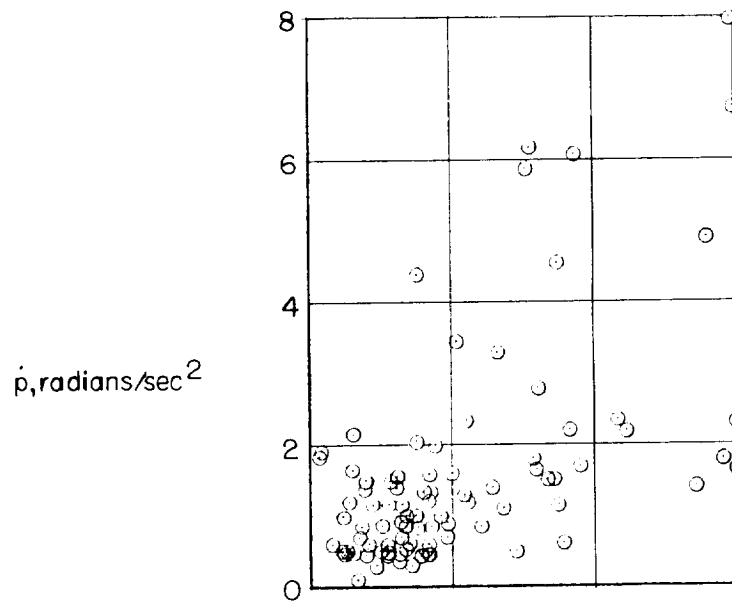Figure 5.- Airplane characteristics in roll as a function of total aileron deflection for air combat maneuvers.
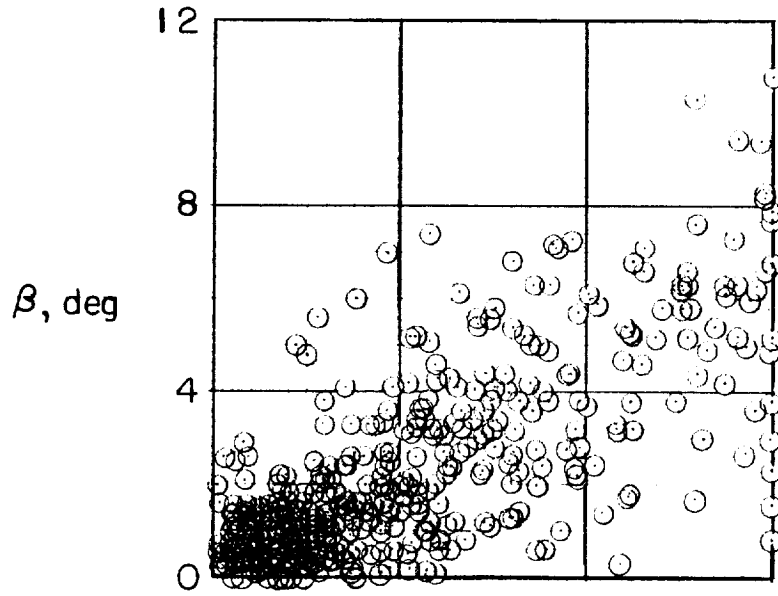
(c) Angle of sideslip.
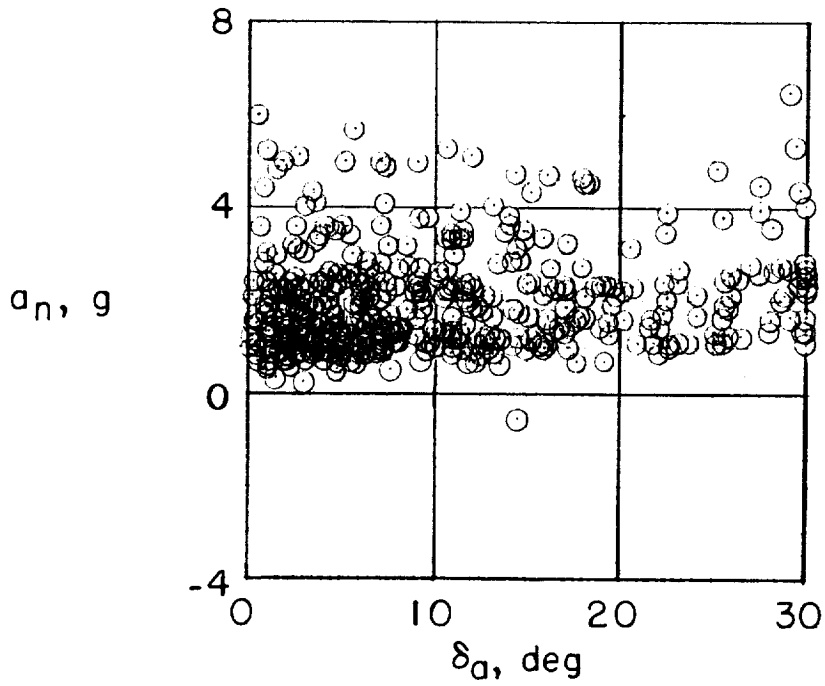
(d) Initial normal acceleration.

Figure 5.- Concluded.
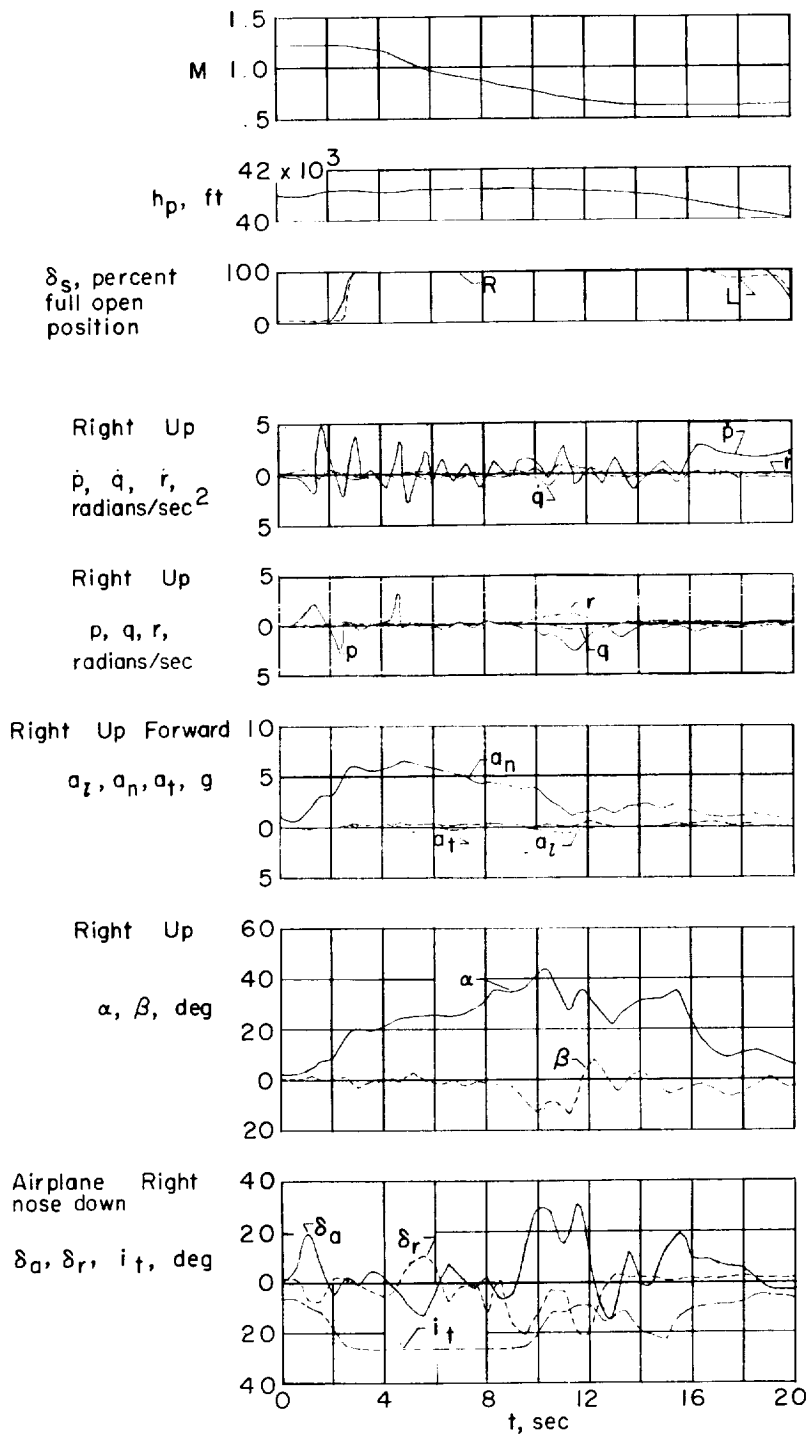
Figure 6.- Time history of an extreme evasive maneuver as performed in air combat maneuvers.
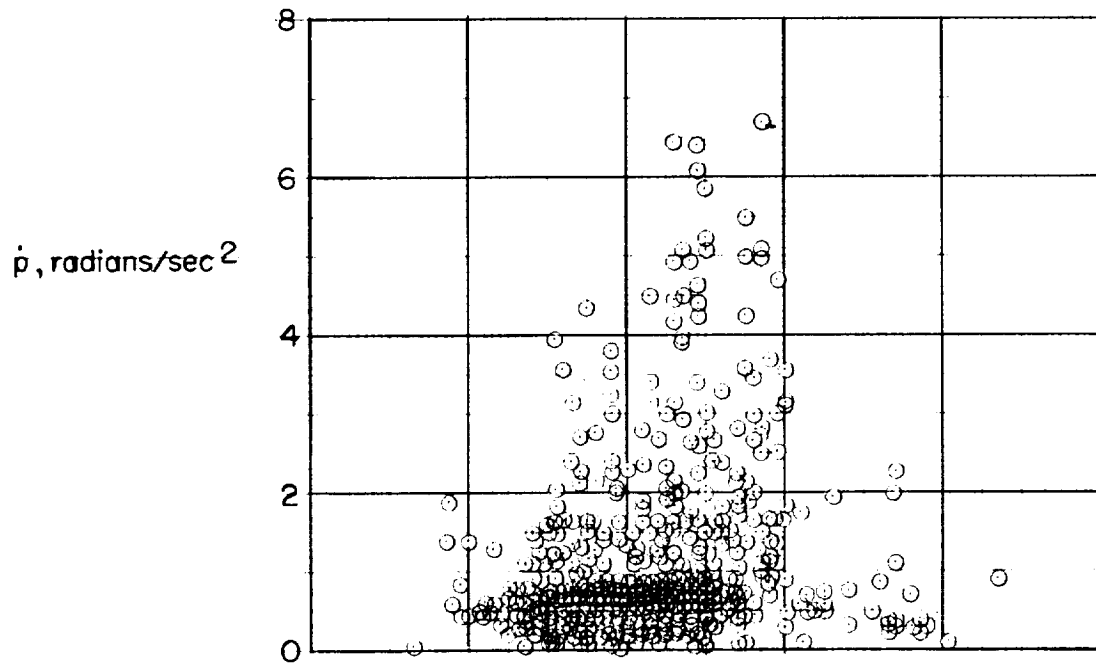
(a) Rolling acceleration.
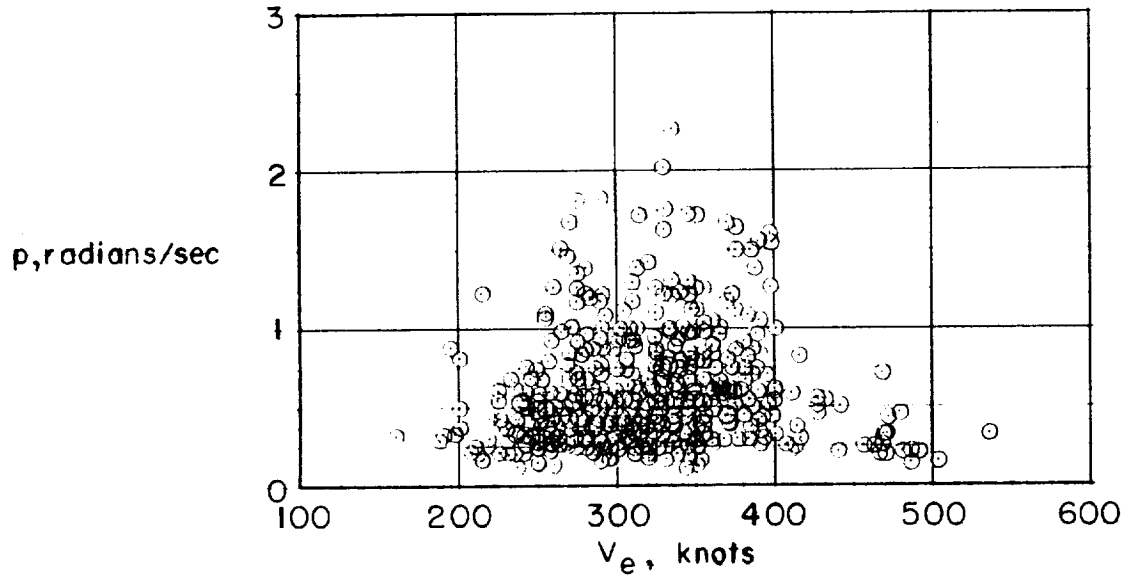
(b) Rolling velocity.

