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# TECHNICAL NOTE

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## LAUNCH CHARACTERISTICS OF THE X-15 RESEARCH AIRPLANE AS DETERMINED IN FLIGHT

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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## SUMMARY

The first 16 air launches of the X-15 airplane demonstrated the feasibility of air launch from an asymmetric position under the wing of the B-52 carrier airplane.

With all dampers operating, launch transients were minimized and no stability problems were encountered. But, when the roll damper failed to function, the X-15 experienced relatively large roll rates in the presence of the carrier airplane, creating the possibility of the X-15 upper vertical tail hitting the cutout in the B-52 wing.

Specific flight data demonstrated that left-aileron settings of from 6° to 8° at launch minimized the right-roll transient. The altitude loss of 3,000 to 9,000 feet before climbout could be effected was a function of launch altitude and recovery angle of attack. The average time for the X-15 to separate 10 feet from the B-52 carrier airplane was about 0.8 second.

Flight-measured separation rates and launch transients agree well with predicted values where the initial conditions and control motions are similar.

## INTRODUCTION

The launching of the XS-1 research airplane from the modified bomb bay of a B-29 airplane in 1946 to achieve the maximum possible performance potential dramatically demonstrated the feasibility of the air-launch technique for manned, rocket-powered, research airplanes. As pointed out in reference 1, no significant problems were encountered during any of the early XS-1 air launches. The further experience gained with subsequent rocket airplanes such as the D-558-II, X-1A, X-1B, X-1E, and the X-2 established even greater confidence in the air-launch technique.

When the X-15 project was originally contemplated, the air-launch method was a logical selection for affording greater performance potential because of the earlier successes. As the project developed, the B-52 airplane was proposed as the carrier vehicle. The minimum ground clearances of this airplane precluded carrying the X-15 in the bomb bay, as in previous launches of the aforementioned aircraft with the B-29 carrier airplane. Thus, a pylon attachment on the underside of the B-52 wing between the right inboard engine nacelle and the fuselage was selected.

Extensive wind-tunnel tests were then conducted in the Langley 7- by 10-foot wind tunnel (refs. 2 and 3) and in the University of Washington wind tunnel to determine the launch transients that might be expected because of the asymmetric carry position. The effect of control position in reducing or aggravating these motions was considered. Six-degree-of-freedom calculations were used also to augment these wind-tunnel data and to aid in establishing the predicted launch characteristics.

Time histories of the first two X-15 air launches were presented in references 4 and 5 and were briefly discussed along with other data obtained during the first two flights of the X-15.

This paper discusses all of the flight-measured launch characteristics of the X-15 research airplane recorded during the first 16 flights. The effects of such variables as weight, damper setting, and launch altitude on the launch characteristics are shown, and the flight-measured characteristics are compared with the wind-tunnel and calculated characteristics.

## SYMBOLS

$a_n$ — normal acceleration, g units

$C_N$ — normal-force coefficient

$g$ — acceleration due to gravity, ft/sec$^2$

$h_p$ — pressure altitude, ft

$\Delta h_p$ — altitude lost during launch, ft

| | |
|---|---|
| $L$ | rolling moment, ft-lb |
| $M$ | Mach number |
| $p$ | rolling velocity, deg/sec |
| $q$ | pitching velocity, deg/sec |
| $r$ | yawing velocity, deg/sec |
| $t$ | time, sec |
| $t_{(z=10\ ft)}$ | time for X-15 to separate 10 feet from the B-52 carrier airplane, sec |
| $V_i$ | indicated airspeed, knots |
| $z$ | separation distance between X-15 and B-52 carrier airplane, ft |
| $\alpha$ | angle of attack, deg |
| $\beta$ | angle of sideslip, deg |
| $\delta_a$ | total aileron deflection, $\delta_{h_{left}} - \delta_{h_{right}}$, deg |
| $\delta_h$ | horizontal-tail deflection, $\frac{\delta_{h_{left}} + \delta_{h_{right}}}{2}$, deg |
| $\delta_v$ | vertical-tail deflection, $\frac{\delta_{v_{upper}} + \delta_{v_{lower}}}{2}$, deg |
| $\theta$ | pitch attitude, deg |
| $\varphi$ | bank attitude, deg |

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Subscripts:

| | |
|---|---|
| L | launch condition |
| max | maximum |
| min | minimum |
| R | recovery condition |

## AIRPLANE

The X-15 airplane is a single-place experimental research airplane designed for penetration into the hypersonic, rarified-atmosphere flight regimes. The airplane is carried aloft under the right wing of a modified B-52 aircraft and is launched at altitudes near 40,000 feet. The X-15 then performs its powered flight mission and glides to a landing.

Three-view drawings of the X-15 airplane are presented in figures 1(a) and 1(b), and photographs of the airplane are shown in figures 2(a) and 2(b). Pertinent physical characteristics are presented in table I.

The X-15 is characterized by a 5-percent-thick midwing of trapezoidal plan form with an aspect ratio of 2.5. All aerodynamic control surfaces are actuated by irreversible hydraulic systems. Longitudinal control is provided by deflection of the slab-type horizontal tail; lateral control is provided by differential deflection of the left and right portions of the horizontal tail. The movable portions of the upper and lower wedge-sectioned vertical tails provide directional control. Auxiliary damping is provided about all three axes in a conventional manner along with a "yar" damper which provides a crossfeed of the yaw-rate signal into the roll damper.

The two X-15 airplanes utilized in the present investigation are each equipped with two XLR11 interim rocket motors, manufactured by the Reaction Motors Division of the Thiokol Chemical Corp. These motors are mounted one above the other in a vertical plane at the rear end of the fuselage. Each rocket motor has four individually controlled firing chambers which utilize an alcohol-water mixture as fuel and liquid oxygen as oxidizer. The combined sea-level thrust of both motors is approximately 13,000 pounds.

The only significant external modifications to the B-52 carrier airplanes are the pylon which carries the X-15, and a notch in the trailing edge of the B-52 wing to accommodate the X-15 upper vertical tail (fig. 1(b)). The pylon is mounted on the underside of the right wing of the B-52 about equidistantly between the fuselage and the inboard engine nacelle. The X-15 servicing and power connections from the B-52 are made in the pylon by use of quick-disconnect fittings. Three shackles, which can be simultaneously released from within the B-52 or the X-15, hold the X-15 in place. The cutout in the trailing edge of the B-52 wing provides a two-foot clearance on either side of the upper vertical tail of the X-15, as shown in figure 1(b) and figure 3. This cutout precluded the use of flaps, which resulted in higher take-off and landing speeds for the B-52/X-15 combination than would normally be expected for an operational B-52.

## INSTRUMENTATION

The following quantities pertinent to this investigation were recorded in the X-15 on NASA internal-recording instruments synchronized by means of a common timer:

- Airspeed and pressure altitude
- Normal acceleration
- Rolling, yawing, and pitching velocities
- Angles of attack and sideslip
- Aileron, vertical-tail, and horizontal-tail deflections



Airspeed and pressure altitude were measured with an NASA pitot-static tube mounted on the end of the nose boom. Also on the nose boom were free-floating vanes used to measure angle of attack and angle of sideslip. The angles presented are the measured angles uncorrected for any induced errors. The angular velocities were referenced to the body-axis system of the airplane. Angle of bank and angle of pitch were obtained by integrating the records of rolling and pitching velocities, respectively. Separation distances of the X-15 from the B-52 carrier airplane at launch were determined by a double integration of the normal accelerometer located at the airplane center of gravity.

Motion-picture coverage of the launch taken from a rearward position on the B-52 and from escort airplanes aided in visualizing the X-15 separation transients (see ref. 4).

## LAUNCH CONFIGURATIONS

A number of configurational differences existed among the 16 flights discussed in this paper. These differences pertained primarily to launch-initiation conditions such as weight, center-of-gravity location, damper gains, speed, and altitude. These configurational data are presented in table II.

The first flight of the X-15, which was planned as a glide flight, is the only lightweight launch which has been performed. All other flights have been fully powered flights, with two exceptions. On one of these flights only seven of the eight chambers ignited; on the other, an engine explosion, following a short period of five-chamber operation, forced the pilot to shut down the engine.

Although it was intended that every launch would be performed with all dampers functioning, only 10 flights were accomplished with all of the dampers operative. On two flights the pitch damper malfunctioned; on four other flights the roll damper malfunctioned. The relationship between damper-switch position and damper gain for all the X-15 damper modes is presented in table III. The first flight was performed with a pitch-damper-switch setting of 2, a roll-damper-switch setting of 2, and a yaw-damper-switch setting of 8. A single switch controls the gains of the roll and yar dampers. The yar damper fails when the gyro for the yaw mode fails (which has not occurred) or when the roll damper fails. As indicated in reference 4, the pitch damper malfunctioned on the first flight. On the next flight, and for all subsequent flights, the roll-damper switch at launch was 4. On the eighth launch, and for subsequent launches, the pitch-damper-switch setting was increased to 4. Both the side-located stick and the center stick have been utilized for controlling during the launch maneuver.



Pilots participating in this investigation represented North American Aviation, Inc., the U.S. Air Force Flight Test Center, and the NASA Flight Research Center, Edwards, Calif.

## DISCUSSION

### General Preflight Studies

As discussed previously, wind-tunnel studies and computations were performed prior to the first flight of the X-15 so that the pilot could be advised on the technique to use in executing a successful launch. The wind-tunnel tests showed that flow fields from the B-52 wing and fuselage create noticeable upwash and sidewash on the X-15. These flow fields are responsible for moments imposed upon the X-15 while in the carry position, as well as for changes in the basic aerodynamic characteristics of the airplanes. The various interaction effects are discussed in detail in references 2 and 3.

Separation effects.- The only indication of a potentially serious problem was the possible rolling of the X-15 in the presence of the B-52 carrier airplane. Because of the limited 2-foot clearance of the X-15 upper vertical tail in the B-52 wing cutout, at a normal heavy-weight separation rate, the X-15 tail could strike the cutout if a bank angle of $20^\circ$ were exceeded before the X-15 dropped below the B-52 wing ($z \approx 2.5$ ft). Figure 4 presents a plot of the predicted rolling moment as a function of Mach number. This predicted rolling moment was believed to be small enough to permit safe launches to be executed with neutral control settings. It was felt that use of aileron to counteract the roll would probably result in roll to the opposite direction (ref. 2). The recommendation was made, therefore, that neutral control should be employed on the first launch.

Recovery effects.- The manufacturer's estimates of transonic buffet following separation and during the recovery indicated that buffet should not be expected below a normal-force coefficient of 0.6, which would correspond to an angle of attack of about 10°. A recovery angle of attack of 8° was selected so that the maximum possible lift-drag ratios could be utilized and a margin below the predicted buffet boundary still be retained.

## First Launch

Following preflight recommendations, the pilot attempted to employ neutral control deflections for the first X-15 launch (table II). The lightweight X-15 separated cleanly, and experienced the predicted right roll and nose-down pitch. Mild buffet was encountered at the trim angle of attack of 8°. The launch was considered successful in all respects even though the pitch damper was not operative (effective pitch-damper-switch position of 0). Reference 4 contains a more complete description of this launch.

