UNCLASSIFIED

[redacted]

Copy 186

NASA TM X-31

IN-05
397272
24P

TECHNICAL MEMORANDUM

X - 31

APPROACH AND LANDING INVESTIGATION AT LIFT-DRAG RATIOS OF 2 TO 4 UTILIZING A STRAIGHT-WING FIGHTER AIRPLANE

By Gene J. Matranga and Neil A. Armstrong

High-Speed Flight Station
Edwards, Calif.

UNCLASSIFIED

CLASSIFICATION CHANGED TO UNCLASSIFIED
AUTHORITY NASA LLZ Memo
DATED: Sept 11, 1974
D E Mann
(Signature)
2-10-75
(Date)

[redacted]

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

WASHINGTON August 1959

[redacted]

UNCLASSIFIED

NASA TM X-31

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

TECHNICAL MEMORANDUM X-31

APPROACH AND LANDING INVESTIGATION AT LIFT-DRAG RATIOS OF 2 TO 4 UTILIZING A STRAIGHT-WING FIGHTER AIRPLANE*

By Gene J. Matranga and Neil A. Armstrong

SUMMARY

A series of landings was performed with a straight-wing airplane to evaluate the effect of low lift-drag ratios on approach and landing characteristics. Landings with a peak lift-drag ratio as low as 3 were performed by altering the airplane configuration (extending speed brakes, flaps, and gear and reducing throttle setting).

As lift-drag ratio was reduced, it was necessary either to make the landing pattern tighter or to increase initial altitude, or both. At the lowest lift-drag ratio the pilots believed a 270° overhead pattern was advisable because of the greater ease afforded in visually positioning the airplane.

The values of the pertinent flare parameters increased with the reduction of lift-drag ratio. These parameters included time required for final flare; speed change during final flare; and altitude, glide slope, indicated airspeed, and vertical velocity at initiation of final flare.

The pilots believed that the tolerable limit was reached with this airplane in the present configuration, and that if, because of a further reduction in lift-drag ratio, more severe approaches than those experienced in this program were attempted, additional aids would be required to determine the flare-initiation point.

INTRODUCTION

Landing unpowered rocket airplanes has always required some measure of pilot concentration because of the comparatively high rates of sink involved. Through the years, the problem has generally become more

---

*Title, Unclassified.

critical with the use of thinner, lower aspect-ratio wings. The results of some landings of this type were reported in references 1 and 2. In reference 1 it was reported that when the Northrop X-4 research airplane performed approaches and landings at low lift-drag ratios (values as low as 4) the largest portion of the flare was made at altitudes above 50 feet. Also, although vertical velocities during the approach varied from 30 to 90 feet per second, the vertical velocities at contact were less than 5.5 feet per second. This experience was generally at lift-drag ratios greater than 4. Advanced vehicles such as the X-15, however, will be landing in a range of lift-drag ratio from 2 to 4. To gain an insight into some of the problems that might be faced when operating these vehicles, a flight investigation of landings at low lift-drag ratios was conducted at the NASA High-Speed Flight Station, Edwards, Calif. A straight-wing fighter airplane capable of investigating the lift-drag-ratio range between 2 and 4 was utilized.

SYMBOLS

a_n	normal acceleration, g units
$a_{n_{max}}$	maximum normal acceleration during final flare, g units
C_D	drag coefficient
C_L	lift coefficient
g	acceleration due to gravity, ft/sec^2
h	geometric altitude above touchdown point, ft
L/D	lift-drag ratio
(L/D)'	effective lift-drag ratio, $\frac{\text{Lift} + (\text{thrust})\sin\alpha}{\text{Drag} - (\text{thrust})\cos\alpha}$
n	normal-load factor
t	time prior to touchdown, sec
V_i	indicated airspeed, knots
V_v	vertical velocity, ft/sec
$\dot{v}$	derivative of forward speed with time, dv/dt, ft/sec^2

x	longitudinal distance from touchdown point, ft
y	lateral distance from touchdown point, ft
α	angle of attack, deg
γ	flight-path angle, deg
Δt	time required for final flare, sec
ΔV_i	increment in indicated airspeed during final flare, knots
φ	bank angle, deg

Subscript:

f	conditions at initiation of final flare

INSTRUMENTATION

The following pertinent quantities were recorded on NASA internal-recording instruments synchronized by a common timer:

Airspeed and altitude
Normal and longitudinal accelerations
Pitching and rolling velocities
Angle of attack
Control positions and control-surface positions

Airspeed, pressure altitude, and angle of attack were sensed on the nose boom; angle of attack was corrected for pitching velocity and normal acceleration.

Ground equipment aided in determining the airplane position during the approach and landing. A modified SCR 584 radar phototheodolite was used to determine the position of the airplane in space down to an altitude of about 1,000 feet. Below this altitude Air Force Flight Test Center Askania Cine-Theodolite cameras determined the position of the airplane. Discussions of the SCR 584 radar phototheodolite and the Askania Cine-Theodolite units are presented in references 3 and 4, respectively.

AIRPLANE

The test airplane is a supersonic fighter type powered by a turbojet engine equipped with afterburner. A three-view drawing and a photograph of the airplane are shown in figures 1 and 2, respectively. The physical characteristics of the airplane are presented in table I.

The airplane has a 3.4-percent-thick straight wing with an aspect ratio of 2.45 and -10° dihedral. Leading- and trailing-edge flaps, which operate independently, and speed brakes mounted on the rear of the fuselage (fig. 1) were used during this investigation. The all-movable horizontal tail is mounted near the top of the vertical tail.

The longitudinal and lateral controls utilize irreversible hydraulic systems, with artificial feel provided for the lateral system through a spring bungee and for the longitudinal system through a spring bungee and bobweight combination. Directional control is obtained through a cable-actuated rudder without the aid of power boost. A three-axis damping system is utilized. To warn the pilot against an impending pitch-up, a stick-shaker was activated at an angle of attack of 10°.

TESTS

Thirty landings were performed to evaluate approach and landing characteristics at low lift-drag ratios. Six of these landings were in the range of the lift-drag ratio from 2 to 3, and ten were in the range from 3 to 4. The remaining landings were at higher lift-drag ratios.

The average wing loading during these landings was about 75 pounds per square foot. When utilized, leading- and trailing-edge flaps were deflected 15°.

Two pilots participated in this investigation. The only instruction given the pilots prior to any of the landings was the request that a particular configuration and engine-power setting be utilized throughout any given approach and landing maneuver. The pilots were free to terminate the approach at any time and availed themselves of this prerogative on four occasions. All landings were performed on the 15,000-foot, east-west runway at Edwards Air Force Base. Because of aircraft-traffic considerations, the pilot was given no instructions relative to a specific touchdown point; hence, no analysis of contact dispersion was attempted.