Figure 7.- Airplane characteristics in roll as a function of equivalent airspeed for air-to-air gunnery maneuvers.
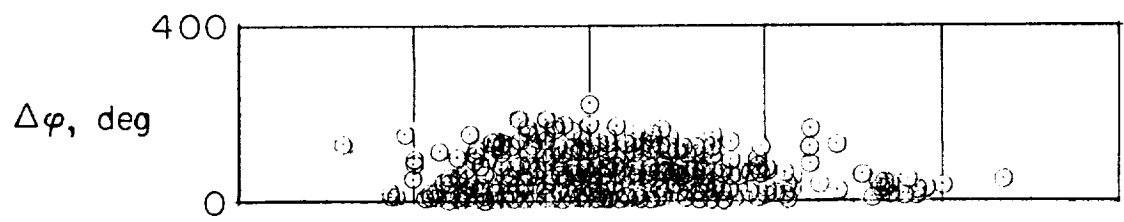
(c) Change in angle of bank.
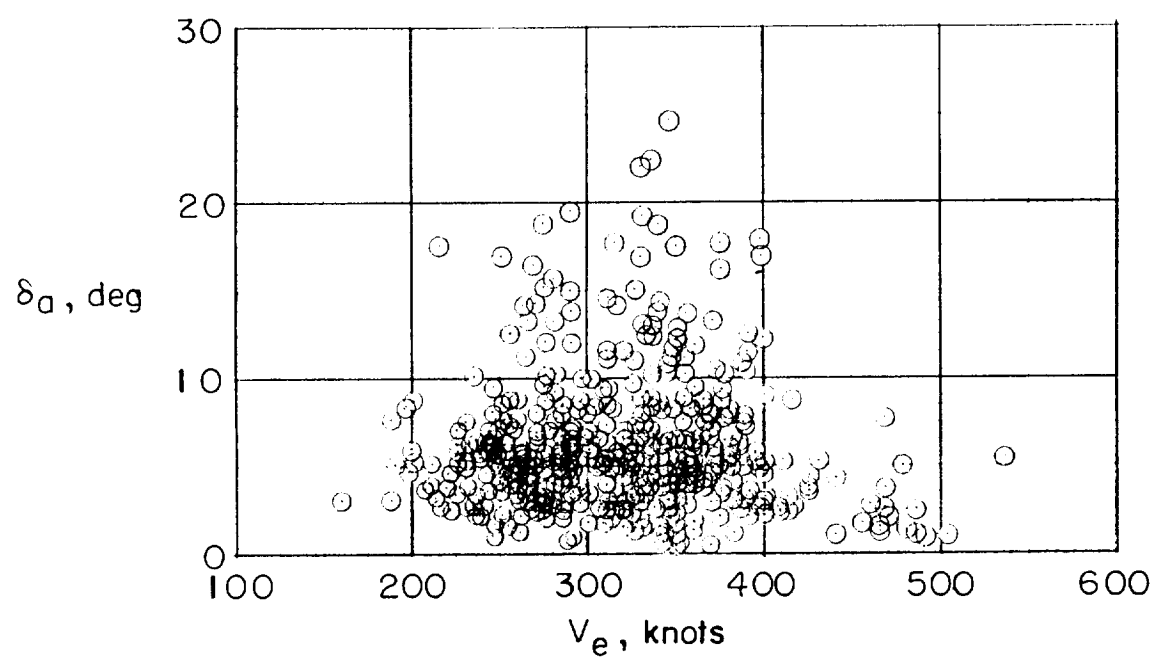
(d) Total aileron deflection.

Figure 7.- Continued.
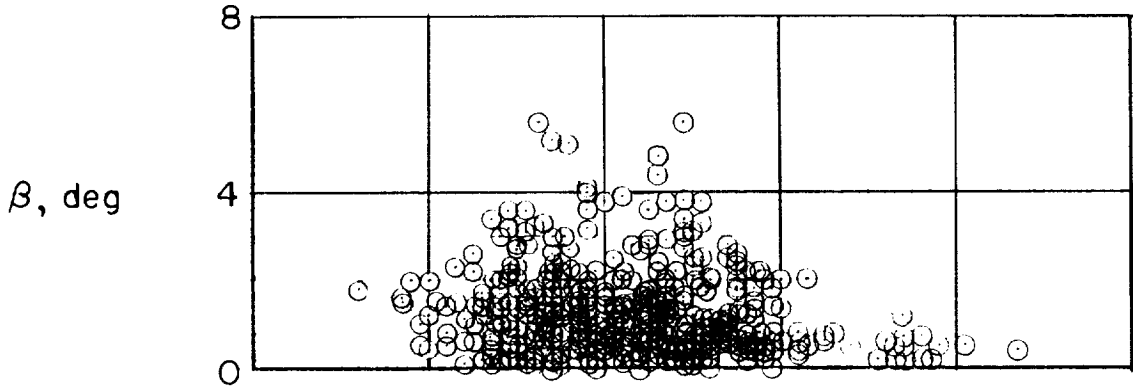
(e) Angle of sideslip.
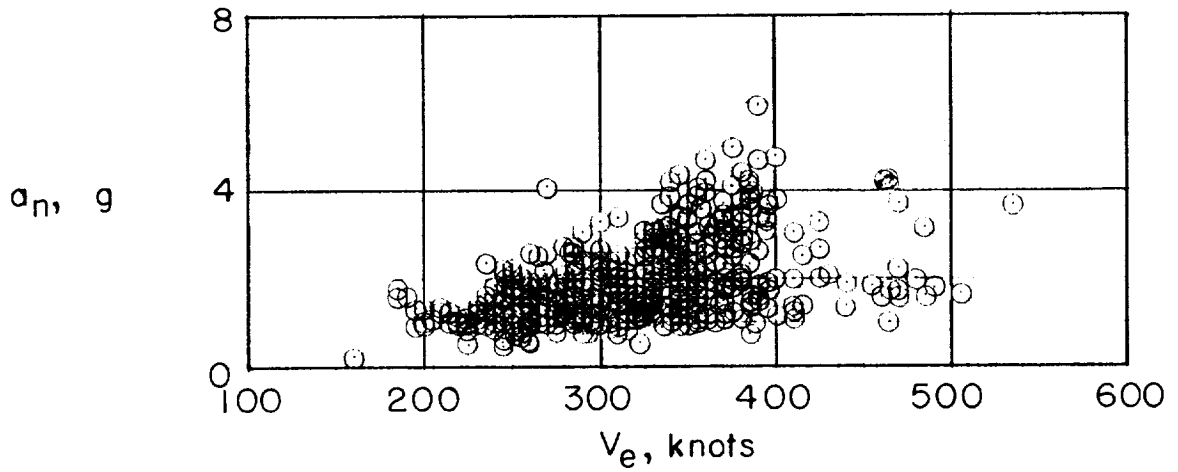
(f) Initial normal acceleration.

