Effect of Fin Slots and Fin Tabs on the Dynamic Stability Characteristics of the Navy Low Drag Bomb

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Nomenclature

d = missile diameter
P = spin rate
S/F = (slot area)/(fin area)
V = total velocity
α = angle of attack
δ,δ_A = fin cant and roll tab angles, respectively

Introduction

DYNAMIC instabilities that arise from rolling motion of four-finned missiles have caused considerable difficulties for missile designers. Catastrophic yaw arising from "locked-in" or "lunar" motion was first described by Schneller[1] and later documented during the flight trials of the Navy's low drag bomb.[2] Magnus instabilities[3] were noted even earlier by R. Kent of the Ballistics Research Laboratory. These instabilities fall into two distinct groups. Magnus instability is characterized by missiles having large rolling velocity, whereas catastrophic yaw is characterized by missiles having small rolling velocity.

In 1961, Lugt[4] pointed out that fin slots might radically change the motion of free rolling cruciform tail configurations by sweeping away a strong wake vortex ordinarily attached to the receding fin at very large angles of attack. Pursuing that possibility, we[5] recently showed how the performance of such a basic configuration in free rolling motion responds to fin slots, at all angles of attack. It was suggested that these results could be used to alleviate the problem of catastrophic yaw of bombs in six-degree-of-freedom motions.

This Note presents the results of a research program to improve the marginal dynamic stability characteristics of the Navy's Mk 81 low drag bomb[2] (see Fig. 1) by introducing fin slots and roll tabs.

Wind Tunnel Tests

Free rolling and free pitching tests were conducted on a full-scale Mk 81 low drag bomb in the Naval Ship Research and Development Center 8 × 10-ft. subsonic wind tunnel. The basic configuration was first tested to determine its steady-state rolling motion as a function of angle of attack, α. A standard bomb was chosen at random and sting-mounted for wind tunnel tests. Its design fin cant was 2° ± 1°. The results are shown in Fig. 2 as case 1. Two modes of motion exist in the region $13° \leq \alpha \leq 25°$: If the missile is stopped, it will remain stopped or locked-in. If it is spun-up above a critical value it will continue to spin slowly. For $\alpha > 25°$, the missile will not spin, and lock-in is the only mode of motion until the missile breaks out at 40°. It then speeds up considerably in either direction. No data were obtained for higher α's because of violent pitch oscillations experienced by the model. However it is expected[6] that the spin would have been much higher at higher α's.

A configuration with interchangeable flat plate fin inserts and a fin cant of 2° was then tested. This configuration with no fin slots ($S/F = 0$) has a higher over-all spin rate (case 2, Fig. 2). The lock-in region was $15° \leq \alpha \leq 47°$. For $\alpha > 47°$, the missile again speeds up in either direction. The next configuration tested has a ratio of slot area to fin area (S/F) of 0.658 (case 3, Fig. 2). The over-all spin rate was reduced, and the speed-up at high α's was reduced to zero. It appears that if the slot is sufficiently large, speed-up at high α's cannot occur. Inserts were then installed in the fins to reduce the slot size. The minimum size slot for which no speed-up occurs was found to be $S/F = 0.180$ (case 4, Fig. 2). If the slot size is reduced further, speed-up occurs at high α's.

Aileron tabs were then added to the configuration to increase the spin rate at low α's. This additional roll torque was needed to overcome the lock-in mode. With the addition of tabs, the slot size had to be readjusted. The optimum configuration had full span, $1\frac{1}{4}$ in. tabs with 12° of cant per tab, and with $S/F = 0.270$ (case 5, Fig. 2). The lock-in mode was completely eliminated, and the direction of spin was always clockwise.

Dynamic pitching stability tests were then conducted on the optimum configuration (case 5) and the standard configuration (case 1). Figure 3 compares the free pitching motions of the two configurations. The addition of slots and tabs decreases the pitching frequency and does not affect the damping rate.

Flight Tests

Ten bombs were dropped from an altitude of 30,000 ft with initial airspeed of 350 knots at the White Sands Missile Range. It is estimated that their steady-state spin rates varied between 30 and 60 rps. Test data indicated that all bombs flew well. The circular error probability (CEP, the estimated radius of a circle that encompasses 50% of the total population) of the bombs (excluding any initial disturbance caused by aircraft separation effects) was 56 ft, or 1.54 mils in the plane normal to the trajectory at impact.

