Comparison of Predicted and Flight Test Trajectories of Stores Jettisoned from Aircraft

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Abstract

RELIABLE methods for trajectory prediction of stores released from combat aircraft are very important. Based on a series of drop tank jettison trials the paper presents a comparison of photographically recorded flight test trajectories with those calculated using aerodynamic coefficients estimated from currently available methods. Trajectories of stores with and without fins in planar motion are considered. Whereas observations show good agreement for the longitudinal component of store motion, the vertically downward motion appears overpredicted for power jettison and underpredicted for gravity release. Probable causes of trajectory discrepancies are indicated.

Contents

Theoretical and wind-tunnel experimental studies of store release trajectory characteristics have been reported extensively in the recent literature. There appears, however, to be a paucity of full-scale flight test data validating predictions made by using theoretical methods or wind-tunnel test data. A series of drop tank jettison trials were carried out in flight by Hindustan Aeronautics Limited in 1973 as part of a flight clearance program on three high-speed jet aircraft types – an unswept trainer and two swept-wing combat airplanes. A wide range of empty and filled fuel tanks, and release speeds from 220-550 knots in straight and level flight, covering both gravity and power release were employed. Also, symmetrical and unsymmetrical jettisoning from both the inboard and outboard pylon stations were covered in the program. Because of their increased criticality, most jettisons were carried out with empty tanks. The store geometries were all similar, comprising of elliptic nose and tail cones with a cylindrical waist. Some of the stores were also fin stabilized.

Even though the general store motion is downward, the trajectories are complex, accompanied as they are by pronounced tumbling motion in both the vertical and transverse planes in an apparently random manner, with pitching and yaw angles ranging over the entire 360 deg, with store pitch rates of up to 5 rad/s observed from the records. Visual observations as well as 64 frames per second motion picture records of the release trajectories were obtained from an accompanying chase aircraft flying in formation. This permitted only planar store motion in a vertical plane parallel to the flight path to be photographed. Significant spanwise outward motion was observed visually but was adjudged to be of minor importance in relation to the vertical motion for the small time scales of interest in the present study.

The store aerodynamic coefficients C_L, C_D, C_M for the present paper were calculated using the methods of Marsden and Haines[1] and Goodwin et al.[2] stretched up to angles of attack up to 32 deg neglecting $\dot{\alpha}$ effects, as otherwise they are applicable only for small angles of incidence, together with similar store drag estimates from DATCOM.[3] A sizeable reduction of the store normal force results due to the damming effect of the wing, since a large central part of the wing may be regarded as essentially a stagnation region so that a store placed in this region develops no normal force. Further, a collateral study of store aerodynamic parameter identification using the cine pictures of the same flight tests by Ramachandra et al.[4] has confirmed the importance of considering the unsteady store motion. The resulting nonlinear aerodynamic effects of α and $\dot{\alpha}$ on the aerodynamic coefficients like C_L, $C_{L\max}$ and C_M are quite significant, indicating the limitations of present wind-tunnel captive store and even drop model aerodynamic test methods for trajectory calculation due to nonreproduction of the unsteady flow condition caused by store rotation velocities. Consequently, both steady and unsteady aerodynamic coefficients must be calculated by including the first, second, and higher order nonlinear terms in α and $\dot{\alpha}$. Viscous flow effects on the C_L, $C_{L\max}$, and C_M are of relatively minor importance compared to the nonstationary effects producing large noncirculatory forces and moments. Whereas all currently available trajectory comparisons between theoretical and captive store trajectories in the literature indicate excellent agreement, present studies show large disparities.

Figure 1 shows a typical calculated and observed dimensionless trajectory comparison for gravity release. It is seen that gravity jettisoned stores have a steeper nondimensional flight path ζ and ξ than that calculated, where ξ and ζ are the horizontal and vertical coordinates of the store centroid nondimensionalized relative to the store length. This is possibly due to the calculated lift using steady aerodynamic coefficients. On the other hand, trajectories of power ejected stores showed the opposite behavior possibly due to the large apparent mass effects.

The observed store pitch angle variation with the dimensionless time τ, θ vs τ (Fig. 1) has a monotonic and divergent

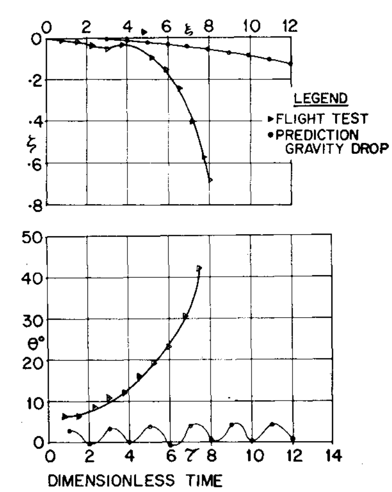

Fig. 1 Typical comparative store trajectory.

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variation compared to the calculated oscillatory behavior for both the gravity and power ejected stores. The nondimensional time τ is defined by $\tau = t/\tilde{t}$, where t is the real time, $\tilde{t} = L_s/V$, for a store of length L_s dropped by an airplane flying at speed V. In the case of power ejected stores, an additional complexity is introduced by the initial pitch rate $\dot{\theta}$ imparted to the store at $\tau = 0$ due to the resultant thrust line not passing through the store centroid. The trajectories have also been observed to be sensitive to $\dot{\theta}$ at $\tau = 0$.

A characteristically pronounced and consistent feature of both the gravity and power ejected store trajectories is their S-shaped behavior (Fig. 1) close to the release point. This may be due to the complicated combined wing-store upwash and downwash field, the relative acceleration between the wing and store, as well as the perturbed aircraft response motion subsequent to store release not taken into account in these calculations.

Parallax errors in length measurements from photographs were minimized by using separate length scales for the port and starboard store trajectories. However, additional factors to which the trajectory discrepancies are attributable are principally 1) variations of ejector thrust, moment, and pylon friction and 2) sloshing of residual fuel and general atmospheric turbulence, which impart a stochastic dispersion pattern to the store path.

References

[1]Marsden, P. and Haines, A. B., "Aerodynamic Loads on External Stores. A Review of Experimental Data and Method of Prediction," British Aeronautical Research Council, Rept. & Memo No. 3503, 1967.

[2]Goodwin, F. K., Dillenius, M. F. E., and Nielsen, J. N., "Prediction of 6-Degree of Freedom Store Separation Trajectories at Speeds up to the Critical Speed," Air Force Flight Dynamics Lab, Rept No. AFFDL-TR-72-8, Vols. I and II, Oct. 1974.

[3]DATCOM-USAF Stability and Control Methods, 1968.

[4]Sudhakar, K., Kiran, N. S., and Ramachandra, S. M., "Application of Parameter Identification Techniques to the Aerodynamic Characteristics of a Family of Externally Carried Stores from Drop Tests," presented at the 29th Annual Meeting, Aeronautical Society of India, May 13-15, 1977.