Figure 7.- Concluded.
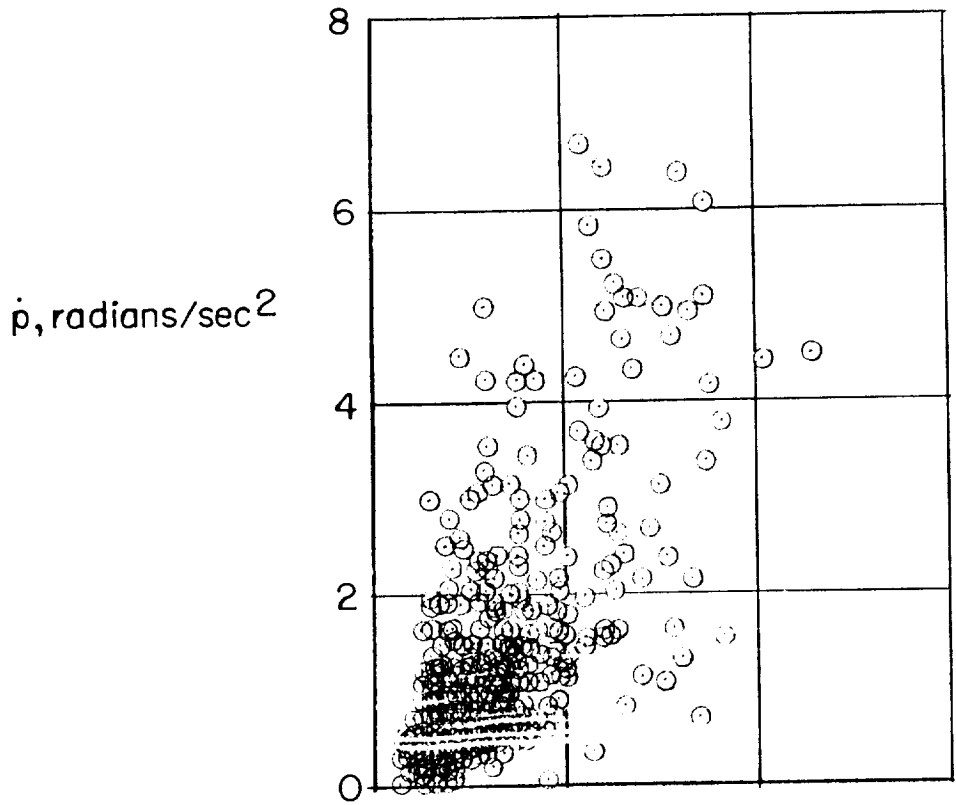
(a) Rolling acceleration.
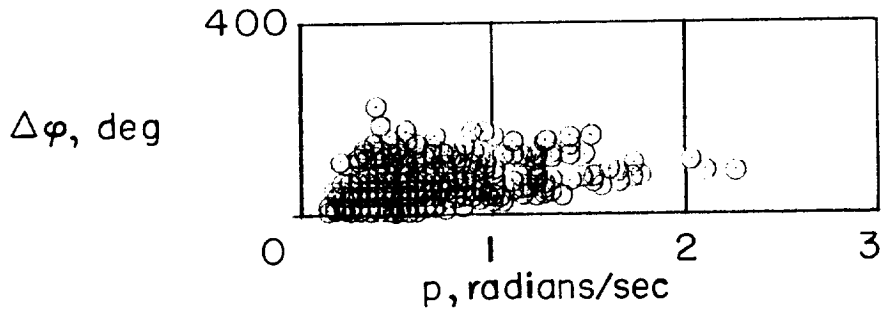
(b) Change in angle of bank.

Figure 8.- Airplane characteristics in roll as a function of rolling velocity for air-to-air gunnery maneuvers.
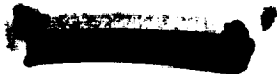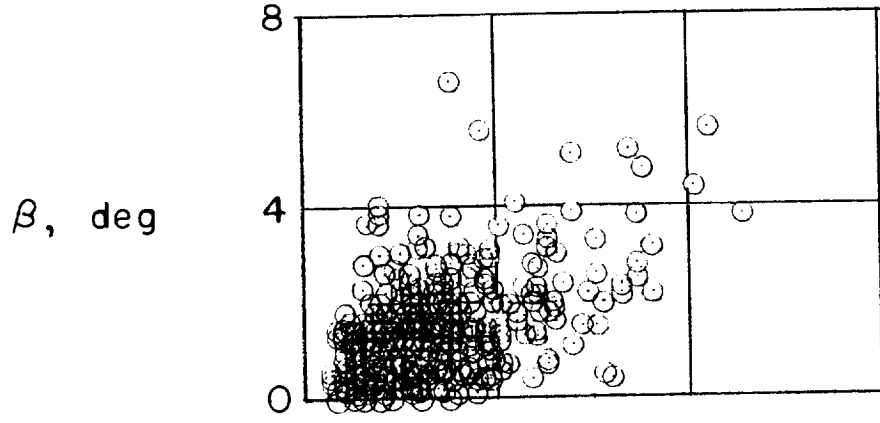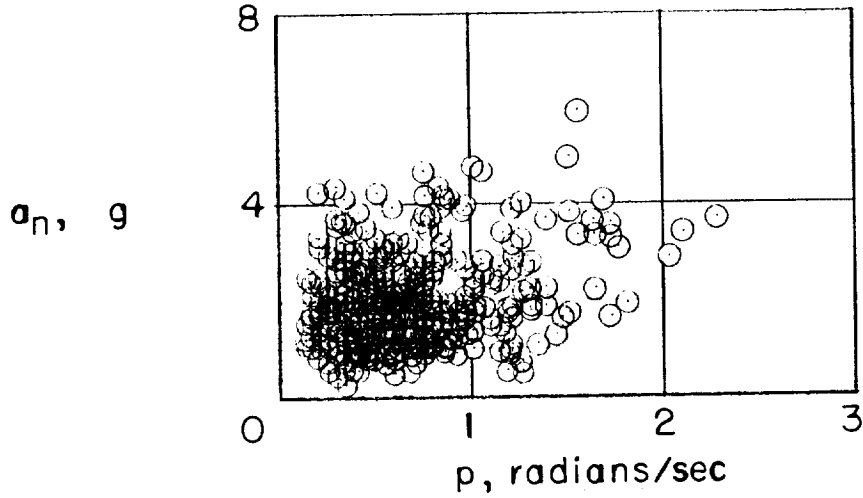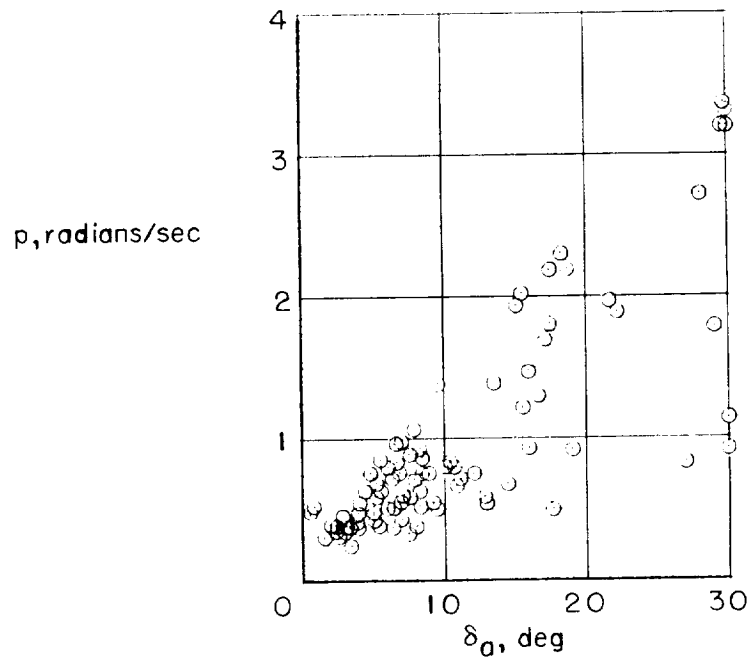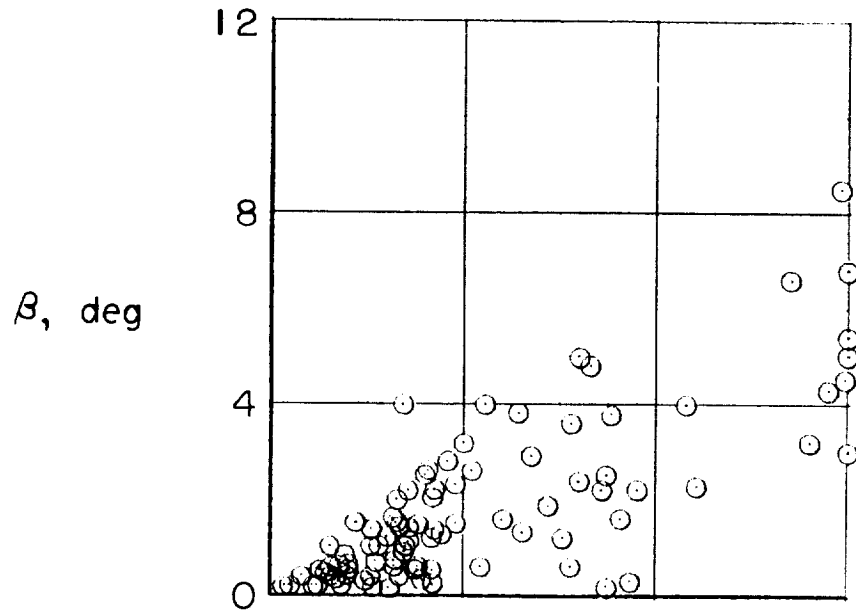
(c) Angle of sideslip.

(d) Initial normal acceleration.