## Typical Launch Time History

A time history of a typical X-15 launch made with all dampers operating is presented in figure 5 (table II, launch 7). The pitch-damper-switch position was 2, roll-damper-switch position was 4, and yaw-damper-switch position was 8. As the X-15 separated, the pilot pulled back on the control stick to recover from the free-fall condition to a trim condition. The roll damper applied corrective aileron to counteract the 22 deg/sec peak roll rate, and the peak right bank angle was held to 9°. The X-15 cleared the B-52 and its flow field ($z \approx 10$ ft) in less than 1 second. With all dampers operating, a trim condition was established about 5 seconds after launch with a minimum of transient motion encountered. A photographic sequence of a normal launch taken from an escort airplane is shown in figure 6. An additional report of a launch performed with all dampers operative is presented in reference 5.

## Effect of Damper Operation

Pitch damper.- As noted previously, figure 5 is a time history of a launch with all dampers operating, with a pitch-damper-switch setting of 2. Increasing the pitch-damper-switch setting to 4 affected the launch characteristics only in that the oscillations in angle of attack and pitching velocity were reduced, or eliminated completely.

Figure 7 presents a time history of an X-15 launch on which the pitch damper malfunctioned resulting, effectively, in a pitch-damper setting of 0 (table II, launch 5). Upon separation, there was a noticeable pitch-down and relatively large excursions in angle of attack. Disconcerted by the longitudinal motion, the pilot induced the rolling motion evidenced in the roll velocity. In this instance, trim flight could not be effected until about 8 seconds following launch. An account of an additional pitch-damper-off launch is included in reference 4.

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*Roll damper*.- A time history of an X-15 launch made with a roll-damper malfunction is presented in figure 8 (table II, launch 3). At launch, the rolling velocity increased rapidly to a peak value of 47 deg/sec with a peak bank angle of 40°. The upper vertical tail of the X-15 dropped below the B-52 wing cutout within 0.5 second. However, even with 2° of aileron opposing the roll, a bank angle of 20° developed within the 0.5 second, and the vertical tail barely cleared the cutout. The pilot finally righted the X-15 to a wings-level trim condition about 7 seconds after separation from the B-52.

*Yaw damper*.- No yaw-damper malfunctions have been encountered during the launches. Even if a yaw-damper malfunction is experienced, it is not expected to create any serious problems, since all predictions indicated little transient motion in the directional plane. The flight data have essentially verified these predictions with no noted vertical-tail motion induced at launch by the pilot or the damper.

*Yar damper*.- As was mentioned previously, the yar damper fails when the roll damper fails. As a result, four launches have been made with the yar damper inoperative. However, since the motions in the directional plane are so small, no adverse conditions have been noted on these launches, or would be expected.

## Resumé of Principal Trends

Figure 9 summarizes several of the more pertinent X-15 launch trends.

*Separation trends*.- This figure shows that the right bank angle can be kept within the desired range of 20° if either the pilot or the damper system applies a peak left-aileron input of from 6° to 8°, reducing the peak right-roll velocity to about 25 deg/sec. Aileron inputs of only 2°, however, will result in peak roll velocities of about 50 deg/sec with corresponding bank angles of almost 40°. At this point, it should be noted that the peak aileron input (usually damper-applied) is generally obtained just as the X-15 clears the B-52 wing cutout. If a fixed aileron deflection opposing the roll were to be applied by the pilot at launch, a value less than the 6° to 8° indicated in the figure would be utilized. In fact, a pilot-applied left-aileron setting of almost 6° at launch showed that the bank angle to the right at separation was negligible (approx. 5°) and that, when the X-15 cleared the B-52 flow field, the X-15 rolled more noticeably to the left.

The peak value of nose-down pitch angle at launch ranged between 0° and 16° for horizontal-tail deflections from about -2° to -6°.

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The time required for the X-15 to separate 10 feet from the B-52 averaged about 0.8 second. The data point in figure 9 at -1.12g was recorded on the lightweight glide flight.

The use of side-located or center-stick controllers did not affect the launch to any noticeable degree.

Recovery trends.- The launches from an altitude of about 40,000 feet resulted in altitude losses of about 3,000 feet before the climbout was effected (fig. 9). The recovery angle of attack for these launches was about 6°. The launches from an altitude of about 45,000 feet resulted in losses of altitude of from 4,000 to 9,000 feet, depending on the recovery angle of attack ($\alpha_R \approx 8°$ to 11°).

Figure 10, which defines the flight-determined buffet boundary, shows that buffet at the launch Mach number (approx. 0.8) occurs at $C_N \approx 0.4$. Figure 11 presents the normal-force coefficient as a function of angle of attack (free of B-52 flow field) at the launch altitude and Mach number. It can be seen that $C_N \approx 0.4$ corresponds to an angle of attack of about 6°. This figure, in conjunction with figure 10, also indicates that the launches have penetrated the buffet region up to a normal-force coefficient of approximately 0.6 and an angle of attack of about 10°. The buffet experienced in flight was mild, however, and no adverse piloting effects were encountered. Flight within the buffet region is relatively short, since the X-15 accelerates rapidly with the engines operating. The first engine chamber was generally ignited within 5 seconds of launch, and full thrust was obtained within about 15 seconds of launch. Within 45 seconds the recovery is completed, and the X-15 is at a supersonic Mach number.

## Comparison of Flight and Predicted Trends

An examination of figures 10 and 11 gives some indication of the comparison between flight test data and predicted trends from wind-tunnel studies (ref. 6). As shown in these figures, the estimates of lift-curve slope were good, whereas the estimated buffet boundary was somewhat optimistic.

Figure 12 shows a comparison of X-15 flight displacements with those predicted for zero control deflection in reference 2 during the first second following launch. Presented as a function of time are separation distance of the X-15 from the B-52 carrier airplane, bank angle, and pitch angle for both the lightweight and the heavyweight launch conditions. Only one lightweight launch was performed. For the lightweight launch (fig. 12(a)), the launch altitude was about 38,000 feet and the Mach number was 0.79. The lightweight predicted data were for a launch altitude of 30,000 feet and a Mach number of 0.60. Also, the weight used to predict the lightweight launch characteristics was about 1,000 pounds lighter than the flight launch weight. Even with the different initial conditions, especially in dynamic pressure, the comparison of flight and predicted data agrees in a qualitative sense. However, the flight-recorded displacements developed more rapidly than predicted.



The crosshatched areas in figure 12(b) indicate the range over which the heavyweight flight data are distributed. The flight and predicted heavyweight initial conditions are in closer agreement than those for the lightweight condition; therefore, the displacement data show better quantitive agreement. The predicted launch altitude was 38,000 feet and the Mach number was 0.75. The flight-measured altitude ranged between about 38,000 feet and 45,000 feet; the Mach numbers were all slightly above 0.8. The flight launch weight was about 2,000 pounds heavier than that used in making the predictions. For the heavyweight conditions, the X-15 in flight separated from the B-52 as predicted. However, bank angle and pitch angle built up more rapidly than predicted. These differences and the spread in the flight results are reflections not only of the differences in initial launch conditions, but also of variations in pilot control input during the launch.

The authors of references 2 and 3 recently performed additional six-degree-of-freedom calculations using initial conditions and control inputs measured in flight. Figure 13 presents a comparison of data previously presented in figure 7 with the new predictions. The agreement between the flight and predicted data for all of the important motions is good over the critical first second. The importance of knowing the initial conditions and probable control motions before attempting to predict the transients immediately following the release is emphasized by comparing figure 12(b) and figure 13. As noted previously, the data of figure 12(b) assume zero control motions throughout the launch as well as initial conditions different from those in flight, resulting in the large spread of flight data. Figure 13, however, duplicates the conditions recorded in flight, which results in the accurate prediction of flight motions. The effects of initial conditions can be seen, especially in the critical roll parameters, by referring to figure 4 and noting that at an altitude of 45,600 feet, increasing Mach number from 0.75 to 0.82 doubles the rolling moment impressed on the X-15 while attached to the B-52.

As was predicted, the directional motions in flight are negligible; therefore, no comparisons of directional displacements are presented.

## CONCLUSIONS

From the first 16 air launches of the X-15 research airplane it is concluded that:



1. Successful launches can be made from an asymmetric carry position on the carrier airplane.

2. With all dampers operating, no problems were encountered during the air-launch phase of the flight, since all transients are minimized. However, with the roll damper inoperative, it is possible that the X-15 upper vertical tail may strike the cutout in the B-52 wing because of the large roll rates experienced in the presence of the carrier aircraft.

3. Specific flight data demonstrated that aileron settings of from 6° to 8° at launch will minimize the roll transient.

4. The altitude lost before climbout can be effected ranges from 3,000 feet to 9,000 feet, depending on the launch altitude and recovery angle of attack.

5. The time for the X-15 to separate 10 feet from the B-52 carrier airplane averages about 0.8 second.

6. Flight-measured separation rates and launch transients agree well with predicted values where the initial conditions and control motions are similar.

Flight Research Center,
National Aeronautics and Space Administration,
Edwards, Calif., December 2, 1960.

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TABLE I.- PHYSICAL CHARACTERISTICS OF THE X-15 AIRPLANE

| | |
|---|---|
| **Wing:** | |
| Airfoil section | NACA 66005 (Modified) |
| Total area (includes 94.98 sq ft covered by fuselage), sq ft | 200 |
| Span, ft | 22.36 |
| Mean aerodynamic chord, ft | 10.27 |
| Root chord, ft | 14.91 |
| Tip chord, ft | 2.98 |
| Taper ratio | 0.20 |
| Aspect ratio | 2.50 |
| Sweep at 25-percent-chord line, deg | 25.64 |
| Incidence, deg | 0 |
| Dihedral, deg | 0 |
| Aerodynamic twist, deg | 0 |
| Flap - | |
| Type | Plain |
| Area (each), sq ft | 8.30 |
| Span (each), ft | 4.50 |
| Inboard chord, ft | 2.61 |
| Outboard chord, ft | 1.08 |
| Deflection, down, deg | 40 |
| Ratio flap chord to wing chord | 0.22 |
| Ratio total flap area to wing area | 0.08 |
| Ratio flap span to wing semispan | 0.40 |
| Trailing-edge angle, deg | 5.67 |
| Sweepback angle of hinge line, deg | 0 |
| **Horizontal tail:** | |
| Airfoil section | NACA 66005 (Modified) |
| Total area (includes 63.29 sq ft covered by fuselage), sq ft | 115.34 |
| Span, ft | 18.08 |
| Mean aerodynamic chord, ft | 7.05 |
| Root chord, ft | 10.22 |
| Tip chord, ft | 2.11 |
| Taper ratio | 0.21 |
| Aspect ratio | 2.83 |
| Sweep at 25-percent-chord line, deg | 45 |
| Dihedral, deg | -15 |
| Ratio horizontal-tail area to wing area | 0.58 |
| Movable surface area, sq ft | 51.77 |
| Deflection - | |
| Longitudinal, up, deg | 15 |
| Longitudinal, down, deg | 35 |
| Lateral differential (pilot authority), deg | ±15 |
| Lateral differential (autopilot authority), deg | ±30 |
| Control system | Irreversible hydraulic boost with artificial feel |

