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A COMPARISON OF THE STABILITY CHARACTERISTICS OF STANDARD FIN AND SLOTTED FIN MARK 81 LOW DRAG BOMBS

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A COMPARISON OF THE STABILITY CHARACTERISTICS OF STANDARD FIN AND SLOTTED FIN MARK 81 LOW DRAG BOMBS

by

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Warfare Analysis Department

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FOREWORD

This report presents the results of a flight test analysis of the stability characteristics of standard fin and slotted fin MARK 81 low drag bombs. This work was authorized under AIRTASK A320 320C/291B/2F00323201.

This report was reviewed by R. D. Cuddy, Head of the Aeroballistics Division.

Released by:

RALPH A. NIEMANN
Head, Warfare Analysis Department

ABSTRACT

This report presents the results of a study to determine if the addition of fin slots and aileron tabs improves the stability characteristics of the MARK 81 low drag bomb. Representative samples of both the standard MARK 81 low drag bomb and the slotted fin version were dropped at three separate flight conditions. Excessively large angular rates were purposely imposed in order to induce large yaw and therefore test the ability of the bombs to stabilize. The results of the study show that fin slots and aileron tabs eliminate catastrophic yaw due to roll lock-in. However, slow damping of an exaggerated initial disturbance can still result for a region of spin rates above resonance. This slow damping phenomenon can possibly be eliminated by proper selection of aileron tab angle.

CONTENTS

I. INTRODUCTION

Dynamic instabilities that arise from the rolling motion of four-finned missiles have caused considerable difficulties for missile designers. Catastrophic yaw arising from "Lock-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, while 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 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] showed how the performance of such a basic configuration in free rolling motion responds to fin slots at all angles of attack and it was suggested that these results could be used to alleviate the problem of catastrophic yaw of bombs in six-degree-of-freedom motions.

More recently, ten MARK 81 low drag bombs were modified with fin slots and fin tabs and flight tested.[6] The circular error probability (CEP, the estimated radius of a circle that encompasses 50% of the total population) of these bombs (excluding any initial disturbance caused by aircraft separation effects) was 56 ft., or 1.54 mils. This value was less than one-half of the expected CEP. All bombs flew well. It was expected that under the same conditions at least one to two of the standard MARK 81 low drag bombs would have been unstable. Although this result did not prove the slotted fin was superior to the solid fin, it was encouraging.

Further wind tunnel tests have been conducted at the Naval Academy and NSRDC[7,8] which show that, at least at subsonic speeds, the slotted fin is superior to the solid fin in that it eliminates roll speed-up, appreciably reduces the induced rolling moment, and increases longitudinal stability at high angles of attack.

In order to determine the amount of improvement realized from modifying the MARK 81 low drag bomb with fin slots and aileron tabs, a flight test program was initiated to compare stability characteristics directly. This report presents the results of that study.

II. TEST SPECIMEN

A flight test program was conducted in order to obtain a direct comparison of stability characteristics of the standard MARK 81 low drag bomb and the modified version. A schematic of the standard bomb is presented in Figure 1. The modified version was identical to the standard bomb except that slots and tabs were added. The fins were modified to contain nearly full exposed semispan slots which were centrally located and swept parallel to the leading edge. The ratio of slot area to fin area was 0.270. Wind tunnel tests had shown that the nominal fin cant was insufficient to eliminate roll lock-in.[6] Consequently, full semispan roll tabs having a 1.25-inch constant chord were added to the fin trailing edge. The tab angle for all bombs was 10 degrees except for two bombs that had 12-degree tabs. The larger tab angle was installed on the two bombs to study the effect of a slightly greater spin rate on stability.

III. FLIGHT TEST RESULTS

Flight tests were conducted at the White Sands Missile Range. Cameras located on the aircraft and the ground yielded good coverage of the entire trajectory. Thirty-one standard bombs and twenty-seven slotted fin bombs with aileron tabs were dropped. Three different release conditions were investigated. The bombs were ejected with intentionally large angular rates in order to properly evaluate their stability. In all cases, the bombs experienced a first maximum pitch of between 60 and 90 degrees. Four different aircraft (A-4F, A-7E, A-4E, A-7A) and two different racks (MAU 9/A, AERO 7A) were used in the test. However, the large initial yaw experienced by all bombs made these differences negligible.

The flight conditions that were investigated are presented in Table 1. Only six, drops of the modified configuration were made at a release condition of 30,000 feet and 350 knots. However, ten modified bombs had been previously dropped at this condition with a lower initial launch disturbance and flew well.[6] Consequently, it was felt that a smaller sample of drops was sufficient for this condition.