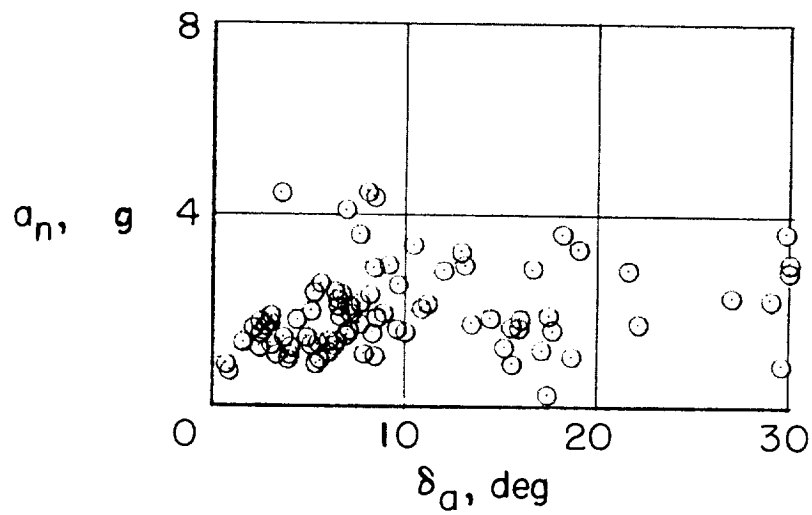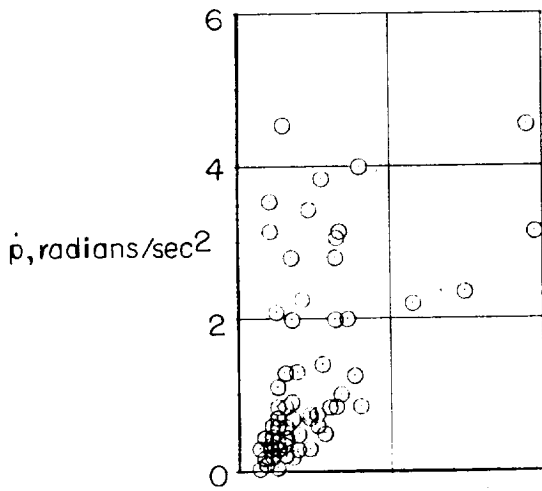Figure 8.- Concluded.
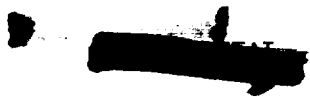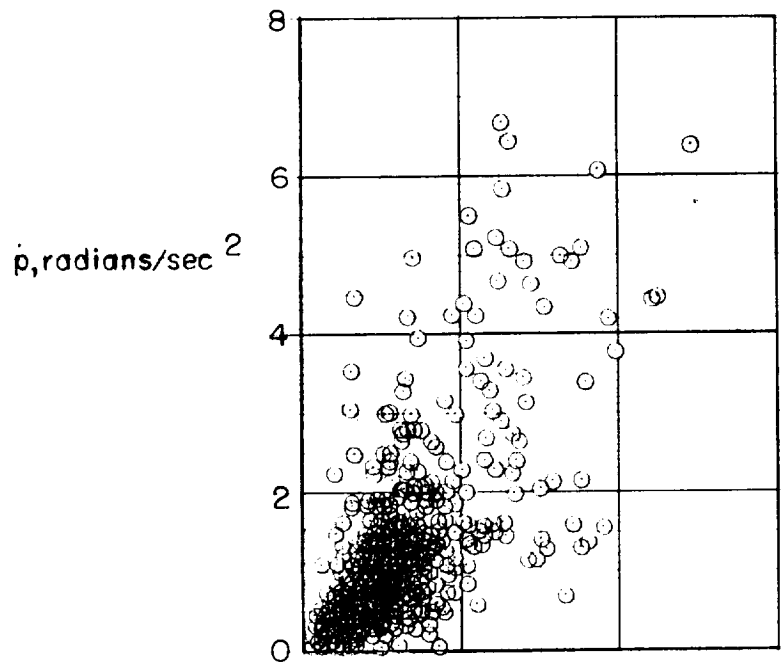
(a) Rolling acceleration.
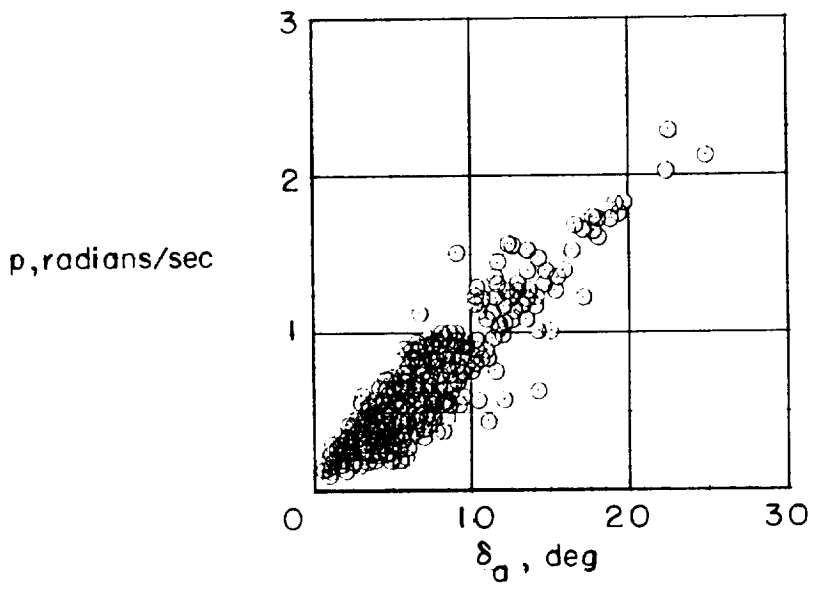
(b) Rolling velocity.

Figure 9.- Airplane characteristics in roll as a function of total aileron deflection for air-to-air gunnery maneuvers.
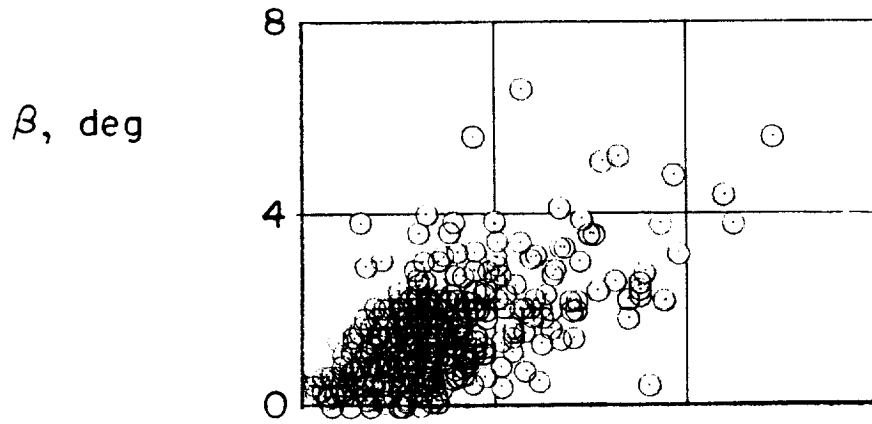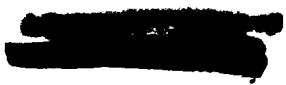
(c) Angle of sideslip.
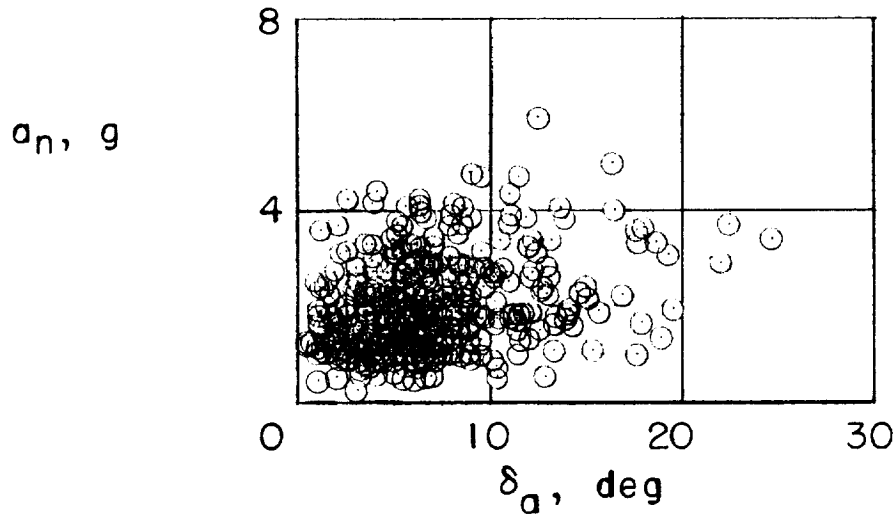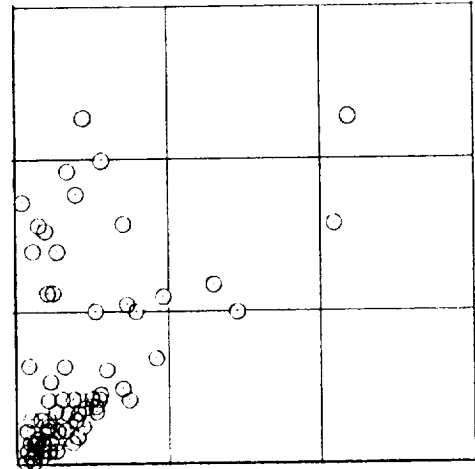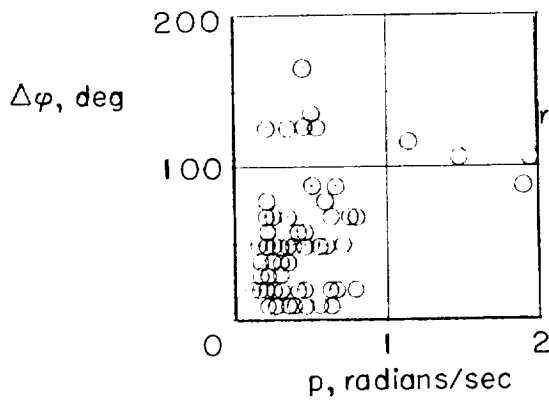

(d) Initial normal acceleration.

Figure 9.- Concluded.
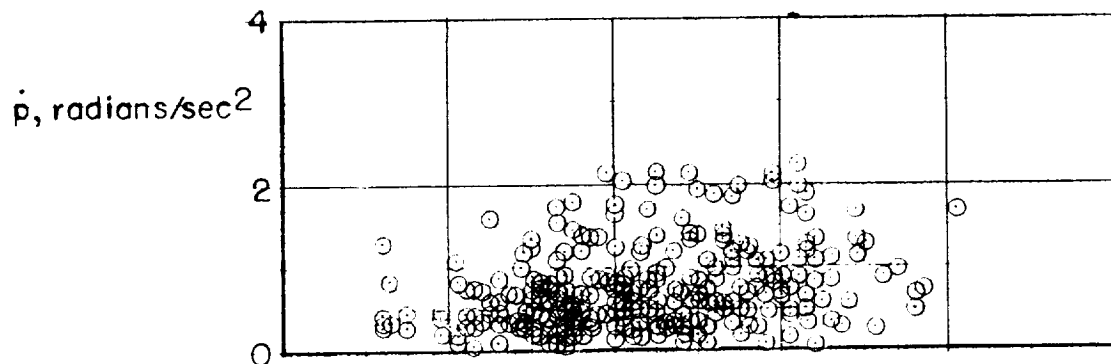
(a) Rolling acceleration.
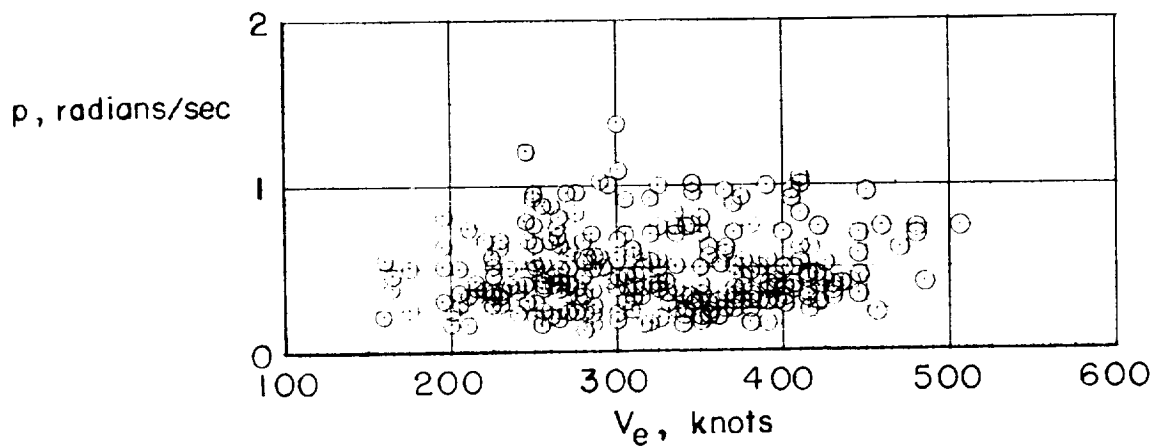
(b) Rolling velocity.