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TABLE I.- PHYSICAL CHARACTERISTICS OF THE X-15 AIRPLANE - Concluded

| | |
|---|---|
| **Upper vertical tail:** | |
| Airfoil section | 10° single wedge |
| Total area, sq ft | 40.91 |
| Span, ft | 4.58 |
| Mean aerodynamic chord, ft | 8.95 |
| Root chord, ft | 10.21 |
| Tip chord, ft | 7.56 |
| Taper ratio | 0.74 |
| Aspect ratio | 0.51 |
| Sweep at 25-percent-chord line, deg | 23.41 |
| Ratio vertical-tail area to wing area | 0.20 |
| Movable surface area, sq ft | 26.45 |
| Deflection, deg | ±7.50 |
| Sweepback of hinge line, deg | 0 |
| Control system | Irreversible hydraulic boost with artificial feel |
| **Lower vertical tail:** | |
| Airfoil section | 10° single wedge |
| Total area, sq ft | 34.41 |
| Span, ft | 3.83 |
| Mean aerodynamic chord, ft | 9.17 |
| Root chord, ft | 10.21 |
| Tip chord, ft | 8 |
| Taper ratio | 0.78 |
| Aspect ratio | 0.43 |
| Sweep at 25-percent-chord line, deg | 23.41 |
| Ratio vertical-tail area to wing area | 0.17 |
| Movable surface area, sq ft | 19.95 |
| Deflection, deg | ±7.50 |
| Sweepback of hinge line, deg | 0 |
| Control system | Irreversible hydraulic boost with artificial feel |
| **Fuselage:** | |
| Length, ft | 50.75 |
| Maximum width, ft | 7.33 |
| Maximum depth, ft | 4.67 |
| Maximum depth over canopy, ft | 4.97 |
| Side area (total), sq ft | 215.66 |
| Fineness ratio | 10.91 |
| **Speed brake (typical for each of four):** | |
| Area, sq ft | 5.57 |
| Span, ft | 1.67 |
| Chord, ft | 3.33 |
| Deflection, deg | 35 |

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TABLE II.- X-15 CONFIGURATIONAL LAUNCH DATA

| Launch no. | Effective damper-switch position | | | Weight, lb | Center of gravity, percent | $h_{p_L}$, ft | $V_{i_L}$, KIAS | $M_L$ |
|---|---|---|---|---|---|---|---|---|
| | Pitch | Roll | Yaw | | | | | |
| 1 | 0 | 2 | 8 | 13,452 | 18.1 | 37,547 | 254 | 0.792 |
| 2 | 2 | 4 | 8 | 32,700 | 20.5 | 37,880 | 258 | .809 |
| 3 | 2 | 0 | 8 | 32,764 | 20.2 | 40,913 | 247 | .827 |
| 4 | 2 | 0 | 8 | 32,775 | 20.3 | 44,947 | 224 | .825 |
| 5 | 0 | 4 | 8 | 32,968 | 21.3 | 44,753 | 219 | .806 |
| 6 | 2 | 4 | 8 | 33,684 | 22.2 | 45,308 | 224 | .832 |
| 7 | 2 | 4 | 8 | 33,497 | 22.2 | 44,888 | 222 | .818 |
| 8 | 4 | 4 | 8 | 33,384 | 21.4 | 44,841 | 227 | .832 |
| 9 | 4 | 0 | 8 | 33,335 | 21.7 | 44,935 | 224 | .824 |
| 10 | 4 | 4 | 8 | 33,393 | 21.4 | 44,801 | 228 | .836 |
| 11 | 4 | 4 | 8 | 33,509 | 21.4 | 44,961 | 221 | .814 |
| 12 | 4 | 4 | 8 | 33,424 | 21.5 | 45,000 | 222 | .820 |
| 13 | 4 | 4 | 8 | 33,394 | 21.5 | 43,025 | 229 | .809 |
| 14 | 4 | 0 | 8 | 33,621 | 21.5 | 44,727 | 224 | .821 |
| 15 | 4 | 4 | 8 | 33,690 | 21.4 | 44,868 | 226 | .829 |
| 16 | 4 | 4 | 8 | 33,675 | 21.4 | 44,961 | 226 | .831 |

TABLE III.- CHARACTERISTICS OF X-15 STABILITY AUGMENTATION SYSTEM

| Switch position | Gain | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Pitch | | Roll | | Yaw | | Yar | |
| | In/deg/sec | Deg/deg/sec | In/deg/sec | Deg/deg/sec | In/deg/sec | Deg/deg/sec | In/deg/sec | Deg/deg/sec |
| 1 | 0.005 | 0.075 | 0.0017 | 0.051 | 0.004 | 0.03 | 0.003 | 0.09 |
| 2 | .010 | .150 | .0033 | .100 | .008 | .06 | .006 | .18 |
| 3 | .015 | .225 | .0050 | .150 | .012 | .09 | .009 | .27 |
| 4 | .020 | .300 | .0067 | .200 | .016 | .12 | .012 | .36 |
| 5 | .025 | .375 | .0083 | .250 | .020 | .15 | .015 | .45 |
| 6 | .030 | .450 | .0100 | .300 | .024 | .18 | .018 | .54 |
| 7 | .035 | .525 | .0117 | .350 | .028 | .21 | .021 | .63 |
| 8 | .040 | .600 | .0134 | .400 | .032 | .24 | .024 | .72 |
| 9 | .045 | .675 | .0150 | .450 | .036 | .27 | .027 | .81 |
| 10 | .050 | .750 | .0167 | .500 | .040 | .30 | .030 | .90 |
| Condition | Servo and surface limits | | | | | | | |
| Normal functioning | Maximum servo-actuator travel = ±1.0 inch or ±15° of horizontal stabilizer | | Maximum servo-actuator travel = ±1.0 inch or ±15° of horizontal stabilizer | | Maximum servo-actuator travel = ±1.0 inch or ±7.5° of vertical stabilizer | | Maximum servo-actuator travel = ±1.0 inch or ±15° of horizontal stabilizer | |
| Mal-functioning | 0.1 inch or 1.5° of horizontal stabilizer | | 0.1 inch or 3° of differential stabilizer | | 0.1 inch or 0.75° of vertical stabilizer | | 0.1 inch or 3° of differential stabilizer | |

V



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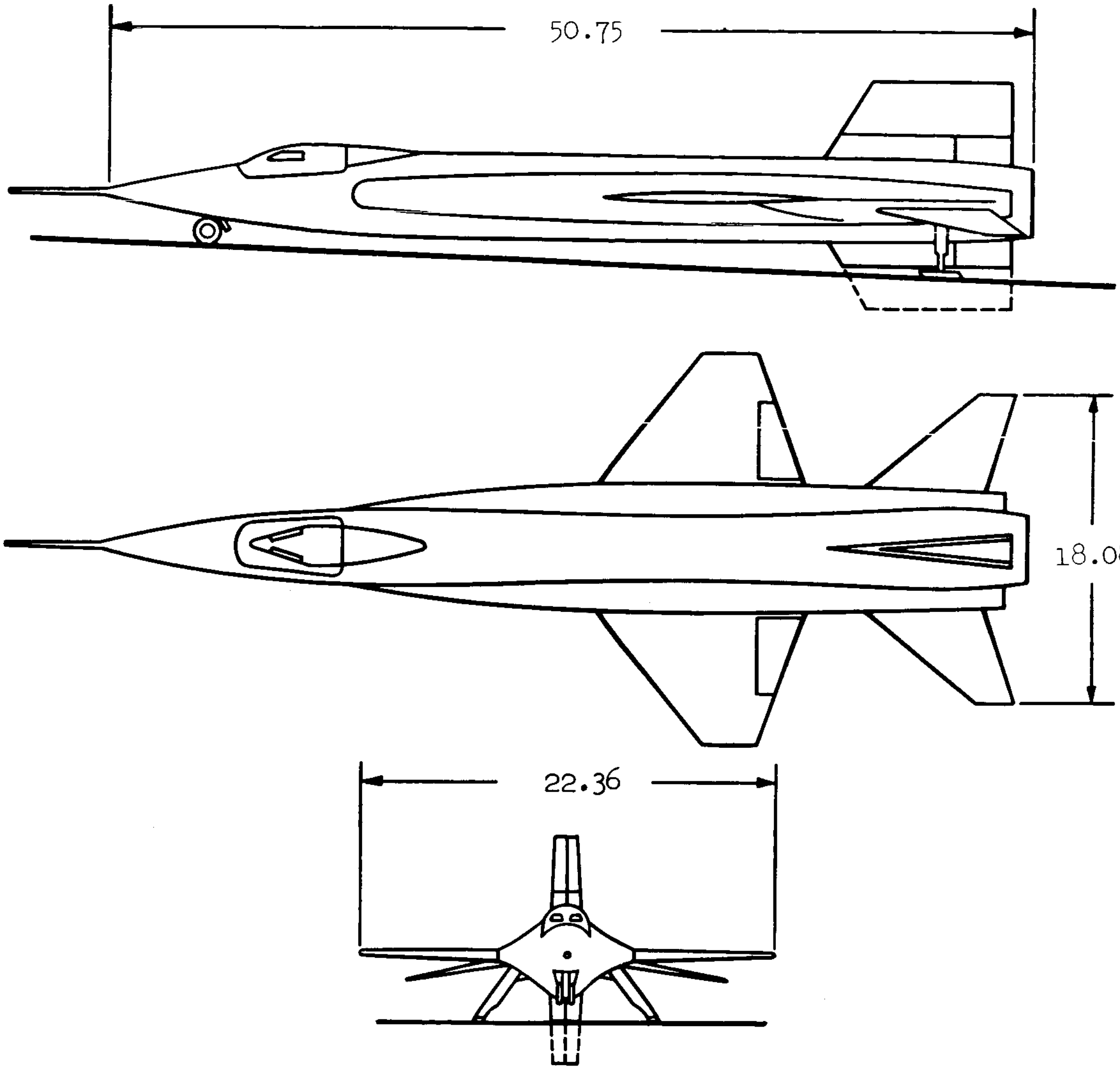
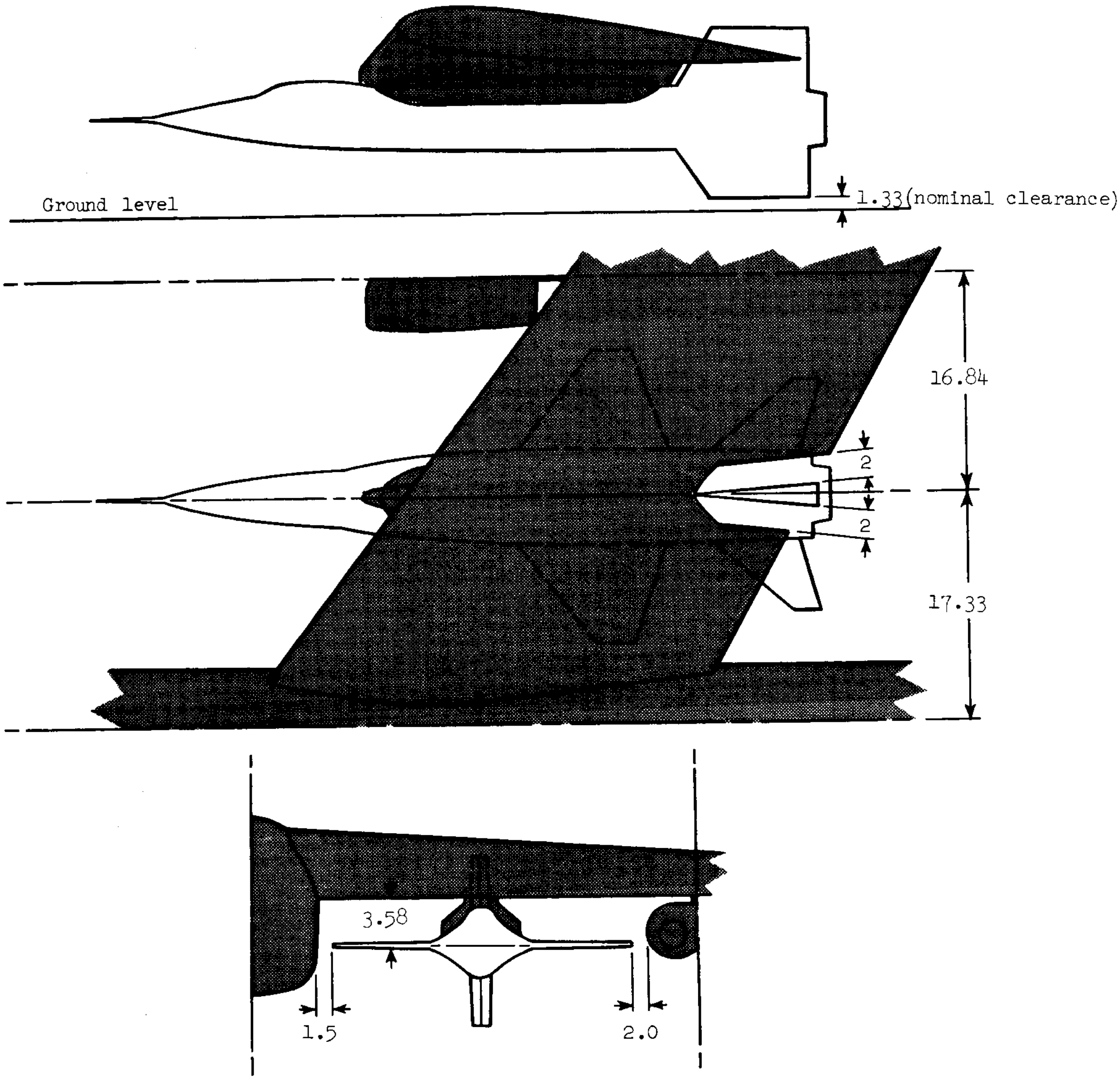


