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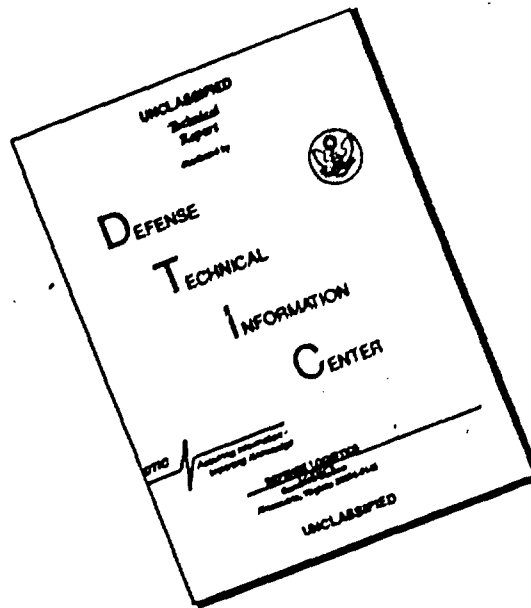
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**THEORETICAL PREDICTIONS OF THE FIRST MAXIMUM
PITCH OF LOW DRAG BOMBS RELEASED FROM
A3D AIRCRAFT IN HORIZONTAL FLIGHT (U)**

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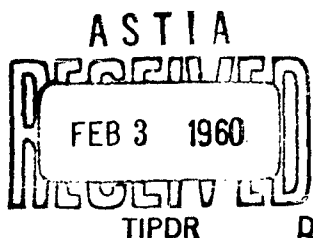
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Theoretical Predictions of the First Maximum
Pitch of Low Drag Bombs Released From
A3D Aircraft in Horizontal Flight (U)

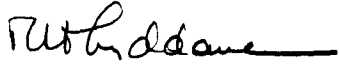
by

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Computation and Analysis Laboratory

NWL REPORT NO. 1683

Task Assignment
NO 103-666-64042/01-064

7 December 1959

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ABSTRACT

This report presents the results of a study to determine a method of predicting the first maximum pitch of low drag bombs ejected from A3D type aircraft by means of the Aero 7A Bomb Ejector Rack. The conclusions reached herein are: (1) the theoretical solution assuming free stream conditions and linear aerodynamic moments is a satisfactory method of predicting first maximum pitch for the conditions under which the test data were obtained, (2) the difference between the observed first maximum pitch of the Mk 81 bomb with nose plug and that of the Mk 81 bomb with nose fuze is due to the difference in the positions of center of gravity which results in the bombs being ejected with different angular rates, (3) there is no apparent correlation between the magnitude of the first maximum pitch and the location of the bomb rack in the bomb bay, and (4) there is no difference apparent between the magnitudes of the first maximum pitch of those bombs that had bad flight and those bombs that had good flight (when released at the same conditions). In addition, it is believed that the theoretical free stream solution developed herein will satisfactorily predict the first maximum pitch of other bombs ejected from the A3D aircraft by the Aero 7A bomb rack provided that (a) the ejection velocity of the bombs is at least 10 feet per second, and (b) the angular velocity of the bombs does not exceed 300 degrees per second, and (c) the ratio of weight to longitudinal cross section area of the bombs is no smaller than that of the subject bombs. A study is now in progress to predict the range effects due to the first maximum pitch reported herein; if this study is concluded satisfactorily, one will have reasonable confidence that the procedures are suitable for use under a variety of conditions, thus eliminating the necessity of extensive ballistic tests for the purpose of preparing bombing tables for the A3D airplane.

FOREWORD

This report contains the results of a study to determine a method of predicting the first maximum pitch of low drag bombs released from the bomb bay of A3D airplane in horizontal flight. The tests that provide the basic data in this report were conducted at the Naval Weapons Laboratory between August 1956 and July 1957 under the direction of J. E. Mitchell, Computation and Analysis Laboratory. These tests were performed and the study was conducted under Task Assignment NO 103-666/64042/01-064. The Naval Air Test Center, Patuxent, Maryland provided the services of the A3D aircraft used in the tests discussed in this report. This report has been reviewed by:

A. L. JONES, Head, Theory and Analysis Division
R. A. NIEMANN, Director, Computation and Analysis
Laboratory

INTRODUCTION

Ballistic tables for the low drag bombs with nose fuze plugs (Electric fuzes) are based on ballistic data obtained from drops at conditions which, it was believed, would produce small initial pitch. Photographic records and dispersion data indicate that these bombs usually had stable flight (i.e., about 90 percent of the bombs were stable). Later, for the purpose of determining whether the ballistic tables for the low drag bombs are applicable to release conditions other than those of the original tests, additional ballistic data were obtained for the Mk 81, Mk 82 and Mk 83 bombs released from the A3D type airplane in a dive (see reference 1) and the Mk 81 and Mk 82 bombs released from the A3D airplane in horizontal flight (see reference 2).

Tests of the Mk 81 and Mk 82 bombs, with nose fuze plugs or with AN/M-103A1 mechanical nose fuze, released from A3D aircraft in horizontal flight indicated that these bombs were unsuitable for service use under the release conditions of the test (approximately 8,000 to 10,000 feet true altitude, 200 to 500 knots true airspeed) due to the large percentage of unstable flights encountered. These unstable flights were attributed to a large pitching motion developed immediately after release, which in turn results from ejecting the Mk 81 and Mk 82 bombs from the Aero 7A bomb ejector rack (the ejector foot of this rack contacts these bombs at a point 3 to 5 inches aft of the center of gravity of the bombs). Some methods of reducing this pitching motion were suggested and results from certain pertinent tests are reported in reference 3.

The Mk 81 and Mk 82 bombs will not be dropped under the conditions of the above tests because of the large percentage of unstable flights which would result. (See reference 4 which restricts the use of bombs below the 500 pound category; the 500 pound bomb is considered unsatisfactory but is not restricted.) However, other low drag bombs and Army-Navy type bombs are expected to have appreciable pitch when released from the A3D airplane. A modification of the ejector cartridge used with the Mk 82 bomb, now under consideration, is expected to result in lower but perhaps still appreciable pitch. It is therefore desirable to consider the results of the tests further in order to determine the best method of preparing bombing tables for

bombs released from the A3D aircraft with large initial pitch. Extensive tests to determine applicable bombing table data over the operational limits of the airplane would be expensive and time consuming. An alternate procedure is suggested in this report; namely, that the first maximum pitch of bombs released from the A3D airplane be predicted by theoretical means by considering the pitching moment produced by the Aero 7A rack and assuming free stream conditions (i.e., assuming that the airflow on the bomb at the instant of release is equivalent to the airspeed of the aircraft). The reduced airflow for that part of the bomb's trajectory within the bomb bay (about two feet) and the difference in direction of airflow because of circulation around the aircraft are neglected. The application of this theory in computations involving various bombs and a wide range of release conditions is discussed in this report. Once the first maximum pitch of the bombs is known one can then attempt to predict the effect on range due to this pitch. The range effect due to the moderate values of first maximum pitch observed for the Mk 81 and Mk 82 bombs released from the AD aircraft in a dive has been successfully determined. (See reference 5.) A study is now under way to determine whether this procedure can be used to compute the effects on the range of low drag bombs released under more severe conditions from A3D aircraft.

DESCRIPTION OF MATERIAL

Bombs

The physical characteristics of the Mk 81 and Mk 82 low drag bombs, and the other bombs in the low drag bomb family (for which the results given in this report are also applicable) are given in Table 1. The weights and center of gravity positions of the individual Mk 81 and Mk 82 low drag bombs considered in this report are given in Appendix A, Tables 2 through 5. The Low Drag General Purpose Bombs, Mk 81, Mk 82, Mk 83 and Mk 84, with nose fuze plugs, and the Low Drag Practice Bombs Mk 86, Mk 87 and Mk 88 incorporate the general features of the Douglas Low Drag Bomb Shape. (The nose fuze plug is designed for use with the electric fuzes now under development for the low drag general purpose bombs.) When the AN/M-103A1 mechanical nose fuze is used it replaces the ogival nose fuze plug and changes the bomb's configuration and center of gravity position markedly (see Appendix A). The low drag practice bombs can be filled with either water or wet sand, but do not have fuzing capabilities.

TABLE 1
PHYSICAL DIMENSIONS OF THE LOW DRAG BOMB FAMILY

Bomb Type	Nominal Weight (lb)	Length (in.)	Diameter (in.)	Transverse Moment of Inertia ² (slugs-ft ²)	Ejection Cartridges Used in Studies	Ejection Velocity (ft/sec)	Center of Gravity ³ (in.)	Center of Buoyancy ⁴ (in.)
Mk 81 (nose plug or fuze) ¹	250	76.1	9.00	15.15	(2) Mk 2 Mod 0	19.4	3.5-5.5	5.5-3.5
Mk 82 (nose plug or fuze) ¹	500	90.9	10.75	39.06	(1) Mk 2 Mod 0 (1) Mk 1 Mod 2	22.4	3.5-5.5	5.5-3.5
Mk 83 (nose plug or fuze) ¹	1000	118.8	14.00	104.57	(1) Mk 2 Mod 0 (1) Mk 1 Mod 2	17.3	2-6	7-3
Mk 84 (nose plug or fuze) ¹	2000	154.0	18.00	360.90	(1) Mk 2 Mod 0 (1) Mk 1 Mod 2	12.6	11.5-12.5	7.5-6.5
Mk 86 (water filled)	141	76.1	9.00	6.82	(2) Mk 2 Mod 0	24.0	7.5-8.5	1.5-0.5
Mk 86 (wet sand filled)	217	76.1	9.00	8.96	(2) Mk 2 Mod 0	20.5	7-8	2-1
Mk 87 (water filled)	221	90.9	10.75	12.05	(2) Mk 2 Mod 0	20.5	7.5-8.5	1.5-0.5
Mk 87 (wet sand filled)	333	90.9	10.75	16.89	(2) Mk 2 Mod 0	17.2	5.5-6.5	3.5-2.5
Mk 88 (water filled)	458	118.8	14.00	36.76	(2) Mk 2 Mod 0	15.1	7.5-8	1.5-0
Mk 88 (wet sand filled)	783	118.8	14.00	60.31	(1) Mk 2 Mod 0 (1) Mk 1 Mod 2	19.0	6-8	3-1

¹All values listed, except length, are applicable to either the fused or non-fused version. The length given in the table is for the bomb with nose fuze plug; while the lengths of the bombs with the AN/M-103A1 mechanical nose fuze (and appropriate tail fuze) are as follows: Mk 81 - 74.1 in, Mk 82 - 86.9 in, Mk 83 - 116.0 in and Mk 84 - 151.5 in. Individual dimensions are given in Tables 2-5, Appendix A.

²Measured through the center of gravity.

³Distance aft of a point on the bomb axis directly under the center of the forward suspension lug.

⁴The distance measured from the center of gravity of the bomb to a point on the bomb axis directly under the forward edge of the Aero 7A bomb ejector foot.

The fins of all of the above bombs are nominally canted 2.0 degrees in the direction that will cause the bomb to spin clockwise as viewed from the rear. All bombs except the Mk 84 are equipped with two suspension lugs 14 inches apart and a hoisting lug midway between the suspension lugs. The Mk 84 bomb is equipped with two suspension lugs which are 30 inches apart.

Bomb Rack

The Douglas Aero 7A 4-hook bomb ejector rack combines, in a single lightweight unit, a 14-inch 2-hook rack and a 30-inch 2-hook rack, each type employing a cartridge actuated ejector. The rack uses a piston type ejector foot, mounted 3.5 inches aft of the mid-point between the lug hooks, which was designed to produce a large tail-down moment and, consequently, safe separation of special weapon stores.

During the tests considered in this report the Aero 7A bomb ejector rack was fitted with two Mk 2 Mod 0 cartridges for ejection of the 250 pound Mk 81 bomb and one Mk 2 Mod 0 and one Mk 1 Mod 2 cartridge for the 500 pound Mk 82 bomb. The theoretical predictions of first maximum pitch, reported herein are based on a release from the Aero 7A rack equipped with (1) two Mk 2 Mod 0 cartridges for bombs weighing less than 500 pounds and (2) one Mk 2 Mod 0 and one Mk 1 Mod 2 cartridge for bombs weighing 500 pounds or more.

The ejection velocity was obtained for each bomb-ejector cartridge combination from the BUAER Ejection Velocity Chart (see Figure 1), Appendix A, and scaled proportionately on the basis of data obtained at the Naval Weapons Laboratory during ground ejection tests of a cylindrical body equivalent (in weight) to the Mk 81 low drag bomb (see reference 6). The BUAER Ejection Velocity Chart indicates an expected 25.5 feet per second ejection velocity when two Mk 2 Mod 0 cartridges are used for ejection of the 250 lb Mk 81 bomb, while an ejection velocity of 19.4 feet per second was observed in limited ground tests conducted at the Naval Weapons Laboratory. (Additional ground tests, the results of which are unpublished, yielded further information which tends to validate the scaled data.)

PROCEDURE

Low Drag Bombs Mk 81 and Mk 82 were released from A3D-1 and A3D-2 type airplanes in joint NATC-NWL tests conducted during the period 31 August 1956 through 16 July 1957. Detailed test conditions are given in Tables 2 through 5, Appendix A. A summary of these test conditions is given below:

Type Bomb	Fuze Configuration	Upper Figure-Number of Bombs Tested Lower Figure-Nominal True Airspeed (kt)			Avg. First Max. Observed Pitch (deg)		
Mk 81	Nose Plug	11	4	2	61	54	46
		250	390	500			
Mk 81	AN/M-103A1	8			46		
		250					
Mk 82	Nose Plug	3	7	5	56	40	34
		270	380	490			
Mk 82	AN/M-103A1	8	1	4	57	38	30
		230	320	470			

The test equipment used in these tests was similar to that described in reference 7 except that in some instances the tracking cameras were fitted with a 48 inch focal length Thompson lens with a doubler that gave an effective focal length of 96 inches.

The yaw histories were computed for each bomb tested from measurements of the apparent attitude of the bomb axis in successive ground camera photographs. The first maximum pitch (total yaw during the first few seconds of flight was confined almost entirely to the vertical plane) in every case was tail downward, and is given for each bomb in Tables 2 through 5, and Figures 2 and 3, Appendix A.

The method used in computing the data above is essentially that given in reference 7 except that in this case the computations are based on the camera records from only one station with the assumption that the total yaw of the bomb was exactly confined to a vertical plane.

The theoretical first maximum pitch due to the ejection force imparted by the Aero 7A ejector foot was computed for each bomb tested using the formulae given in Appendix B which assumes that (a) the air stream through which the bomb falls is unaffected by the presence of the airplane and (b) the aerodynamic restoring and damping moments are linear functions of the angle of attack. Values of -3.8 and -165.0 were used for the aerodynamic parameters $C_{m\alpha}$ (the restoring moment coefficient) and C_{mq} (the damping moment coefficient), respectively, for all test conditions. The individual release conditions and center of gravity positions of each bomb and the average weight and moment of inertia of the bombs were used in the computations.