For the initial landings in each configuration constant power settings of about 80-percent engine rpm were utilized. As the pilot became familiar with the handling qualities of the configuration, landings were performed with successively lower constant power settings until landings at idle power were achieved. To obtain lift-drag ratios from 3 to 4, the landing gear and flaps were extended and engine power was reduced to idle.

Extending the speed brakes resulted in a further reduction of the lift-drag ratio to the 2 to 3 range. Several landings were also performed with the leading-edge flaps locked closed.

REDUCTION OF DATA

The drag workup for presentation in this paper was calculated by the accelerometer method discussed in reference 5. All values of lift-drag ratio were determined from the internal-recording instruments and agreed well with the values computed from the space-positioning data by using the general equation:

$$\tan \gamma = \left[\frac{1}{(L/D)'}\right]\left(\frac{1}{\cos \varphi}\right) + \left(\frac{\dot{v}}{ng}\right)\left(\frac{1}{\cos \varphi}\right)$$

Since the actual value of bank angle could only be indirectly determined in flight, comparisons were limited to conditions of wings-level gliding flight.

Modifying lift and drag for engine thrust provides the effective lift-drag ratio $(L/D)'$ (see SYMBOLS). Mean thrust values calculated from the engine manufacturer's curves show levels of about 300 pounds at 80-percent engine rpm and about -300 pounds at idle power.

RESULTS AND DISCUSSION

General

Data compiled from several maneuvers yield the basic aerodynamic relationships of angle of attack, drag coefficient, and lift-drag ratio as a function of lift coefficient presented in figure 3. With the landing gear and flaps extended and the engine reduced to zero thrust, the peak value of lift-drag ratio is about 4 and the minimum drag coefficient is approximately 0.09. With the speed brakes extended the drag coefficient is increased by almost 0.04 throughout the lift range covered, and the peak lift-drag ratio is reduced to about 3. In both instances there is a broad flat peak to the lift-drag-ratio curve above a lift coefficient of about 0.45 and extending to the highest lift coefficients experienced during this investigation. This would correspond to angles of attack in excess of about 7°.

Reducing engine rotational speeds to idle lowers the peak of the effective lift-drag-ratio curve to values as low as 2.7, as compared with the values near 3 shown in figure 3.

An examination of the data from several landings performed with leading-edge flaps locked closed revealed no noticeable alterations in any of the relationships presented in figure 3.

Landing Pattern

Figures 4 and 5 illustrate the effect of reducing the lift-drag ratio on the approach and landing pattern of the airplane. Figure 4(a) shows the typical pattern, figure 4(b) shows the time history of the approach
and landing, and figure 4(c) shows the time history of the final flare of H
the airplane when the peak effective lift-drag ratio was near 4. The 1
pilot performed a 360° overhead approach with the high key, or initial, 1
point almost over the touchdown point at an altitude slightly less than 7
25,000 feet (fig. 4(a)). The size of the pattern is indicated by maximum longitudinal and lateral distances away from the touchdown of 22,000 feet. The average rate of sink was about 170 feet per second, and the approach speed increased from an initial value of 240 knots indicated airspeed to 280 knots indicated airspeed before the flare was initiated (fig. 4(b)).

Figure 5(a) shows the landing pattern, figure 5(b) shows the time history of the approach and landing, and figure 5(c) shows the time history of the final flare of the airplane when the peak effective lift-drag ratio was near 3. A 270° pattern was employed in this instance. The high key point was similar in altitude to that of the previously discussed maneuver but somewhat different in lateral displacement, with slightly higher approach speeds. However, the maximum longitudinal distance from the touchdown point was reduced by one-third, and the maximum lateral distance was reduced by more than one-half (fig. 5(a)). The average vertical velocity was increased to slightly less than 300 feet per second (fig. 5(b)).

From these data it is obvious that as lift-drag ratio is reduced, the landing pattern must either be made tighter or initial altitude increased, or both. As lift-drag ratio is reduced, not only are the steady-state glide rates of sink increased, but the tight turns (bank angles of 60° were common) caused even higher rates of sink.

Because of the high altitudes, which placed stringent demands upon pilot judgment in precisely positioning the airplane at high key, the pilots believed that as lift-drag ratio was reduced, a 270° pattern such as that of figure 5(a) was more satisfactory and provided adequate visibility of the touchdown point throughout the approach. The stick-shaker furnished a convenient angle-of-attack guide for the pilots as they performed their patterns, since they knew by the stick-shaker activation when an angle of attack of 10° had been exceeded. Additional pilot comments disclosed that with patterns as steep as those experienced in the range of lift-drag ratio from 2 to 3, hitting the desired landing spot is relatively easy.

Flare

On the landing approach with the effective lift-drag ratio ranging between 3 and 4 (fig. 4(b)), even though the airplane was still completing the base leg of the pattern, a gradual flare was initiated at an altitude of about 3,500 feet as indicated by the reduction in vertical velocity. About 21 seconds prior to touchdown a final, rapid flare was performed starting just above an altitude of 1,000 feet, and is indicated by the rapid increase in angle of attack and normal acceleration. The touchdown was completed with a forward velocity of 185 KIAS and a vertical velocity of 1 foot per second (fig. 4(c)). Total time consumed from the initiation of the gradual flare to touchdown was about 38 seconds.

In the landing of figure 5(b) (effective lift-drag ratio generally between 2 and 3) the gradual flare was initiated at an altitude of about 7,000 feet while the airplane was on the base leg of the pattern. About 17 seconds prior to touchdown the final flare was performed starting at an altitude of about 1,000 feet. Touchdown was completed with a forward velocity of 180 KIAS and a vertical velocity of 1 foot per second (fig. 5(c)). In this maneuver the time consumed from the initiation of the gradual flare to touchdown was about 40 seconds. Although the time required to complete the gradual flare was similar in the lift-drag-ratio range of 3 to 4 (fig. 4(b)) and the lift-drag-ratio range of 2 to 3 (fig. 5(b)), the initial altitude was twice as great for the maneuver in the lift-drag-ratio range of 2 to 3. This gives some indication of the urgency the pilot undoubtedly feels in attempting to retard the high sink rates experienced in the lower lift-drag-ratio configuration.

Figure 6 summarizes the parameters which seem to illustrate best the final-flare characteristics. Initial altitude, initial airspeed, initial vertical velocity, initial glide angle, change of airspeed during the flare, time required to flare, and maximum normal acceleration recorded during the final flare are plotted as a function of effective lift-drag ratio at the initiation of the final flare. Note that the final flare is defined in terms of flight-path deviation rather than initiation of pilot control; this was found to offer a more satisfactory correlation.