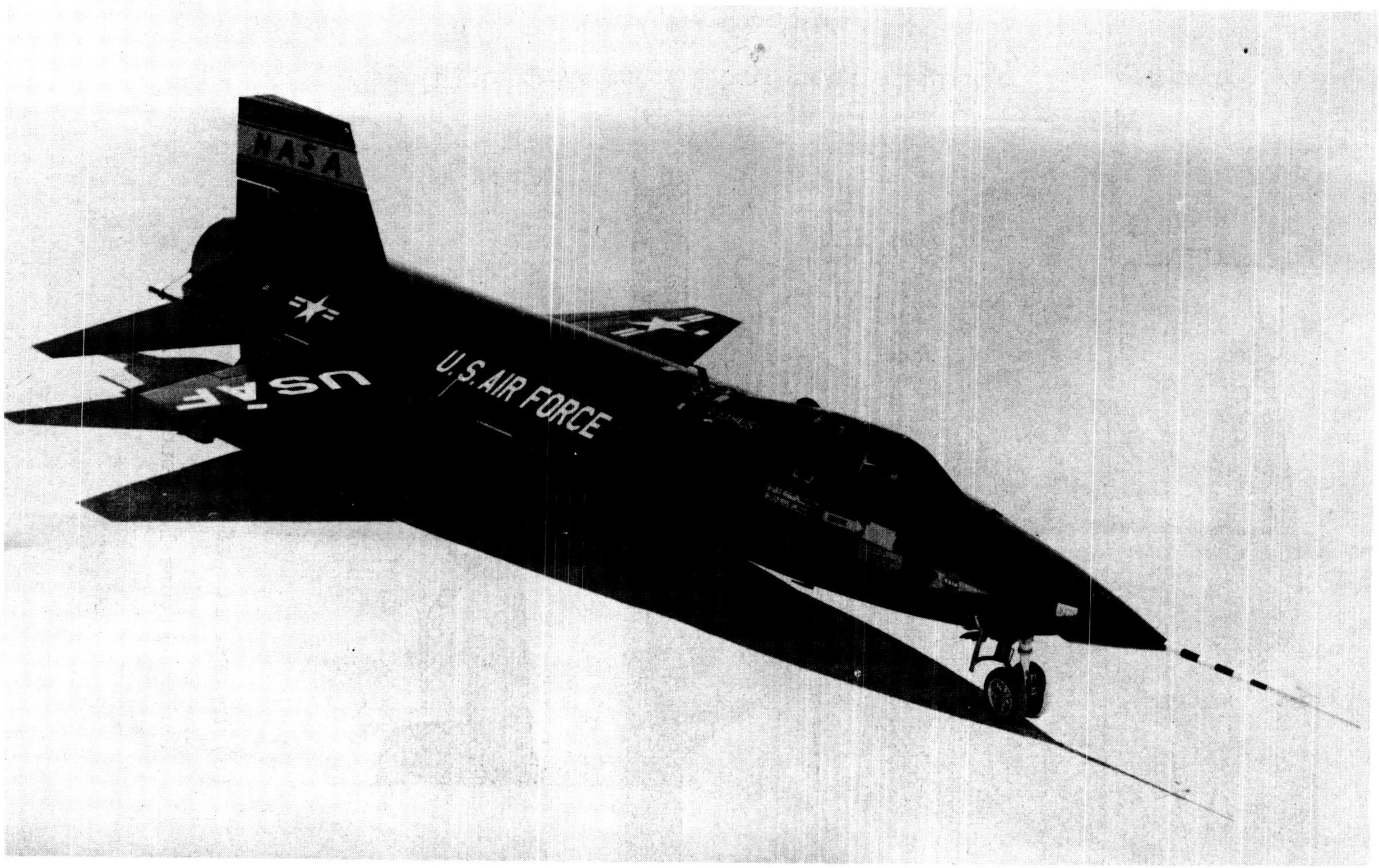

(a) Alone.

Figure 1.- Three-view drawing of the X-15 airplane. All dimensions in feet.



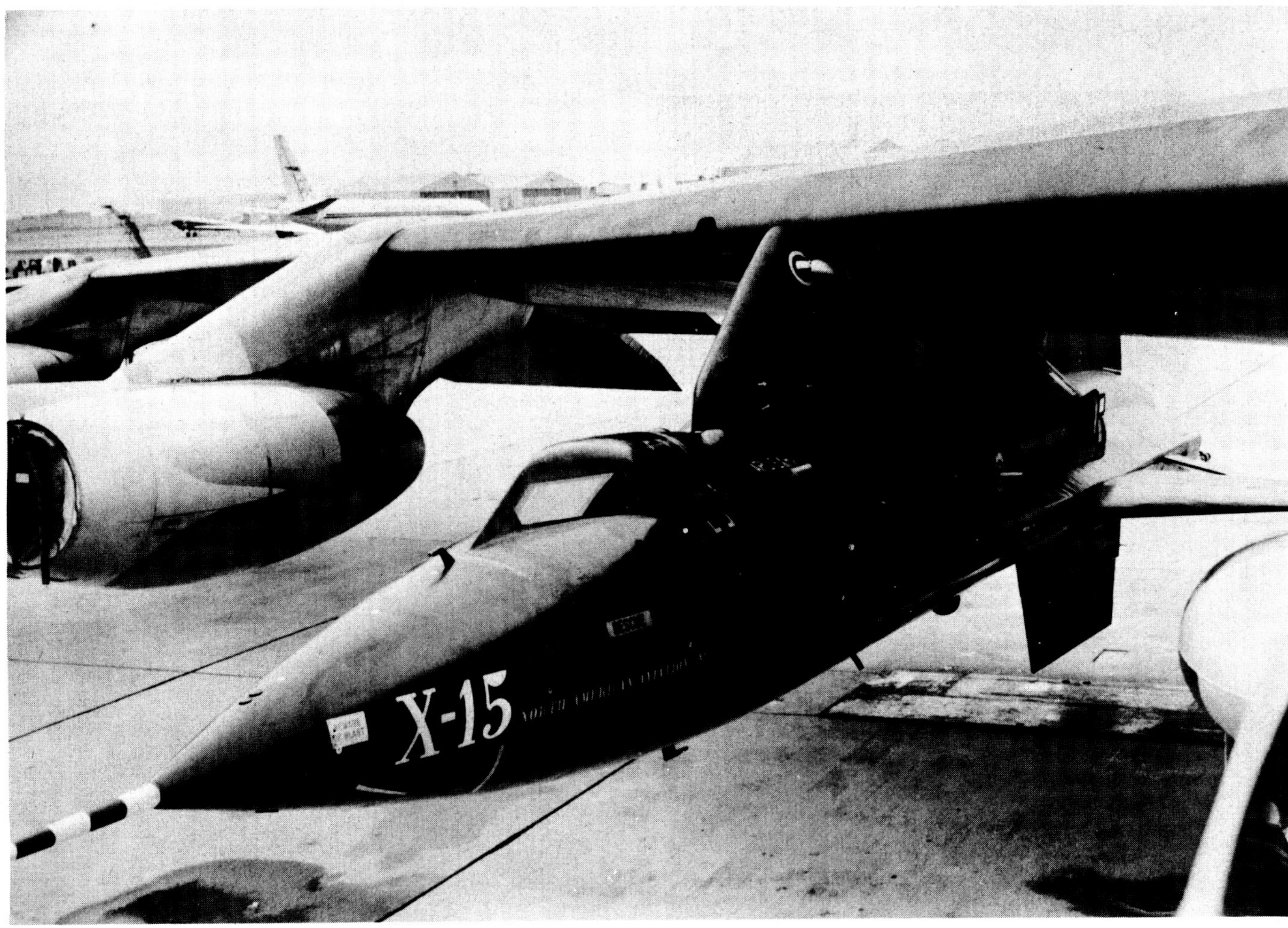

(b) In presence of B-52 carrier airplane.