A comparison of the theoretical and observed first maximum pitch is presented in Tables 2 through 5, Appendix A, and in Figures 4 through 6, Appendix A.

A large percentage of the Mk 81 and Mk 82 bombs released from the A3D airplane had bad flight (see reference 2). Some of these bombs had large total yaw (referring to that angle between the velocity vector and the axis of the bomb) throughout their trajectories while others exhibited this behaviour for a relatively short time (from 3 to 12 seconds). In all instances, where the information could be obtained, the large total yaw was found to have occurred during a time when the spin and yaw rates of the bombs were equal. There is no apparent correlation between the relatively small variations in the magnitude of the first maximum pitch of the bombs at a given release condition and the bad flight (see Figures 2 through 6, Appendix A). Therefore, the first maximum pitch for the bombs which had bad flight will not be excluded in the comparison of observed and computed first maximum pitch in this report. There is no apparent correlation between the magnitude of the first maximum pitch and bomb rack position in the bomb bay (see Figures 4 and 5, Appendix A). Rack position, therefore, will not be considered in the analysis reported herein.

RESULTS

It is evident that a difference of approximately 15 degrees exists (see Figure 2, Appendix A) when a comparison is made between the magnitude of the observed first maximum pitch of the Mk 81 bomb with nose fuze plug and that of the Mk 81 bomb with the AN/M-103A1 mechanical time fuze. This difference is due to the change in the length of the moment arm for the Mk 81 bomb (about 1.5 inches less on the average for the bomb with fuze than for the bomb with nose fuze plug, see Tables 2 and 3, Appendix A, and Figure 7 of Appendix C). No difference is noted between the magnitude of the observed first maximum pitch of the Mk 82 bomb with nose fuze and that of the Mk 82 bomb with nose fuze plug although in this case the average difference in the length of the moment arm was 0.8 inch. The data of Figure 8, Appendix C, show that this difference in moment arm would lead to a difference in first maximum pitch of 6 to 10 degrees over the conditions of the subject test. The experimental data at low values of dynamic pressure fail to show this difference but at the higher values of Q the bombs with nose plug generally have a larger value of pitch, as expected.

The theoretical calculations of first maximum pitch for the Mk 82 bomb with nose fuze plug and with AN/M-103A1 mechanical nose fuze are in very good agreement with the observations (see Figures 5 and 6). In view of the accuracy of the observed first maximum pitch (in general about ± 3 to 5 degrees) the above comparison for the Mk 82 low drag bomb is considered satisfactory.

The comparison of the theoretical first maximum pitch with the values observed for the Mk 81 bombs indicates that the theoretical values agree with those observed in the region of dynamic pressure of 5000 lb/ft-sec^2 . At larger values of dynamic pressure the theoretical and measured values fail to match by 10 to 20 degrees. It is believed that this much discrepancy is acceptable but a final answer on this point cannot be obtained until the sensitivity of the impact point of the bomb to the magnitude of the first maximum pitch is determined.

Since the theoretical values of first maximum pitch appear to match the observed values satisfactorily (for the range of release conditions tested) it is believed that this method can be used to predict the first maximum pitch of other bombs under certain conditions, thus eliminating the necessity of actually testing at numerous release conditions. The predictions should be limited to bombs which (a) are ejected with similar or larger ejection velocities, (b) have an angular velocity not exceeding 300 degrees per second, and (c) have similar or larger ratios of weight to product of length and diameter in order to avoid conditions where the lift forces due to the local air stream about the aircraft may become important. Predictions of initial pitch greater than the value of 70 degrees made under the test conditions reported herein may be invalid because the assumption of free stream flow may no longer be satisfactory when the bomb has very large initial angular rate. (Data for bombs ejected with smaller velocities are now being obtained and will be analyzed as soon as they become available.)

Information on the initial pitch is of value in the computation of ballistic tables since it can be used in computing the effect on range due to launching phenomena. As a result of an investigation reported in reference 5 it has been concluded that satisfactory results can be obtained (assuming that the necessary aerodynamic data are available) by using this method, at least for the moderate values of initial yaw (15 to 30 degrees) observed for bombs released from the AD aircraft in dive. A study of the accuracy of the prediction of range effects for the more severe conditions discussed in this report is under way. The computed theoretical first maximum pitch for various low drag bombs is given in Appendix C, Tables 6 through 15 and Figures 7 through 16. Each table and figure covers the operational limitations of the A3D type airplane with respect to altitude and airspeed. It should be noted that the accuracy of the data for the water filled Mk 86, Mk 87 and Mk 88 bombs, which have smaller weight to longitudinal cross section area ratios than the Mk 81 and Mk 82 bombs, is subject to question. Although the Mk 84 bomb has smaller ejection velocity than the bombs tested, the accuracy of the data is probably adequate because of its higher ratio of weight to cross sectional area.

CONCLUSIONS

Based on the results obtained in the comparison of observed and theoretical first maximum pitch for the Mk 81 and Mk 82 low drag bombs it is concluded that:

a. The theoretical solution assuming free stream conditions and linear aerodynamic moments is a satisfactory method of predicting first maximum pitch for the conditions under which the test data were obtained.

b. The difference between the observed first maximum pitch of the Mk 81 bomb with nose plug and that of the Mk 81 bomb with nose fuze is due to the difference in the positions of center of gravity which results in the bombs being ejected with different angular rates.

c. There is no apparent correlation between the magnitude of the first maximum pitch and the location of the bomb rack in the bomb bay.

d. There is no apparent difference between the magnitudes of the first maximum pitch of those bombs that had bad flight and those bombs that had good flight (when released at the same conditions).

In addition, it is believed that the theoretical free stream solution developed herein will satisfactorily predict the first maximum pitch of other low drag bombs ejected from the A3D airplane by the Aero 7A bomb rack provided that (a) the ejection velocity of the bombs is at least 10 feet per second, (b) the angular velocity of the bombs at release does not exceed 300 degrees per second, and (c) the ratio of weight to longitudinal cross section area of the bombs is no smaller than that of the subject bombs.

FUTURE PLANS

The effect on range due to first maximum pitch of Mk 81 and Mk 82 bombs is being determined by the computation of trajectories. If these ranges satisfactorily match the observed ranges (see reference 2), it is planned to incorporate into the computations of ballistic tables corrections for the effect on range due to first maximum pitch.

Ballistic data are now being obtained on the Mk 83 low drag bomb with the AN/M-103A1 mechanical nose fuze and with nose fuze plug, and the Mk 84 low drag bomb with nose fuze plug. With these data and the results of previous tests of the Mk 83 bomb reported in reference 8, further comparison of observed and theoretical first maximum pitch will be made.

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APPENDIX A

BUAER EJECTION VELOCITY CHART

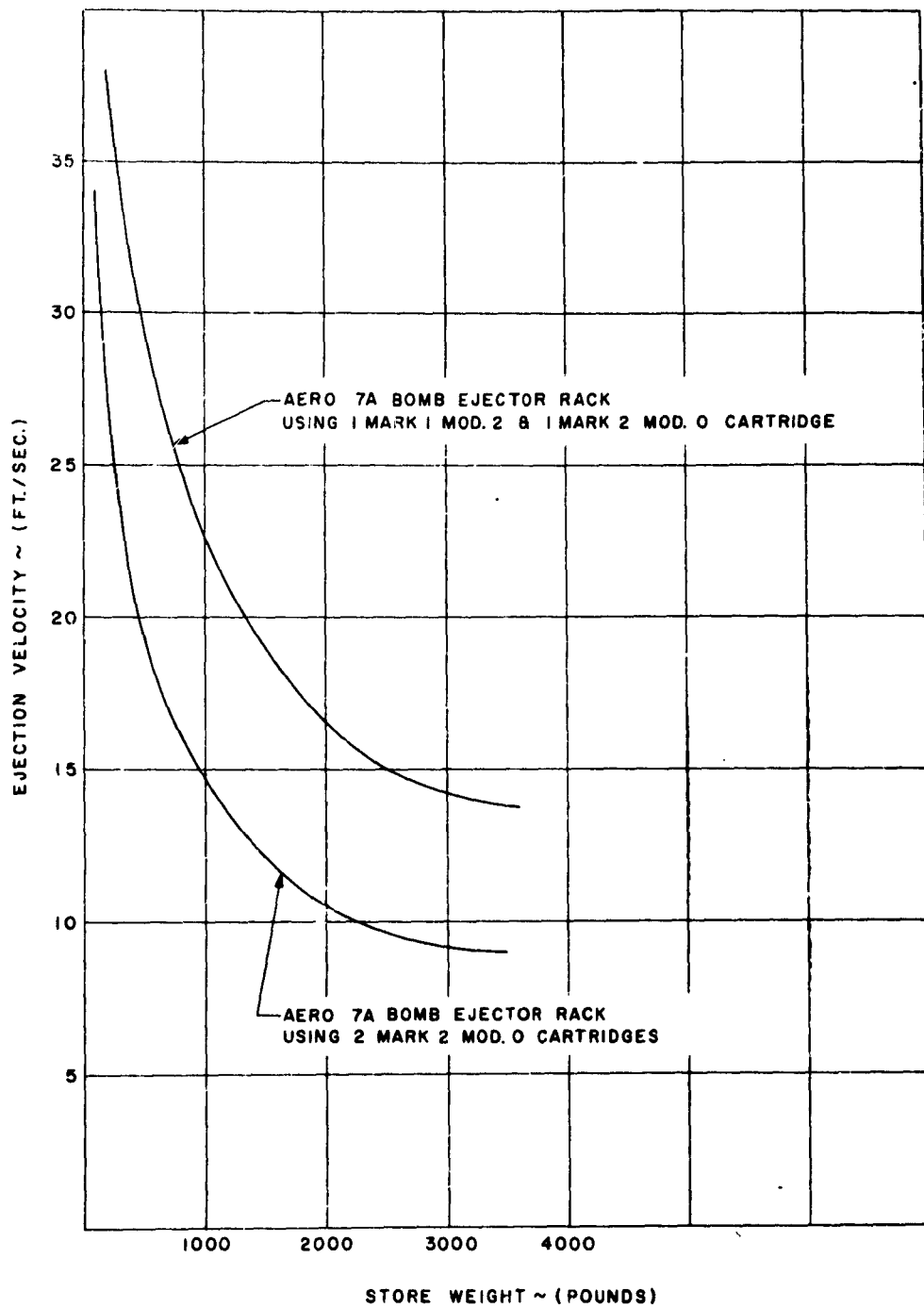


FIGURE 1

TABLE 2

PHYSICAL DATA AND FIRST MAXIMUM PITCH OF 250 LB
MK 81 MOD 1 LOW DRAG BOMB FITTED WITH NOSE FUZE PLUG

NRL Assigned Bomb Number	Date of Drop	Drop Number	Time of Drop	True Altitude (ft)	True Airspeed (kt)	Dynamic Pressure ¹ $\frac{1}{2}\rho V^2$ (lb/ft-sec ²)	Bomb Weight ² (lb)	Center of Gravity ³ (in.)	Moment Arm ⁴ (in.)	Rack Position ⁵	First Maximum Pitch Observed ⁶ (deg)	Theoretical ⁷ (deg)	Difference First Maximum Pitch ⁸ (deg)
70	14 Mar 1957	4	11.1	7470	219	4.2	250	3.7	5.4	2F	19	27	-5
68	14 Mar 1957	4	12.2	7290	228	4.5	255	3.5	5.5	3F	66	65	1
69	14 Mar 1957	3	14.0	7000	228	4.5	249	3.6	5.4	4F	60	64	-4
73	10 Jul 1957	1	09.50	10340	250	5.0	254	3.5	5.5	3F	73	73	0
77	10 Jul 1957	5	10.47	10310	252	5.1	246	3.4	5.6	1F	63	63	0
75	10 Jul 1957	3	10.32	10230	252	5.1	246	3.5	5.5	2F	70	62	8
84	10 Jul 1957	14	13.28	10310	253	5.1	250	4.0	5.0	1A	55	56	-1
89	10 Jul 1957	20	14.17	10330	254	5.2	244	3.6	5.4	1A	54	61	-7
76	10 Jul 1957	6	10.57	10330	253	5.2	253	3.5	5.5	1A	52	63	-11
81	10 Jul 1957	19	14.11	10290	265	5.6	248	3.6	5.4	1F	61	58	3
82	10 Jul 1957	12	13.13	10290	365	11.8	252	4.0	5.0	2F	58	37	21
79	10 Jul 1957	9	12.52	10320	319	12.0	236	5.0	4.0	2A	52	29	23
83	10 Jul 1957	13	13.21	10230	404	13.1	240	5.0	5.2	3F	57.9	39	18
85	10 Jul 1957	16	15.52	10160	504	20.3	247	3.5	4.0	1F	49	28	21
87	10 Jul 1957	10	16.01	10160	504	20.3	240	3.5	5.5	3F	47	31	16
									5.5	2A	45.9	31	14

¹Dynamic Pressure = $q = \frac{1}{2} \rho v^2$ where ρ = standard density at altitude and V = true airspeed

²Individual bomb weights are listed although nominal weights of 250 pounds and 500 pounds were used for the Mk 81 and Mk 82 bombs, respectively, for calculation of the individual theoretical first maximum pitch.

³Distance aft of a point on the bomb axis directly under the center of the forward suspension lug.

⁴Distance from the center of gravity of the bomb to a point on the bomb axis directly under the forward edge of the Aero 7A rack bomb ejector foot.

⁵Bomb location in the bomb bay where F = forward station 319.825 inches (from the airplane nose) and A = aft station 415.195 inches (from the airplane nose) and 1, 2, 3, and 4 are positions port-outboard, port-inboard, starboard-inboard, and starboard-outboard, respectively.

⁶Obtained from observed test data.

⁷Obtained from theoretical free stream equation solution.

⁸Observed first maximum pitch minus theoretical first maximum pitch.

⁹Bombs which exhibited bad flight.

TABLE 3

PHYSICAL DATA AND FIRST MAXIMUM PITCH OF 250 LB
MK 81 MOD 1 LOW DRAG BOMB FITTED WITH AN/M-103AL MECHANICAL NOSE FUZE

NWL Assigned Bomb Number	Date of Drop	Drop Number	Time of Drop	True Altitude (ft)	True Airspeed (kt)	Dynamic Pressure ¹ $\times 10^{-3}$ (lb/ft-sec ²)	Bomb Weight ² (lb)	Center of Gravity ³ (in.)	Moment Arm ⁴ (in.)	Rack Position ⁵	First Maximum Pitch Observed ⁶ (deg)	Theoretical ⁷ (deg)	Difference First Maximum Pitch ⁸ (deg)
71	14 Mar 1957	5	1425	7500	218	4.1	259	5.1	3.9	1F	53	48	5
72	21 Mar 1957	1	1534	3960	229	5.1	245	5.0	4.0	3A	43	45	-2
64	11 Mar 1957	5	1735	10320	257	5.3	252	5.0	4.0	3F	47	44	3
63	11 Mar 1957	4	1540	10210	261	5.4	248	5.0	4.2	1F	45	46	-1
61	11 Mar 1957	2	1512	10250	266	5.7	257	5.0	4.0	4F	40	43	-3
60	11 Mar 1957	1	1506	10320	269	5.8	247	5.0	4.0	3F	45	42	3
62	11 Mar 1957	3	1530	10230	269	5.8	249	5.1	3.9	2F	47	42	5
65	11 Mar 1957	6	1742	10270	272	5.9	252	5.0	4.0	4F	49	42	7

¹Dynamic Pressure = $Q = 1/2 \rho V^2$ where ρ = standard density at altitude and V = true airspeed.