Figure 10.- Airplane characteristics in roll as a function of equivalent airspeed for air-to-ground gunnery and bombing maneuvers.

$\Delta\varphi$, deg

(c) Change in angle of bank.

δ_a, deg

V_e, knots
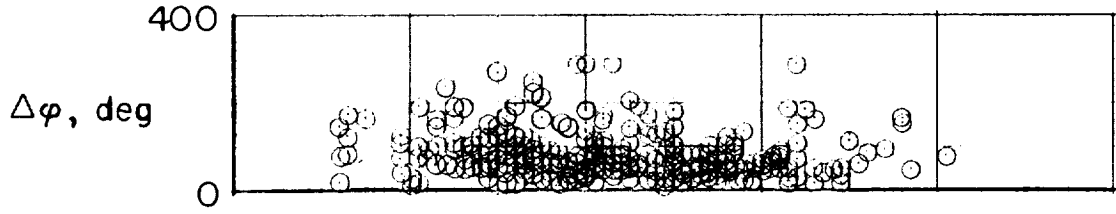
(d) Total aileron deflection.

Figure 10.- Continued.

(e) Angle of sideslip.

(f) Initial normal acceleration.

Figure 10.- Concluded.

$\dot{p}$,radians/sec^2

(a) Rolling acceleration.

(c) Rolling acceleration.

$\Delta\varphi$, deg

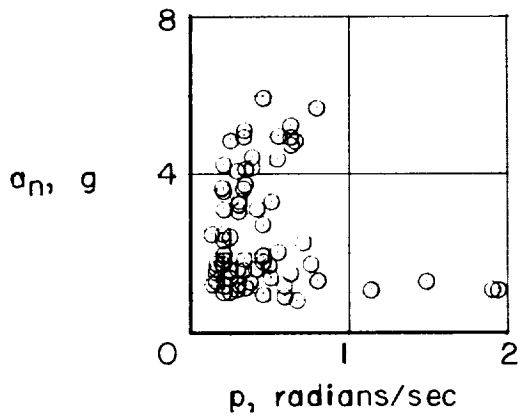p, radians/sec

p,radians/sec

δ_a, deg
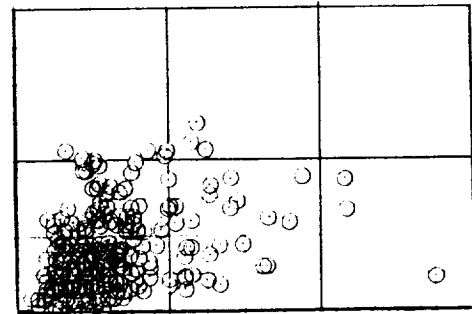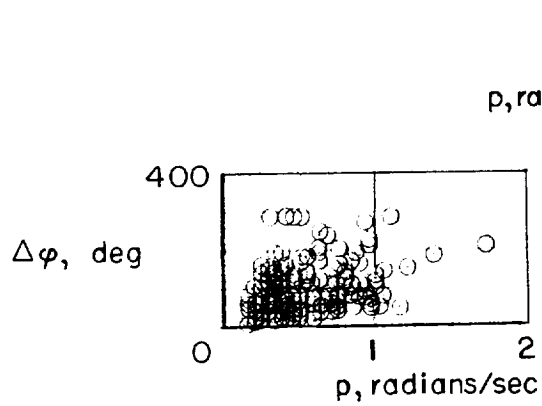
(b) Change in angle of bank.
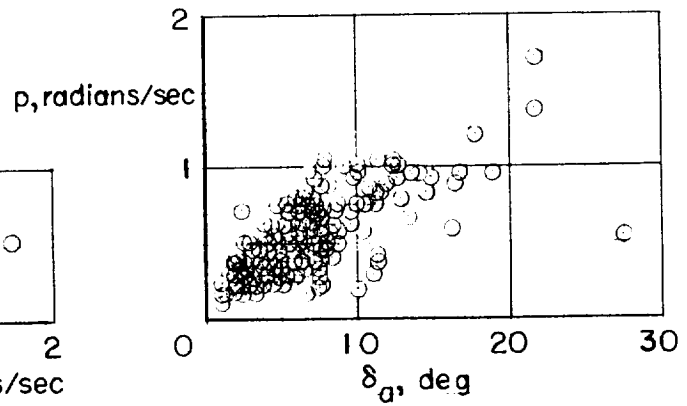
(d) Rolling velocity.

