

NWL TECHNICAL REPORT TR-2403

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**THE EFFECT OF FIN SLOTS AND
FIN TABS ON THE DYNAMIC STABILITY
CHARACTERISTICS OF THE NAVY LOW DRAG BOMB**

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THE EFFECT OF FIN SLOTS AND FIN TABS
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OF THE NAVY LOW DRAG BOMB

by

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FOREWORD

This report presents the results of a study to improve the dynamic stability characteristics of the Navy's Mk 81 Low Drag Bomb. This work was authorized under WEPTASK No. A32-320-291-70F-17323201

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ABSTRACT

This report presents the results of a research program to improve the dynamic stability characteristics of the Navy's Mk 81 Low Drag Bomb by introducing fin slots and roll tabs. Wind tunnel tests and flight tests were conducted to prove the design.

It appears that fin slots and roll tabs are a promising fix for stabilizing the bomb. However, more drops with larger initial release disturbances must be conducted before this result can be considered conclusive.

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INTRODUCTION

Dynamic instabilities which arise from rolling motion of 4-finned missiles have caused considerable difficulties for missile designers. Catastrophic yaw arising from "locked-in" or "lunar" motion was first described by Schneller¹ and later documented during the flight trials of the Navy's Low Drag Bomb.² Magnus instabilities³ were noted even earlier by Dr. 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, Lugt⁴ 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 the possibility, we⁵ 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 6-degree of freedom motions.

It is the purpose of this paper to present the results of a research program to improve the dynamic stability characteristics of the Navy's Mk 81 Low Drag Bomb by introducing fin slots and roll tabs.

WIND TUNNEL TESTS

The Navy's Mk 81 Low Drag Bomb has always suffered from marginal dynamic stability characteristics.² At least one in ten of these bombs falls short due to excessive yawing motion produced by roll lock-in.⁵ Consequently, it was felt that this configuration (shown in Figure 1) has been in great need of fixing.

Free rolling and free pitching tests were conducted on a full-scale Mk 81 Low Drag Bomb in the NSRDC 8 x 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. This configuration was a standard bomb, chosen at random, and sting mounted for wind tunnel tests. Its design fin cant was two degrees $\pm$ one degree. The steady state spin versus angle of attack is shown in Figure 2. Two modes of motion exist between 13 degrees and 25 degrees angle of attack. In this region 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. Above 25 degrees angle of attack, the missile will not spin and lock-in is the only mode of motion until the missile breaks out at 40 degrees. It then speeds up considerably in either direction. No data were obtained for higher angles of attack because of violent pitch oscillations experienced by the model. However it is expected that the spin would have been much higher at higher angles of attack.⁶

A configuration with interchangeable flat plate fin inserts and two degrees of fin cant was then installed and tested in the wind tunnel. This configuration with no fin slots ($S/F = 0$) has a higher over all spin rate (Figure 3). The lock-in region began at 15 degrees angle of attack and extended to 47 degrees. Above 47 degrees 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. The over all spin rate was reduced and the speed-up at high angles of attack was reduced to zero. It appears that if the slot is sufficiently large, speed-up at high angles of attack 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. Figure 5 presents the steady state spin versus angle of attack for a configuration whose $S/F = .180$. If the slot size is reduced from this value, speed-up occurs at high angles of attack.

Aileron tabs were then added to the configuration to increase the spin rate at low angles of attack. 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, 1-1/4 in. tabs with 12 degrees of cant per tab, and a ratio of slot area to fin area (S/F) of .270. Steady state spin versus angle of attack for the optimum configuration is presented in Figure 6. 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 and the standard configuration. Figure 7 is a comparison of the free pitching motion of the two configurations. The addition of slots and tabs decreases the pitching frequency and does not affect the damping rate.

FLIGHT TESTS

In order to further prove the design, flight testing was conducted at the White Sands Missile Range. Ten bombs were dropped from an altitude of 30,000 feet with airspeed of 350 knots. It is estimated that their steady state spin varied between 30 and 60 revolutions per second. Test data indicated that all bombs flew well. An aircraft mounted camera disclosed only moderate release disturbances in the first few feet of fall.

A ballistic analysis indicated that the dispersion, CEP, of the bombs (excluding any initial disturbance due to aircraft separation effects) was 56 feet or 1.54 mils in the plane normal to the trajectory at impact. The CEP, referred to here is defined as the estimated radius of a circle which encompasses 50 percent of the total population.