²Individual bomb weights are listed although nominal weights of 250 pounds and 500 pounds were used for the Mk 81 and Mk 82 bombs, respectively, for calculation of the individual theoretical first maximum pitch.

³Distance aft of a point on the bomb axis directly under the center of the forward suspension lug.

⁴Distance from the center of gravity of the bomb to a point on the bomb axis directly under the forward edge of the Aero 7A rack bomb ejector foot.

⁵Bomb location in the bomb bay where F = forward station 319.825 inches (from the airplane nose) and A = aft station 415.195 inches (from the airplane nose) and 1, 2, 3, and 4 are positions port-outboard, port-inboard, starboard-inboard, and starboard-outboard, respectively.

⁶Obtained from observed test data.

⁷Obtained from theoretical free stream equation solution.

⁸Observed first maximum pitch minus theoretical first maximum pitch.

⁹Bombs which exhibited bad flight.

¹⁰Center of gravity position, and therefore, moment arm unknown. Average values of 5.0 inches and 4.0 inches, respectively, were used in the theoretical calculations.

TABLE 4

PHYSICAL DATA AND FIRST MAXIMUM PITCH OF 500 LB
MK 82 MOD 1 100 DRAG BOMB FITTED WITH NOSE FUZE PLUG

NWL Assigned Bomb Number	Date of Drop	Drop Number	Time Drop	True Altitude (ft)	True Airspeed (kt)	Dynamic Pressure ¹ ρV^2 (lb/ft-sec ²)	Bomb Weight ² (lb)	Center of Gravity ³ (in.)	Moment Arm ⁴ (in.)	Rack Position ⁵	First Maximum Pitch Observed ⁶ (deg)	Theoretical ⁷ (deg)	Difference First Maximum Pitch ⁸ (deg)
56	16 Jul 1957	4	1010	10430	264	5.5	500	3.6	5.4	2A	599	65	- 6
55	16 Jul 1957	3	1005	10400	266	5.6	501	4.1	4.9	2F	569	58	- 2
61	16 Jul 1957	11	1642	10300	274	6.0	497	4.3	4.7	3F	549	55	- 1
11	5 Sep 1956	1	1540	5170	320	9.6	- 11	4.510	4.7	- 11	43	41	- 2
54	16 Jul 1957	2	1000	10350	394	12.4	500	3.6	5.4	3A	439	44	- 1
65	16 Jul 1957	15	1725	10250	353	12.4	496	3.1	5.9	3F	41	47	- 6
57	16 Jul 1957	7	1400	10270	397	12.6	503	3.6	5.4	3F	43	44	- 1
64	16 Jul 1957	14	1711	10230	400	12.8	494	3.8	5.2	2A	42	42	0
12	5 Sep 1956	2	1542	4990	370	12.8	- 11	4.510	4.510	- 11	31	35	- 4
16	6 Sep 1956	2	1235	1950	370	14.1	- 11	4.510	4.510	- 11	35	33	2
13	5 Sep 1956	3	1553	5010	434	17.8	- 11	4.510	4.510	- 11	31	30	1
52	11 Jul 1957	2	1248	10290	510	20.7	503	3.9	5.1	3F	38	32	6
62	16 Jul 1957	12	1650	7120	512	21.0	510	4.1	4.9	3A	329	30	2
53	16 Jul 1957	1	0950	10150	529	22.4	499	4.5	4.5	3F	33	27	6
18	6 Sep 1956	4	1305	1720	466	22.4	- 11	4.510	4.510	- 11	38	27	11

¹Dynamic Pressure = $Q = 1/2 \rho V^2$ where ρ = standard density at altitude and V = true airspeed.

²Individual bomb weights are listed although nominal weights of 250 pounds and 500 pounds were used for the Mk 81 and Mk 82 bombs, respectively, for calculation of the individual theoretical first maximum pitch.

³Distance aft of a point on the bomb axis directly under the center of the forward suspension lug.

⁴Distance from the center of gravity of the bomb to a point on the bomb axis directly under the forward edge of the Aero 7A rack bomb ejector foot.

⁵Bomb location in the bomb bay where F = forward station 319.825 inches (from the airplane nose) and A = aft station 415.195 inches (from the airplane nose) and 1, 2, 3, and 4 are positions port-outboard, port-inboard, starboard-inboard, and starboard-outboard, respectively.

⁶Obtained from observed test data.

⁷Obtained from theoretical free stream equation solution.

⁸Observed first maximum pitch minus theoretical first maximum pitch.

⁹Bombs which exhibited bad flight.

¹⁰Center of gravity position, and therefore moment arm unknown. Average values of 4.5 inches for each were used in the theoretical calculations.

¹¹Insufficient data or unknown.

TABLE 5

PHYSICAL DATA AND FIRST MAXIMUM PITCH OF 500 LB
MK 82 MOD 1 LOW DRAG BOMB FITTED WITH AN/M-103A1 MECHANICAL NOSE FUZE

NWL Assigned Bomb Number	Date of Drop	Drop Number	Time Drop	True Altitude (ft)	True Airspeed (kt)	Dynamic Pressure ¹ $\times 10^{-3}$ (lb/ft-sec ²)	Bomb Weight ² (lb)	Center of Gravity ³ (in.)	Moment Arm ⁴ (in.)	Rack Position ⁵	First Maximum Pitch		Difference First Maximum Pitch ⁸ (deg)
											Observed ⁶ (deg)	Theoretical ⁷ (deg)	
48	14 Mar 1957	6	1650	7040	212	4.0	520	5.3	3.7	3F	58 ⁹	53	5
50	14 Mar 1957	8	1710	7080	218	4.2	527	4.9	4.1	2F	58	57	1
49	14 Mar 1957	7	1656	7090	218	4.2	514	4.6	4.4	4F	52	60	-8
51	14 Mar 1957	9	1722	7120	224	4.4	520	4.8	4.2	1F	58	57	1
42	13 Mar 1957	4	1120	10110	246	4.8	512	4.4	4.6	1F	62 ⁹	60	2
41	13 Mar 1957	3	1114	10140	248	5.0	512	5.6	3.4	2F	47	53	-6
40	13 Mar 1957	2	1106	10080	248	5.0	502	4.8	4.2	4F	53	54	-1
39	13 Mar 1957	1	1100	10110	253	5.1	498	4.6	4.4	3F	68 ⁹	55	13
15	6 Sep 1956	1	1228	1940	317	10.3	- 11	4.5	4.10	- 11	38	38	0
17	6 Sep 1956	3	1243	1380	415	18.0	- 11	4.5	4.10	- 11	27	29	-2
45	13 Mar 1957	6	1342	10260	481	18.4	517	5.5	3.5	4F	30 ⁹	23	7
44	13 Mar 1957	5	1335	10250	492	19.3	511	5.3	3.7	3F	32	25	7
47	13 Mar 1957	8	1403	10200	497	19.8	512	4.6	4.4	1F	31 ⁹	28	3

¹Dynamic Pressure = $Q = \frac{1}{2} \rho V^2$ where ρ = standard density at altitude and V = true airspeed.

²Individual bomb weights are listed although nominal weights of 250 pounds and 500 pounds were used for the Mk 81 and Mk 82 bombs, respectively, for calculation of the individual theoretical first maximum pitch.

³Distance aft of a point on the bomb axis directly under the center of the forward suspension lug.

⁴Distance from the center of gravity of the bomb to a point on the bomb axis directly under the forward edge of the Aero 7A rack bomb ejector foot.

⁵Bomb location in the bomb bay where F = forward station 319.825 inches (from the airplane nose) and A = aft station 415.195 inches (from the airplane nose) and 1, 2, 3, and 4 are positions port-inboard, port-inboard, starboard-inboard, and starboard-outboard, respectively.

⁶Obtained from observed test data.

⁷Obtained from theoretical free stream equation solution.

⁸Observed first maximum pitch minus theoretical first maximum pitch.

⁹Bombs which exhibited bad flight.

¹⁰Center of gravity position, and therefore moment arm unknown. Average values of 4.5 inches for each were used in the theoretical calculations.

¹¹Insufficient data or unknown.

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250-LB MK 81 MOD 1 LOW DRAG G. P. BOMB

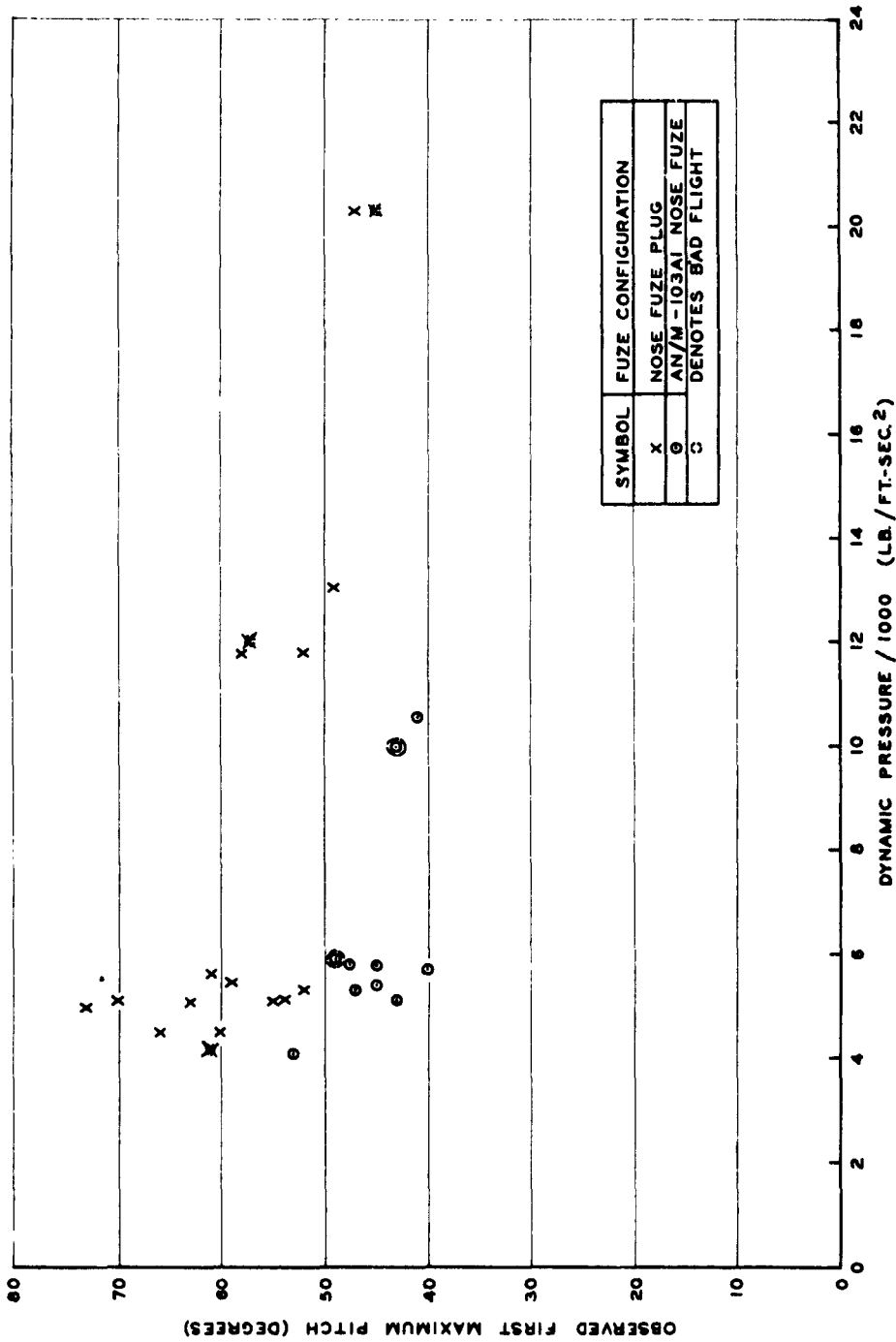


FIGURE 2

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500-LB MK 82 MOD 1 LOW DRAG G. P. BOMB

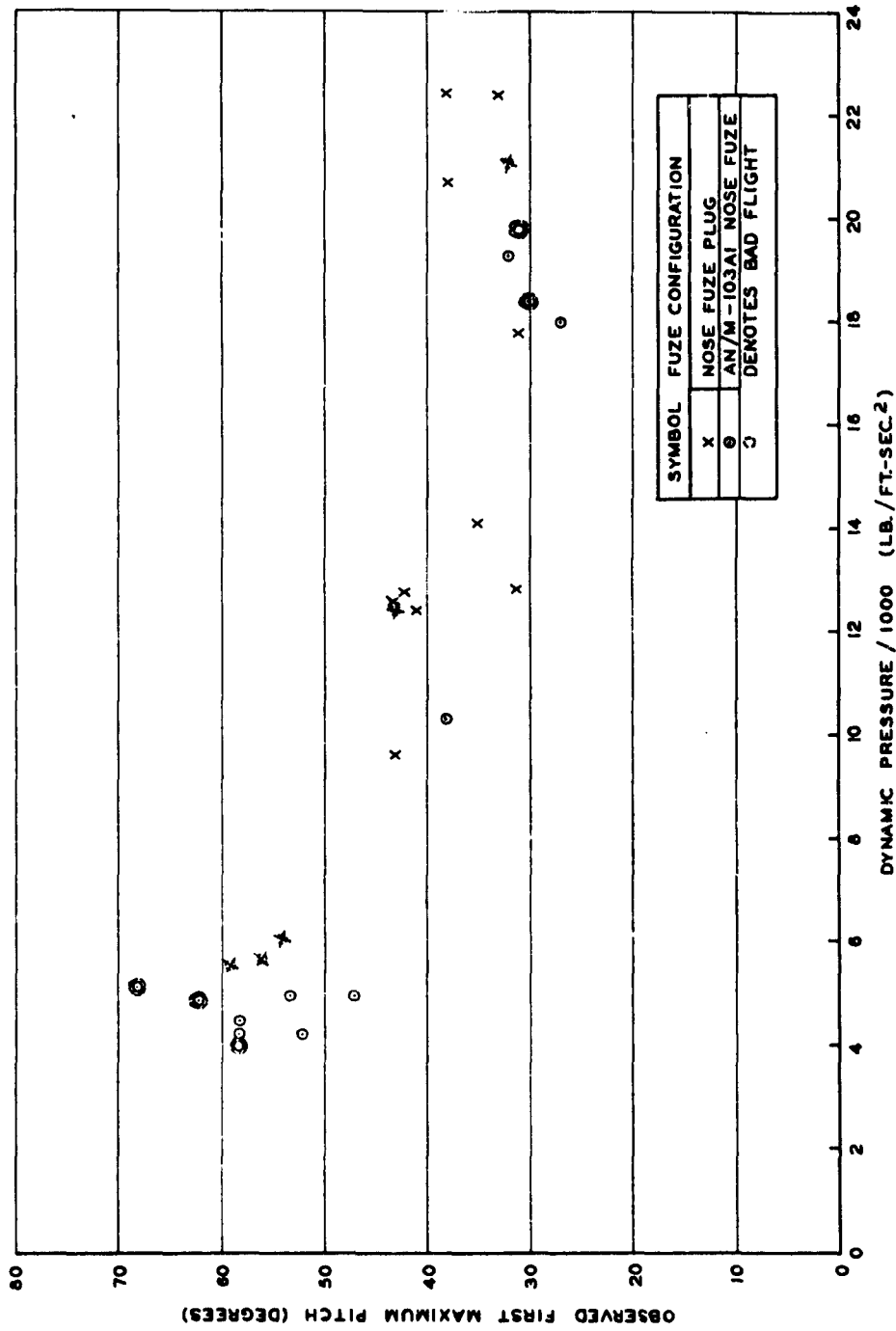


FIGURE 3

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250-LB MK 81 MOD 1 LOW DRAG G. P. BOMB