Figure 11.- Airplane characteristics in roll as a function of rolling velocity and total aileron deflection for air-to-ground gunnery and bombing maneuvers.
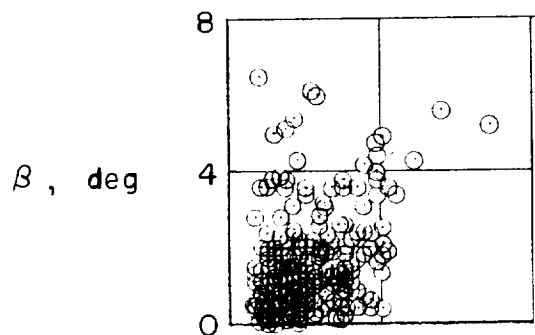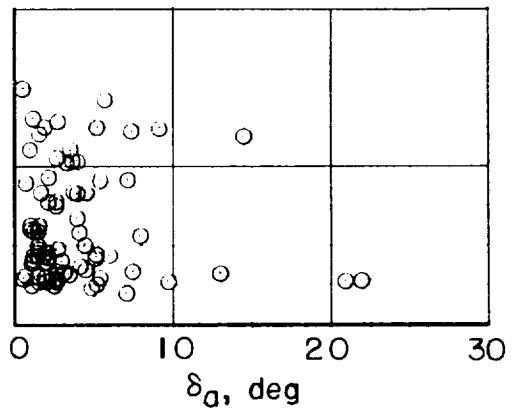
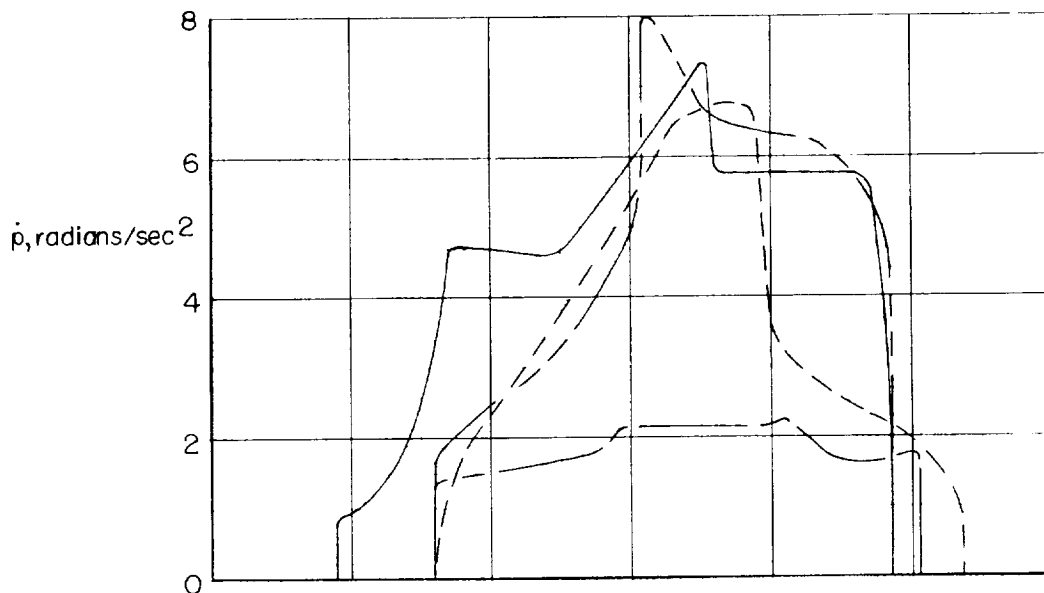(e) Angle of sideslip.
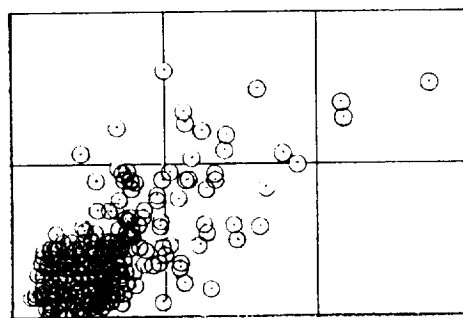
(g) Angle of sideslip.
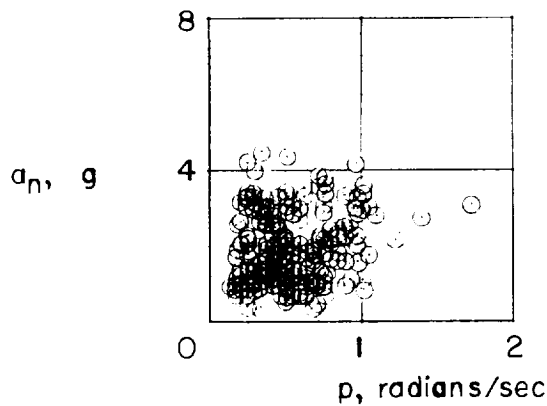
(f) Initial normal acceleration.
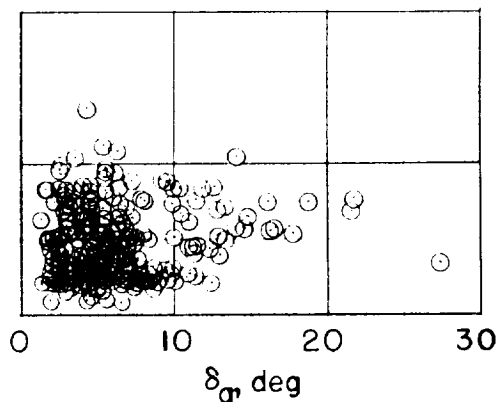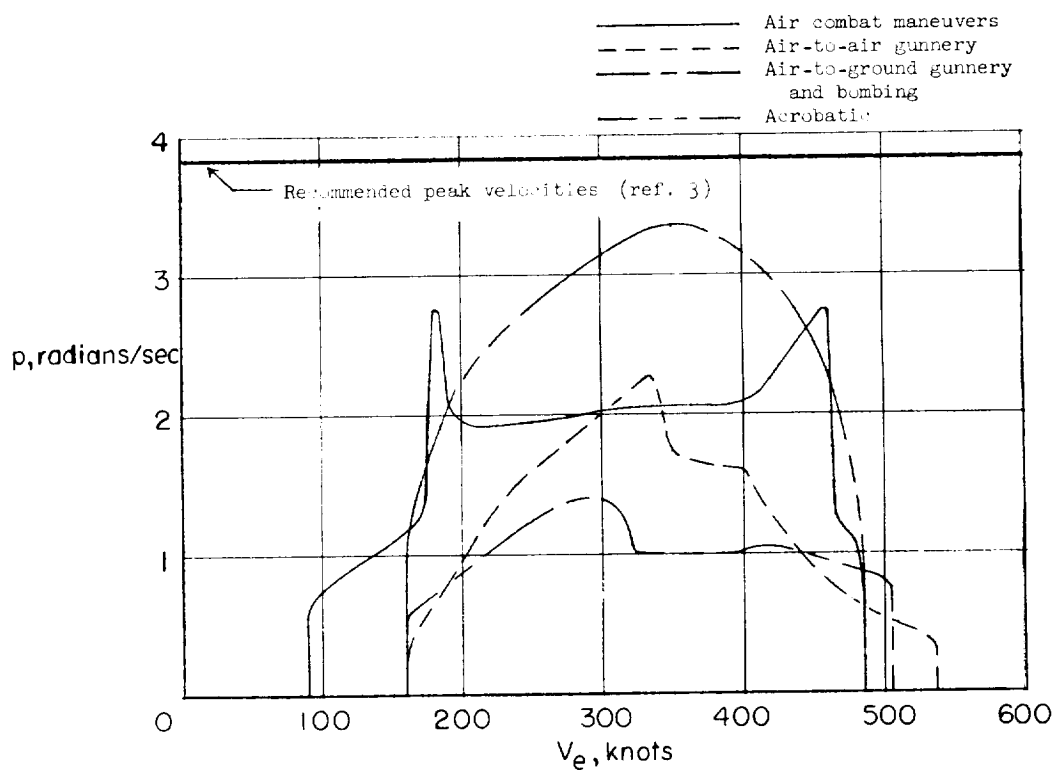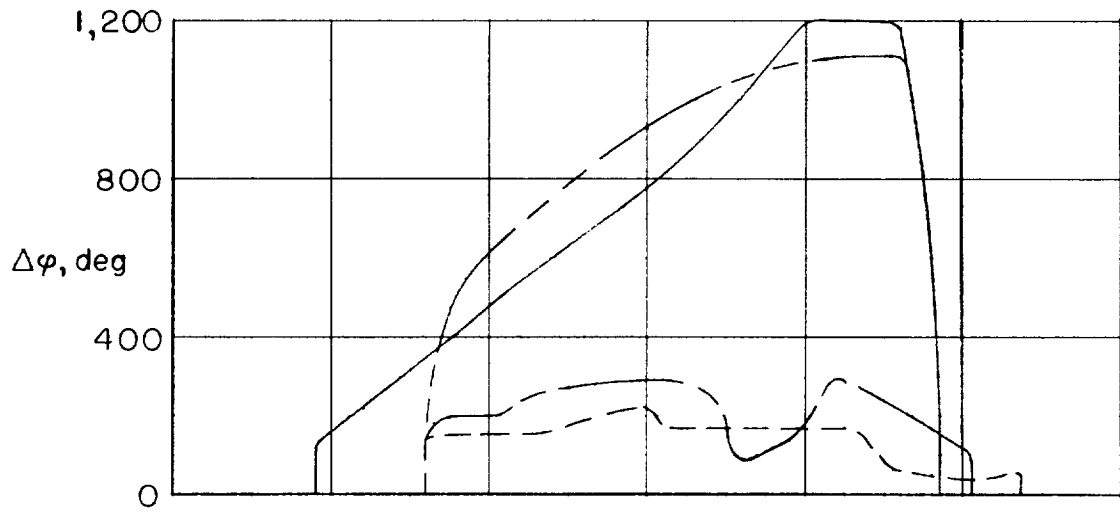
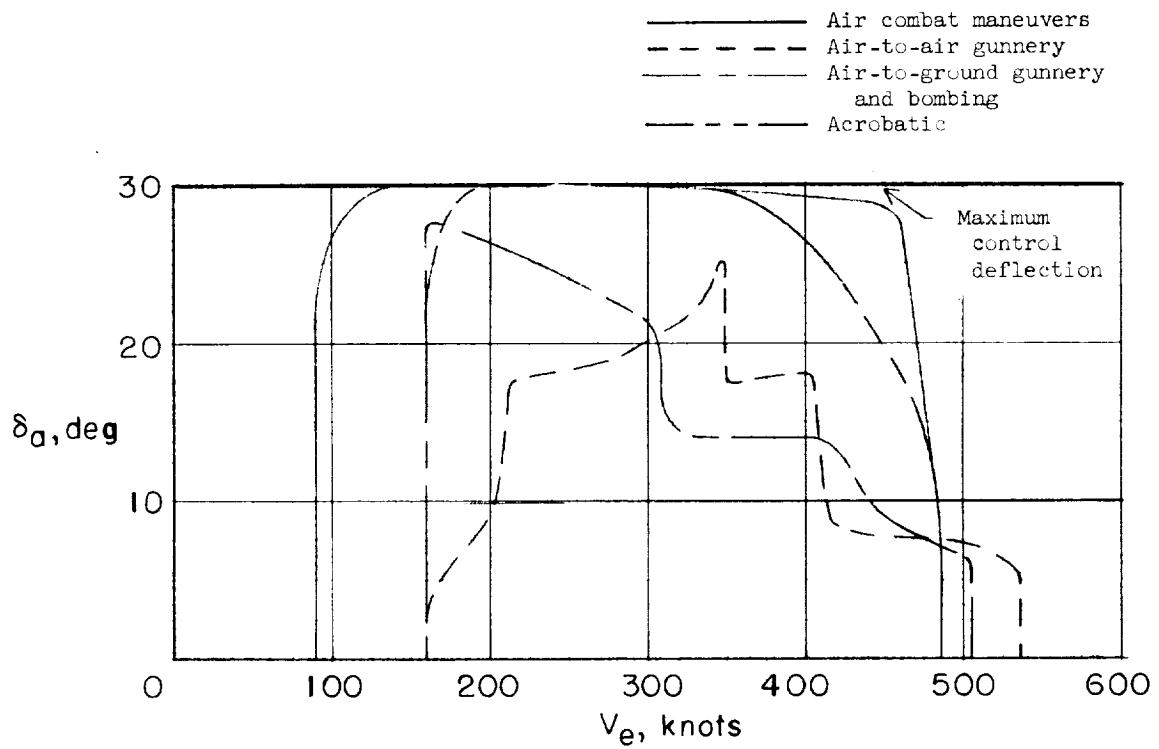(h) Initial normal acceleration.

Figure 11.- Concluded.
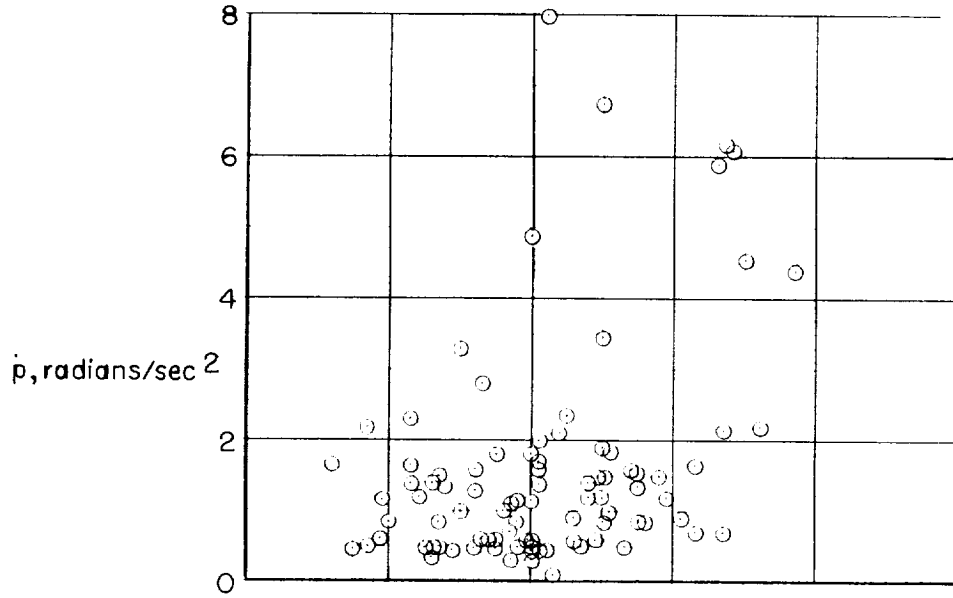
(a) Rolling acceleration.
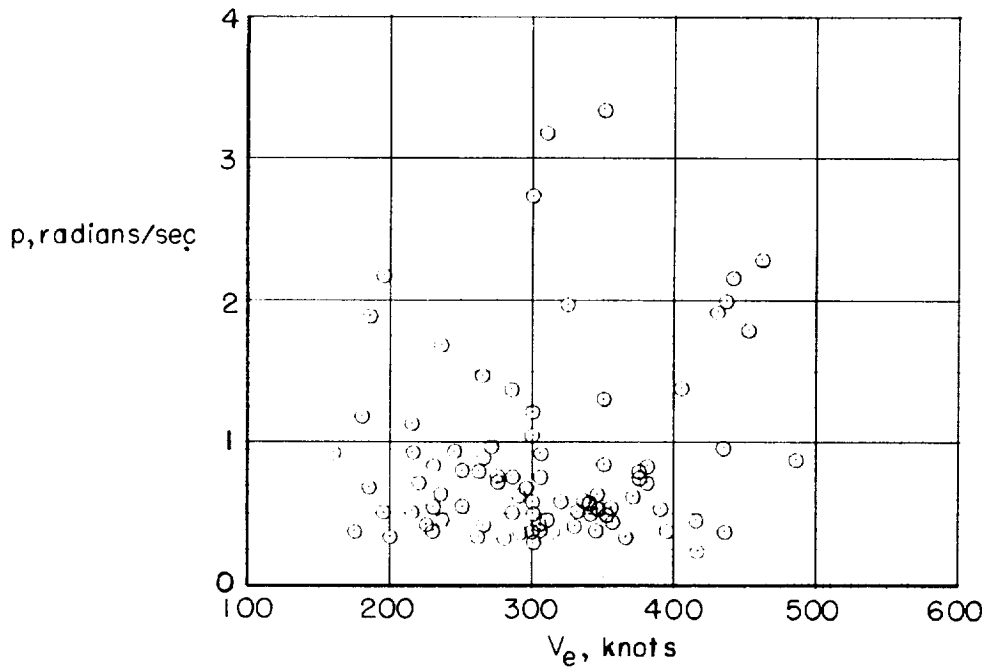
(b) Rolling velocity.