The initial drops (10 drops) made at the release condition of 20,000 feet and 300 knots had, in many cases, virtually no roll or spun counter-clockwise indicating reduced net spin rate (since the standard bomb has cant to produce clockwise spin). This sample was again tested (11 drops) and the initial sample (designated NWEF 69, 85, 86, 88, 90, 91, 97, 101, 102, 103) was eliminated from the analysis since it was apparent that the aileron tabs were improperly installed.

Five additional drops (designated D-7, D-22, D-23, D-25, D-28.) were not analyzed due to lack of flight film.

Films from the flight program outlined in Table 1, showing the detailed release and yawing motion of the stores, were analyzed. These films revealed that four standard configurations (designated D-16, D-17, D-19, D-20) developed instabilities (yaw grows in magnitude with time) of the roll-yaw coupling type. In all of these cases, the spin was nearly equal to the nutation frequency during the unstable portion of the trajectory. Flights D-17 and D-20 were extremely bad in that these bombs developed a nearly "flat spin" which in one case lasted from launch to impact (D-17). The other bomb (D-20) damped only a few seconds before impact.

All modified configurations appeared to be stable (the yawing motion does not grow in magnitude with time). However, drops D-33, D-38, D-34B and D-32, were slow to damp the launch disturbance. Drop D-33 required 25 seconds (22 cycles) for the yaw to damp (an extremely bad flight). Drops D-38, D-34B and D-32 required 10 cycles of yaw or less to damp.

Both the slow-damping modified bombs and the unstable standard bombs were dropped at an altitude of 20,000 feet and a velocity of 300 knots. A plot of roll rate versus time of flight for this flight condition (Figure 2) reveals an interesting trend. All fast-damping modified bombs fall into the envelope encompassed by the solid lines. All slow-damping modified bombs have spin rates encompassed by the envelope of dashed lines. All fast-damping standard bombs have spin rates encompassed by the dotted and dashed lines. The unstable standard bombs which were in resonance for either all or most of the flight (D-16, D-17, D-19, D-20) have spin rates encompassed by the dotted lines.

It would appear that the unstable standard bombs lock-in at the nutation frequency (1 cycle/sec). The fast-damping standard bombs roll through resonance and attain their design spin rate. The slow-damping modified bombs roll at rates significantly higher than the fast-damping standard bombs. Since these rates are significantly higher than the nutation frequency for these bombs[6] one might conclude that the Magnus torque appears to adversely affect the damping characteristics in this region. It is also interesting to note that the slowest damping modified bomb had the lowest roll rate-time history in this envelope. One might also conclude that at higher spin rates the Magnus torque is stablizing for the modified bombs (solid line envelope). It should also be noted that the extremities of the envelopes depicted in Figure 2 do not indicate impact points but merely where the data end.

The modified bombs had extremely wide variations in spin histories and one might suspect that the tabs were not installed with sufficient care. However, one might also suspect that the variations in spin histories were due in part to variations in roll damping characteristics with angle of attack.

IV. CONCLUSIONS

The following conclusion was made on the basis of the results of this study:

The fin slot-tab modification to the MARK 81 low drag bomb eliminates catastrophic yaw due to roll lock-in. However, slow damping can still occur at moderate spin rates when the release disturbance is extremely large. This slow damping phenomenon possibly can be minimized by proper selection of aileron tab angle.

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APPENDIX A

TABLE 1

FLIGHT CONDITIONS AND TEST DROPS FOR THE
STANDARD LOW DRAG BOMB AND MODIFIED CONFIGURATION.

RELEASE CONDITIONS		TEST SPECIMENS	
ALTITUDE	VELOCITY	STANDARD CONFIGURATION	MODIFIED CONFIGURATION
30,000 FEET	350 KNOTS	10 DROPS	6 DROPS
20,000 FEET	500 KNOTS	8 DROPS	10 DROPS
20,000 FEET	300 KNOTS	13 DROPS	11 DROPS