Figure 1.- Concluded.




(a) Alone. E-5250

Figure 2.- Photograph of the X-15 airplane.




(b) In presence of B-52 carrier airplane. E-5087

Figure 2.- Concluded.

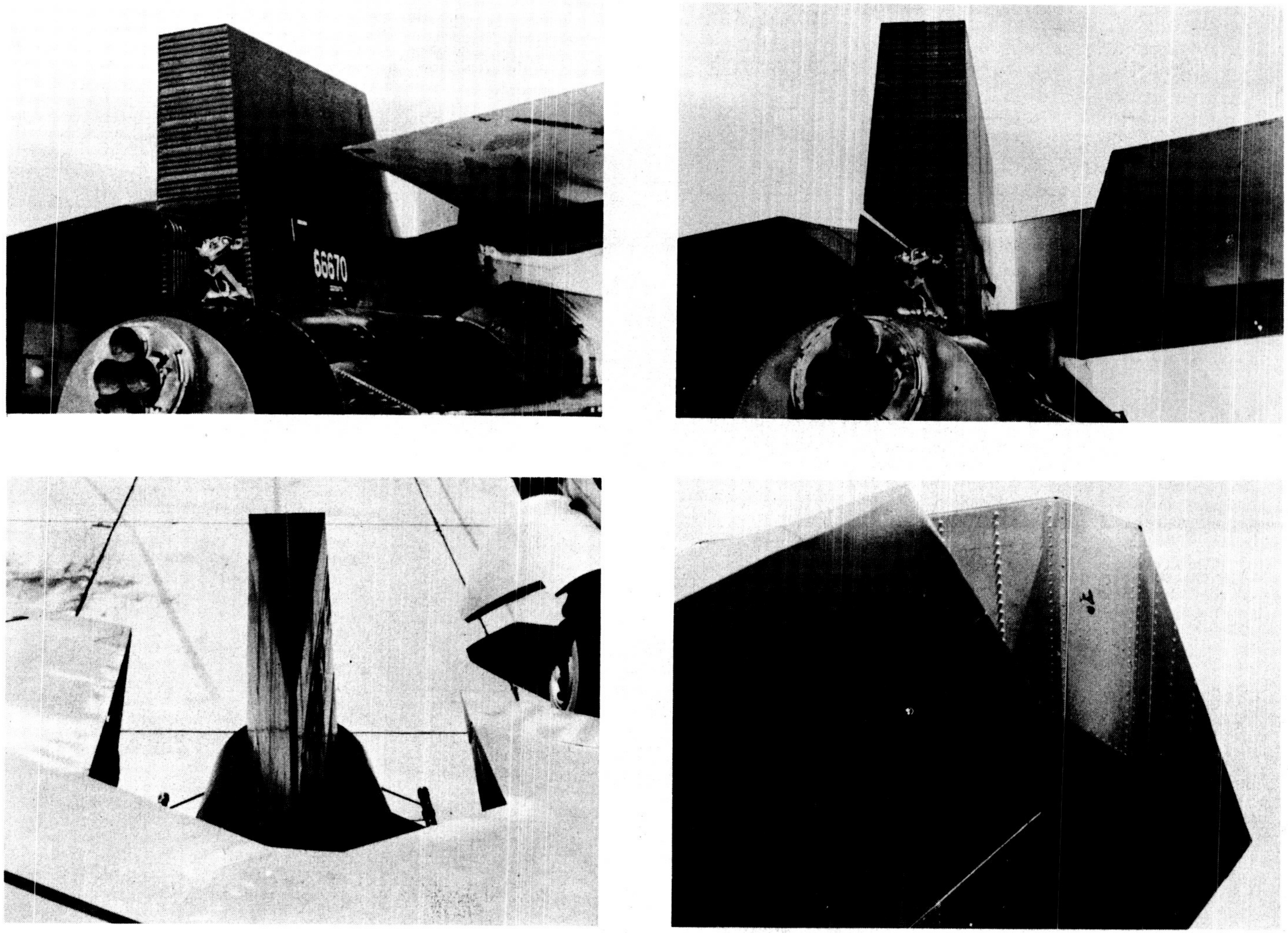



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Figure 3.- Photographs of the X-15 upper vertical tail in the B-52 wing cutout.

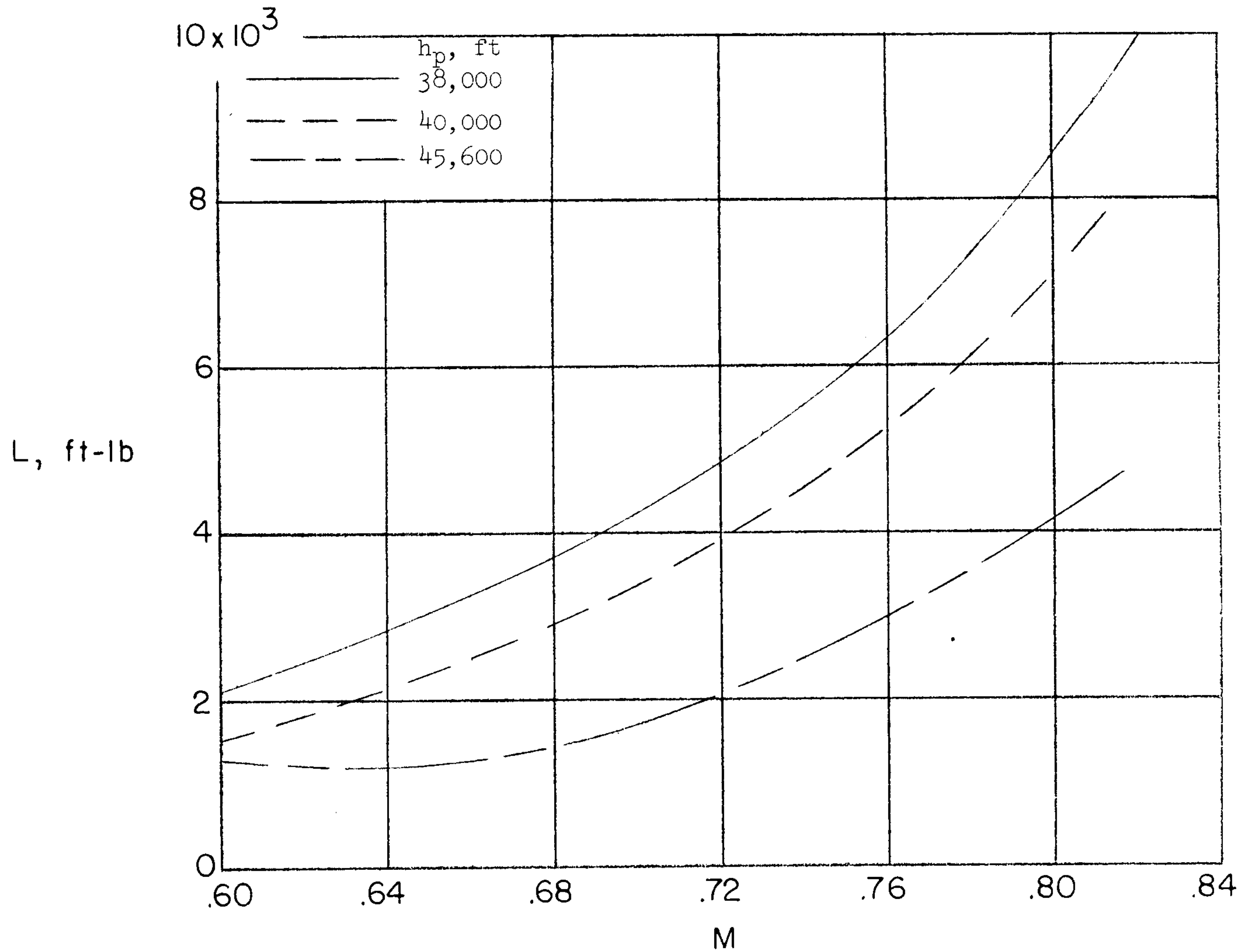


Figure 4.- Predicted rolling moment on X-15 while attached to B-52 as a function of Mach number. X-15 control surfaces at zero.

