

AERODYNAMIC CHARACTERISTICS OF THE X-15/B-52 COMBINATION

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INTRODUCTION

Past aerial launchings of research airplanes have been made from the center-line location of the carrier airplane. In the case of the X-15/B-52 combination the carry location chosen is beneath the 18-percent-semispan station of the right wing between the fuselage and the inboard engine nacelle. The reason for the choice of this location has been stated previously in the "X-15 Research Airplane Development Status" paper. With such an asymmetrical location, questions immediately arise as to the carry and launching safety and the aerodynamic-loads problems confronting the combination.

Investigations were therefore undertaken by the National Advisory Committee for Aeronautics to determine (1) the carry loads and mutual aerodynamic interference effects from high-speed wind-tunnel tests and (2) the drop characteristics of the X-15 through the B-52 flow field from low-speed dynamic-model drop tests and six-degree-of-freedom calculations. The purpose of this paper is to present briefly the major results of these investigations.

SYMBOLS

α_{B-52}	angle of attack of B-52 water line, deg
α_{X-15}	angle of attack of X-15 center line, deg
$C_{D,trim}$	drag coefficient that corresponds to zero pitching moment (trim)
R	Reynolds number
M	Mach number
C_l	rolling-moment coefficient
C_n	yawing-moment coefficient

h	altitude, ft
C_L	lift coefficient
C_m	pitching-moment coefficient
L	lift, lb
M_Y	pitching moment, ft-lb
M_Z	yawing moment, ft-lb
M_X	rolling moment, ft-lb
q	dynamic pressure
z	distance along Z-axis, ft
α_0	initial angle of attack of X-15, deg
W	weight, lb
θ	pitch angle, deg
V	velocity, ft/sec
ψ	yaw angle, deg
ϕ	roll angle, deg

HIGH-SPEED TUNNEL TESTS AND RESULTS

A drawing of the X-15/B-52 combination is presented in figure 1. Here the X-15 is shown pylon mounted on the B-52 in the carry location. The detail sketch shows the outline of the B-52 wing cut out to accommodate the X-15 vertical tail and the three points of suspension. The top and front views show the longitudinal and spanwise relative location of the two airplanes. A photograph of the 1/40-scale models of the combination mounted in the Langley high-speed 7- by 10-foot tunnel is shown in figure 2. Both models were internally instrumented with six-component strain-gage balances, with the B-52 model having additional strain gages and a pressure gage located in the right horizontal-tail panel to obtain a qualitative measure of tail buffet as affected by the X-15 installation. Some results of these buffet

tests will be presented subsequently in the paper by Messrs. Runyan and Sweet. The parameters varied in these wind-tunnel tests were: Mach number, angles of attack and sideslip, and control deflections of both models. In addition, tests were made with the X-15 model mounted in the presence of the B-52 by means of a sting so that the effects of separation distance between the airplane models could be determined.

Presented in figures 3 and 4 are the effects of the X-15 on the B-52 aerodynamic characteristics for longitudinal trim at a Mach number of 0.75 and a Reynolds number of 2.25×10^6 . Figure 3 presents the lift and drag coefficients and figure 4 presents the rolling- and yawing-moment coefficients plotted against the angle of attack of the B-52 fuselage waterline. The solid curves represent the B-52 alone (with wing cutout) and the dashed curves represent the combination of the B-52 and the X-15. It should be noted that the B-52 wing has a root incidence of 6° relative to the fuselage and hence the angle of attack for zero lift (fig. 3) is approximately -6° on the α -scale. The cruise angle-of-attack range to be studied is indicated in both figures 3 and 4 by the arrows. The addition of the X-15 produced essentially no change in the pitching-moment characteristics, and pitching-moment data therefore are not presented. The most noteworthy effect of the X-15 is an increase of approximately 30 percent in minimum trim drag and 15 percent in the cruise range. The cutout in the B-52 wing to accommodate the X-15 vertical tail caused small right-wing-down rolling moments and small nose-right yawing moments. The addition of the X-15 reduced both the rolling and yawing moments. The maximum rolling moment indicated would require less than 0.1 percent spoiler deflection for trim, and the yawing moments correspond to less than 0.1° in sideslip angle.

