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BALLISTIC ANALYSIS OF FIRING TABLE DATA FOR 155MM, M825 SMOKE PROJECTILE

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SEPTEMBER 1990

U.S. ARMY LABORATORY COMMAND

BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

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13. ABSTRACT *(Maximum 200 words)*

Firing Table Range Data from Dugway Proving Ground, Utah, for the developmental 155mm, M825 Modified Product Improved Smoke Projectile has been reduced and analyzed. Ballistic comparisons between all base versions of the M825 projectile as well as with the M483A1 projectile are discussed. The concept of Ballistic Match/Similitude between two rounds is also expounded upon.

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I. Introduction

The main purpose of this report is to present an analysis of firing table data from the M825 modified product improvement program (MOD PIP) test conducted from July 1988 thru September 1988 at Dugway Proving Ground. Such an analysis will consider whether the M825 MOD PIP Base projectile is ballistically matched or ballistically similar to the M483A1 projectile and whether existing aiming data for the M825 Standard Base projectile will suffice for the M825 MOD PIP Base projectile. Results of a previous analysis comparing the standard base and an earlier version of the domed steel base will also be briefly described.

There is a requirement that the M825 MOD PIP Base projectile be either ballistically matched or ballistically similar to the M483A1 projectile. If this is so, then tabular aiming data for the M483A1 projectile may be used for the M825 MOD PIP projectile either as is or with just simple constant corrections to muzzle velocity, drag and/or deflection.

In a study of ballistic match/ballistic similitude between two projectiles, a test plan is first devised. The test plan is then executed over a period of time at a proving ground. (A test plan for the M825 MOD PIP test conducted July 1988 thru September 1988 at Dugway Proving Ground had been previously formulated where no green bag charges were used.) Range data is collected as the test is executed and this range data is used as input to a reduction program which will determine ballistic parameters for the modified point mass trajectory model [1] in order to match observed conditions.

Ballistics are determined for each set of rounds grouped by projectile, charge and quadrant elevation (QE). Such ballistics have values determined after all non standard variations due to weights, meteorological conditions, etc. have been eliminated. The ballistics that one usually deals with in a ballistic match/similitude test are ballistic coefficient (drag effects), lift factor (deflection effects), standard muzzle velocities and precision probable error. One then studies over all groups how the two projectiles differ in ballistic coefficient and related range, lift factor and related deflection, standard muzzle velocity and precision. After such study one then tries to make a statement about ballistic match/similitude between the two projectiles.

There currently exists an addendum firing table for the M825 Standard Base projectile and its designation is FT 155 ADD-Q-0 (REV). This addendum is provisional and the basic firing table is FT 155-AN-1. It simulates the base projectile to the optimum height of burst as well as the ejected phosphorus felt wedges from the burst point to the ground.

The M825 Standard Bas- projectile is an aluminum base projectile which has a QE restriction of less than 950 … en fired hot using the M203A1 propelling charge. This restriction is due to the rou… oming unstable as a result of the phosphorus payload melting and producing a liqu…

The M825 MOD PIP projectile is a domed steel base projectile with one inch cut off from the boattail and with a payload of 'fat spec' phosphorus felt wedges. The term 'fat spec' refers to the fact that the radius of the phosphorus felt wedges has been increased to have a more compact fit within the shell, thereby, enhancing stability. The development program for the M825 MOD PIP base projectile has been an on-going project since April, 1985. It is now a stable projectile over all charges, elevations and temperatures. However, the ballistics for the M825 MOD PIP projectile obtained in the above test must be compared to past ballistics of the M825 Standard Base projectile. If they are found to be different, a new firing table addendum will have to be constructed and new fire control input will have to be generated for the Army field computers.

II. Review of Previous Testing

Prior to development and testing of the M825 projectile with the modified PIP base, there existed a M825 PIP Base projectile as a predecessor to the modified PIP version. The M825 PIP Base projectile was not adopted because it had stability problems similar to those of the M825 Standard Base projectile.

Although the M825 MOD PIP Base projectile is the principal subject of this report, a firing table test of the M825 PIP Base projectile was conducted at Dugway Proving Ground in early 1986 and the results of this test will be briefly restated. Such results, as presented in a Ballistic Research Laboratory interim memorandum report by Messrs. Kochenderfer and Wall, showed that the M825 PIP Base projectile had less muzzle velocity (by about 1.5 m/s) at all charges tested, flew with less drag at the subsonic velocities (approximately 2 percent to 5 percent) and flew over all charges with substantially more drift (by about 4 percent to 12 percent) than the M825 Standard Base projectile.

The modified PIP version of the M825 round is expected to give results that will vary from these due to inherent physical differences.[2] Figures 1 and 2 show the M825 projectile and the physical differences between the various bases. Average physical characteristics of all the M825 variants are listed in Table 1. Note the difference in the sizes of the bases and ratios of length to diameter (L/D).