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 reported⁷ in 1956, it may be inferred that the Magnus coefficient is tolerably small for stability at large roll rates for small angles of attack. The 1956 report describes drops of two 1000 pound Mk 83 Bombs with 7 degrees fin cant released at 140 knots from 30,000 feet. They developed a roll rate of 40 revolutions per second and flew very well.

Magnus data from wind tunnel tests of the unslotted configuration⁸ also are consistent with dynamic stability at the high spin rates for low angles of attack. 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.

CONCLUSIONS

It appears that fin slots and roll tabs are a promising fix for stabilizing the Navy Mk 81 Low Drag Bomb. However, more drops with larger initial release disturbances must be conducted before this result can be considered conclusive.

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NOMENCLATURE

d	Missile Diameter
F	Fin Area
S	Slot Area
V	Total Velocity
α	Angle of Attack
δ	Fin Cant Angle
σ_A	Roll Tab Angle

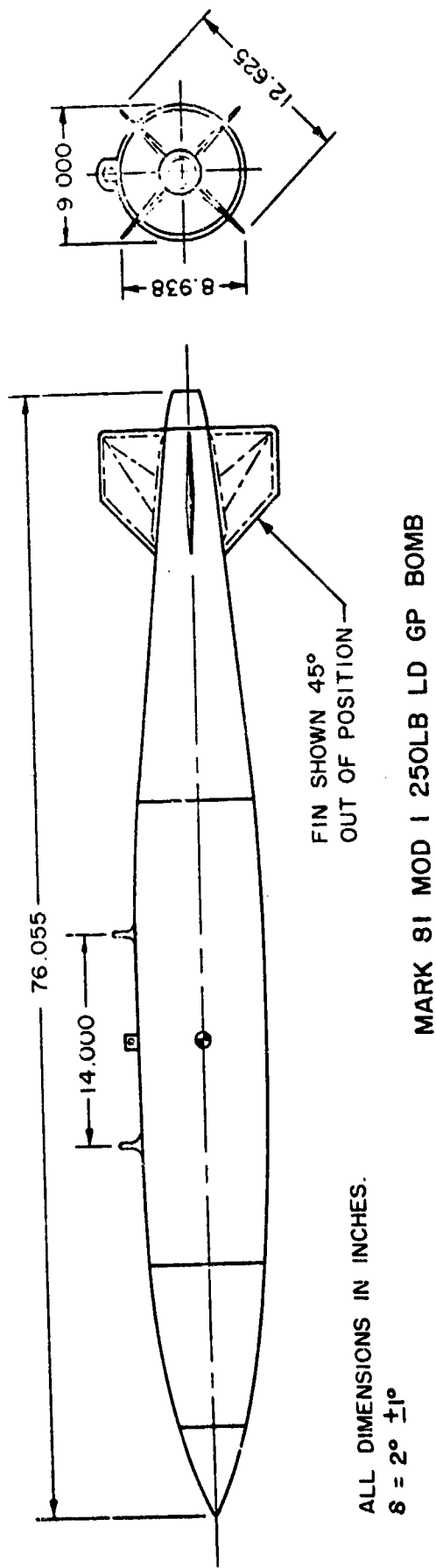


Figure 1. - Schematic of the Mk 81 Low Drag Bomb

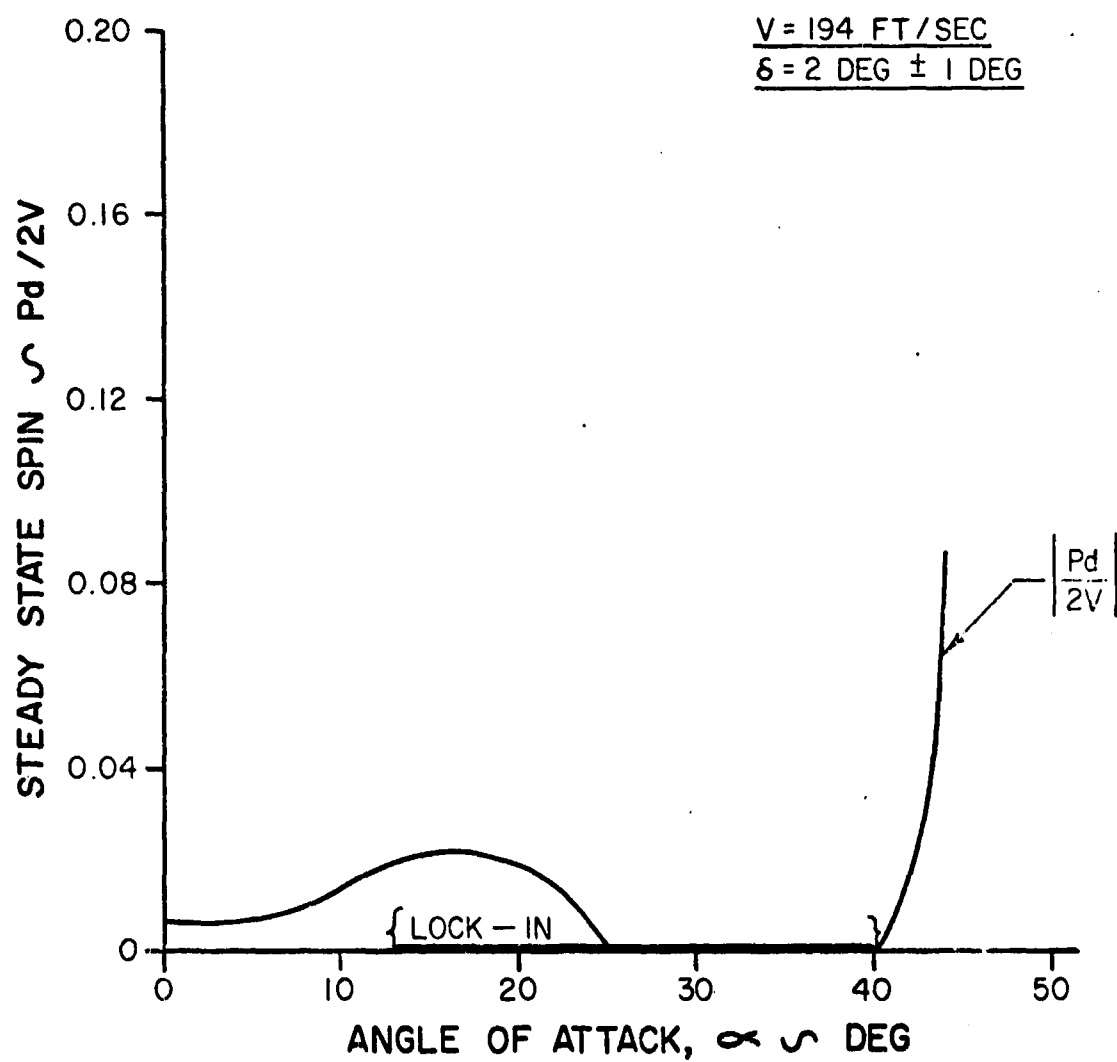


Figure 2. - Steady State Spin Versus Angle of Attack
for the Mk 81 Low Drag Bomb

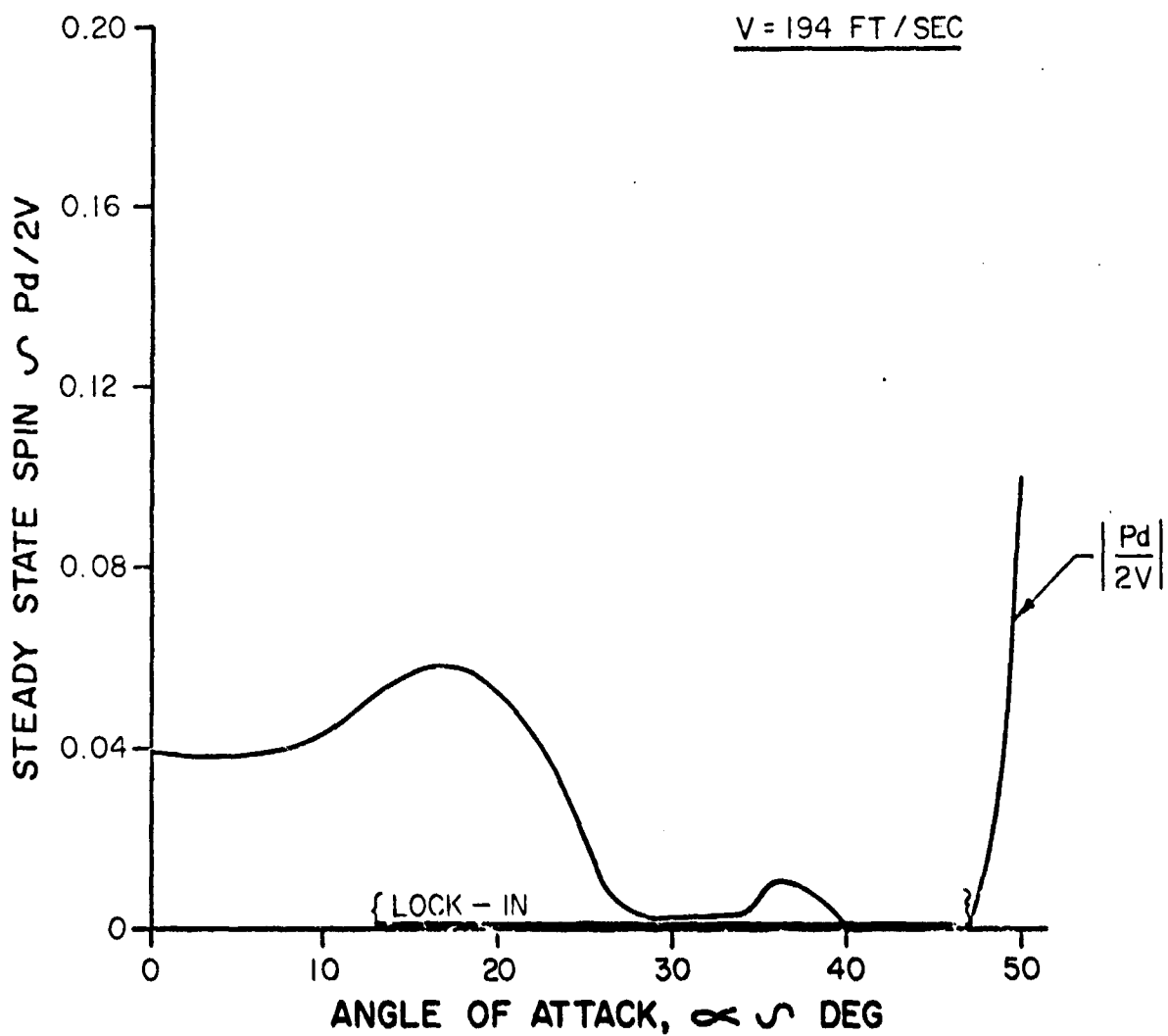


Figure 3. - Steady State Spin Versus Angle of Attack for the
Mk 81 Low Drag Bomb (S/F = 0, $\delta = 2$ Deg.)