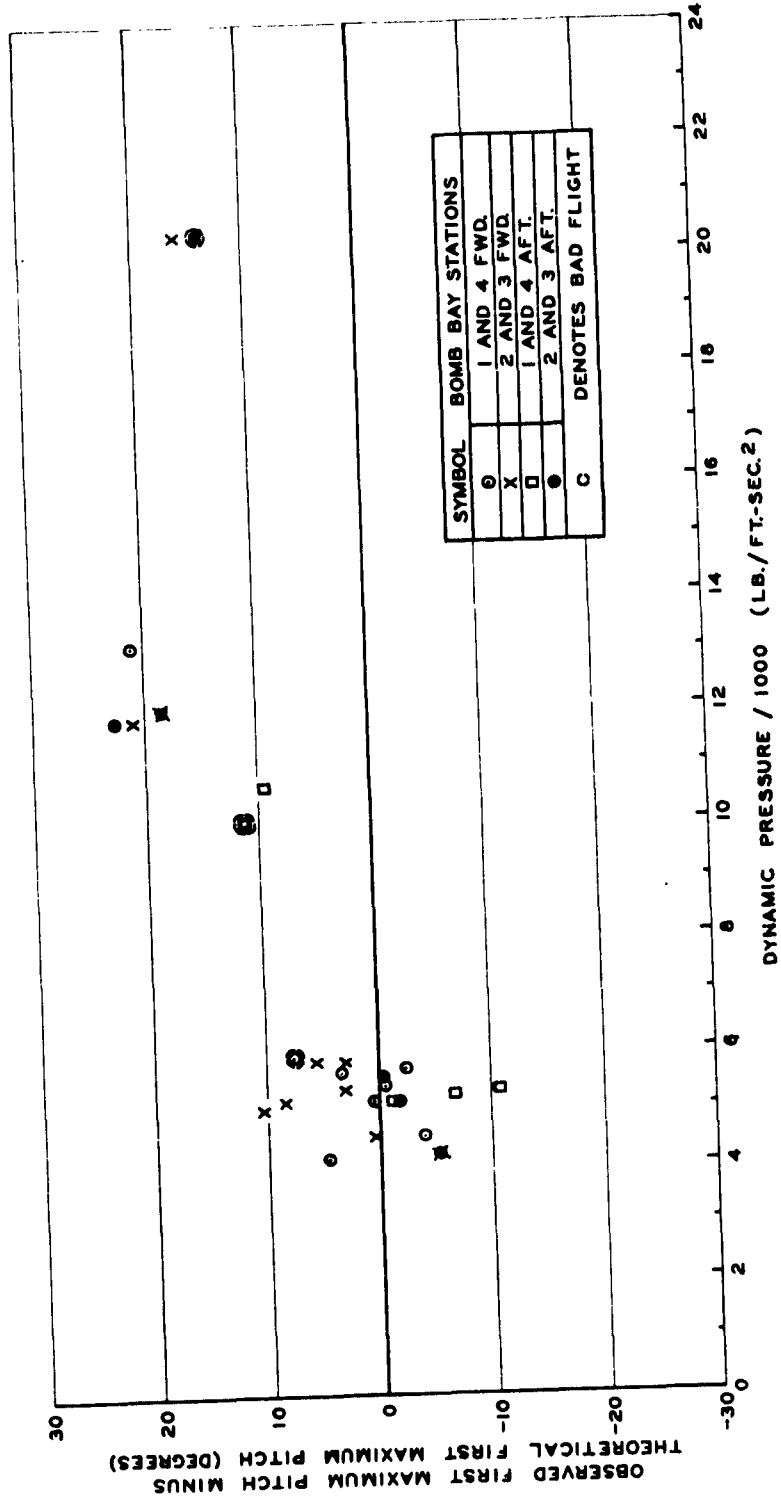


FIGURE 4

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500-LB MK 82 MOD 1 LOW DRAG G. P. BOMB

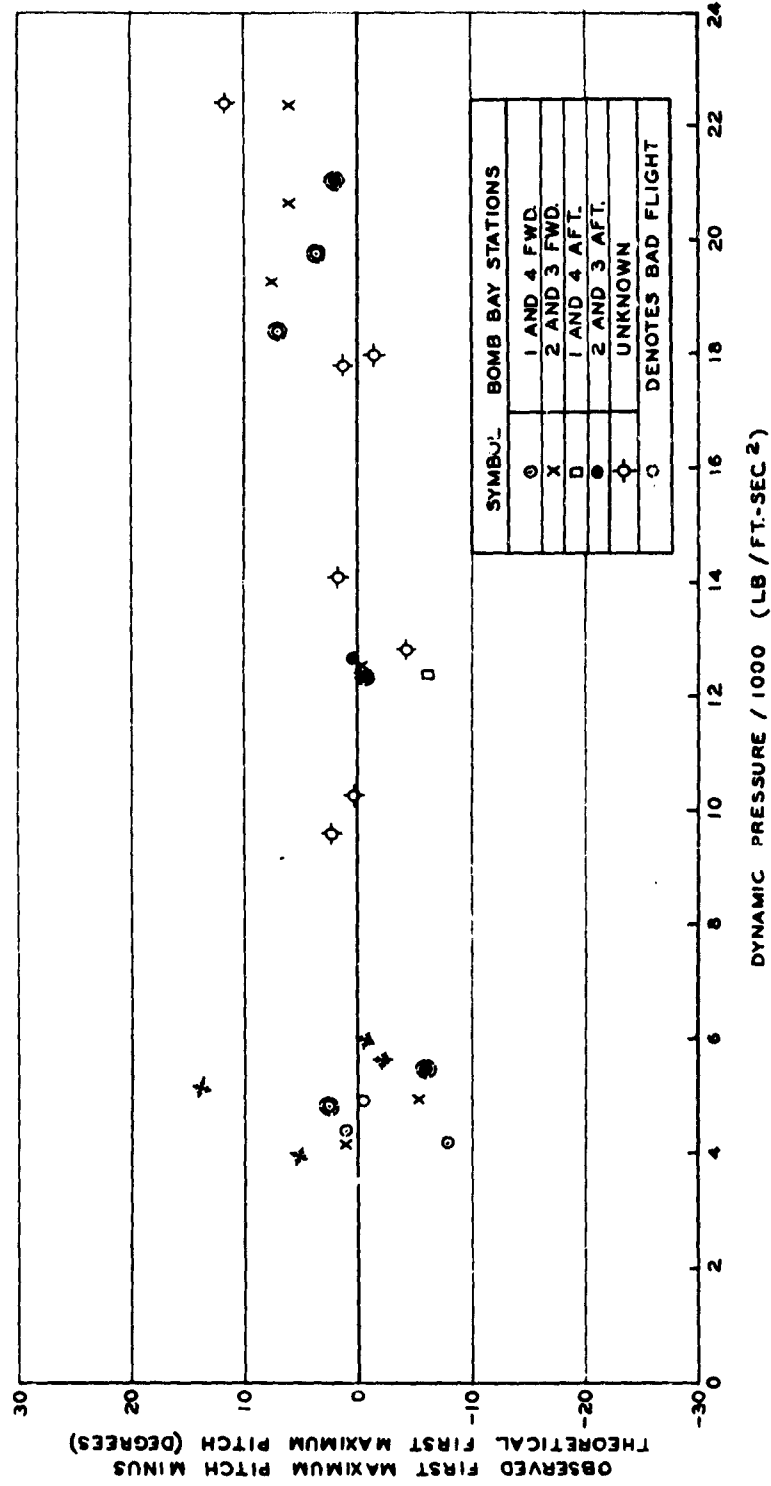


FIGURE 5

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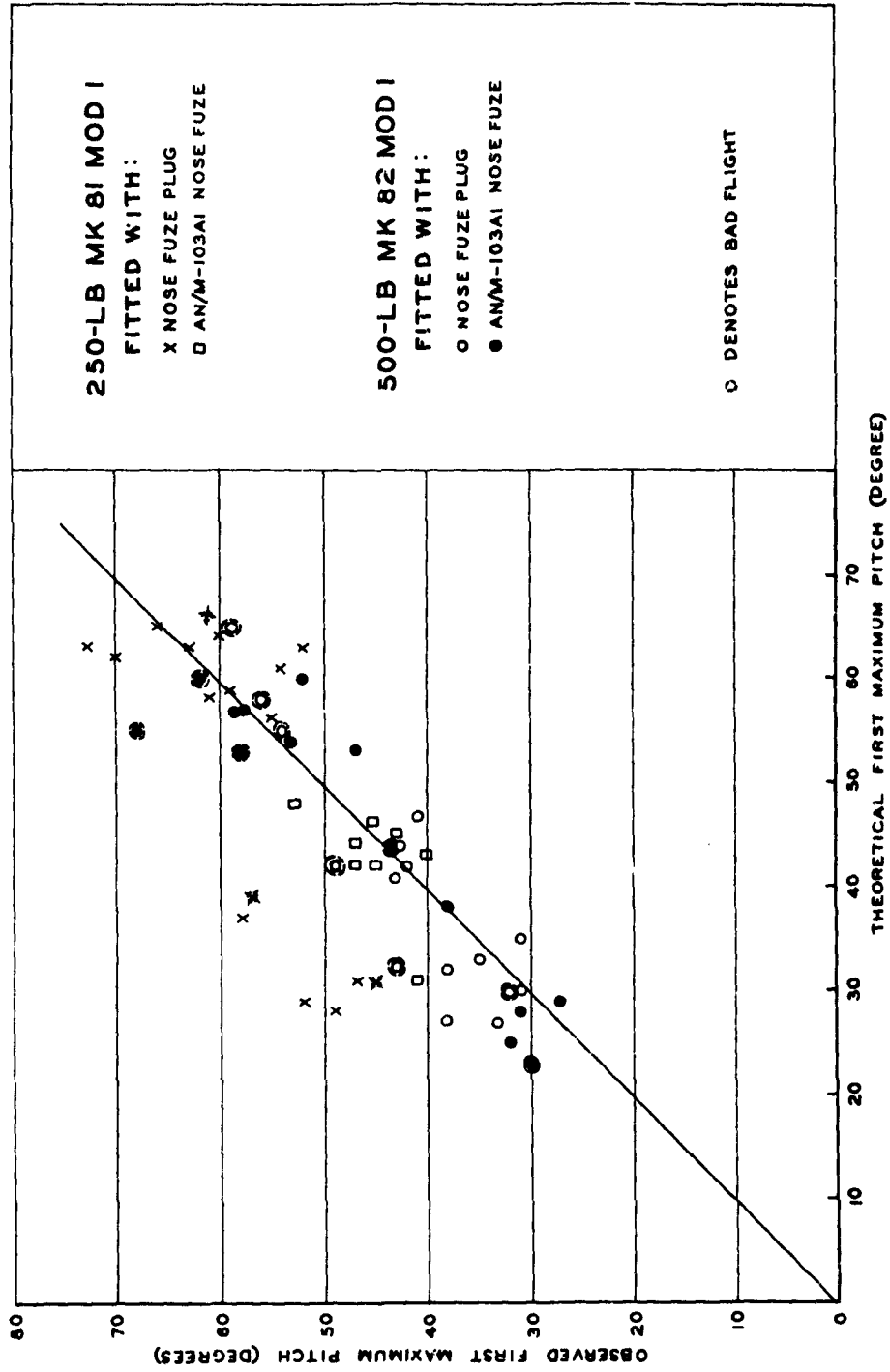


FIGURE 6

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APPENDIX B

DERIVATION OF THE EQUATION
USED TO CALCULATE FIRST MAXIMUM PITCH

The ejection force of the launcher is assumed to be constant through the ejection stroke and to have a value which would produce the ejection velocity measured in static tests (in the static tests the launcher was placed on its side and hence "gravity free" values of velocity were obtained). The aerodynamic restoring and damping moments were assumed to be a linear function of angle of attack. The bomb had no appreciable spin. The value of angle of attack at the end of the ejector stroke was calculated for the extreme test conditions, was found to be small (less than five degrees) and is neglected in the derivation.

The acceleration, a , due to the ejection force is approximated by the following equation:

$$a = E_j^2 / 2l,$$

where E_j = the vertical velocity, obtained at the end of the ejector stroke, which would be produced in a gravity free situation.

l = the length of the ejection stroke (0.533 feet).

For bombs ejected from aircraft flying horizontally, the vertical acceleration of the center of gravity, y , is

$$\ddot{y} = a + g = \frac{E_j^2}{2l} + g$$

The ejection time, t_{ej} , is given by

$$t_{ej} = \left(\frac{2y}{a} \right)^{1/2} = 2l / (E_j^2 + 2lg)^{1/2}$$

where l is the value of y at the end of the ejection stroke.

The angular acceleration of the bomb body, $\ddot{\alpha}_{ej}$ during ejection, is approximated by

$$I\ddot{\alpha}_{ej} = dma$$

$$\text{or } \ddot{\alpha}_{ej} = \frac{dm E_j^2 / 2\ell}{I}$$

where d = the moment arm, i.e., the distance from the bomb's center of gravity to a point on the bomb axis directly under the forward edge of the bomb ejector foot,

m = the mass of the bomb, and

I = the transverse moment of inertia measured through the bomb's center of gravity.