As shown in figure 6, with the reduction of lift-drag ratio from 4 to 2, the altitude at the initiation of flare increased from 200 feet to 1,500 feet and the vertical velocity increased from 50 feet per second to over 150 feet per second. The indicated airspeed at the initiation of flare increased from a value of 235 knots near a lift-drag ratio of 4 to about 275 knots near a lift-drag ratio of 3, then generally held steady at that value with a further reduction in the lift-drag ratio. This can be explained by the fact that the maximum allowable speed with the gear and flaps extended is 296 KIAS and a portion of that speed must be bled-off during the gradual flare. However, the pilots did feel that this limit of 296 KIAS would not have been exceeded in any case because the additional advantage gained with an increase in forward speed would have been more than overcome by the greater increase in the resultant vertical velocity. The change in indicated airspeed during the final flare was about 60 knots near a lift-drag ratio of 4 and increased to 100 knots near a lift-drag ratio of 2. Time to execute the flare increased from 13 seconds to more than 20 seconds with a reduction in lift-drag ratio. The glide angle at the initiation of flare also increased from a value of 7.5° near a lift-drag ratio of 4 to about 20° near a lift-drag ratio of 2. Only maximum normal acceleration used to execute the flare remained relatively constant, with a value near 1.5g. The pilot's anxiety as the lift-drag ratio was reduced from values near 4 to values near 2 can be appreciated when it is considered that during this change in lift-drag ratio the altitude at the initiation of final flare increased more than 7 times, while the time to execute the flare did not quite double.

Of interest, also, is the fact that for all the lowest lift-drag-ratio landings the pilot exceeded the 10° angle-of-attack stick-shaker boundary during the final flare. Yet, he felt he was forced to chance the possibility of a pitch-up in order to successfully execute the flare.

As mentioned previously, the pilots' primary concern throughout the flare was the question of their ability to arrest the high sink rates. In this respect, they reported that ground effect was beneficial, enabling them to make good landings from improvable approaches, primarily by increasing the time available for final corrections, by increasing apparent stability, and by reducing rate of sink. Sink rates at touchdown were always 2 feet per second or lower, even though the rates of sink at 50 feet ranged between 20 and 40 feet per second.

PILOT OPINIONS

Pilot impressions and opinions add considerably to the analysis of the flare. The pilots could not set forth any specific criterion upon which they based their initiation of flare. Rather, they indicate it depends upon the interrelation of many factors, including speed, altitude, rate of sink, and position with respect to the desired touchdown point. This interrelationship accounts for most of the scatter in the data presented in figure 6. As the lift-drag ratio is reduced, the pilots feel strongly that the degree of judgment required progressively increases to a point at which, in order to accomplish more severe approaches, additional aids would be necessary to determine the flare-initiation point.

Visual cues and the instruments presently provided were barely sufficient to accomplish this investigation. It was also recommended by the pilots that no landings should be attempted in the lift-drag-ratio range of 2 to 3 without an ample learning period, starting at higher lift-drag-ratio levels. Adequate control seems to be available at all times, and handling qualities do not seem to be a problem when landing this airplane. Pilot comment also indicates that for airplanes where the lift-drag ratio in the landing configuration is markedly lower than in the clean configuration, an additional time and speed margin may be obtained by delaying gear and flap extension until a successful flare is assured.

CONCLUDING REMARKS

During a series of landings with a straight-wing fighter airplane, peak lift-drag ratios as low as 3 were achieved by altering the airplane configuration (extending speed brakes, flaps, and gear and reducing throttle setting).

As lift-drag ratio was reduced, it was necessary either to make the landing pattern tighter or to increase initial altitude, or both. The pilots believed a 270° overhead pattern was advisable at the lowest lift-drag ratio because of the greater ease afforded in visually positioning the airplane with respect to the runway.

All pertinent flare parameters, with the exception of the maximum normal acceleration used to execute the flare, increased with the reduction of lift-drag ratio from 4 to 2 at the initiation of flare. During this reduction, the time required to execute the flare almost doubled and the altitude at the initiation of flare increased more than 7 times.

The pilots believed that the tolerable limit was reached with this airplane in the present configuration and that additional aids would be required to determine the flare-initiation point if, because of a further reduction in lift-drag ratio, more severe approaches than those experienced in this program were attempted.

High-Speed Flight Station,
National Aeronautics and Space Administration,
Edwards, Calif., April 2, 1959.

REFERENCES

1. Stillwell, Wendell H.: Results of Measurements Made During the Approach and Landing of Seven High-Speed Research Airplanes. NACA RM H54K24, 1955.

2. Day, Richard E.: Measurements Obtained During the Glide-Flight Program of the Bell X-2 Research Airplane. NACA RM L53G03a, 1953.

3. Brunn, Cyril D., and Stillwell, Wendell H.: Mach Number Measurements and Calibrations During Flight at High Speeds and at High Altitudes Including Data for the D-558-II Research Airplane. NACA RM H55J18, 1956.

4. Taylor, Albert E.: Evaluation of Take-Off and Landing Facility. AFFTC Tech. Memo. 58-12, U. S. Air Force, Apr. 1958.

5. Beeler, De E., Bellman, Donald R., and Saltzman, Edwin J.: Flight Techniques for Determining Airplane Drag at High Mach Numbers. NACA TN 3821, 1956.

TABLE I.- GEOMETRIC CHARACTERISTICS OF THE AIRPLANE

Wing:	
Airfoil section	Modified biconvex
Area, sq ft	196.1
Span, ft	21.94
Mean aerodynamic chord, ft	9.55
Root chord, ft	12.98
Tip chord, ft	4.89
Aspect ratio	2.45
Taper ratio	0.378
Sweep at 25-percent chord, deg	18.1
Sweep at the leading edge, deg	27.3
Incidence, deg	0
Dihedral, deg	-10
Airfoil thickness ratio	0.0336
Leading-edge flaps (per side) -	
Area, sq ft	8.50
Mean chord, ft	1.012
Deflection limit, deg	-30
Type	Plain
Trailing-edge flaps (per side) -	
Area, sq ft	11.55
Mean chord, ft	2.52
Deflection limit, deg	45
Type	Plain
Ailerons (per side) -	
Area, sq ft	4.73
Mean chord, ft	1.716
Span, ft	2.75
Deflection limit, deg	±15
Average test wing loading, lb/sq ft	75
Tail:	
Horizontal tail -	
Airfoil section	Modified biconvex
Area, sq ft	48.2
Mean aerodynamic chord, ft	4.415
Span, ft	11.92
Root chord, ft	6.16
Tip chord, ft	1.917
Aspect ratio	2.95
Taper ratio	0.311
Root thickness ratio	0.0493
Tip thickness ratio	0.0261
Tail length, 25-percent wing mean aerodynamic chord to 25-percent horizontal-tail mean aerodynamic chord, ft	18.72
Sweep at 0.25 mean aerodynamic chord, deg	10.12
Deflection limit, deg	5 to -17
Vertical tail -	
Airfoil section	Modified biconvex
Area, sq ft	35.1
Span, ft	5.46
Mean aerodynamic chord, ft	6.88
Aspect ratio	0.849
Taper ratio	0.371
Tail length, 25-percent wing mean aerodynamic chord to 25-percent vertical-tail mean aerodynamic chord, ft	15.13
Sweep at 25-percent mean aerodynamic chord, deg	35
Rudder -	
Area, sq ft	4.3
Span, ft	2.92
Average chord, ft	1.375
Deflection limit, deg	±25
Yaw damper -	
Area, sq ft	1
Span, ft	1
Average chord, ft	1
Deflection limit, deg	±20
Fuselage:	
Frontal area, sq ft	25
Length, ft	51.25
Fineness ratio	9.09
Speed brakes (per side):	
Area, sq ft (projected frontal area at maximum deflection)	4.13
Chord, ft	2.50
Deflection limit, deg	60
Weight:	
Average landing weight, lb	14,000
Center-of-gravity location, percent mean aerodynamic chord	6.12
Moments of inertia (average landing weight), slug-ft^2:	
I_X	3,520
I_Y	55,700
I_Z	56,700
Product of inertia (average landing weight), slug-ft^2:	
I_{XZ}	3,075