Figure 12.- Airplane characteristics in roll as a function of equivalent airspeed for acrobatic maneuvers.

(c) Change in angle of bank.

(d) Total aileron deflection.

Figure 12.- Continued.

(e) Angle of sideslip.

(f) Initial normal acceleration.

Figure 12.- Concluded.

(a) Rolling acceleration.

(b) Change in angle of bank.

Figure 13.- Airplane characteristics in roll as a function of rolling velocity for acrobatic maneuvers.

(c) Angle of sideslip.

(d) Initial normal acceleration.

Figure 13.- Concluded.

(a) Rolling acceleration.

(b) Rolling velocity.

Figure 14.- Airplane characteristics in roll as a function of total aileron deflection for acrobatic maneuvers.

(c) Angle of sideslip.

(d) Initial normal acceleration.

Figure 14.- Concluded.

(a) Rolling acceleration.

(c) Rolling acceleration.

(b) Change in angle of bank.
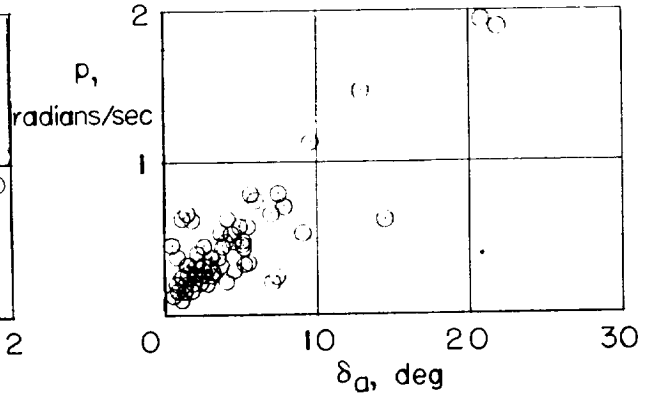
(d) Rolling velocity.

Figure 15.- Airplane characteristics in roll as a function of rolling velocity and total aileron deflection for all maneuvers initiated at supersonic speeds.
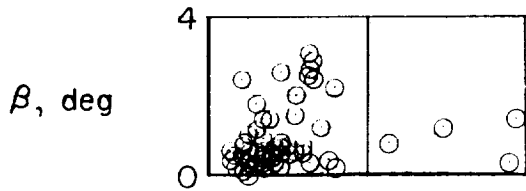
(e) Angle of sideslip.
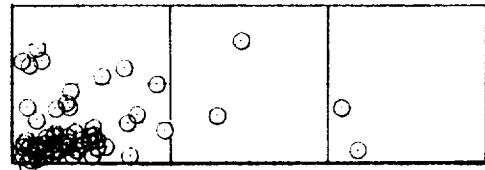
(g) Angle of sideslip.

(f) Initial normal acceleration.

(h) Initial normal acceleration.

Figure 15.- Concluded.

(a) Rolling acceleration.

————————	Air combat maneuvers
— — — — —	Air-to-air gunnery
— — — —	Air-to-ground gunnery and bombing
— — —	Acrobatic

(b) Rolling velocity.

Figure 16.- Summary of airplane roll characteristic boundaries as a function of equivalent airspeed for all maneuvers.
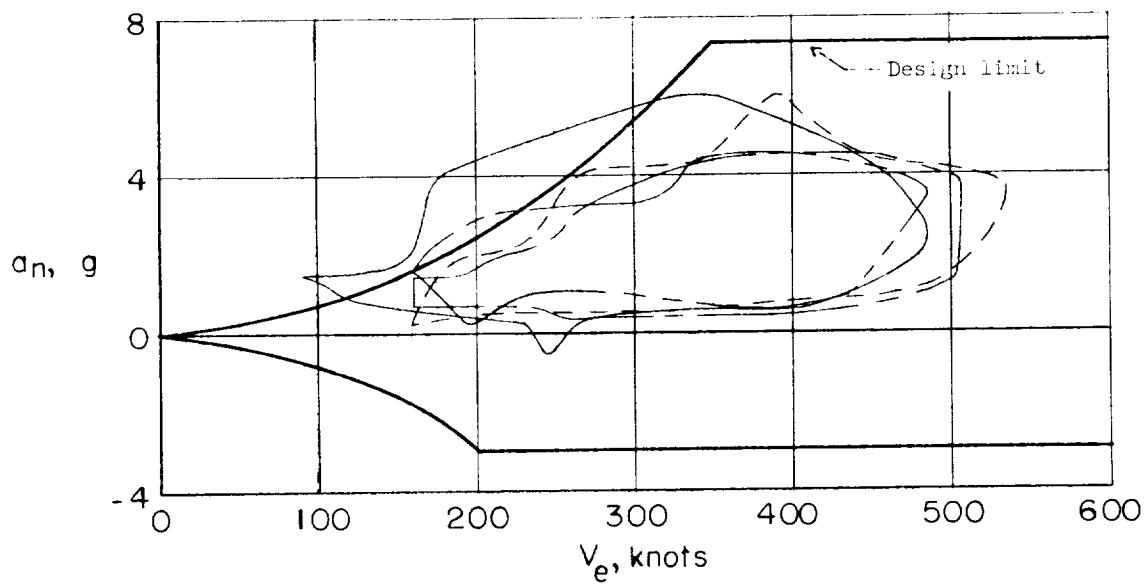
(c) Change in angle of bank.

Air combat maneuvers
Air-to-air gunnery
Air-to-ground gunnery
   and bombing
Acrobatic

(d) Total aileron deflection.

Figure 16.- Continued.
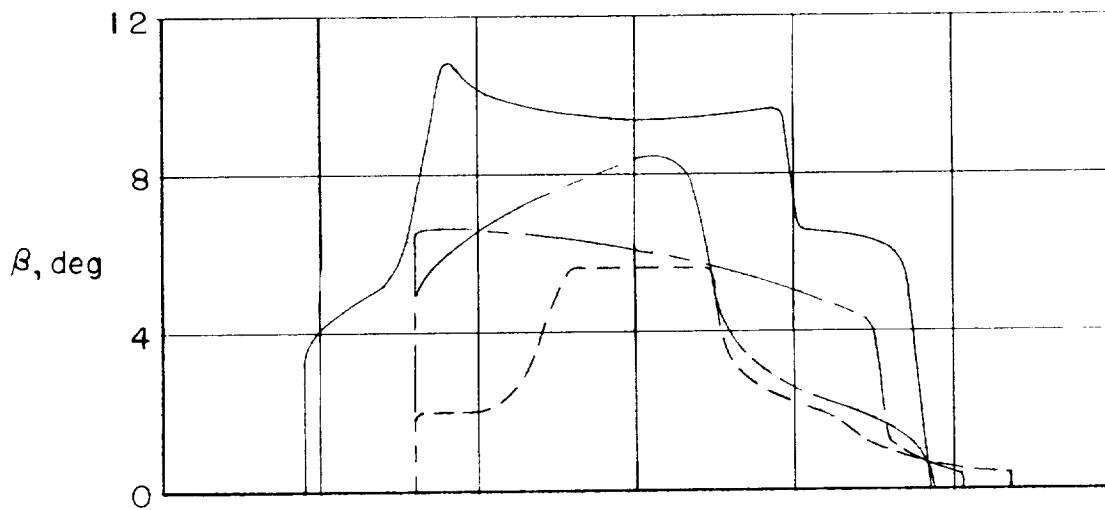
(e) Angle of sideslip

Air combat maneuvers
Air-to-air gunnery
Air-to-ground gunnery and bombing
Acrobatic

(f) Initial normal acceleration.