Then the angular velocity of the bomb at the end of the ejection stroke

$$\dot{\alpha}_{ej} = \frac{dmE_j^2}{I2\ell} \cdot t_{ej} = \frac{dmE_j^2}{I} \left(\frac{1}{(E_j^2 + 2\ell g)} \right)^{1/2}$$

The angle of attack of a bomb, assuming linear theory, is

$$\alpha = K_1 e^{(\lambda_1 + i\omega_1)t} + K_2 e^{(\lambda_2 + i\omega_2)t}$$

If spin can be neglected (since it is negligible during the first maximum pitch), the ω_1 is equal to $-\omega_2$, while λ_1 is equal to λ_2 . Making these substitutions, neglecting the value of angle of attack at the end of the ejector stroke, and evaluating the constants of integration K_1 and K_2 ,

$$\alpha = \frac{\dot{\alpha}_{ej}}{\omega} \sin \omega t e^{\lambda t}$$

where ω = the pitch rate (radians/sec) = $\frac{V}{2b} \left(\frac{-C_{m\alpha} \pi \rho_h b^5}{2 I} \right)^{1/2}$

and λ = the pitch damping factor = $\frac{VC_{mq} \pi \rho_h b^4}{32 I}$

where $C_{m\alpha}$ = the restoring moment coefficient,

C_{mq} = the damping moment coefficient,

V = the true airspeed,

b = the diameter of the bomb,

ρ_h = the density at altitude "h".

The magnitude of the pitch at the end of a quarter cycle, a_m , is given by

$$a_m = \frac{dmE_j^2}{I(E_j^2 + 2\ell g)^{1/2}} e^{-\frac{\pi\lambda}{2\omega}}$$

APPENDIX C

TABLE 6

PREDICTED FIRST MAXIMUM PITCH (DEGREES)250-lb Mk 81 Mod 1 Low Drag G. P. Bomb

	Upper Figure				Center Figure				Lower Figure							
	3.5 In. Moment Arm				4.5 In. Moment Arm				5.5 In. Moment Arm							
	True Airspeed (Knots)															
	100	150	200	220	240	260	280	300	325	350	375	400	450	500	550	600
1,000		57	43	39	35	33	30	28	26	24	23	21	19	17	16	14
			55	50	46	42	39	36	34	31	29	27	24	22	20	18
			67	61	56	51	48	45	41	38	35	33	30	27	24	22
10,000		66	50	45	41	38	35	33	30	28	26	25	22	20	18	17
			64	58	53	49	46	43	39	36	34	32	28	26	23	21
					65	60	56	52	48	45	42	39	35	31	28	26
20,000			59	54	49	46	43	40	37	34	32	30	26	24	22	20
				69	64	59	55	51	47	44	41	38	34	31	28	25
							67	63	57	53	50	47	41	37	34	31
30,000				65	60	55	51	48	44	41	38	36	32	29	26	24
							66	62	57	53	49	46	41	37	34	31
									69	64	60	56	50	45	41	38
40,000						69	64	60	55	51	48	45	40	36	33	30
										66	62	58	51	46	42	39
													63	57	51	47
50,000										66	62	58	51	46	42	39
													66	60	54	50
															66	61
60,000													66	60	54	50
															69	64

ALTITUDE ABOVE SEA LEVEL (FEET)

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TABLE 7
PREDICTED FIRST MAXIMUM PITCH (DEGREES)

500-lb Mk 82 Mod 1 Low Drag G. P. Bomb

Altitude Above Sea Level (Feet)	Upper Figure 3.5 In. Moment Arm		Center Figure 4.5 In. Moment Arm										Lower Figure 5.5 In. Moment Arm			
			True Airspeed (Knots)													
	100	150	200	220	240	260	280	300	325	350	375	400	450	500	550	600
1,000		63	48	43	40	37	34	32	29	27	25	24	21	19	17	16
			61	56	51	47	44	41	38	35	33	31	27	24	22	20
				68	62	57	53	50	46	43	40	37	33	30	27	25
10,000			55	50	46	43	40	37	34	32	30	28	25	22	20	18
				65	59	55	51	47	44	41	38	36	32	28	26	24
						67	62	58	54	50	46	43	39	35	32	29
20,000			66	60	55	51	47	44	41	38	35	33	29	27	24	22
						65	61	57	52	49	46	43	38	34	31	28
								69	64	59	55	52	46	42	38	35
30,000					67	62	57	53	49	46	43	40	36	32	29	27
								69	63	59	55	52	46	41	38	34
											67	63	56	50	46	42
40,000								67	62	57	53	50	45	40	36	33
											69	64	57	52	47	43
													70	63	57	52
50,000											69	65	57	52	47	43
													66	66	60	55
60,000														66	60	55

ALTITUDE ABOVE SEA LEVEL (FEET)

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TABLE 8

PREDICTED FIRST MAXIMUM PITCH (DEGREES)1000-lb Mk 83 Mod 2 Low Drag G. P. Bomb

Altitude Above Sea Level (Feet)	Upper Figure		Center Figure												Lower Figure		
	3.0 In. Moment Arm		5.0 In. Moment Arm												7.0 In. Moment Arm		
	True Airspeed (Knots)																
	100	150	200	220	240	260	280	300	325	350	375	400	450	500	550	600	
1,000	50	33	25	23	21	19	18	17	15	14	13	12	11	10	9	8	
		55	41	38	35	32	30	28	26	24	22	21	19	17	15	14	
			58	53	48	44	41	39	35	32	30	29	26	23	21	19	
10,000	58	38	29	27	25	23	21	19	18	17	16	15	13	12	11	10	
		64	48	43	40	37	34	32	29	27	25	24	21	19	18	16	
			68	62	57	53	49	45	42	39	36	34	31	27	25	23	
20,000	69	46	35	32	29	27	25	23	22	20	19	17	16	14	13	12	
			58	53	49	45	42	39	36	33	31	29	26	23	21	19	
					69	63	58	54	50	46	43	41	35	32	29	27	
30,000		55	42	39	36	33	30	28	26	24	22	21	19	17	15	14	
			70	64	58	54	50	47	43	40	38	35	31	28	25	23	
							66	66	61	57	53	49	44	39	36	33	
40,000		66	53	48	44	41	38	35	33	30	28	26	23	21	19	18	
						67	62	59	54	50	47	44	39	35	32	29	
										70	65	62	55	49	45	41	
50,000			68	62	57	52	49	46	42	39	36	34	30	27	25	23	
									70	65	60	57	51	46	42	38	
														64	59	53	
60,000						67	63	59	54	50	47	44	39	35	32	29	
														65	59	54	
																68	

ALTITUDE ABOVE SEA LEVEL (FEET)

TABLE 9

PREDICTED FIRST MAXIMUM PITCH (DEGREES)2000-1b Mk 84 Mod 1 Low Drag G. P. Bomb

Altitude Above Sea Level (Feet)	Upper Figure			Center Figure											Lower Figure						
	4.5 In. Moment Arm			5.5 In. Moment Arm											6.5 In. Moment Arm						
	True Airspeed (Knots)																				
	100	150	200	220	240	260	280	300	325	350	375	400	450	500	550	600					
1,000	38	25	19	17	16	15	14	13	12	11	10	10	8	8	7	6					
	45	31	23	21	20	18	17	15	14	13	12	12	10	9	8	8					
	55	37	27	25	23	21	20	18	17	16	15	14	12	11	10	10					
10,000	44	29	22	20	19	17	16	15	14	13	12	11	10	9	8	7					
	54	36	27	25	23	21	19	18	17	16	14	13	12	11	10	9					
	64	43	32	29	27	25	23	21	20	18	17	16	14	13	12	11					
20,000	53	36	27	24	22	20	19	18	16	15	14	13	12	11	10	9					
	65	43	33	30	27	25	23	22	20	19	17	16	14	13	12	11					
		51	38	35	32	30	27	26	24	22	21	19	17	15	14	13					
30,000	65	43	32	29	27	25	23	22	20	18	17	16	14	13	12	11					
		53	40	36	33	30	28	26	24	23	21	20	18	16	14	13					
		62	47	42	39	36	33	31	29	27	25	23	21	19	17	16					
40,000		54	41	37	34	31	29	27	25	23	22	20	18	16	15	14					
		66	50	45	41	38	35	33	31	28	26	25	22	20	18	17					
			59	53	49	45	42	39	36	33	31	29	26	23	21	20					
50,000		70	52	48	44	40	37	35	32	30	28	26	23	21	19	17					
			64	58	53	49	46	43	39	37	34	32	28	26	23	21					
				69	63	58	54	50	47	43	40	38	34	30	27	25					
60,000			67	61	56	52	48	45	42	39	36	34	30	27	25	22					
					68	63	59	55	51	47	44	41	37	33	30	27					
							70	65	60	56	52	49	43	39	35	32					

ALTITUDE ABOVE SEA LEVEL (FEET)

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TABLE 10
PREDICTED FIRST MAXIMUM PITCH (DEGREES)
141-lb Mk 86 Low Drag Practice Bomb (Water Filled)

	Upper Figure			True Airspeed (Knots)											Lower Figure		
	0.5 In. Moment Arm			Center Figure											2.5 In. Moment Arm		
	100	150	200	220	240	260	280	300	325	350	375	400	450	500	550	600	
1,000	12	8	6	6	5	5	4	4	4	3	3	3	3	2	2	2	2
	36	24	18	16	15	14	13	12	11	10	10	9	8	7	7	6	6
	60	40	30	27	25	23	21	20	18	17	16	15	14	12	11	10	10
10,000	15	10	8	7	6	6	5	5	5	4	4	4	4	3	3	3	3
	45	30	23	20	19	17	16	15	14	13	12	11	10	9	8	7	7
		50	38	33	31	28	26	25	23	22	20	19	17	15	14	13	13
20,000	18	12	9	8	8	7	6	6	6	5	5	5	4	4	3	3	3
	54	36	27	24	22	20	19	18	16	15	14	13	12	11	10	9	9
		60	45	41	38	35	32	30	28	26	24	22	20	18	16	15	15
30,000	22	14	11	10	9	8	8	7	6	6	6	5	5	4	4	4	4
	65	43	33	30	27	25	23	22	20	19	17	16	14	13	12	11	11
			54	49	45	42	39	36	33	31	29	27	24	22	20	18	18
40,000	27	18	14	12	11	10	10	9	8	8	7	7	6	5	4	4	4
			41	37	34	31	29	27	25	23	21	20	18	16	15	14	14
			68	62	57	52	48	45	42	39	36	34	31	27	25	23	23
50,000	35	23	18	16	15	13	12	12	11	10	9	9	8	7	6	6	6
		70	52	48	44	40	37	35	32	30	28	26	23	21	19	18	18
						67	62	58	54	50	47	44	39	35	32	29	29
60,000	45	30	22	20	19	17	16	15	14	13	12	11	10	9	8	7	7
			67	61	56	52	48	45	41	38	36	34	30	27	24	22	22
									69	64	60	56	50	45	41	37	37

ALTITUDE ABOVE SEA LEVEL (FEET)

TABLE 11
PREDICTED FIRST MAXIMUM PITCH (DEGREES)
217-1b Mk 86 Low Drag Practice Bomb (Wet Sand Filled)

Upper Figure 0.5 In. Moment Arm	Center Figure 1.5 In. Moment Arm										Lower Figure 2.5 In. Moment Arm					
	100	150	200	220	240	260	280	300	325	350	375	400	450	500	550	600
1,000	14	9	7	6	6	5	5	5	4	4	4	4	3	3	3	3
	42	28	21	19	18	16	15	14	13	12	11	11	9	8	8	7
	70	47	35	32	29	27	25	23	22	20	19	18	16	14	13	12
10,000	16	11	8	8	7	6	6	5	5	5	4	4	4	3	3	3
	49	33	25	22	21	19	18	16	15	14	13	12	11	10	9	8
		55	41	37	34	32	29	27	25	23	22	21	18	16	15	14
20,000	20	13	10	9	8	8	7	7	6	6	5	5	4	4	4	3
	59	40	30	27	25	23	21	20	18	17	16	15	13	12	11	10
		66	49	45	41	38	35	33	30	28	26	25	22	20	18	16
30,000	24	16	12	11	10	9	9	8	7	7	6	6	5	5	4	4
		48	36	33	30	28	26	24	22	21	19	18	16	14	13	12
			60	55	50	46	43	40	37	34	32	30	27	24	22	20
40,000	30	21	15	14	13	12	11	10	9	9	8	8	7	6	5	5
		60	45	41	38	35	32	30	28	26	24	23	20	18	16	15
				69	63	58	54	50	46	43	40	38	34	30	27	25
50,000	39	26	20	18	16	15	14	13	12	11	10	10	9	8	7	7
			59	53	49	45	42	39	36	33	31	29	26	23	21	20
							70	65	60	56	52	49	43	39	36	33
60,000	50	33	25	23	21	19	18	17	15	14	13	13	11	10	9	8
				69	63	58	54	50	47	43	40	38	34	30	28	25
											67	63	56	50	46	42

TABLE 12 PREDICTED FIRST MAXIMUM PITCH (DEGREES)221-lb Mk 87 Low Drag Practice Bomb (Water Filled)

Altitude Above Sea Level (Feet)	Upper Figure			Center Figure											Lower Figure		
	0.5 In. Moment Arm			1.5 In. Moment Arm											2.5 In. Moment Arm		
	True Airspeed (Knots)																
	100	150	200	220	240	260	280	300	325	350	375	400	450	500	550	600	
1,000	9	6	5	4	4	3	3	3	3	3	2	2	2	2	2	2	2
	27	18	13	12	11	10	10	9	8	8	7	7	6	5	5	4	4
	45	30	22	20	19	17	16	15	14	13	12	11	10	9	8	7	7
10,000	11	7	5	5	4	4	4	4	3	3	3	3	2	2	2	2	2
	32	21	16	14	13	12	11	11	10	9	8	8	7	6	6	5	5
	53	35	26	24	22	20	19	18	16	15	14	13	12	11	10	9	9
20,000	13	9	6	6	5	5	5	4	4	4	3	3	3	3	3	2	2
	38	26	19	17	16	15	14	13	12	11	10	10	9	8	7	6	6
	64	43	32	29	27	25	23	21	20	18	17	16	14	13	12	11	11
30,000	16	10	8	7	7	6	6	5	5	4	4	4	3	3	3	3	3
	47	31	23	21	20	18	17	16	14	13	13	12	10	9	9	8	8
		52	39	36	33	30	28	26	24	22	21	20	17	16	14	13	13
40,000	20	13	10	9	8	8	7	7	6	6	5	5	4	4	4	3	3
	59	40	30	27	25	23	21	20	18	17	16	15	13	12	11	10	10
		66	49	45	41	38	35	33	30	28	26	25	22	20	18	17	17
50,000	26	17	13	12	11	10	9	9	8	7	7	6	6	5	5	4	4
		51	39	35	28	26	25	24	24	22	21	19	17	15	14	13	13
			64	58	54	49	46	43	40	37	34	32	29	26	23	21	21
60,000	33	22	17	15	14	13	12	11	10	10	9	8	7	7	6	6	6
		67	50	45	42	38	36	33	31	29	27	25	22	20	18	17	17
					69	64	60	56	51	48	44	42	37	33	30	28	28

ALTITUDE ABOVE SEA LEVEL (FEET)