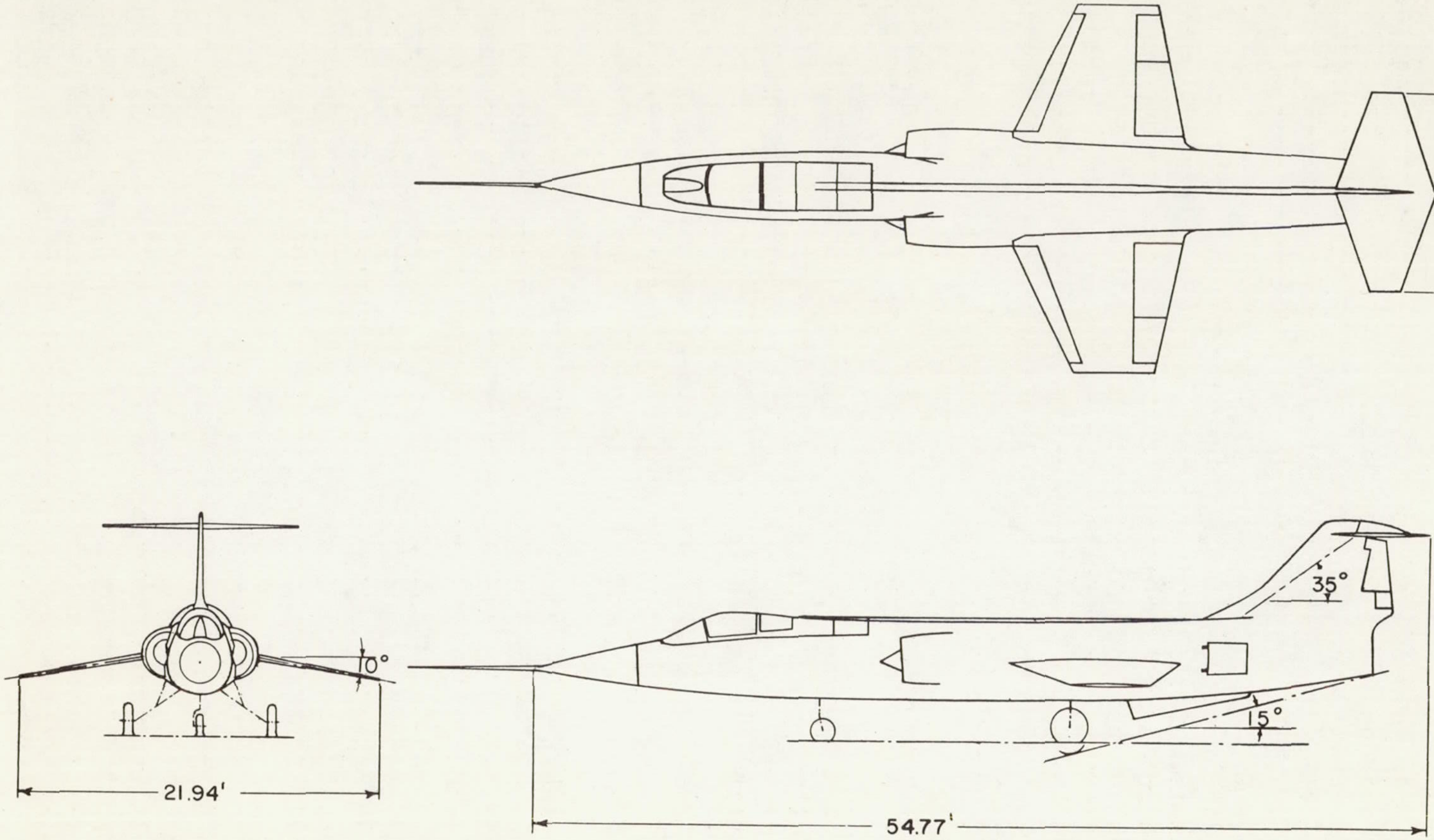


Figure 1.- Three-view drawing of the test airplane.