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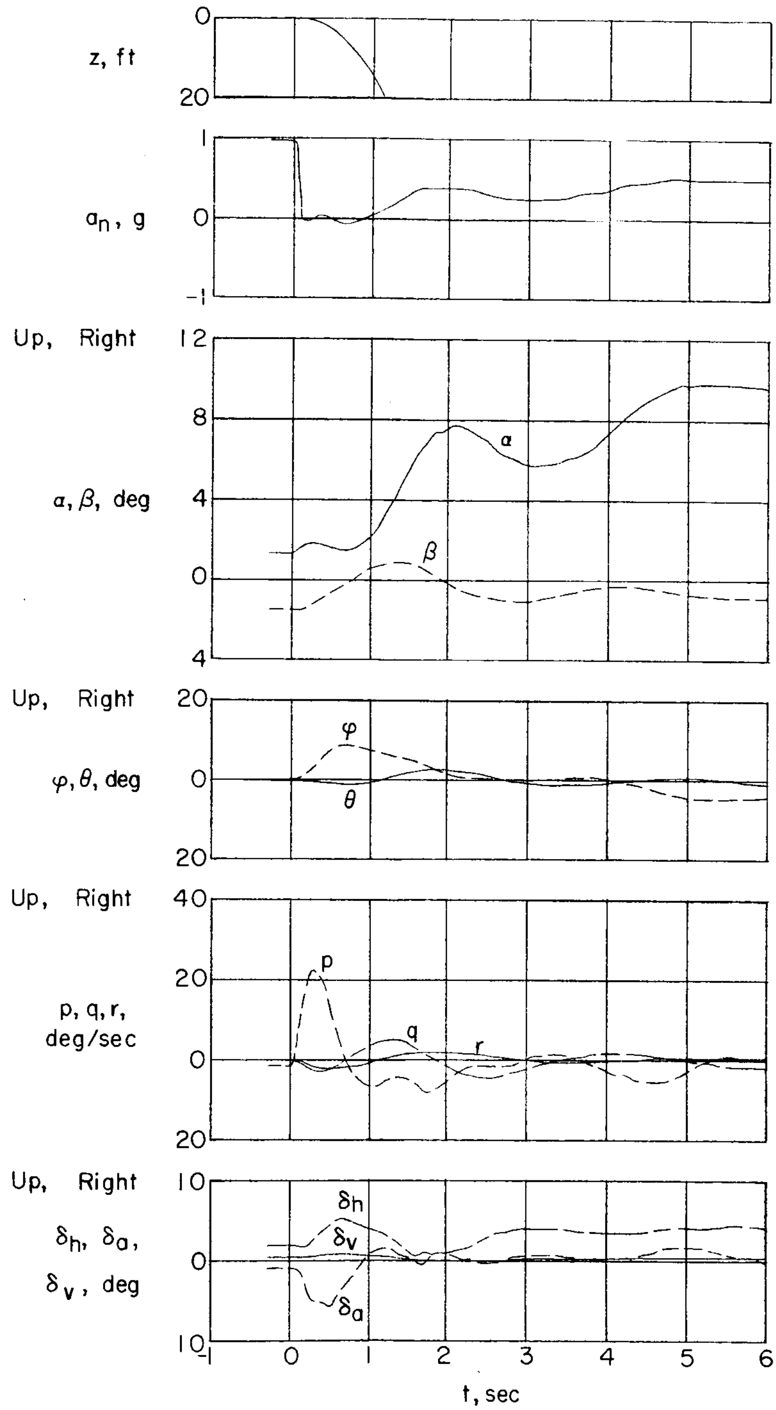
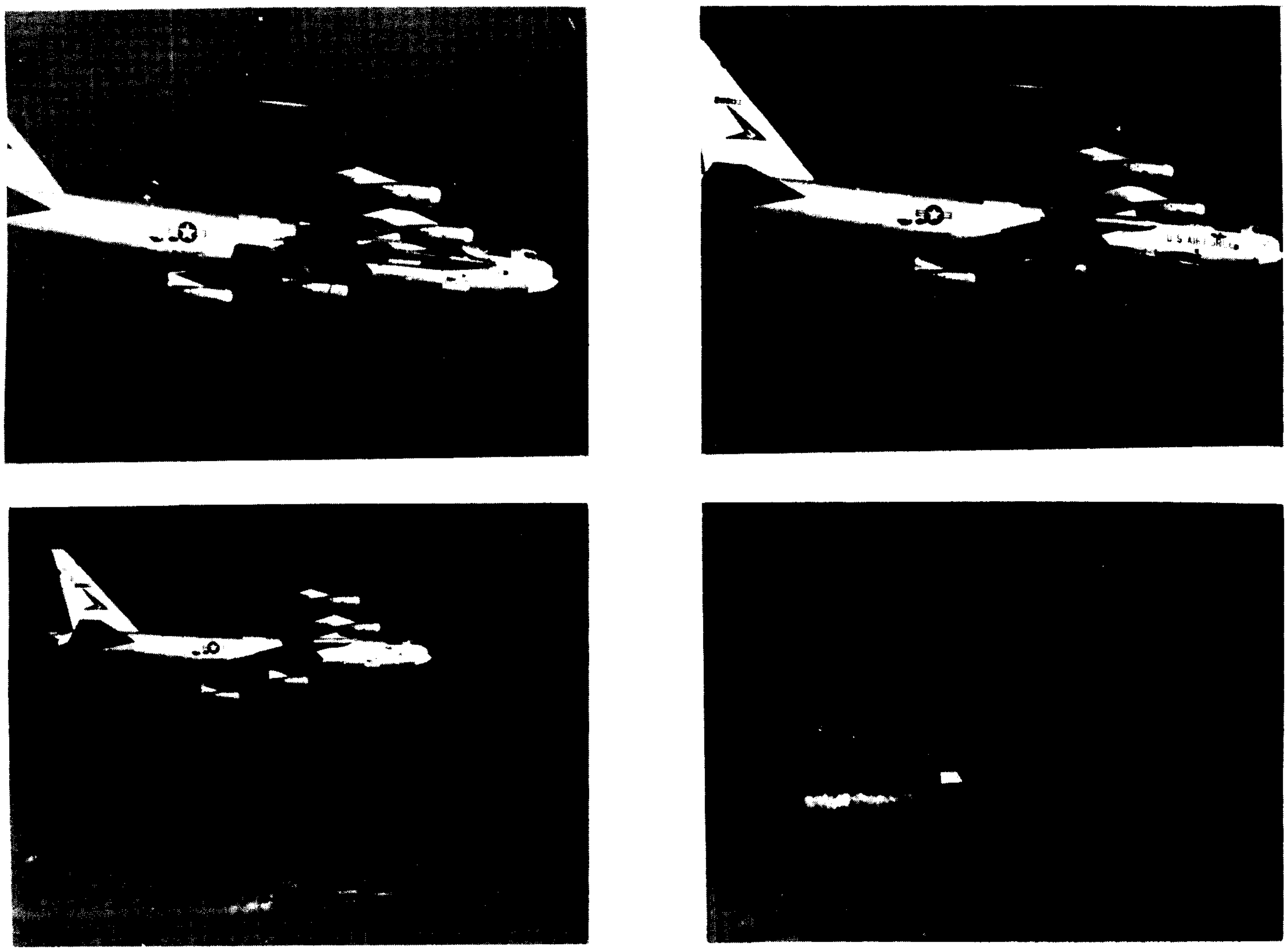



Figure 5.- Time history of a typical X-15 launch with all dampers operating. $h_{p_L}$ = 44,888 feet; $V_{i_L}$ = 222 KIAS; $M_L$ = 0.818.



L-61-14

Figure 6.- Photographic sequence of a normal launch with all dampers operating.

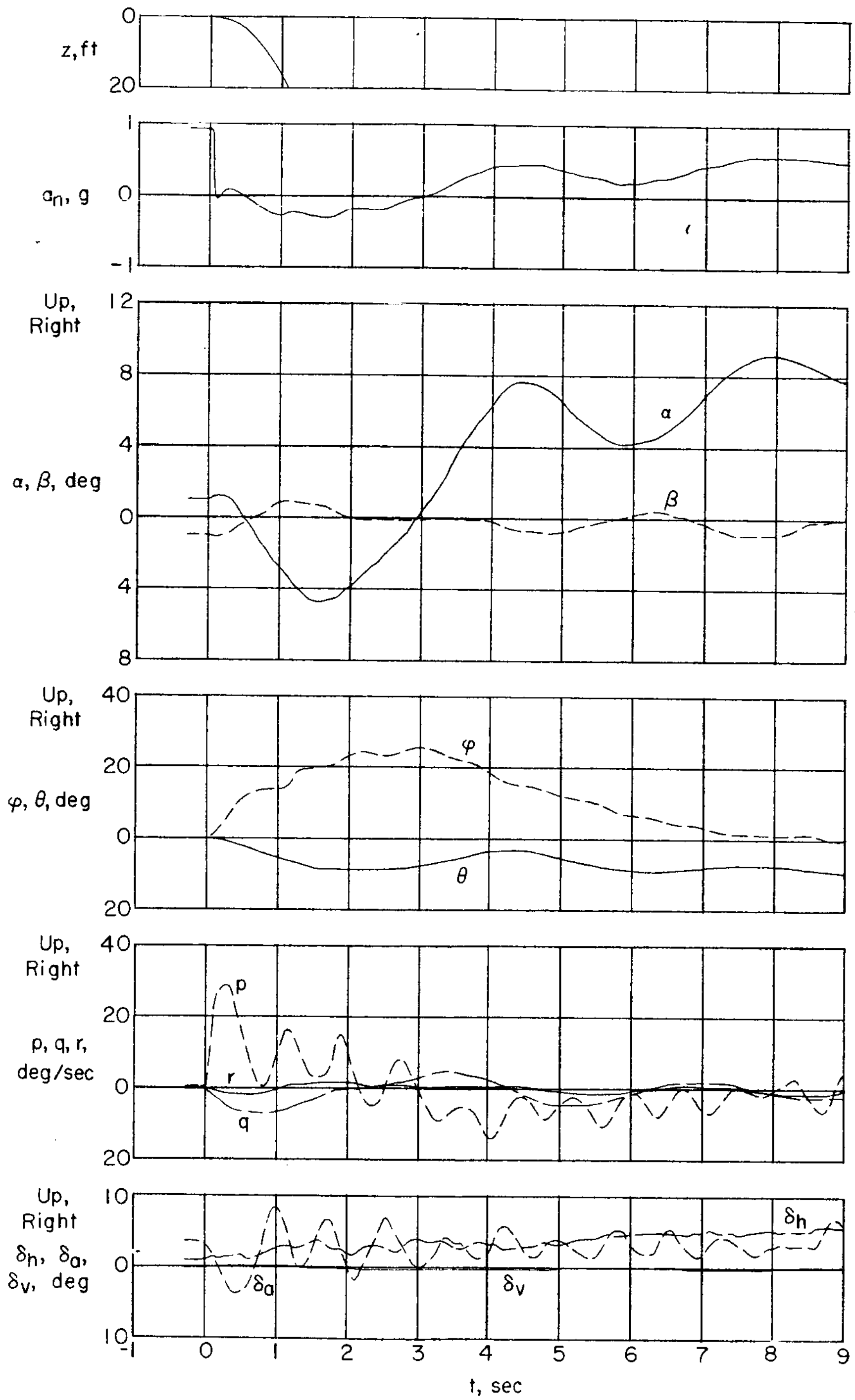



Figure 7.- Time history of an X-15 launch with pitch damper malfunctioned. $h_{p_L}$ = 44,753 feet; $V_{i_L}$ = 219 KIAS; $M_L$ = 0.806.