The effects of Mach number on the X-15 aerodynamic characteristics are presented in figures 5 and 6. The lift and pitching-moment coefficients are presented in figure 5 and the rolling- and yawing-moment coefficients are presented in figure 6. All coefficients are plotted against angle of attack of the combination with the lower α -scale referred to the X-15 center line and the upper α -scale referred to the B-52 waterline. As would be surmised from past flow-interference experience (ref. 1), the effect of increasing Mach number generally caused larger magnitudes and variations with α for all aerodynamic coefficients. Note that the rolling-moment coefficient usually decreases with increasing angle of attack.

The effects of the B-52 flow field on the X-15 aerodynamic loads for a Mach number of 0.75 and an assumed altitude of 38,000 feet are presented in figures 7 and 8. In these figures the lift in pounds and the pitching, rolling, and yawing moments in foot-pounds are plotted as functions of the angle of attack of the combination. The solid curves are the free-stream loads and the dashed curves represent the

X-15 loads in the carry location. The B-52 flow field reduced the lift load to approximately one-third of the free-stream level and produced large nose-down pitching moments throughout the angle-of-attack range. This lift and moment variation for the carry location indicate a load-center movement from 145 percent mean aerodynamic chord ahead of the center of gravity at $\alpha = -4^\circ$ to 110 percent mean aerodynamic chord behind the center of gravity at $\alpha = 4^\circ$. The negative moment at $\alpha = -4^\circ$ is as would be expected to result from downflow on the forebody of the X-15. At $\alpha = 4^\circ$, however, theoretical studies indicate that the pitching moments should be or tend to be positive because of downflow on the X-15 tail induced by the B-52 wing. The large negative moment is therefore presumed to result from a localized upflow induced by the cutout in the B-52 wing to accommodate the vertical tail of the X-15. Additional data obtained with a larger cutout indicate such a "flow-sink" effect. Although sizable yawing moments are in evidence at the extreme angles, the moment is small at $\alpha = 1^\circ$, which is the design drop angle. A particular point to note is the large right-wing-down rolling moments that decrease with increased angle of attack.

The effects of separation distance between the X-15 and B-52 airplanes are presented in figures 9 and 10. The abscissa for these curves is the separation distance z in feet. The ordinates are lift in pounds and the pitching, rolling, and yawing moments in foot-pounds. The conditions shown are for design launch conditions, that is, an altitude of 38,000 feet, a Mach number of 0.75, and an X-15 center-line angle of attack of 1° . Although large initial inputs are indicated for all components except the yawing moment, these inputs diminished rapidly with small changes in distance. An interesting point to note is the initial decrease in the lift. The reason for this decrease is not completely understood, although it is presumed to be associated with the movement of horizontal tail out of the localized region of upwash generated by the cutout in the B-52 wing.

DYNAMIC-MODEL DROP TESTS AND RESULTS

The dynamic-model drop tests made to determine launch safety and drop characteristics utilized the constant Froude number similarity technique (ref. 2). In this procedure the models are ballasted and the free-stream velocity is reduced so that model and prototype translational accelerations are equal, whereby similar trajectory time histories are produced. The effects of Mach number cannot, however, be determined from this simulation because of incompatible velocity

criteria. Motion-picture records were obtained to show the results of the drop tests for both the empty-weight and the full-weight conditions.¹

Drop tests made to determine the effect of sideslip indicated that significant rolling motions were induced but were not considered to be critical. Photographic records of the X-15 vertical-tail motions in the B-52 wing cutout indicated adequate clearance for all conditions investigated. The drop-tests results indicated that safe drops should be expected for all fully loaded conditions. The same is true for the weight-empty condition if nose-up pitch control is avoided.

DROP TRAJECTORY CALCULATIONS

In order to determine the effects of Mach number and altitude at the higher Mach numbers, six-degree-of-freedom calculations were made on the IBM 704 electronic computer. The static aerodynamic inputs for these calculations were obtained from the high-speed tunnel results. The natural first inclination in such a program is to compare calculated drop motions with the dynamic-model drop-test results. Figures 11 and 12 present such a comparison. The abscissas are full-scale time in seconds and the ordinates are separation distance z in feet and pitch angle θ , roll angle ϕ , and yaw angle ψ in degrees. The solid curves represent the experimental drop characteristics and the dashed curves represent the calculated results. The calculated results underpredict the variations in separation distance; agree well with the experimental pitch and yaw angles; and, initially underpredict and then overpredict roll angle. The roll time histories indicate rolling velocities of approximately 15° and 20° per second for the calculated and experimental results, respectively. Consideration of the parameters to be estimated in calculations such as these indicates that the correlation of the results of the best available techniques and the experimental results is acceptable.