Figure 2.- Photograph of the test airplane. E-3022

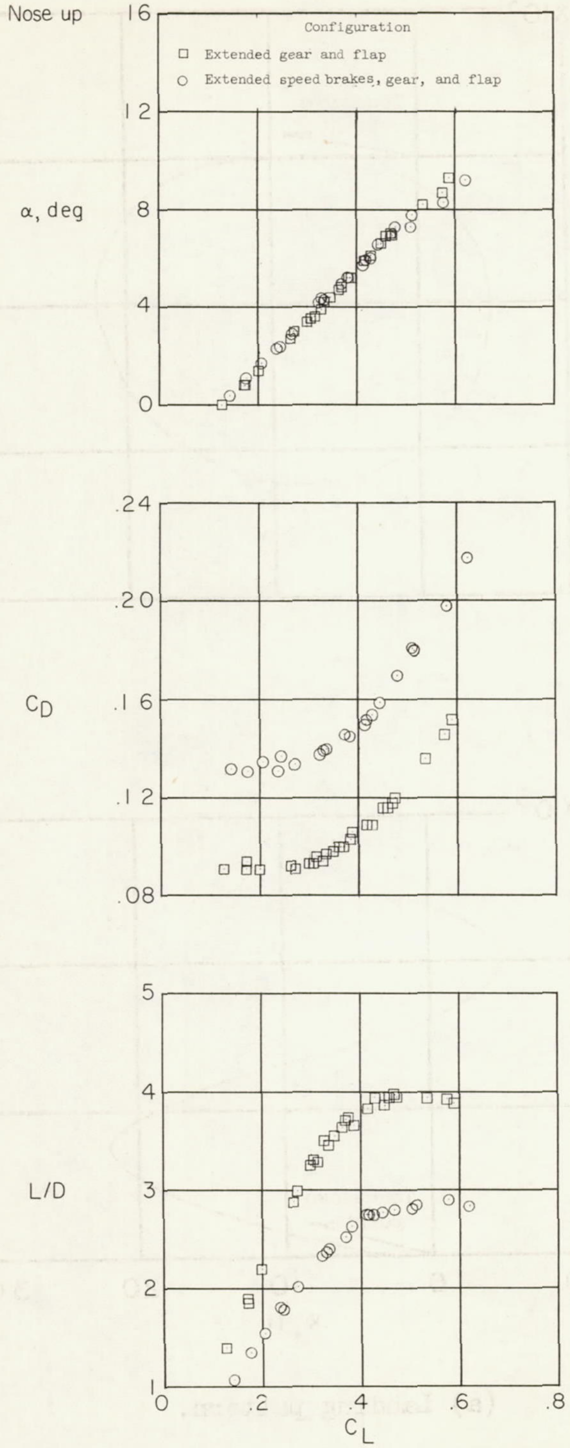
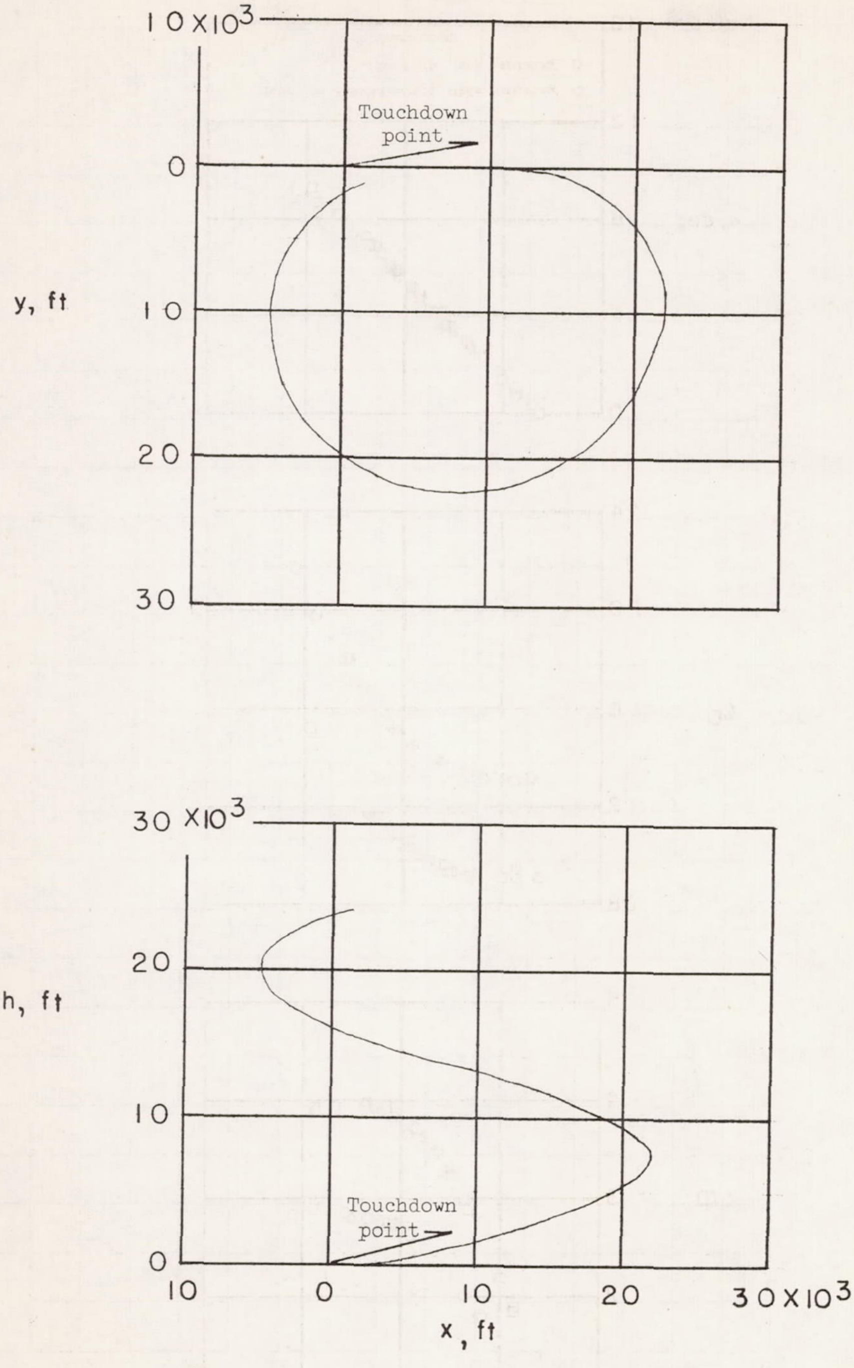
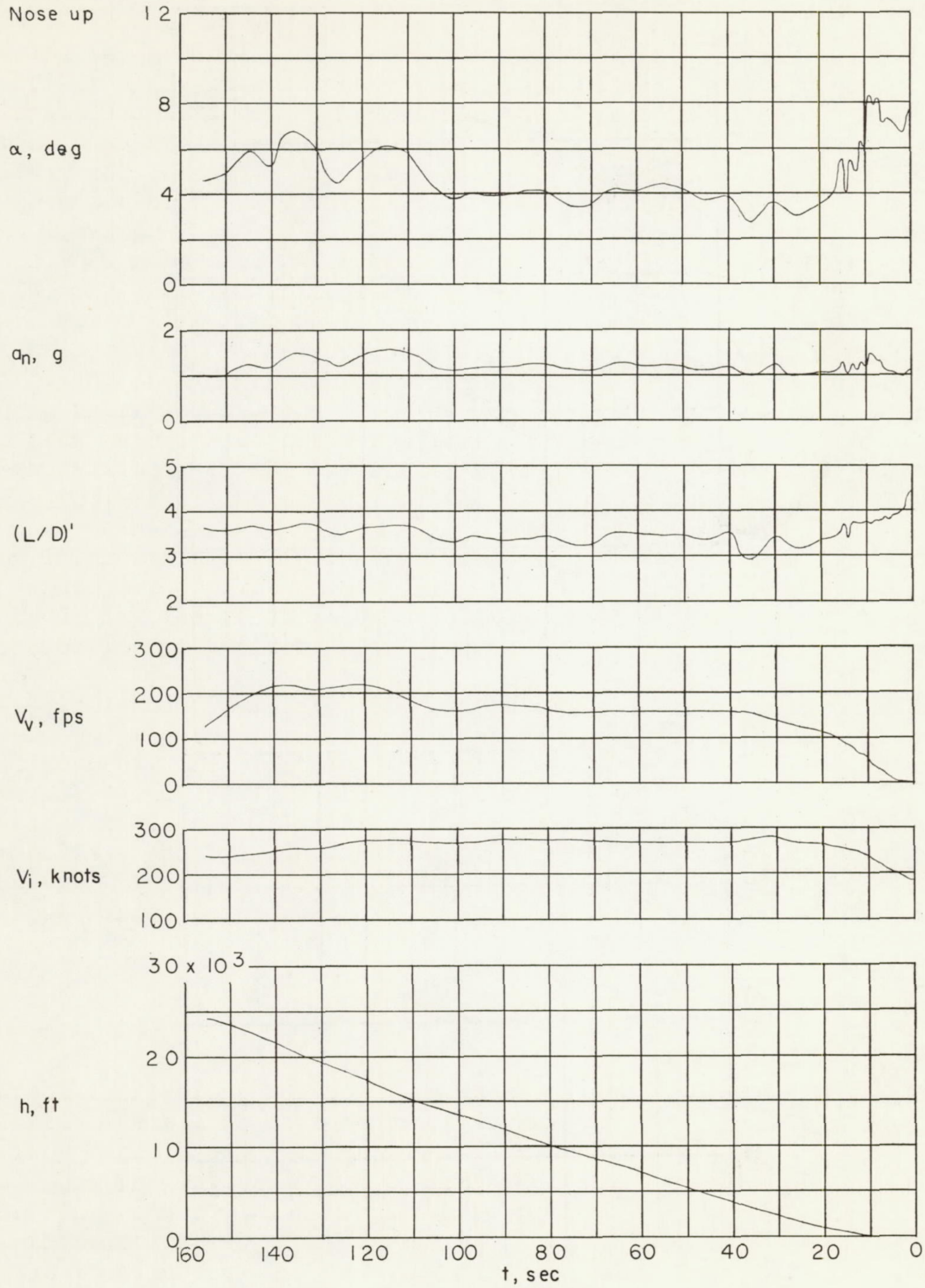