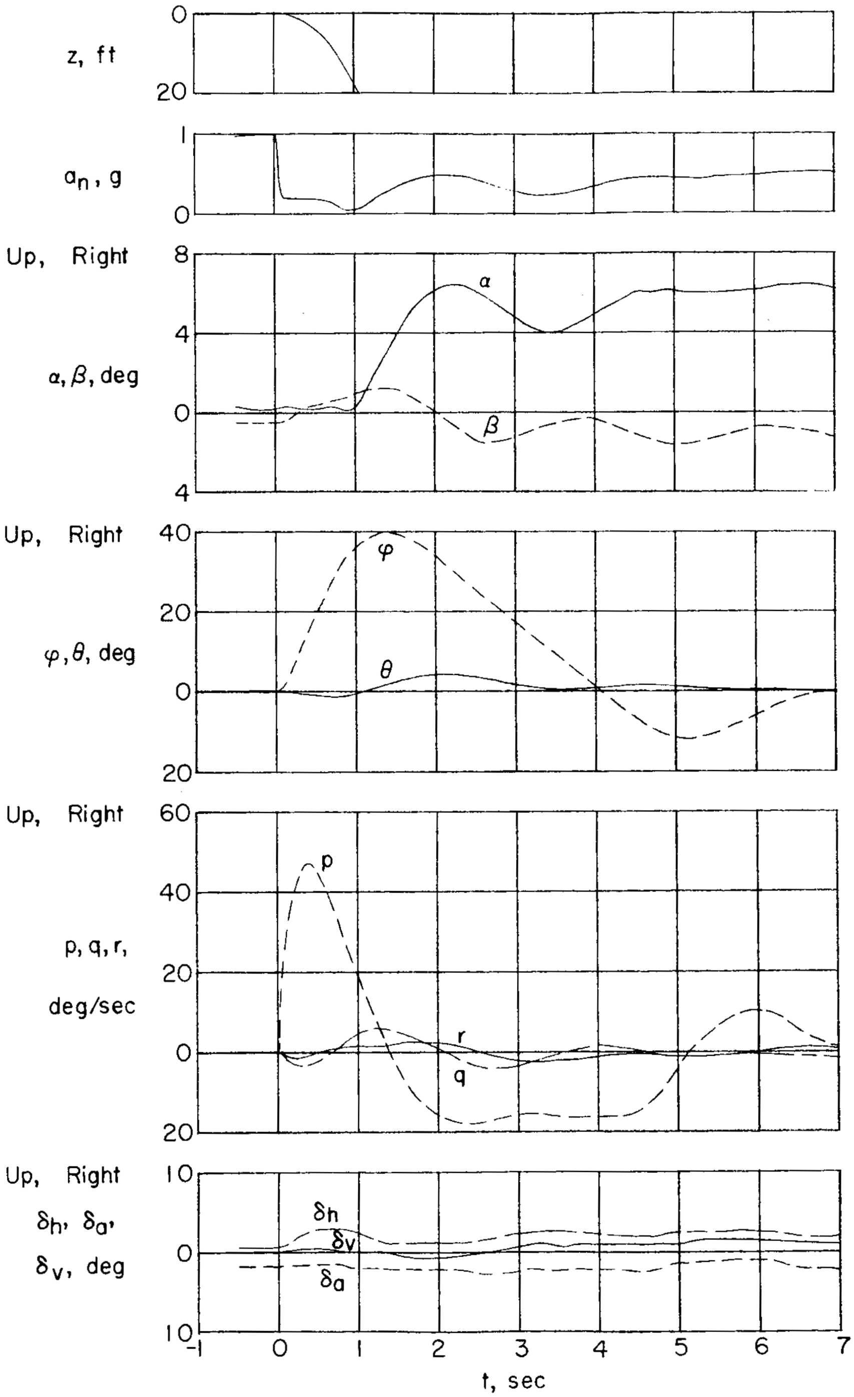



Figure 8.- Time history of an X-15 launch with roll damper malfunctioned. $h_{p_L}$ = 40,913 feet; $V_{i_L}$ = 247 KIAS; $M_L$ = 0.827.

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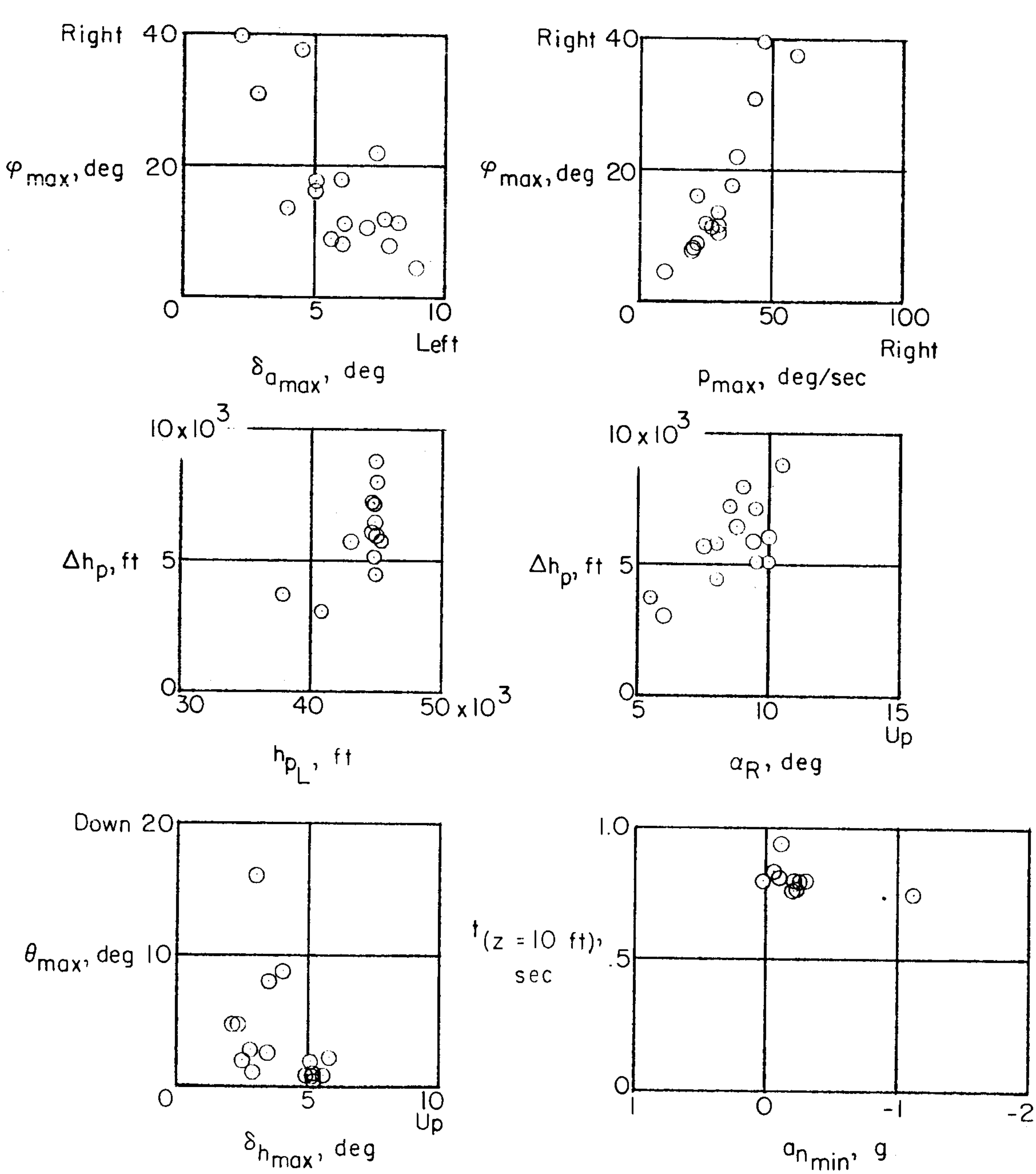


Figure 9.- Summary of flight-determined X-15 launch parameters.

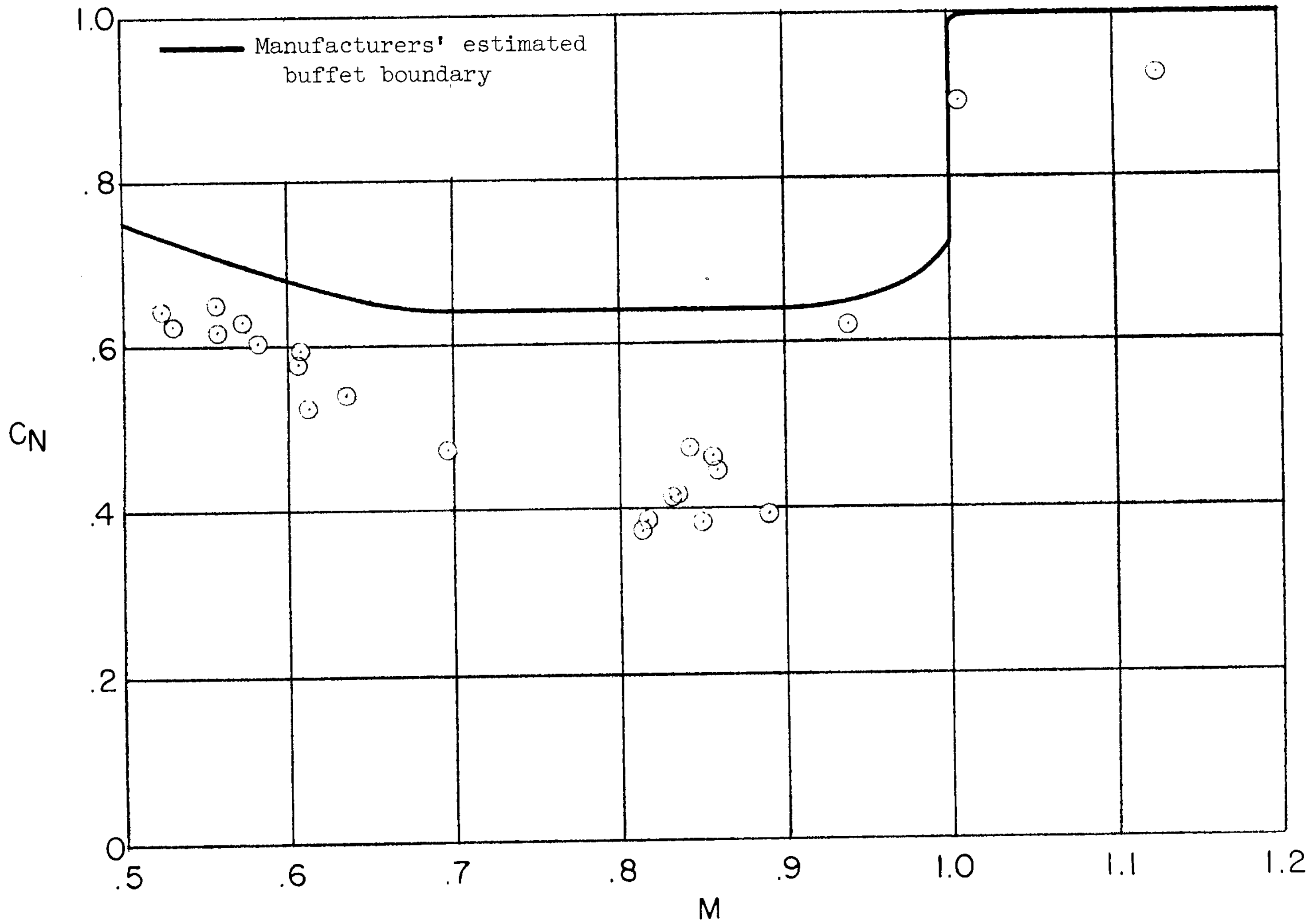


Figure 10.- X-15 flight-determined buffet boundary expressed in terms of normal-force coefficient and Mach number.