The calculated X-15 drop motions for two Mach numbers are presented in figures 13 and 14. Again, the separation distance and pitch, roll, and yaw angles are plotted as functions of time. The assumed conditions are an altitude of 38,000 feet and full-weight characteristics. The solid curves represent motions at $M = 0.60$ and the dashed curves represent motions at $M = 0.75$. It should be noted in this and the remaining figures that the B-52 airplane is assumed in straight and level flight and therefore the effect of changing the primary variable produced attendant changes in others. In this case changing Mach number caused changes in α and q . The initial X-15

¹These results are presented in film L-344, which is available on loan from NACA Headquarters.

angle of attack α_0 and the B-52 trim angles of attack α_{B-52} are listed for reference in the legend. Increasing Mach number caused only small changes in z and ψ , reduced the θ -motion somewhat, but reversed the rolling motion ϕ . The initially smaller roll angle existing at $M = 0.60$ is due primarily to the higher angle of attack and therefore lower rolling-moment input.

Presented in figures 15 and 16 are the calculated X-15 drop motions at two altitudes. The parameters shown are the same as for the previous figures. The assumed conditions are the full-weight characteristics and a Mach number of 0.75. The solid curve represents 30,000 feet and the dashed curve represents 38,000 feet. The effect of increasing altitude is to reduce the intensity of the motions, particularly roll. This result is due to the lower dynamic pressure associated with and the higher angle of attack required at the higher altitude.

CONCLUDING REMARKS

In summary, results of high-speed wind-tunnel tests indicate that the X-15 installation increases the B-52 drag at cruise conditions by approximately 15 percent. The B-52 flow field induces sizable changes in the X-15 aerodynamic loads. These loads are increased with Mach number and have steep gradients with separation distance. The results of low-speed dynamic-model drop tests and six-degree-of-freedom calculations indicated that safe drops should be obtained.

REFERENCES

1. Alford, William J., Jr.: Theoretical and Experimental Investigation of the Subsonic-Flow Fields Beneath Swept and Unswept Wings With Tables of Vortex-Induced Velocities. NACA Rep. 1327, 1957. (Supersedes NACA TN 3738.)
2. Scherberg, Max, and Rhode, R. V.: Mass Distribution and Performance of Free Flight Models. NACA TN 268, 1927.