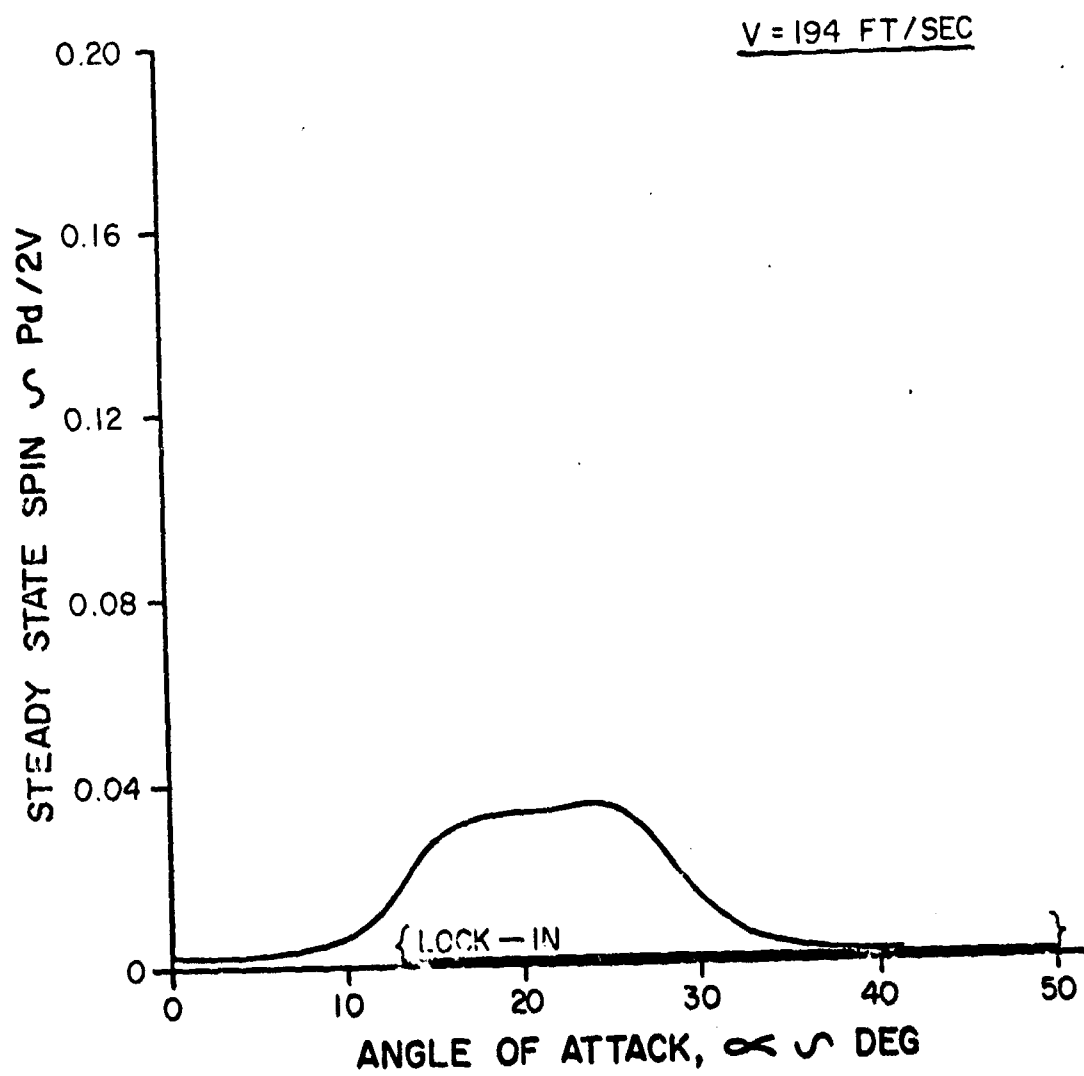


Figure 4. - Steady State Spin Versus Angle of Attack for the
Mk 81 Low Drag Bomb (S/F = .658 ϕ ~ 2 Deg)