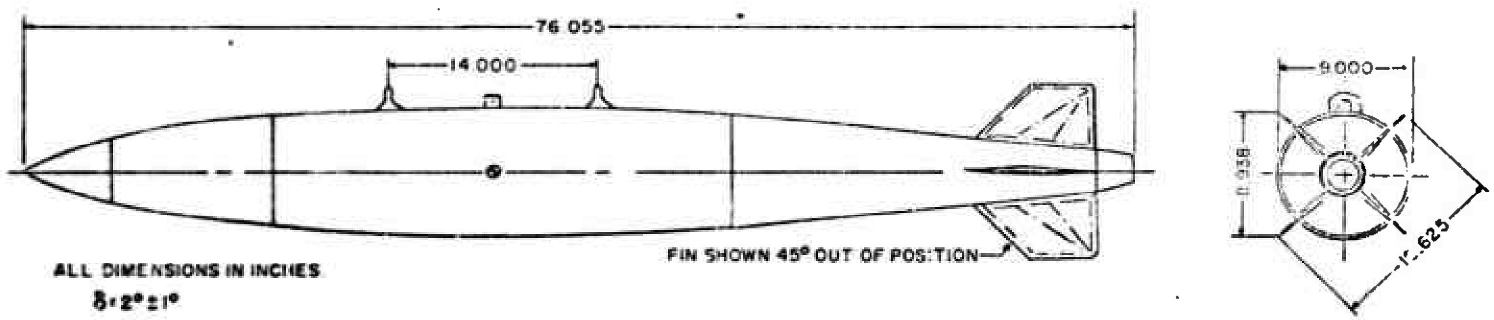

FIGURE 1

Schematic of the MARK 81 Low Drag Bomb

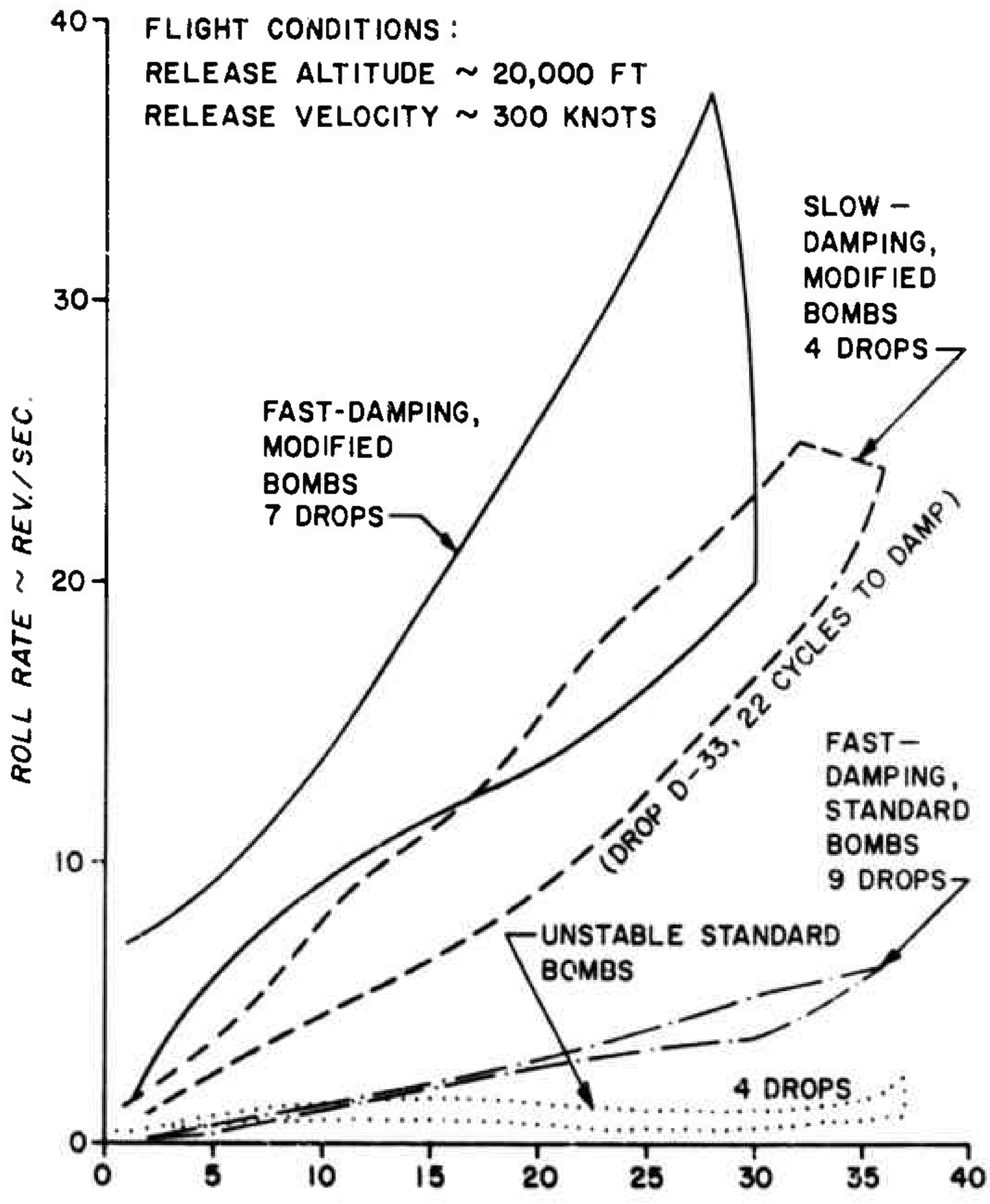

FIGURE 2

Time of Flight ~ Sec.
Roll Rate Versus Time of Flight for
Standard and Modified MARK 81 Low Drag Bombs

APPENDIX B

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