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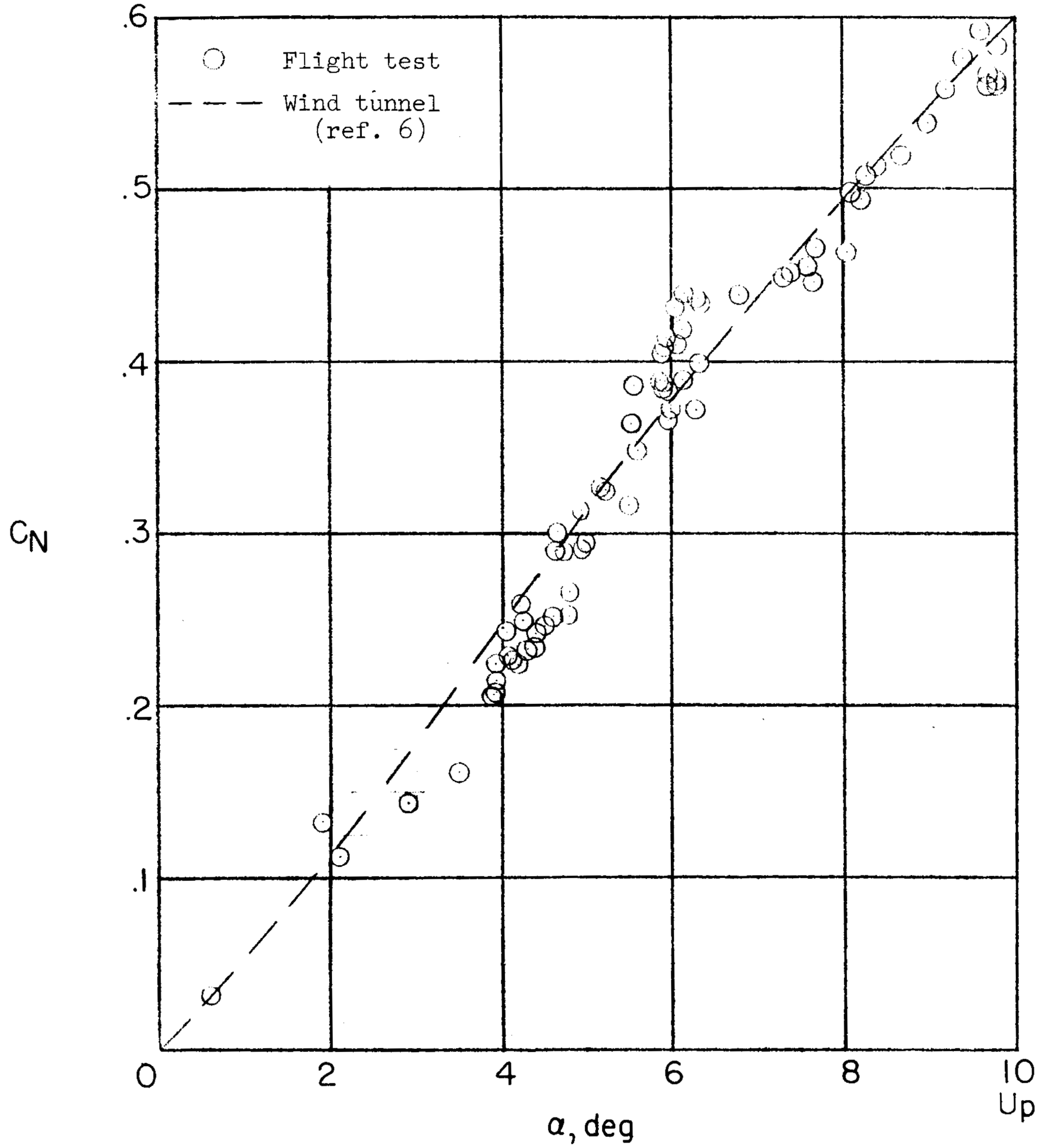
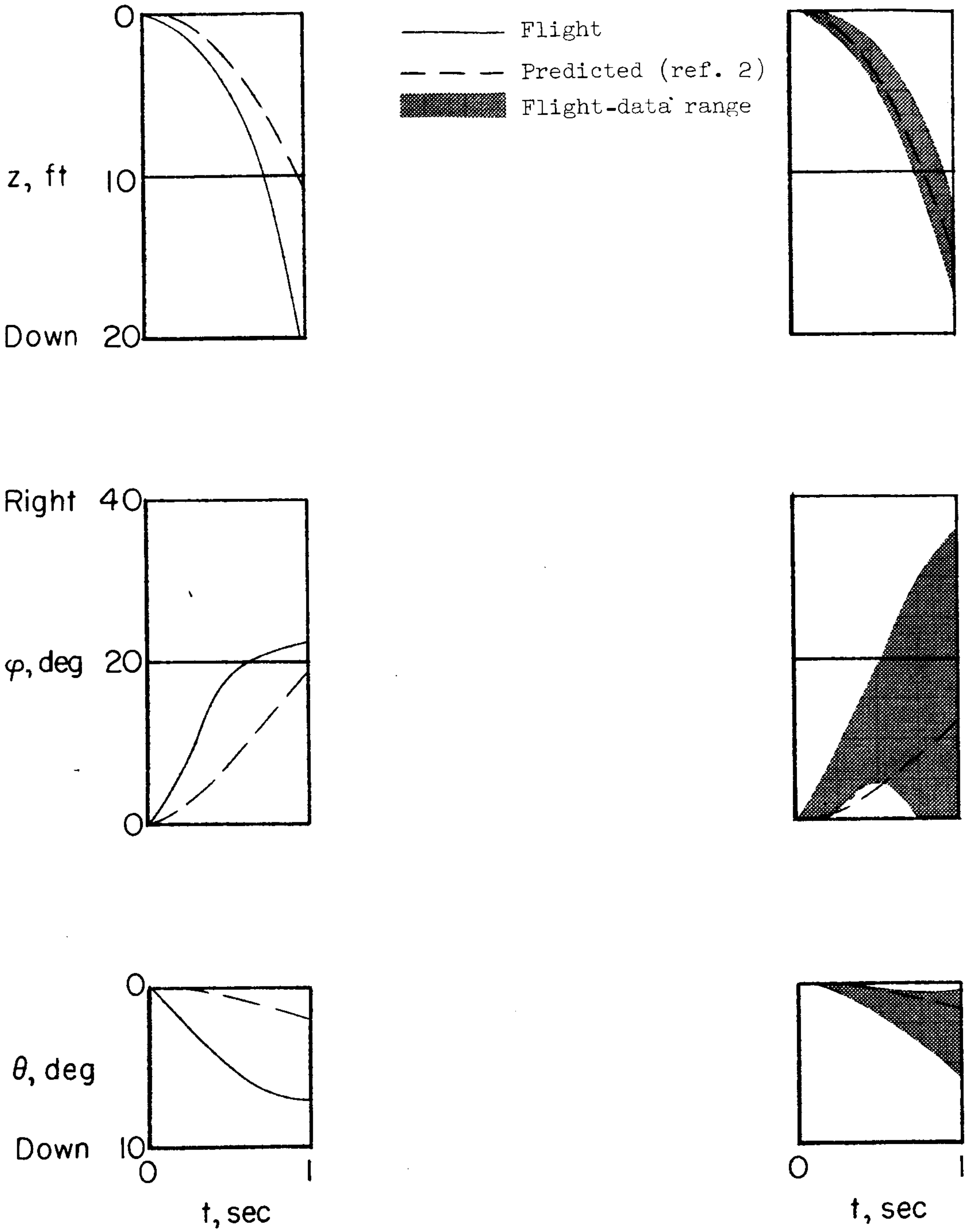



Figure 11.- X-15 normal-force coefficient as a function of angle of attack, free of B-52 flow field. $h_p \approx 45{,}000$ feet; $M \approx 0.80$ to 0.85.




(a) Lightweight.

(b) Heavyweight.

Figure 12.- Comparison of X-15 flight and predicted launch displacements.

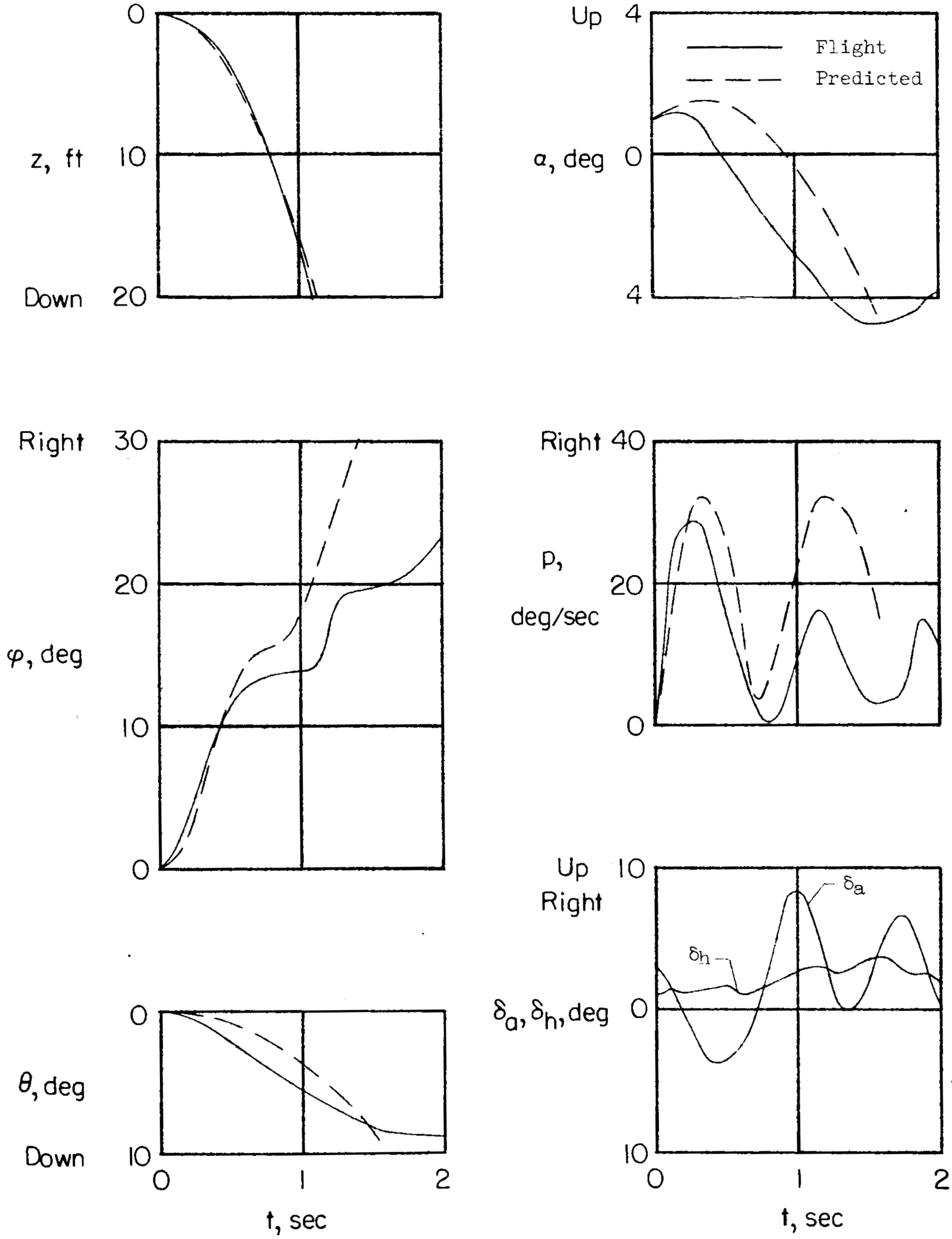



Figure 13.- Comparison of flight and predicted launch time histories. $h_{p_L}$ = 44,753 feet; $V_{i_L}$ = 219 KIAS; $M_L$ = 0.806.