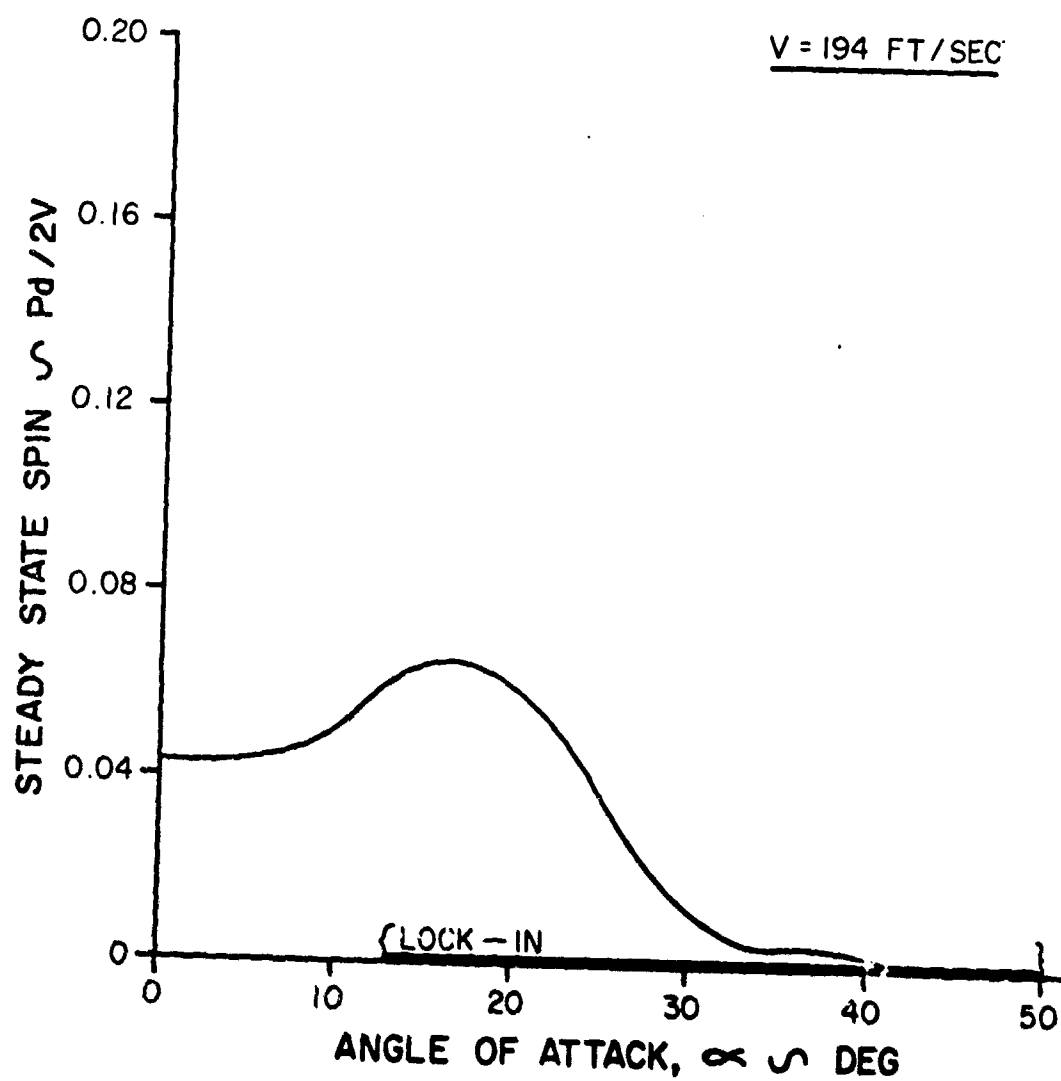


Figure 5. - Steady State Spin Versus Angle of Attack for the
Mk 81 Low Drag Bomb (S/F = .180 $\alpha' = 2$ Deg.)