Discussion of Stability

The problem with the Low Drag Bomb is the sporadic instability due to roll-pitch resonance with lock-in in a conical yawing mode. The fin tabs are introduced to push the roll rate across resonance without lock-in. This was successful in the flight tests thus far with low release disturbances.

From these tests and also from two drops reported[7] in 1956, it may be inferred that the Magnus coefficient is tolerably small for stability at large roll rates for small α's. The 1956 report describes drops of two 1000-lb Mk 83 Bombs with 7° fin cant released at 140 knots from 30,000 ft. They developed a roll rate of 40 rps and flew very well.

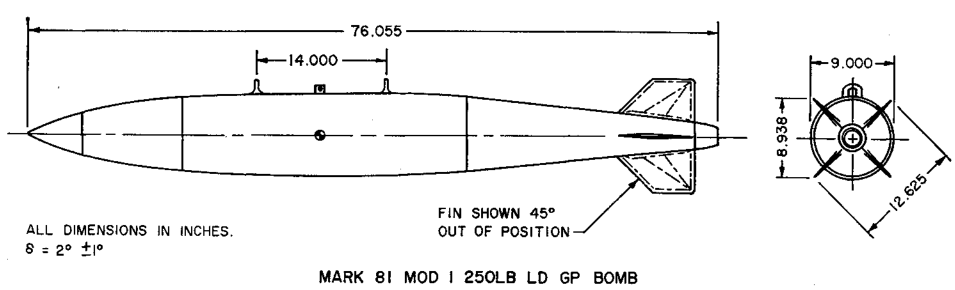

Fig. 1 Schematic of the mk 81 low drag bomb.

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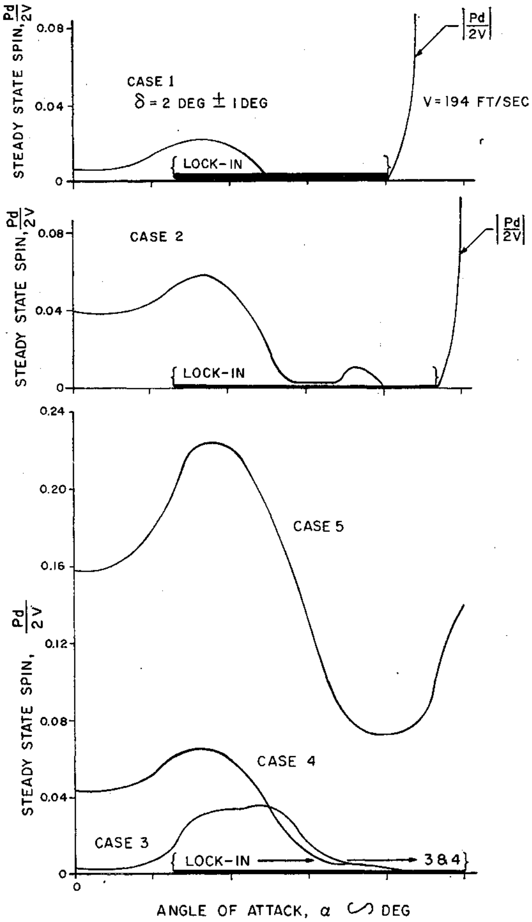

Fig. 2 Steady-state spin vs angle of attack for the mk 81 low drag bomb.

Magnus data from wind-tunnel tests of the unslotted configuration[8] also are consistent with dynamic stability at the high spin rates for low α's. However, for the slow (retrograde) mode of conical yaw above 15° or 20°, the wind-tunnel Magnus data interpreted by quasi-linear theory suggest that the bomb would be unstable. It is therefore necessary to conduct further tests with severe release disturbances producing large first maximum yaws, say near 45°. It would also be illuminating to conduct further wind tunnel tests to find the effects of fin slots on the Magnus coefficients.

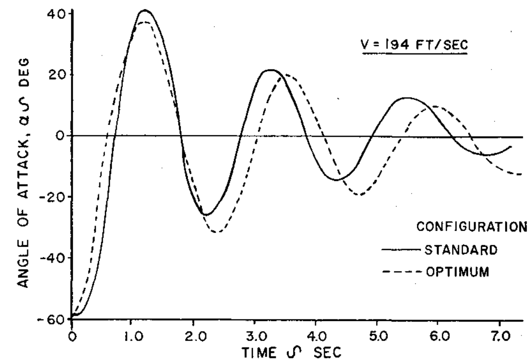

Fig. 3 Angle of attack vs time for the mk 81 low drag bomb.

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