X-15 / B-52 COMBINATION

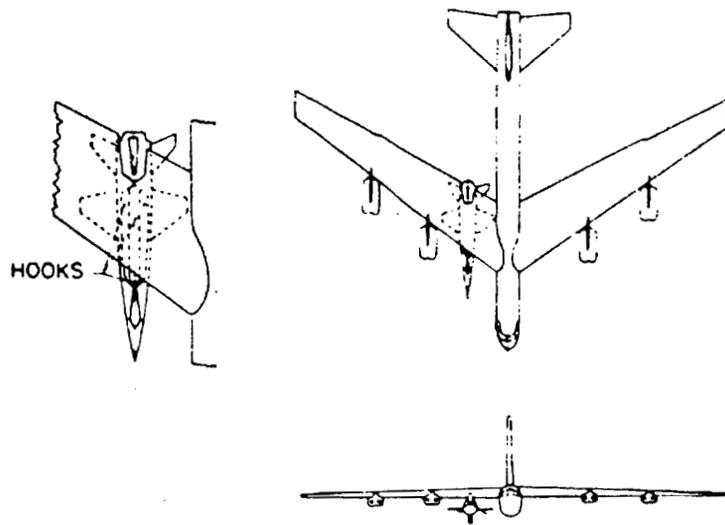


Figure 1

X-15 AND B-52 MODELS IN LANGLEY HIGH-SPEED
7- BY 10-FT WIND TUNNEL



Figure 2

EFFECT OF X-15 ON B-52 AERODYNAMIC CHARACTERISTICS

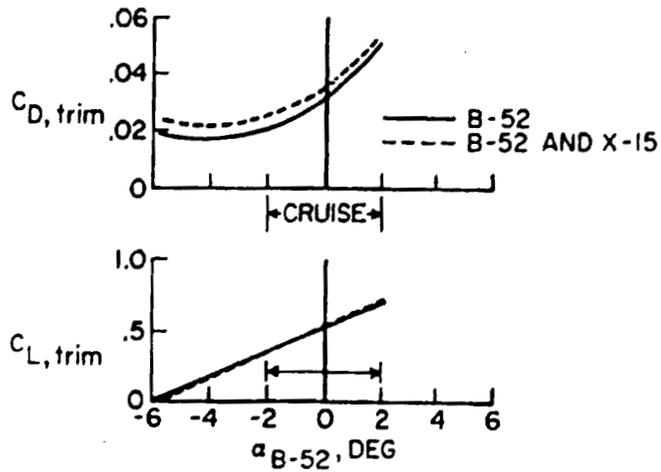
LONGITUDINAL; $M = 0.75$; $R = 2.25 \times 10^6$ 

Figure 3

EFFECT OF X-15 ON B-52 AERODYNAMIC CHARACTERISTICS

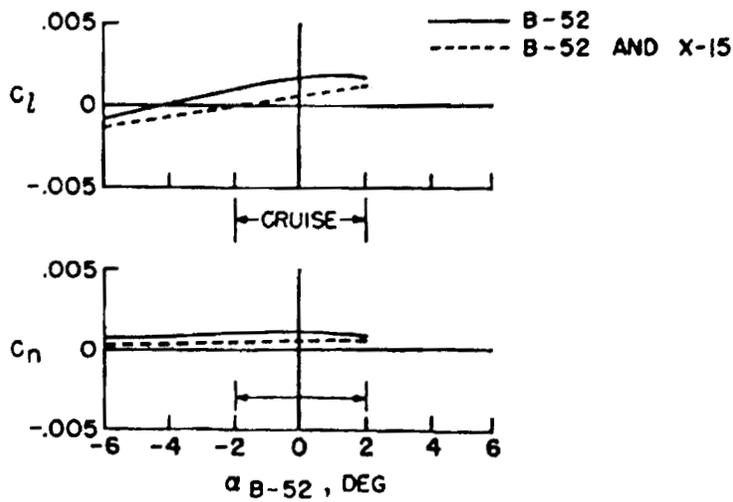
LATERAL ; $M = 0.75$; $R = 2.25 \times 10^6$ 