Figure 16.- Concluded.
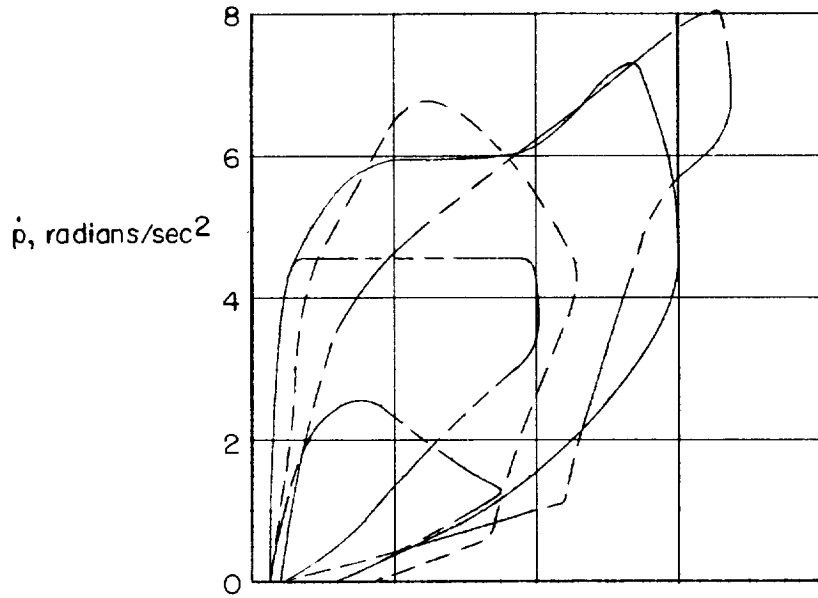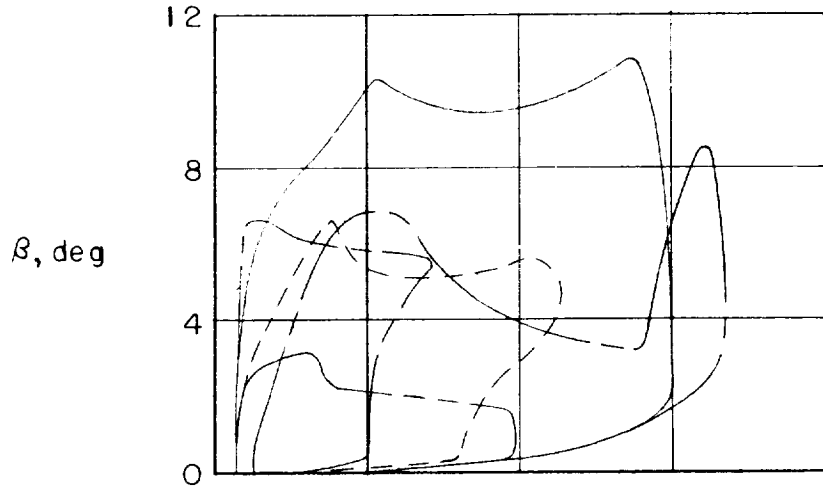
(a) Rolling acceleration.
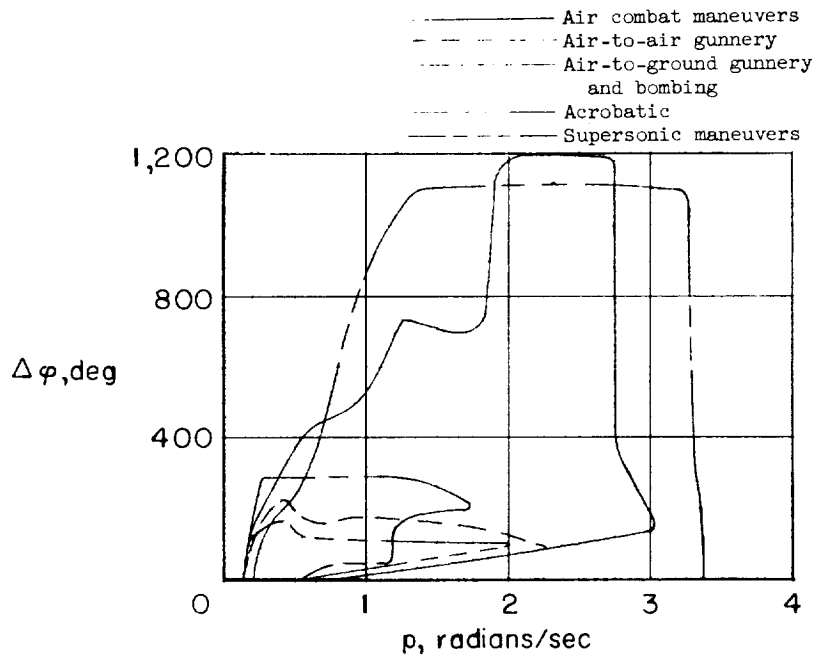
(b) Change in angle of bank.

Figure 17.- Summary of airplane roll characteristic boundaries as a function of rolling velocity for all maneuvers.
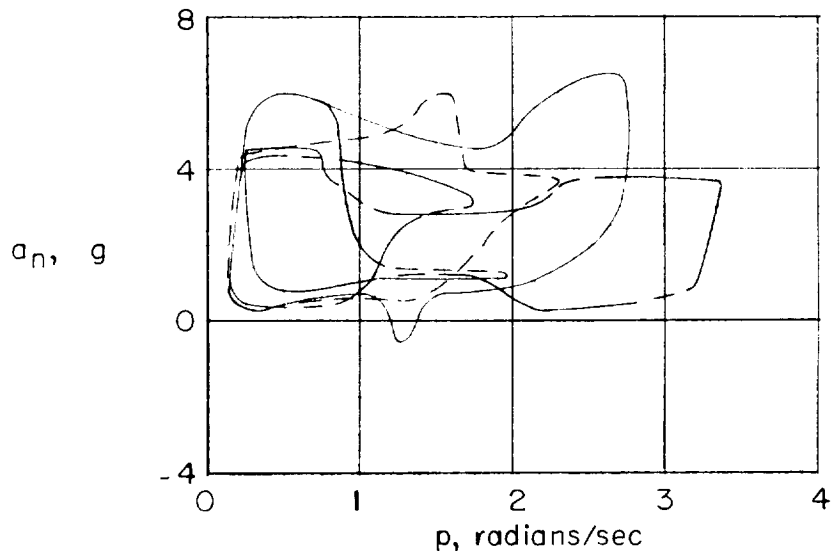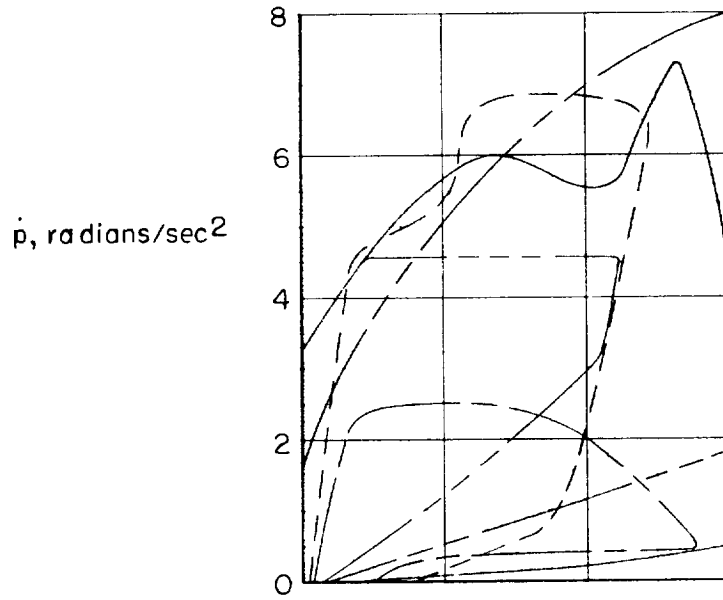
12-1-58H

(c) Angle of sideslip.

———————— Air combat maneuvers
— — — — Air-to-air gunnery
——— — ——— Air-to-ground gunnery and
bombing
—— — —·— Acrobatic
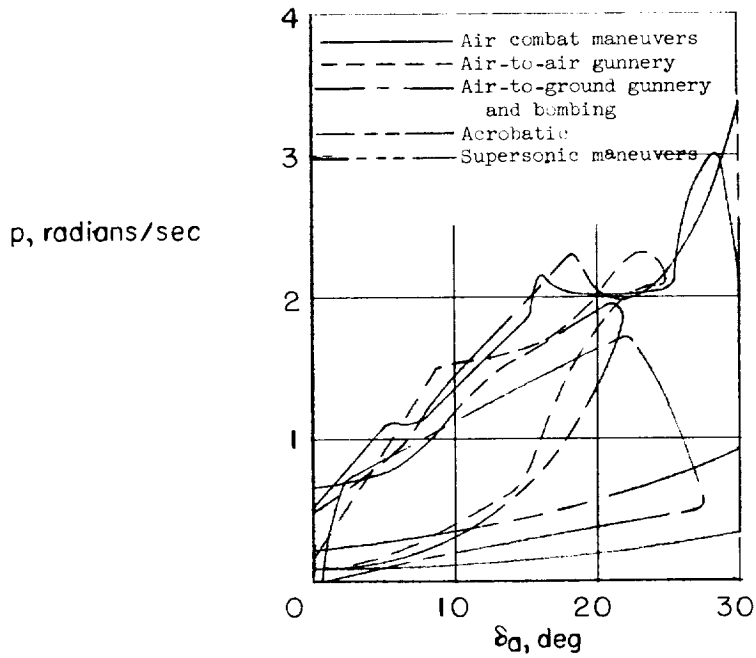—— — — — Supersonic maneuvers

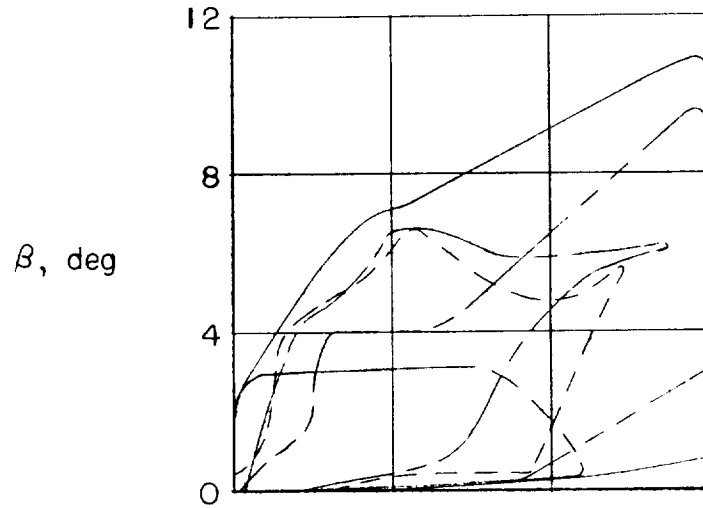(d) Initial normal acceleration.

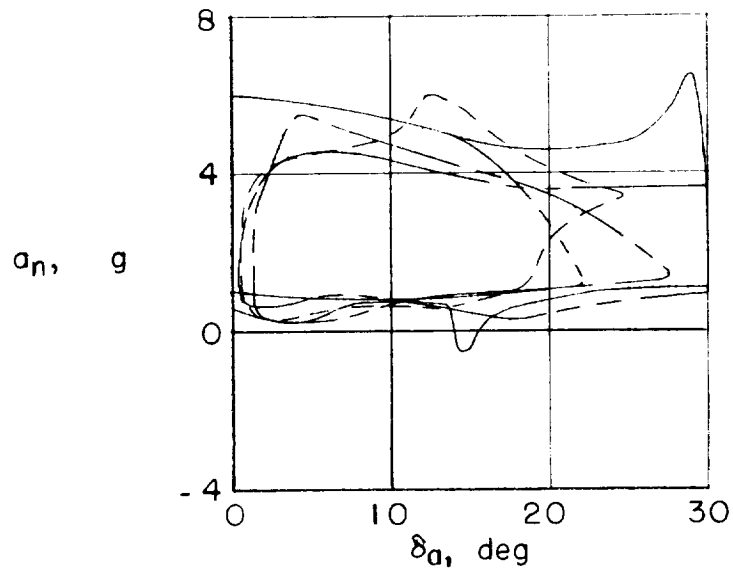Figure 17.- Concluded.

(a) Rolling acceleration.

(b) Rolling velocity.

Figure 18.- Summary of airplane roll characteristic boundaries as a function of total aileron deflection for all maneuvers.

(c) Angle of sideslip.

Air combat maneuvers
Air-to-air gunnery
Air-to-ground gunnery
and bombing
Acrobatic
Supersonic maneuvers

(d) Initial normal acceleration.

Figure 18.- Concluded.