Figure 3.- Angle of attack, drag coefficient, and lift-drag ratio presented as a function of lift coefficient.



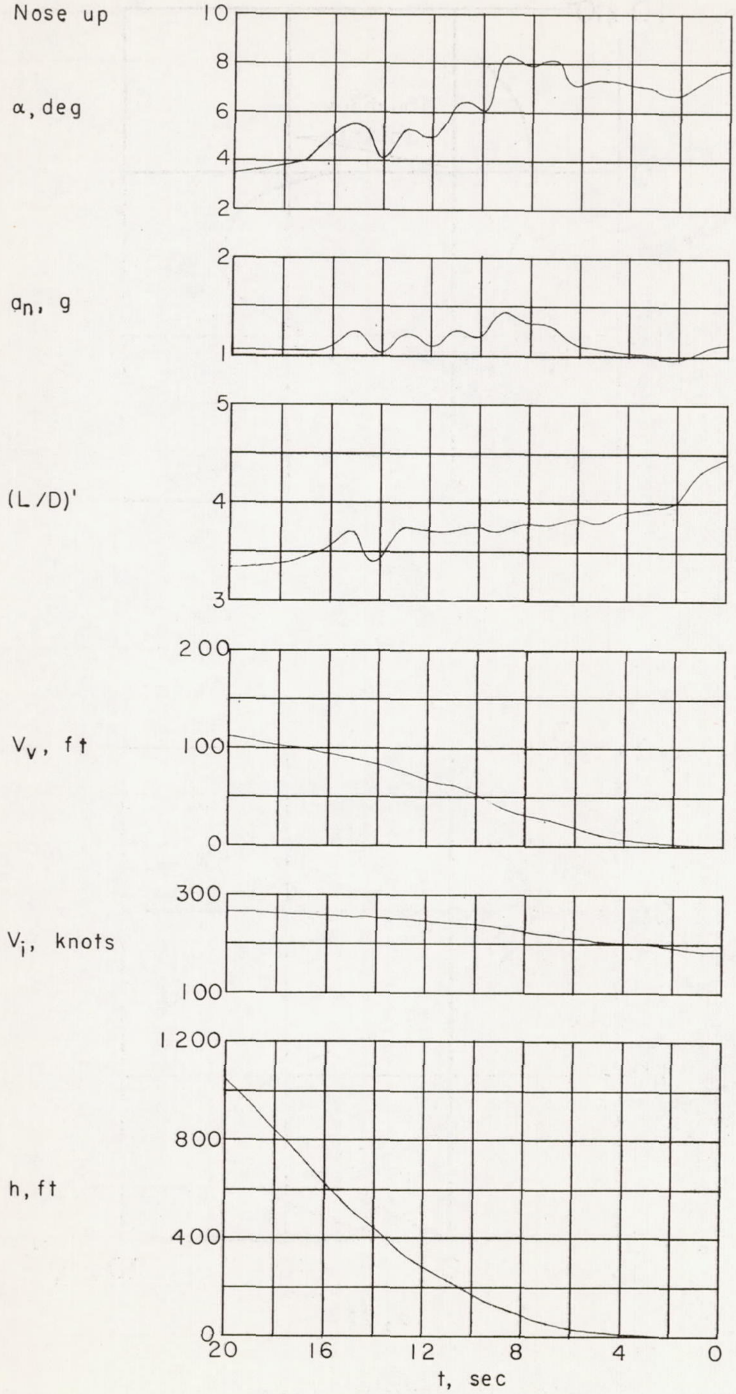
(a) Landing pattern.

Figure 4.- Typical approach and landing characteristics for the airplane when the peak effective lift-drag ratio is near 4.