Figure 4

EFFECT OF MACH NUMBER ON X-15 AERODYNAMIC CHARACTERISTICS
LONGITUDINAL; CARRY POSITION

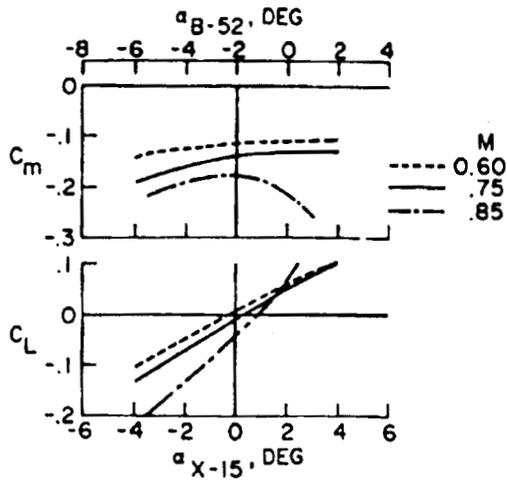


Figure 5

EFFECT OF MACH NUMBER ON X-15 AERODYNAMIC CHARACTERISTICS
LATERAL; CARRY POSITION

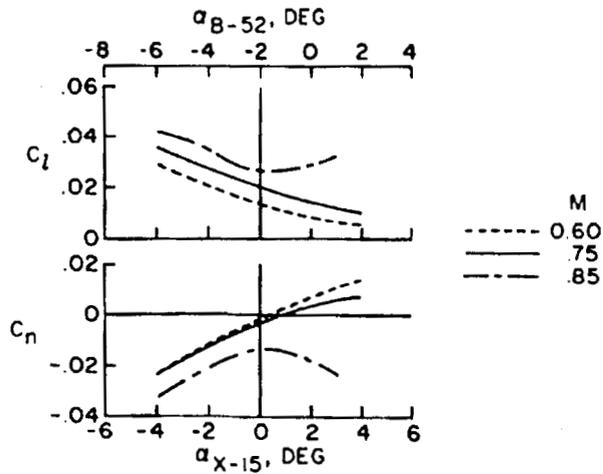


Figure 6

EFFECT OF B-52 ON X-15 AERODYNAMIC LOADS
 LONGITUDINAL; $M=0.75$; $h=38,000$ FT; $R=0.92 \times 10^6$

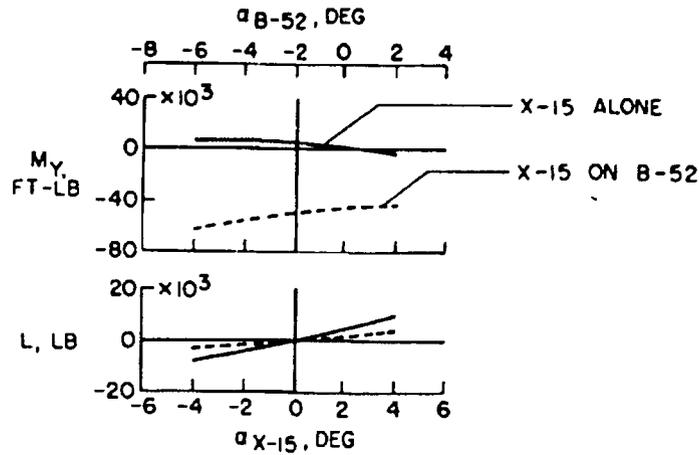


Figure 7

EFFECT OF B-52 ON X-15 AERODYNAMIC LOADS
 LATERAL; $M=0.75$; $h=38,000$ FT; $R=0.92 \times 10^6$

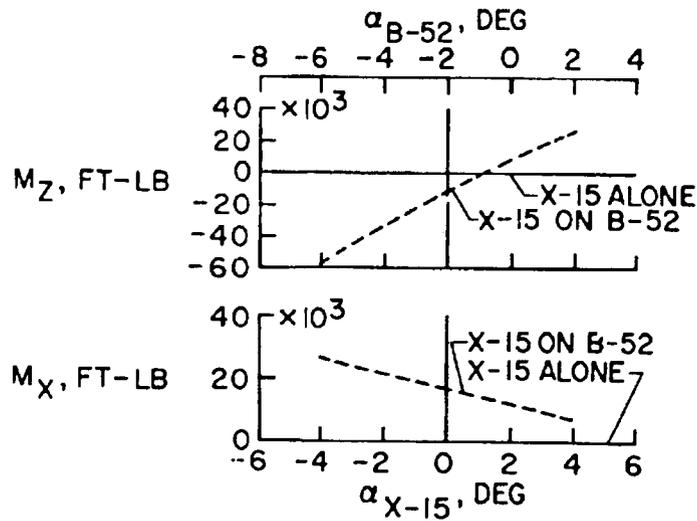


Figure 8

EFFECT OF SEPARATION DISTANCE ON X-15 AERODYNAMIC LOADS
 LONGITUDINAL; $M = 0.75$, $h = 38,000$ FT, $\alpha_0 = 10^\circ$