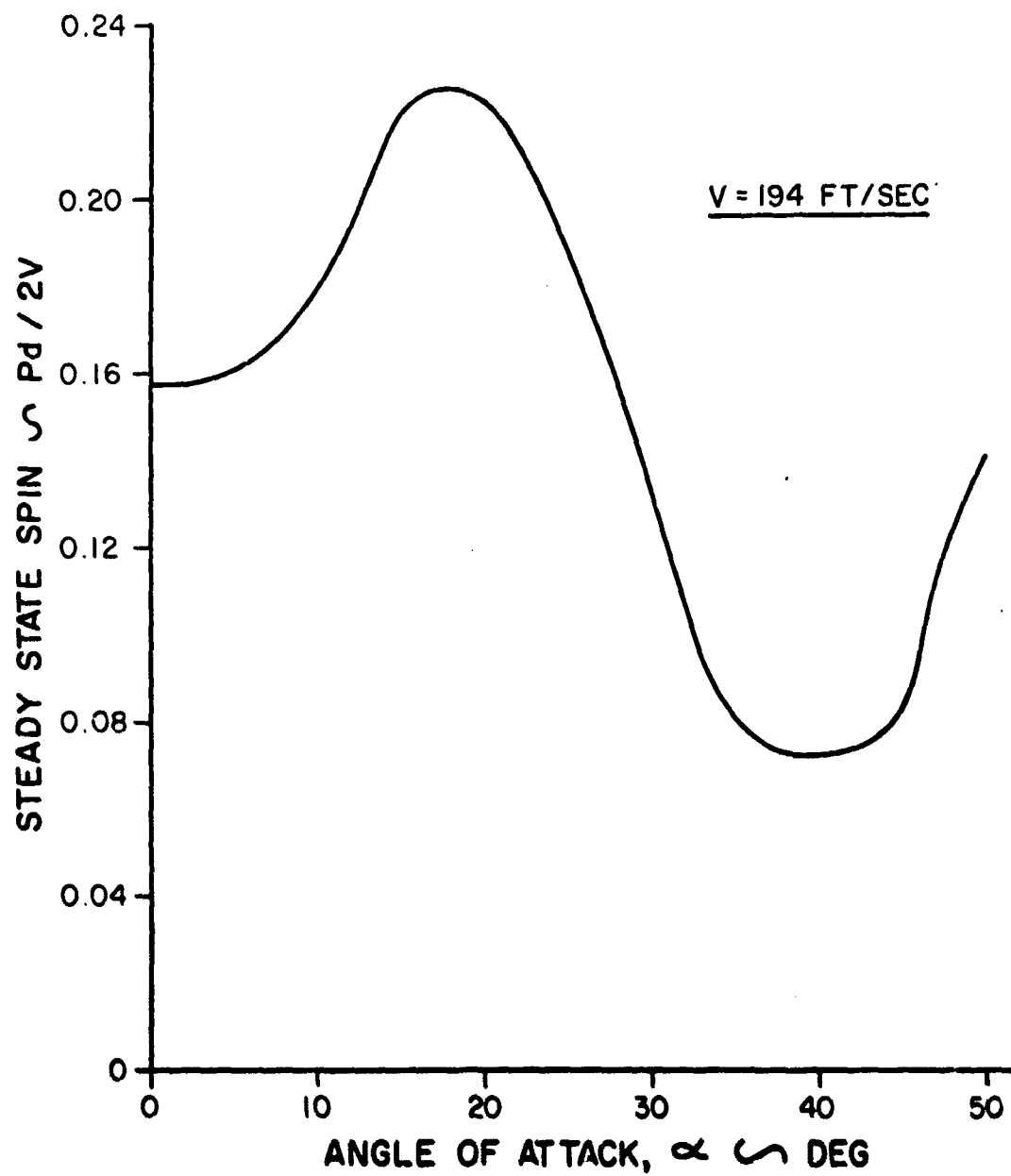


Figure 6. - Steady State Spin Versus Angle of Attack for the
Mk 81 Low Drag Bomb (S/F = .270 δ = 2 Deg. α_A = 12 Deg.)