TABLE 13

PREDICTED FIRST MAXIMUM PITCH (DEGREES)

333-lb Mk 87 Low Drag Practice Bomb (Wet Sand Filled)

Altitude Above Sea Level (Feet)	Upper Figure 2.0 In. Moment Arm		True Airspeed (Knots)												Center Figure 3.0 In. Moment Arm		Lower Figure 4.0 In. Moment Arm			
	100	150	200	220	240	260	280	300	325	350	375	400	450	500	550	600				
1,000	39 58	26 39 52	19 29 39	18 27 35	16 24 32	15 22 30	14 21 28	13 19 26	12 18 24	11 17 22	10 16 21	10 15 19	9 13 17	8 12 15	7 11 14	6 10 13				
10,000	46 68	30 45 61	23 34 45	21 31 42	19 28 38	18 26 35	16 25 33	15 23 30	14 21 28	13 19 26	12 18 24	11 17 23	10 15 20	9 14 18	8 13 17	8 11 15				
20,000	55	37 55	27 41 55	25 38 50	22 34 46	21 32 42	20 30 39	18 27 37	17 25 34	16 24 31	15 22 29	14 21 27	12 19 25	11 16 22	10 15 20	9 14 18				
30,000	63	45 67	33 50 67	31 46 61	28 42 56	26 39 51	24 36 48	22 33 45	21 31 41	19 29 38	18 27 36	17 25 33	15 23 30	13 20 27	12 18 25	11 17 22				
40,000		56	42 63	39 58	35 53 70	33 49 65	30 45 60	28 42 56	26 39 52	24 36 48	23 34 45	21 32 42	19 28 38	17 25 34	16 23 31	14 21 28				
50,000			55	50	46 68	42 63	39 59	37 55	34 51 68	31 47 62	29 44 58	27 41 55	25 37 49	22 33 44	20 30 40	18 27 36				
60,000				65	59	54	51	47	44 66	40 61	38 57	35 53	32 48 64	28 42 56	26 39 51	24 35 47				

ALTITUDE ABOVE SEA LEVEL (FEET)

TABLE 14

PREDICTED FIRST MAXIMUM PITCH (DEGREES)458-lb Mk 88 Low Drag Practice Bomb (Water Filled)

Altitude Above Sea Level (Feet)	Upper Figure			Center Figure			Lower Figure									
	0.5 In. Moment Arm			1.5 In. Moment Arm			2.5 In. Moment Arm									
	True Airspeed (Knots)															
	100	150	200	220	240	260	280	300	325	350	375	400	450	500	550	600
1,000	5	3	3	2	2	2	2	2	2	1	1	1	1	1	1	1
	15	10	8	7	6	6	5	5	5	4	4	4	3	3	3	3
	25	17	12	11	10	10	9	8	8	7	7	6	6	5	5	4
10,000	6	4	3	3	2	2	2	2	2	2	2	2	1	1	1	1
	18	12	9	8	7	7	6	6	5	5	5	4	4	4	3	3
	29	20	15	13	12	11	10	10	9	8	8	7	7	6	5	5
20,000	7	5	4	3	3	3	3	2	2	2	2	2	2	1	1	1
	22	14	11	10	9	8	8	7	7	6	6	5	5	4	4	4
	36	24	18	16	15	14	13	12	11	10	10	9	8	7	7	6
30,000	9	6	4	4	4	3	3	3	3	3	2	2	2	2	2	2
	26	18	13	12	11	10	9	9	8	8	7	7	6	5	5	4
	44	29	22	20	18	17	16	15	14	13	12	11	10	9	8	7
40,000	11	7	6	5	5	4	4	4	3	3	3	3	2	2	2	2
	33	22	17	15	14	13	12	11	10	10	9	8	7	7	6	6
	56	37	28	25	23	21	20	19	17	16	15	14	12	11	10	9
50,000	15	10	7	7	6	6	5	5	4	4	4	4	3	3	3	3
	44	29	22	20	18	17	16	15	13	12	12	11	10	9	8	7
		48	36	33	30	28	26	24	22	21	19	18	16	15	13	12
60,000	19	13	9	9	8	7	7	6	6	5	5	5	4	4	3	3
	57	38	27	26	24	22	20	19	17	16	15	14	13	11	10	9
		63	47	43	39	36	34	32	29	27	25	24	21	19	17	16

ALTITUDE ABOVE SEA LEVEL (FEET)

TABLE 15

PREDICTED FIRST MAXIMUM PITCH (DEGREES)783-lb Mk 88 Low Drag Practice Bomb (Wet Sand Filled)

Altitude Above Sea Level (Feet)	Upper Figure		Center Figure										Lower Figure				
	0.5 In. Moment Arm		1.5 In. Moment Arm										2.5 In. Moment Arm				
			True Airspeed (Knots)														
	100	150	200	220	240	260	280	300	325	350	375	400	450	500	550	600	
1,000	9	6	5	4	4	3	3	3	3	3	2	2	2	2	2	2	
	27	18	14	12	11	10	10	9	8	8	7	7	6	5	5	5	
	45	30	23	21	19	17	16	15	14	13	12	11	10	9	8	8	
10,000	11	7	5	5	4	4	4	4	3	3	3	3	2	2	2	2	
	32	21	16	15	13	12	11	11	10	9	9	8	7	6	6	5	
	53	35	27	24	22	20	19	18	16	15	14	13	12	11	10	9	
20,000	13	9	6	6	5	5	5	4	4	4	3	3	3	3	2	2	
	39	26	19	18	16	15	14	13	12	11	10	10	9	8	7	6	
	64	43	32	29	27	25	23	21	20	18	17	16	14	13	12	11	
30,000	16	10	8	7	7	6	6	5	5	4	4	4	4	3	3	3	
	47	31	24	22	20	18	17	16	15	13	13	12	11	9	9	8	
		52	39	36	33	30	28	26	24	22	21	20	18	16	14	13	
40,000	20	13	10	9	8	8	7	7	6	6	5	5	4	4	4	3	
	59	40	30	27	25	23	21	20	18	17	16	15	13	12	11	10	
		66	49	45	41	38	36	33	31	28	26	25	22	20	18	16	
50,000	26	17	13	12	11	10	9	9	8	7	7	6	6	5	5	4	
		51	38	35	32	20	28	26	24	22	21	19	17	15	14	13	
			64	59	53	49	46	43	40	37	34	32	29	26	23	21	
60,000	33	22	17	15	14	13	12	11	10	9	9	8	7	7	6	6	
		66	50	45	41	38	36	33	31	28	27	25	22	20	18	17	
					69	64	59	55	51	47	44	41	37	33	30	28	

ALTITUDE ABOVE SEA LEVEL (FEET)

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250-LB MK 81 MOD 1 LOW DRAG G.P. BOMB

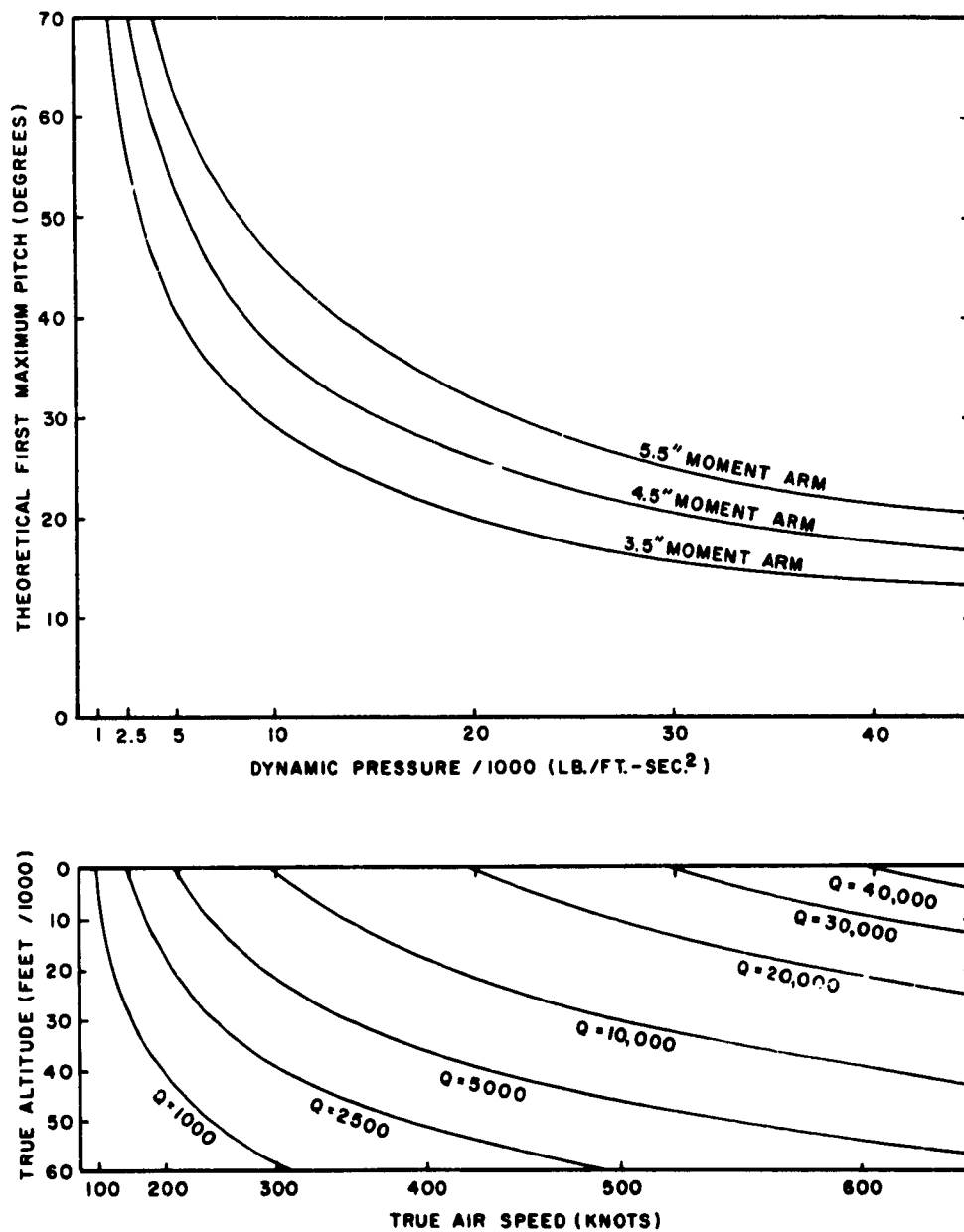


FIGURE 7

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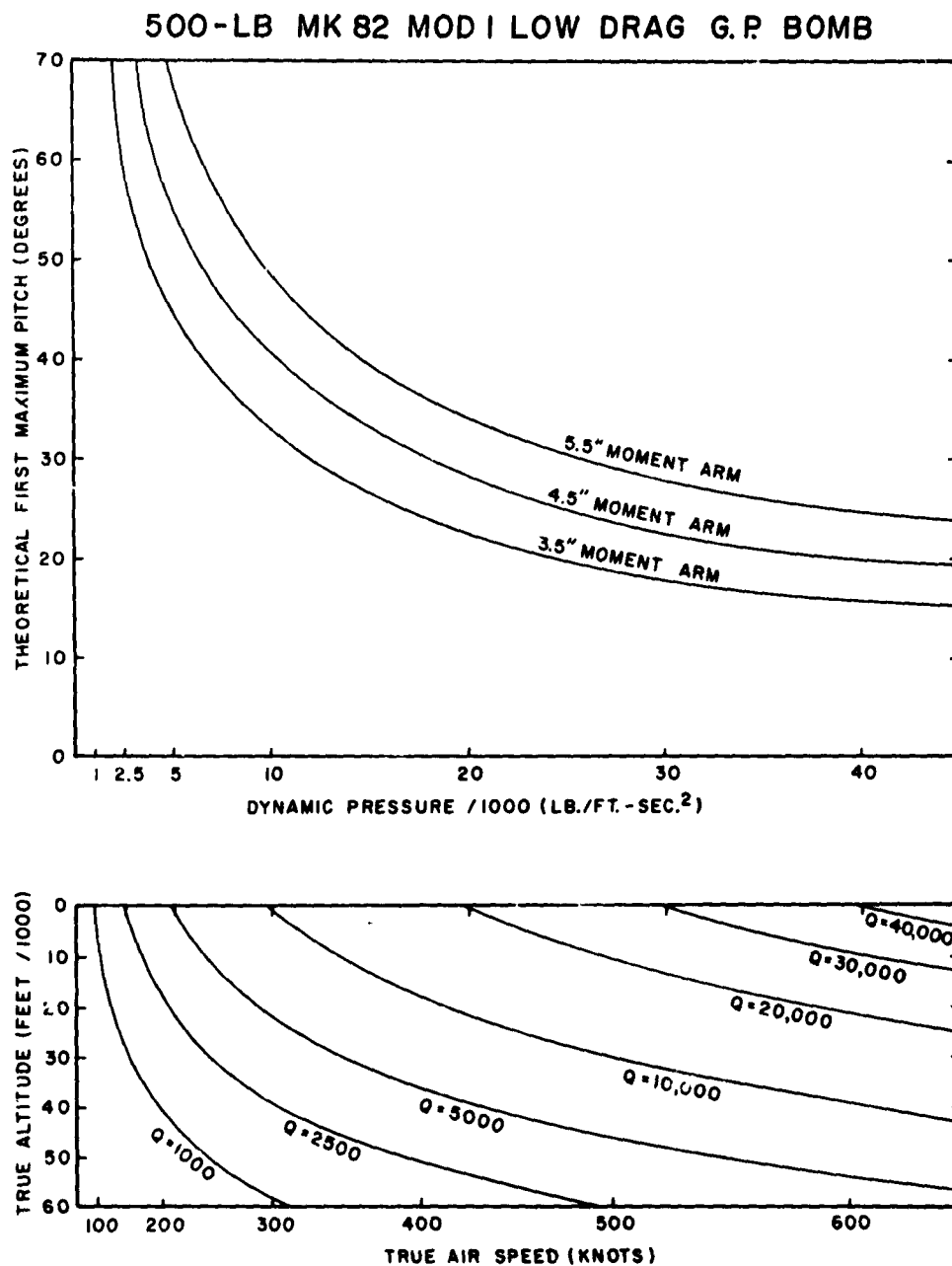


FIGURE 8

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1000-LB MK 83 MOD 2 LOW DRAG G.P. BOMB