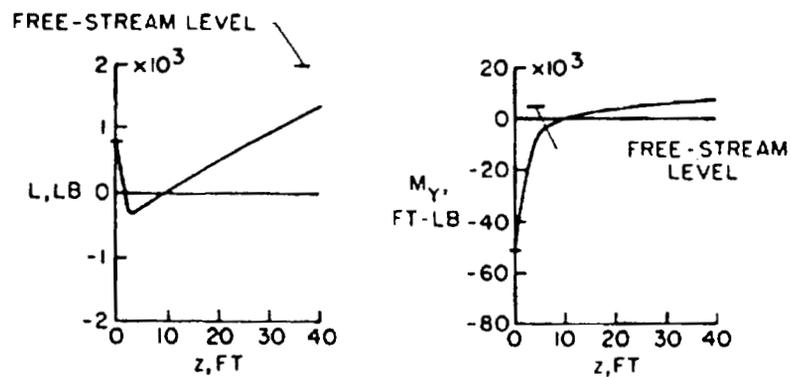


Figure 9

EFFECT OF SEPARATION DISTANCE ON X-15 AERODYNAMIC LOADS
 LATERAL; $M = 0.75$, $h = 38,000$ FT, $\alpha_0 = 1.0^\circ$

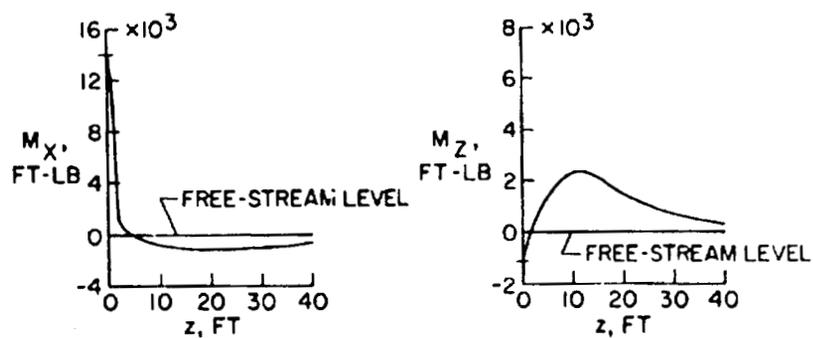


Figure 10

COMPARISON OF CALCULATED AND EXPERIMENTAL
DROP MOTIONS

LONGITUDINAL; V CORRESPONDS TO $M=0.60$; $h=30,000$ FT;
 $\alpha_0=1.8^\circ$; $W=12,366$ LB

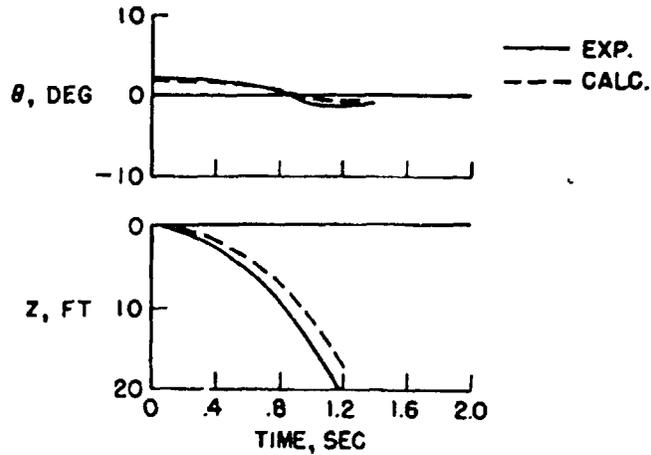


Figure 11

COMPARISON OF CALCULATED AND EXPERIMENTAL
DROP MOTIONS

LATERAL; V CORRESPONDS TO $M=0.60$; $h=30,000$ FT;
 $\alpha_0=1.8^\circ$ $W=12,366$ LB