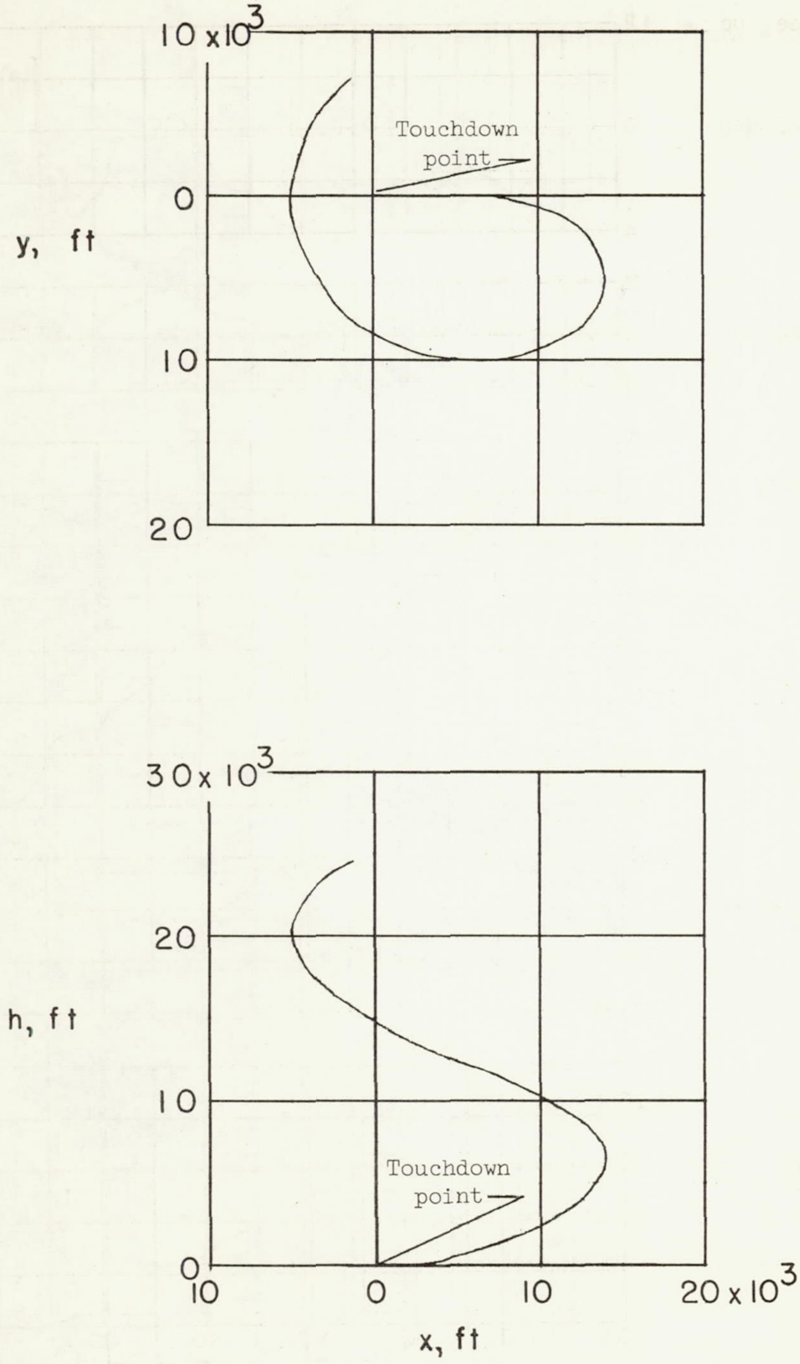
(b) Time history of the approach and landing.

Figure 4.- Continued.



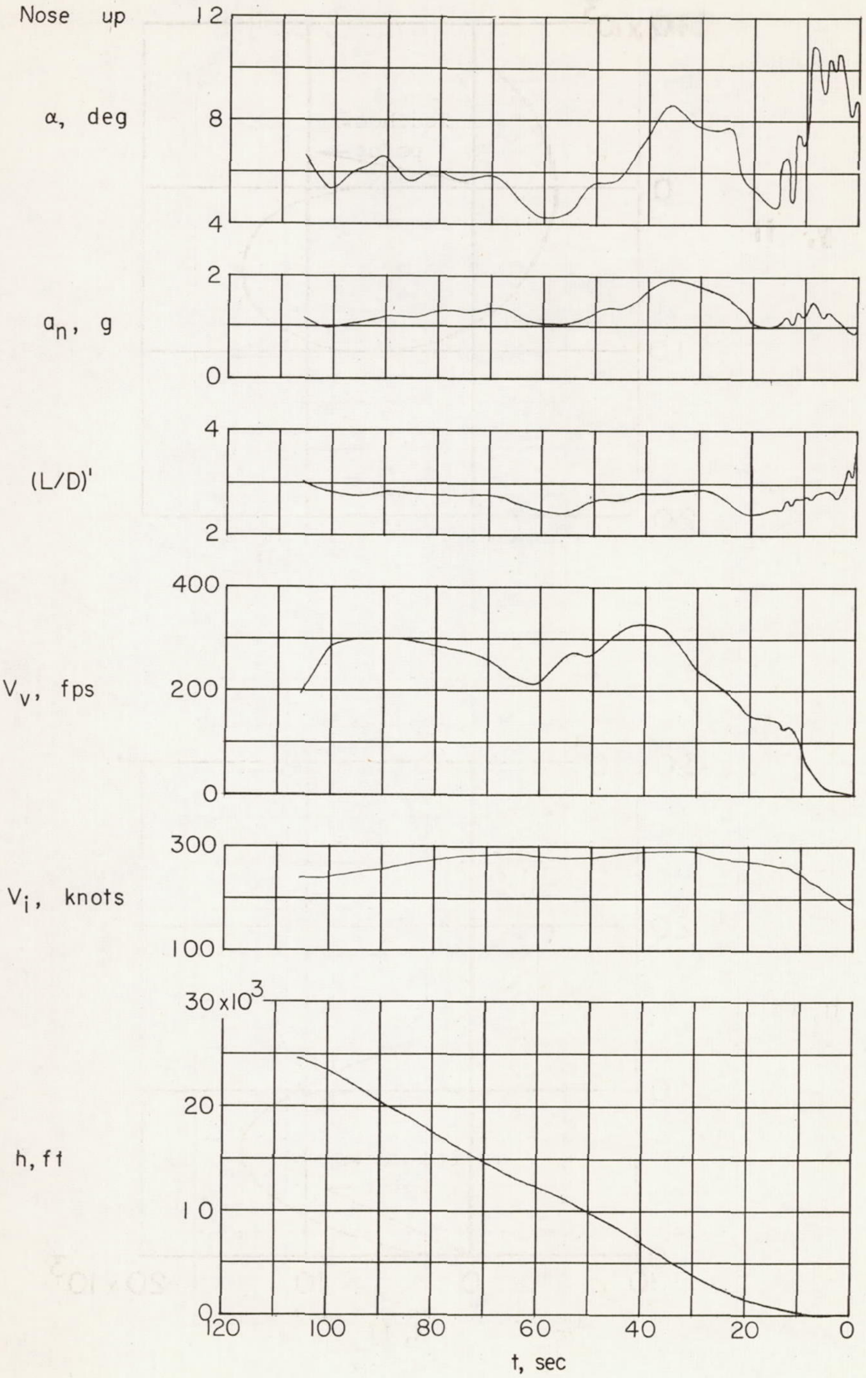
(c) Time history of the final flare.

Figure 4.- Concluded.