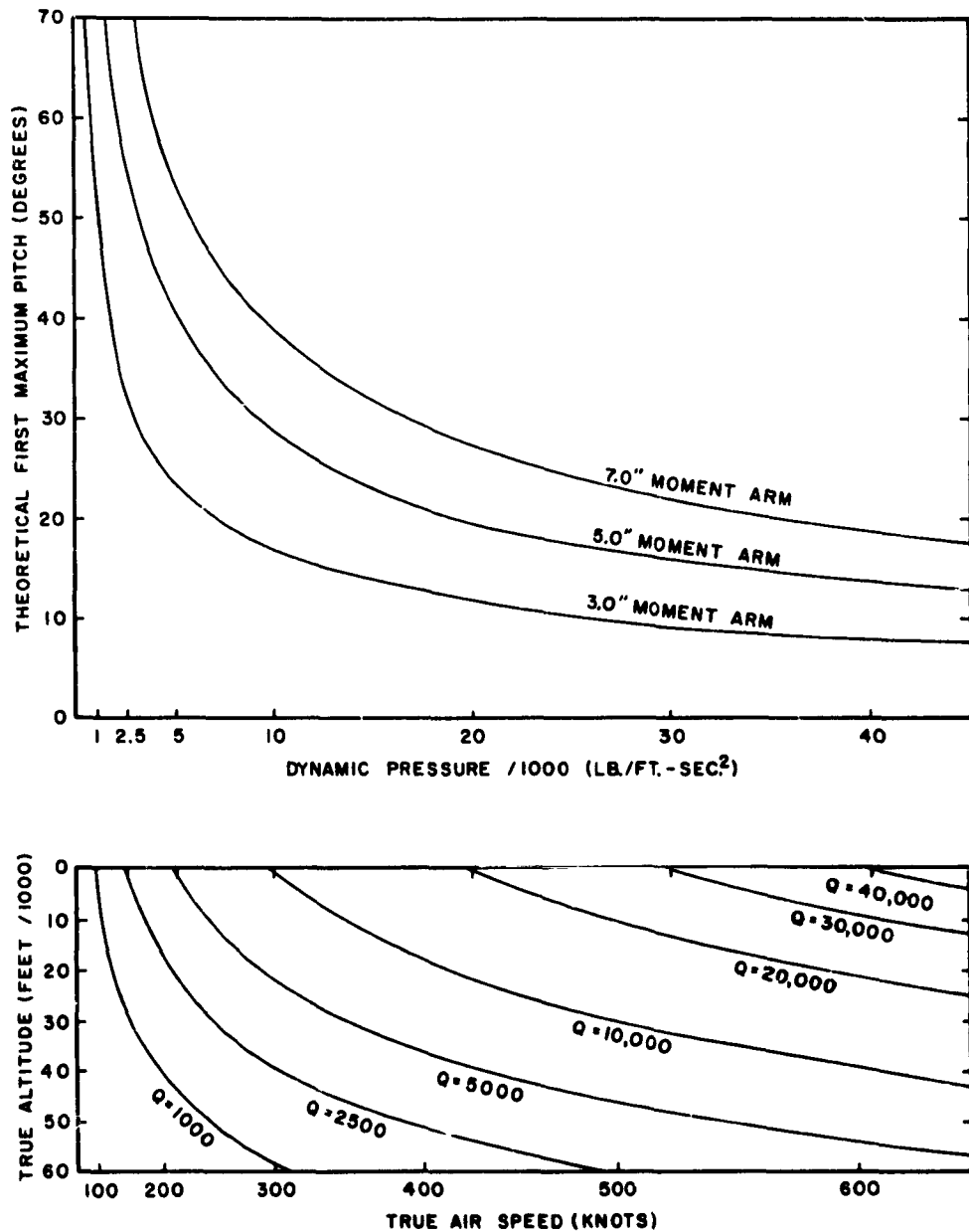


FIGURE 9

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2000-LB MK 84 MOD I LOW DRAG G.P. BOMB

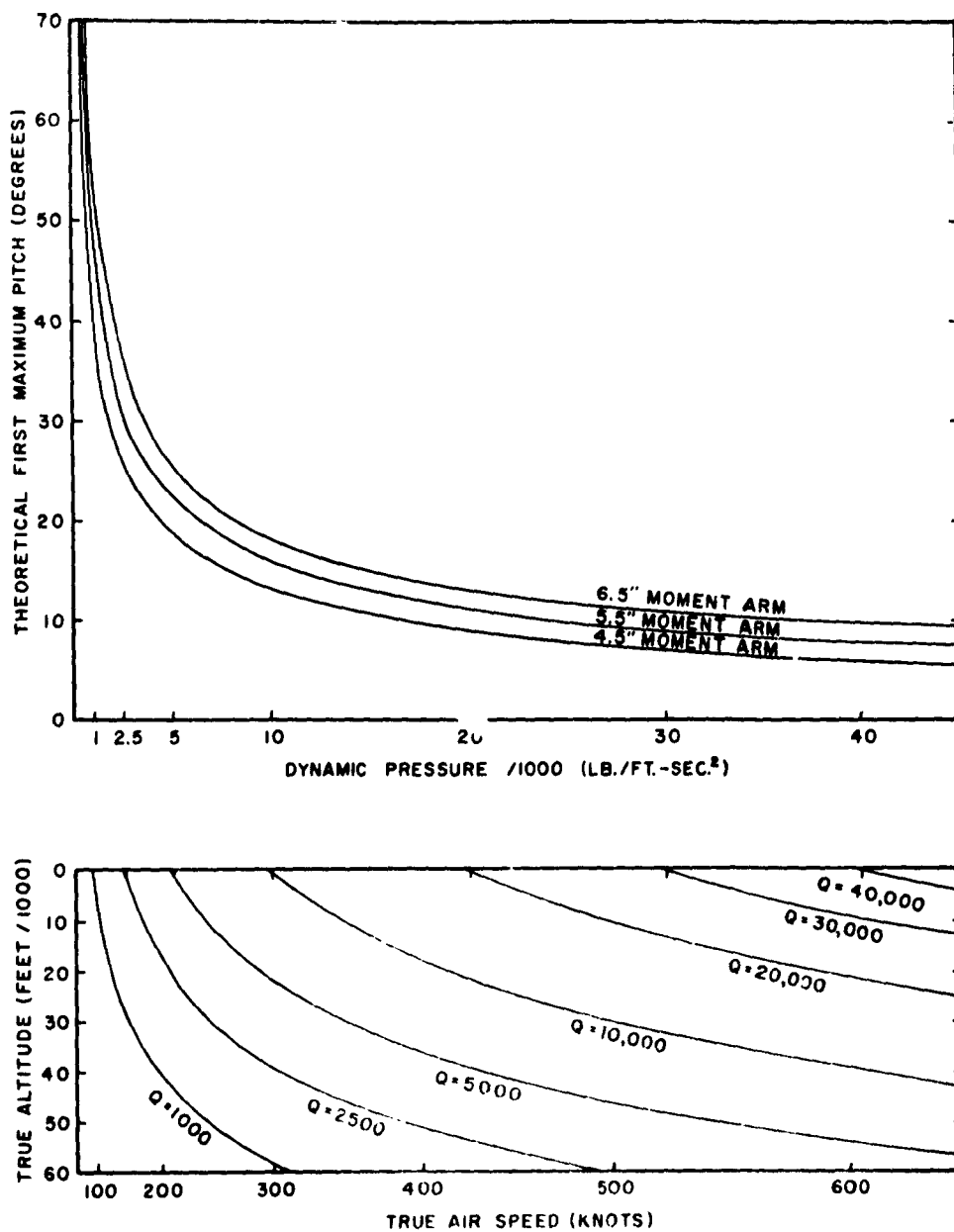


FIGURE 10

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141-LB MK 86 LOW DRAG PRACTICE BOMB (WATER FILLED)

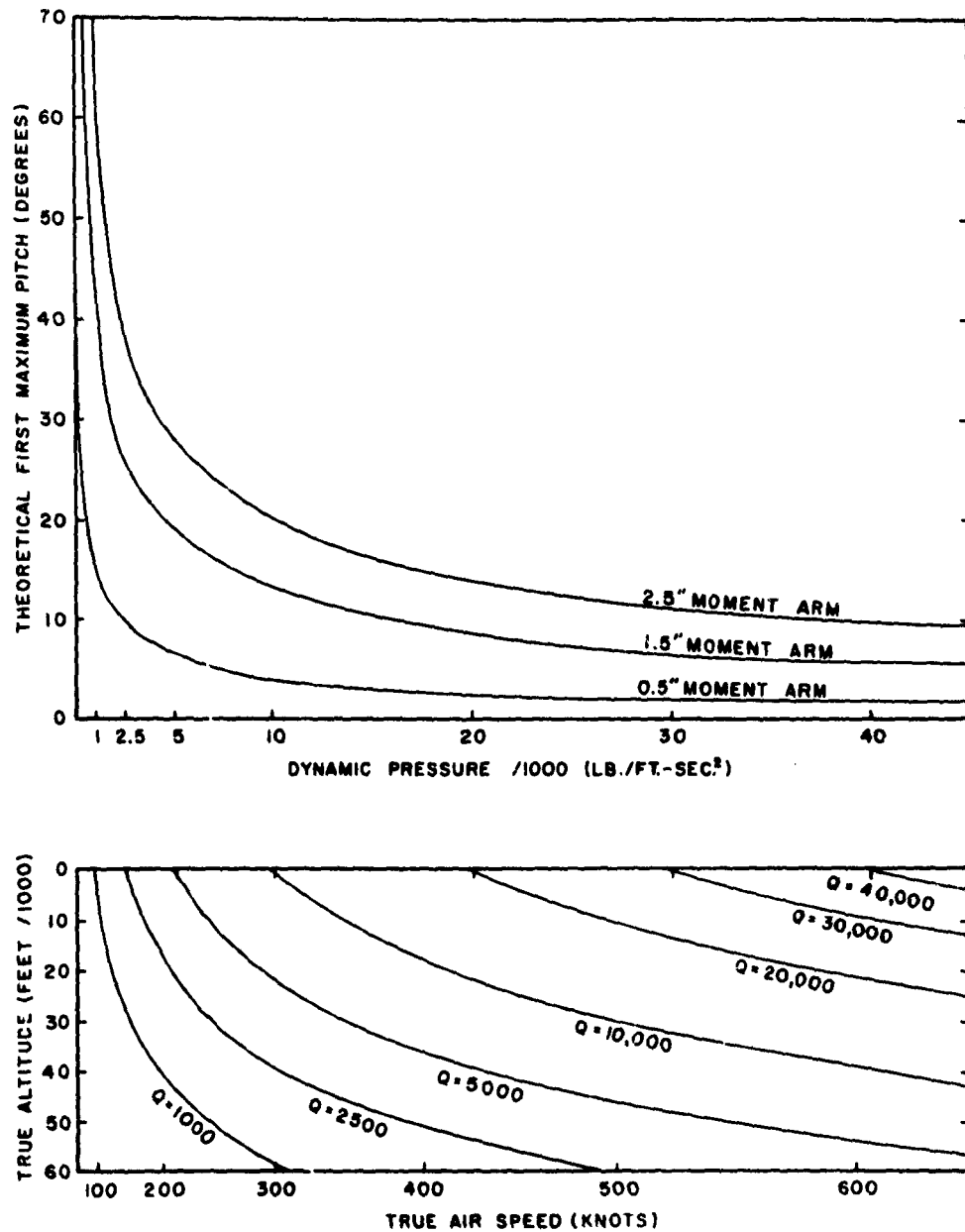


FIGURE 11

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217-LB MK 86 LOW DRAG PRACTICE BOMB (WET SAND FILLED)

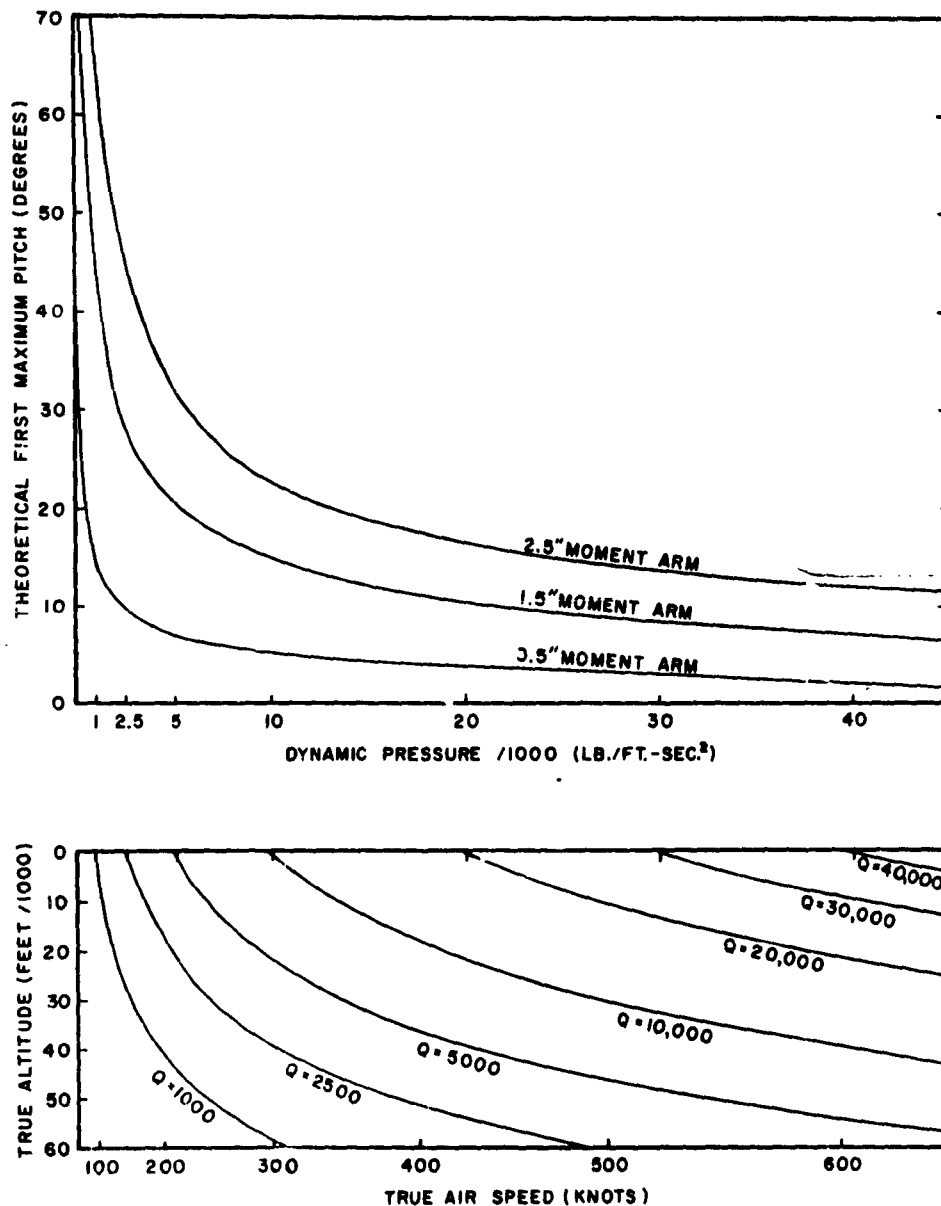


FIGURE 12

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221-LB MK 87 LOW DRAG PRACTICE BOMB (WATER FILLED)