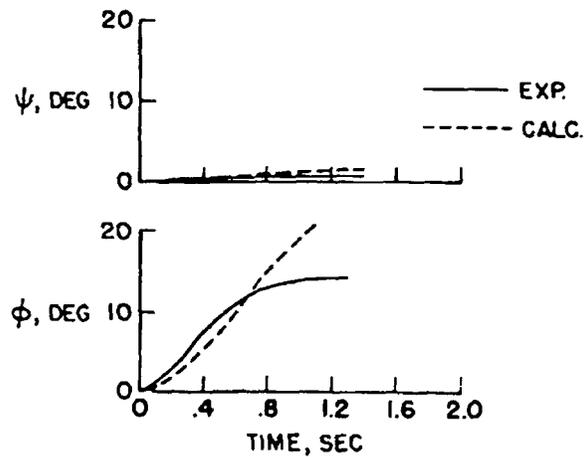


Figure 12

CALCULATED X-15 DROP MOTIONS
FOR TWO MACH NUMBERS
LONGITUDINAL; $h = 38,000$ FT; $W = 31,635$ LB

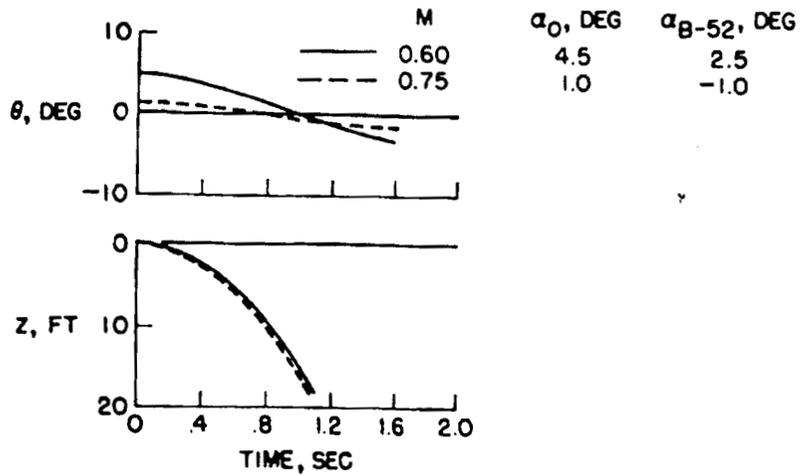


Figure 13

CALCULATED X-15 DROP MOTIONS
FOR TWO MACH NUMBERS
LATERAL; $h = 38,000$ FT; $W = 31,635$ LB

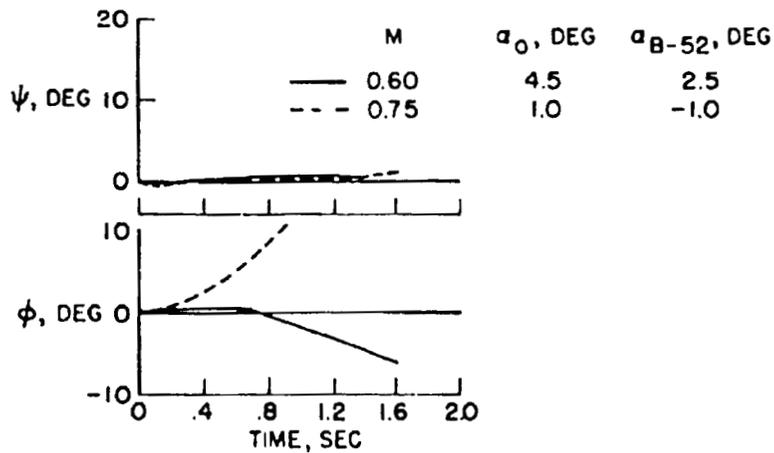


Figure 14

CALCULATED X-15 DROP MOTIONS AT TWO ALTITUDES
LONGITUDINAL; $M=0.75$; $W=31,635$ LB

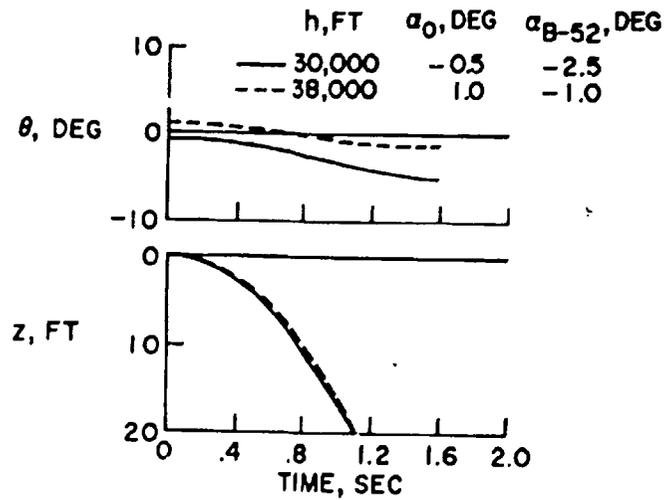


Figure 15

CALCULATED X-15 DROP MOTIONS AT TWO ALTITUDES
LATERAL; $M=0.75$; $W=31,635$ LB

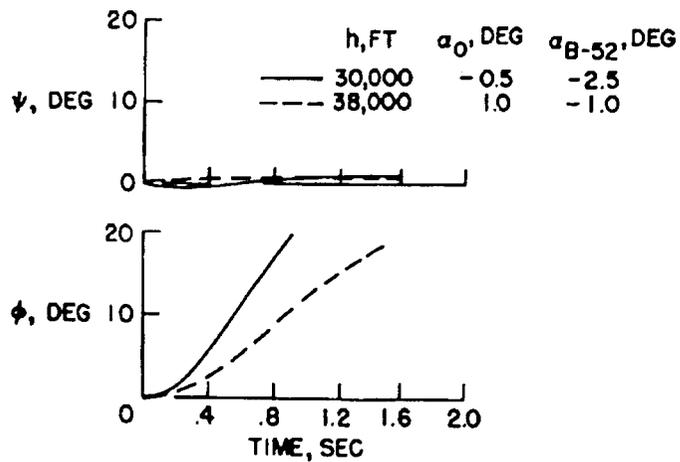


Figure 16