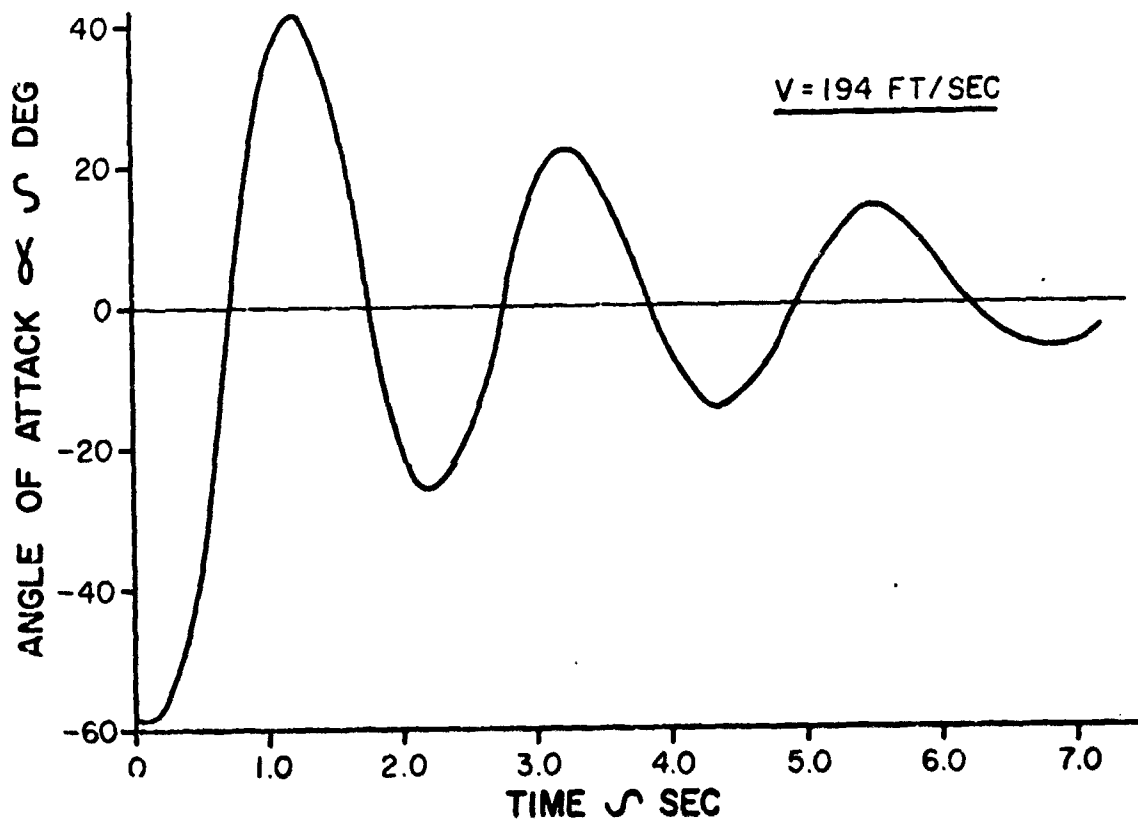


Figure 7A - Angle of Attack Versus Time for Standard
Mk 81 Low Drag Bomb

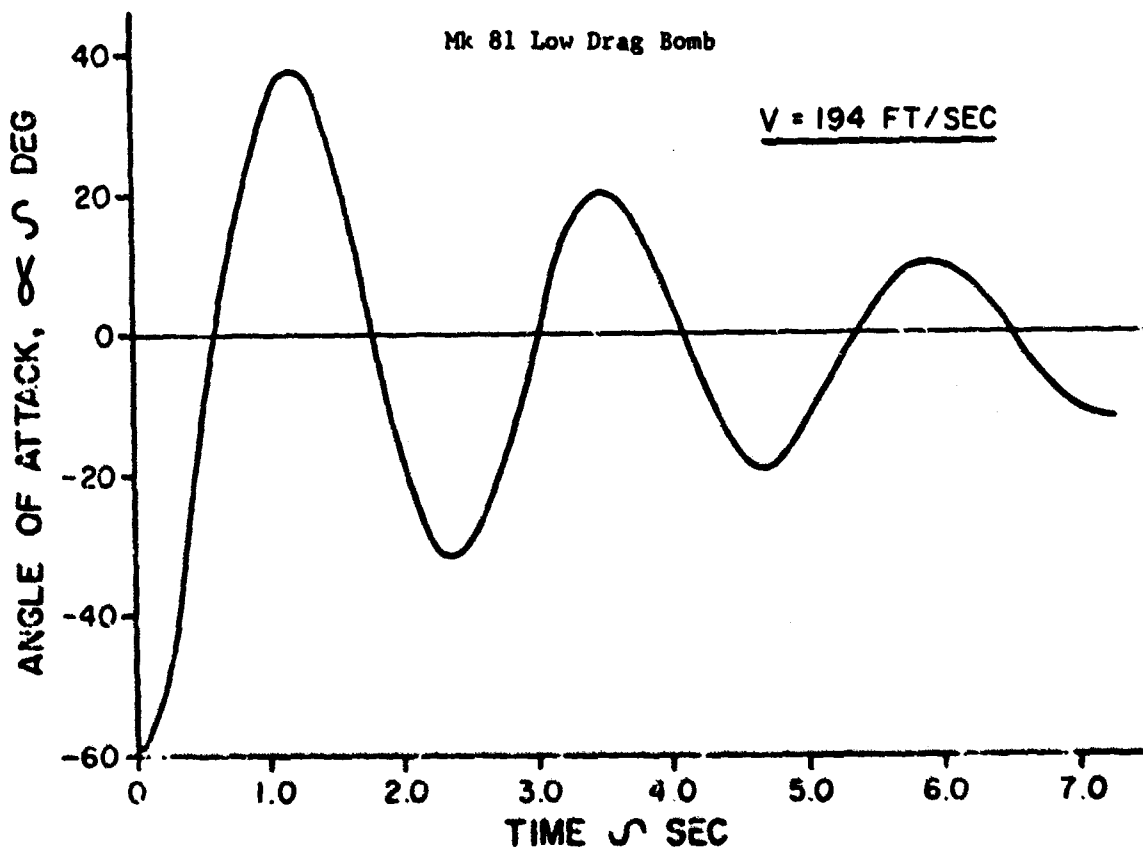


Figure 7B - Angle of Attack Versus Time for Optimum Configuration

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