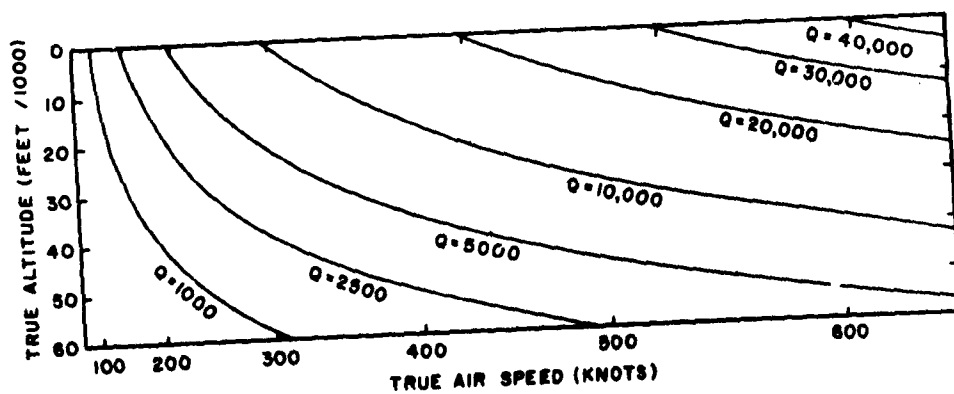
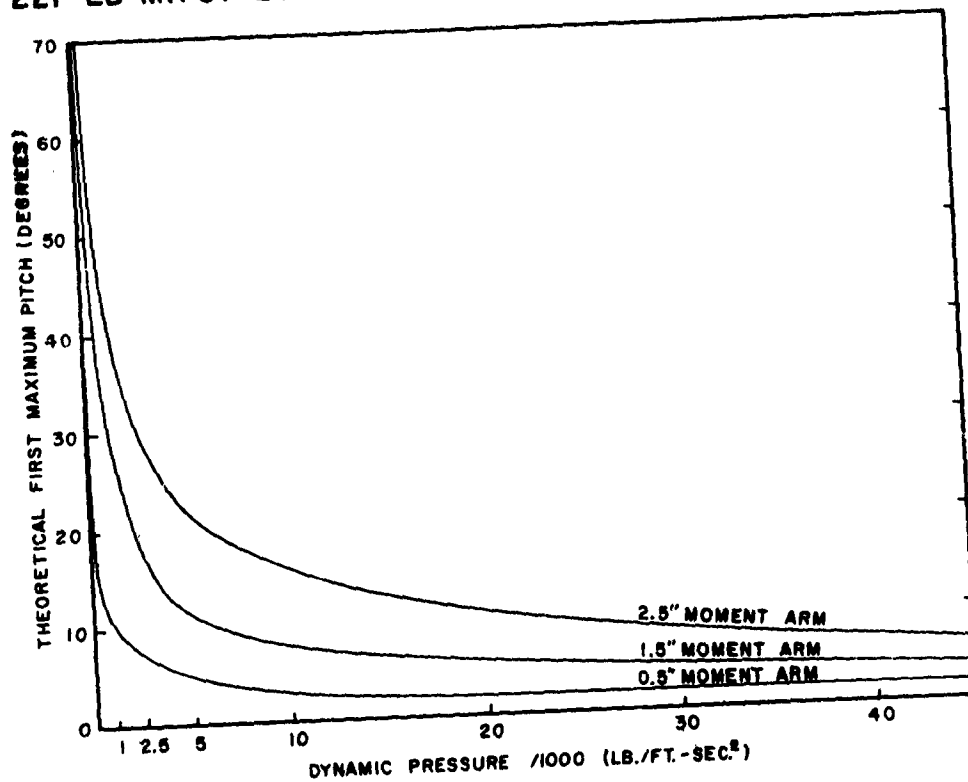


FIGURE 13

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333-LB MK 87 LOW DRAG PRACTICE BOMB (WET SAND FILLED)

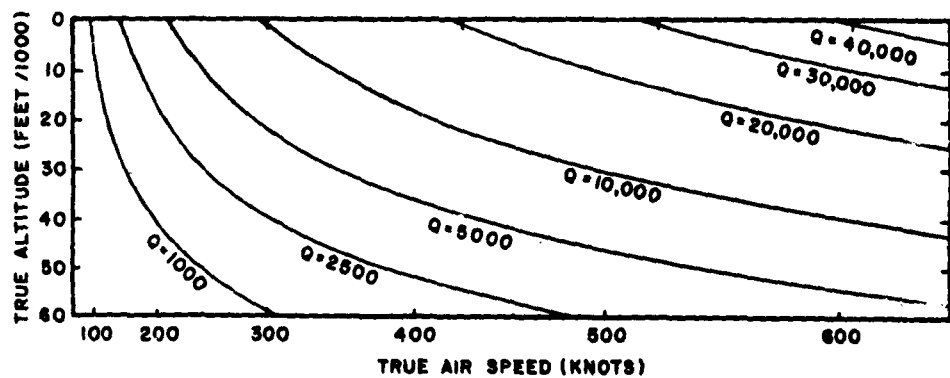
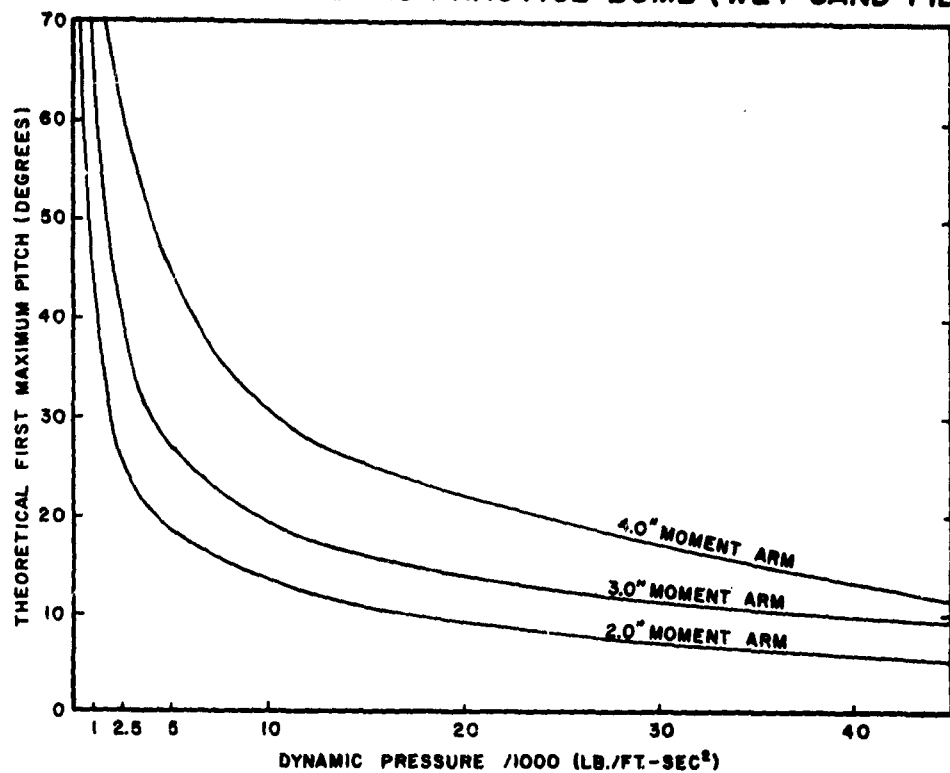


FIGURE 14

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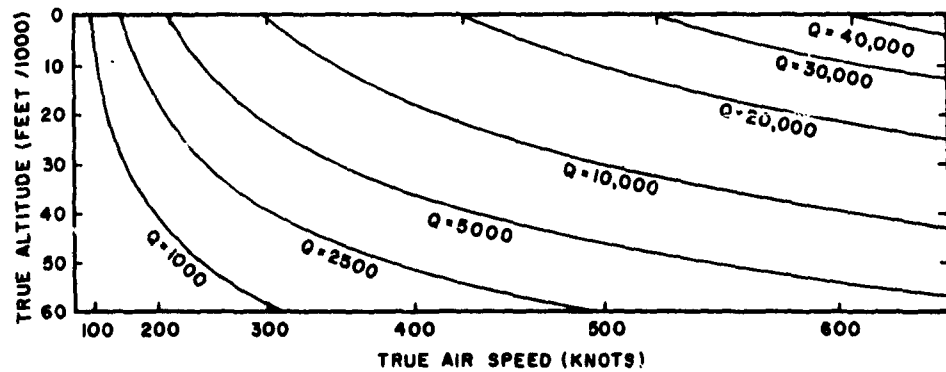
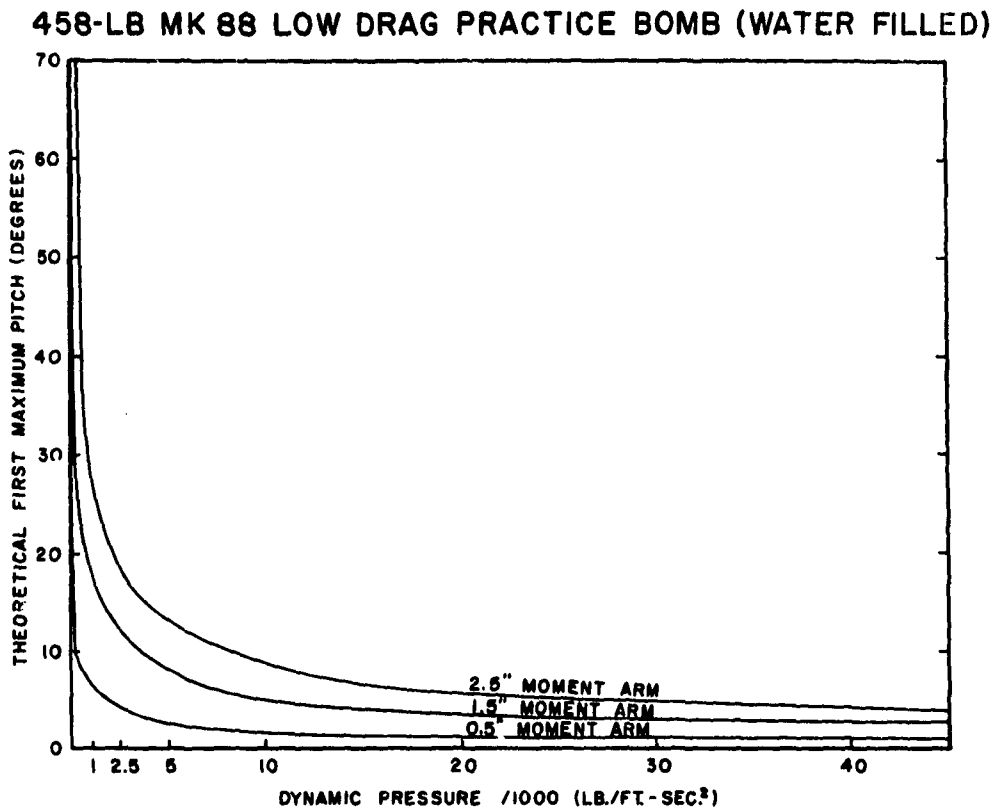


FIGURE 15

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783-LB MK 88 LOW DRAG PRACTICE BOMB (WET SAND FILLED)

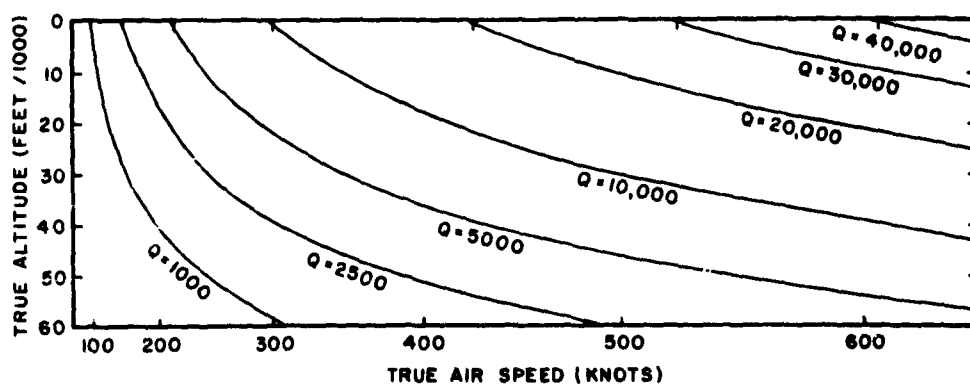
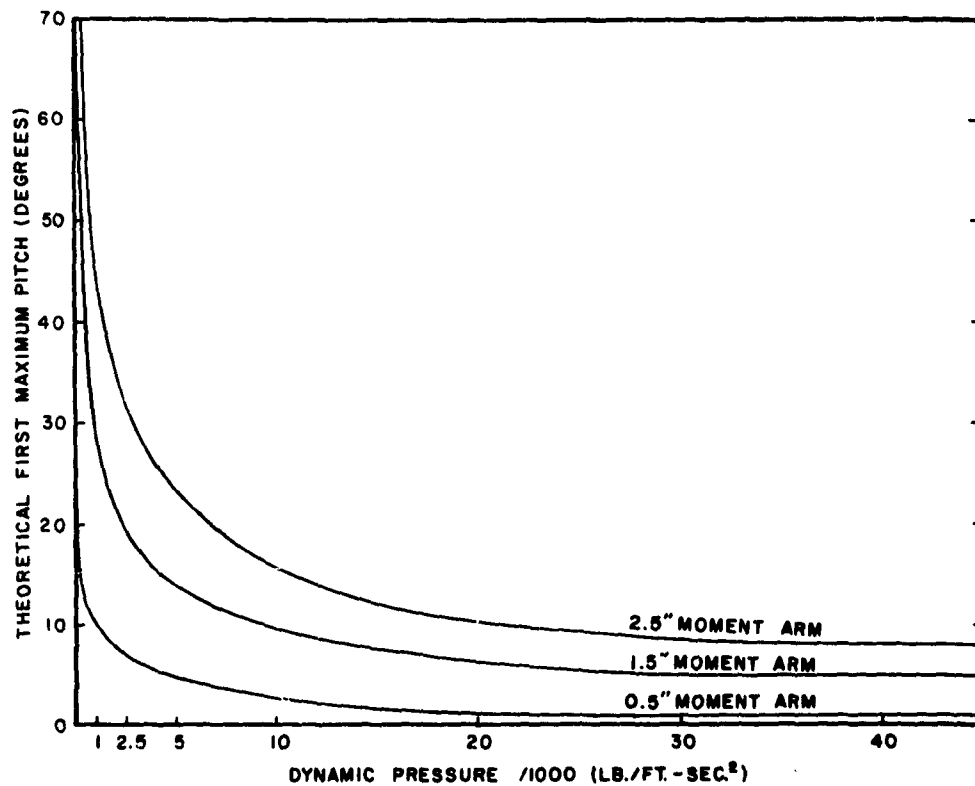


FIGURE 16

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THEORETICAL PREDICTIONS OF THE FIRST MAXIMUM PITCH OF LOW DRAG BOMBS RELEASED
FROM A3D AIRCRAFT IN HORIZONTAL FLIGHT (U). NWL REPORT NO. 1483

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