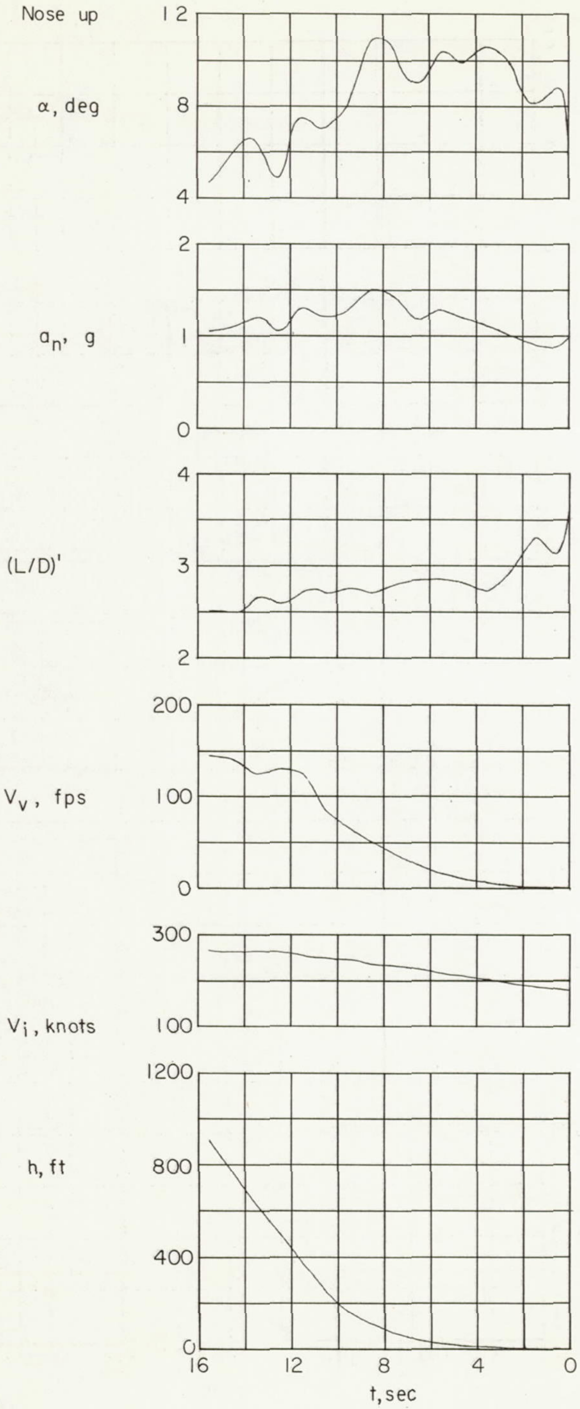
(a) Landing pattern.

Figure 5.- Typical approach and landing characteristics for the airplane when the peak effective lift-drag ratio is near 3.



(b) Time history of the approach and landing.

Figure 5.- Continued.



(c) Time history of the final flare.

Figure 5.- Concluded.

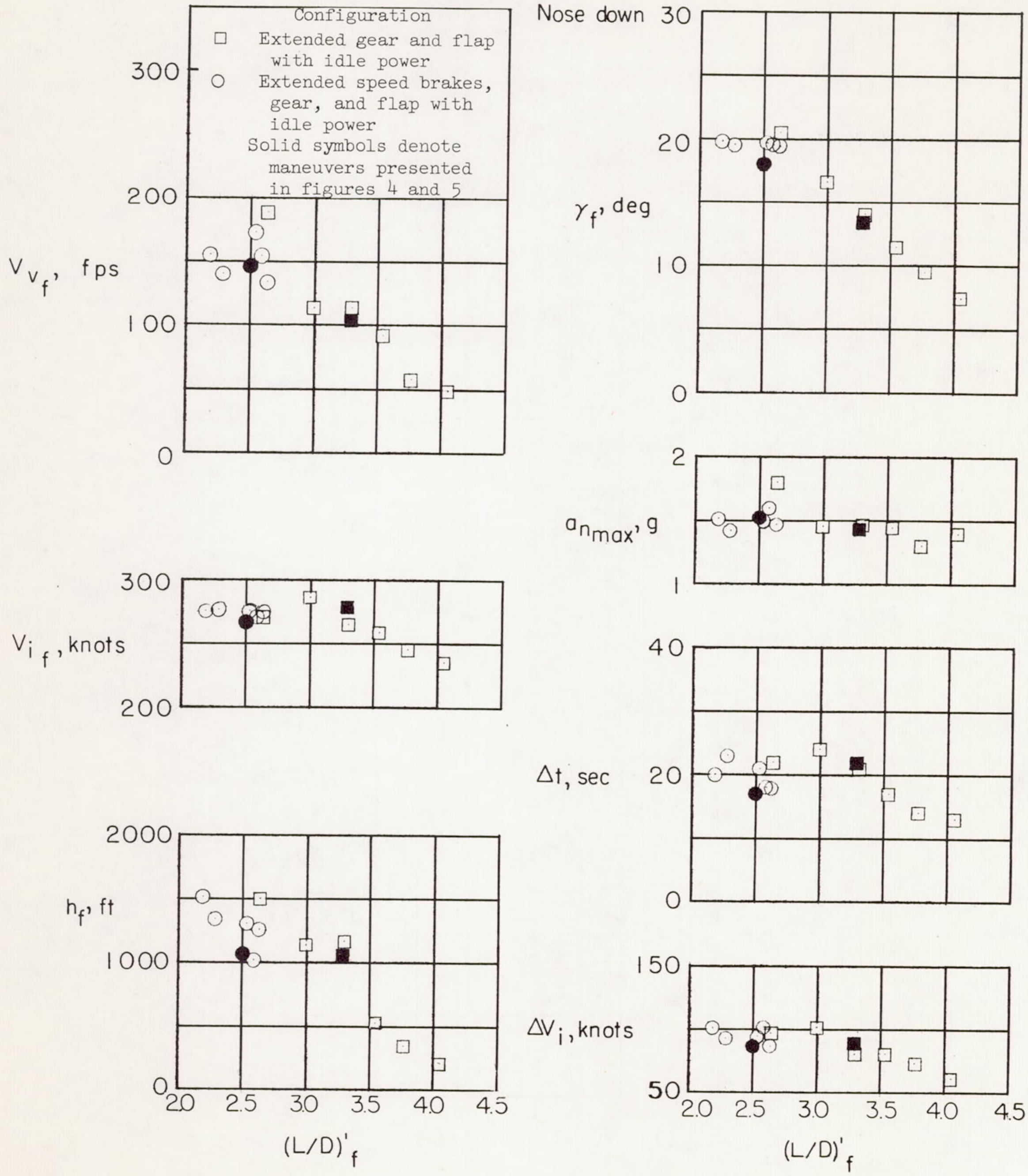


Figure 6.- Characteristics of final-flare parameters.

UNCLASSIFIED

[redacted]

[redacted]

UNCLASSIFIED