III. Results of Test

1. Muzzle Velocity

Based on a student-t test on means [3] at the 5 percent level of significance using the data in Table 2, there is no significant difference in standard muzzle velocities between the M825 MOD PIP Base projectile and the M483A1 projectile. This was true throughout the test no matter what charge or howitzer was fired. Probable error values in muzzle velocity tended to be larger for the M198 howitzer than for the M109A1 howitzer. In the test standard muzzle velocities of the M483A1 projectile differed significantly in comparison with values derived from FCI 155-AN-A documents shown in Table 3 at some charges. This probably refects occasion to occasion differences. The standard muzzle velocity for the M825 MOD PIP Base projectile at the M203A1 (8R) propelling charge is significantly less than that for the M825 Standard Base projectile given in the FCI for the same charge.

2. Ballistic Coefficient

Figure 3 shows that C-multipliers (Ballistic Coefficient multipliers) for the MOD PIP test were consistently less than one while C-multipliers for the M825 Standard Base projectile from the FCI document were consistently greater than one. This means that the M825 Standard Base projectile flies with less drag than the M483A1 projectile while the M825 MOD PIP projectile flies with more drag than the M483A1 projectile. For charges shown, these deviations translate into decreases in range of up to 300 meters between the M825 MOD PIP projectile and M483A1 projectile depending on charge and QE. Likewise, range differences between the M825 Standard Base projectile and the M825 MOD PIP projectile are up to 500 meters. These range differences are much greater than one probable error in range when firing the M483A1 projectile from the M109A1 and/or M198 howitzers.

3. Lift Factor

Figure 4 shows that L-multipliers (Lift Factor multipliers) for the MOD PIP test were consistently greater than one while L-multipliers for the M825 Standard Base projectile from the FCI document tended to be less than one. This means that the M825 Standard Base projectile flies with less drift than the M483A1 projectile while the M825 MOD PIP projectile flies with more drift than the M483A1 projectile. For charges shown these deviations translate into differences in deflection of up to 60 meters between the M483A1 projectile and the M825 MOD PIP projectile depending on charge and QE. These deflection differences are much greater than one probable error in deflection when firing the M483A1 projectile from the M109A1 and/or M198 howitzers.

4. Maximum Charge

Figures 5 and 6 show that for the M203A1 (8R) propelling charge the M825 MOD PIP projectile flies with more drag than the M825 Standard Base projectile and with more drift. Combining standard muzzle velocity differences with drag differences, this can translate into a difference in slant range of up to 600 meters depending on QE. (Note that the M483A1 projectile is not compatible with this propelling charge.)

5. Correction Factors

In looking at Figures 7 thru 12 and at Figures 13 thru 18, suppose one represents the C and L multiplier data points with a constant line. The partial derivatives of range to ballistic coefficient (percent) or deflection to lift factor ($\partial X / \partial C$ or $\partial Z / \partial L$) obtained from the reduction results can be used to compare the observed values of ballistic coefficient (C) and lift factor (L) to average conditions; the resulting range and deflection differences are within approximately one probable error boundaries for the M483A1 projectile fired with the M109A1 and/or M198 howitzers. Table 4 gives an illustration for charge 4W. Extensions to the other charges can easily be derived.

6. Precision Probable Error

Table 5 shows comparisons of precision probable errors between projectiles M483A1 and the M825 with the MOD PIP Base. Each charge, howitzer and QE combination consists of approximately 5 round groups for each projectile. A statistical F-test on variances [3] reveals that there is no difference in range or deflection precision at the 10 percent level of significance in 18 out of 20 cases.

IV. Conclusions

The current NATO-accepted definition of ballistic similitude is as follows:

"Two types of projectiles with the same fuze are ballistically similar if their external shape, mass, center of gravity, transverse and longitudinal moments of inertia, surface finish, and driving band characteristics are sufficiently close to insure that their mean points of impact do not differ by more than one probable error in range and one probable error in deflection, after the application for each propellant zone (charge) of a constant correction to muzzle velocity and/or air density for range and a constant angular or percentage correction for deflection."

The document which mentions the definition of ballistic similitude also states "If none of the corrections mentioned in the definition are necessary for mean points of impact to be within one probable error, then the two projectiles are ballistically matched."

The M825 MOD PIP Base projectile is not ballistically matched to the M483A1 projectile. Test results showed large deviations in range and deflection greater than one probable error. However, they have been determined to be ballistically similar. Test results bear this out. Over all charges and conditions tested, corrections to ballistic coefficient (C) and lift factor (L) were found so that the NATO definition of ballistic similitude can be satisfied.

There is a need for new aiming data for the M825 MOD PIP projectile since ballistics are significantly different than those of the M825 Standard Base projectile. A new test plan, to be conducted for an initial production test of the M825 MOD PIP Base projectile, will be required to develop the new aiming data. Such a test will be more extensive than the developmental test since all charges will be utilized.

Finally, no significant differences were found in precision probable error in range or deflection between the M483A1, M825 Standard Base and M825 MOD PIP Base projectiles.

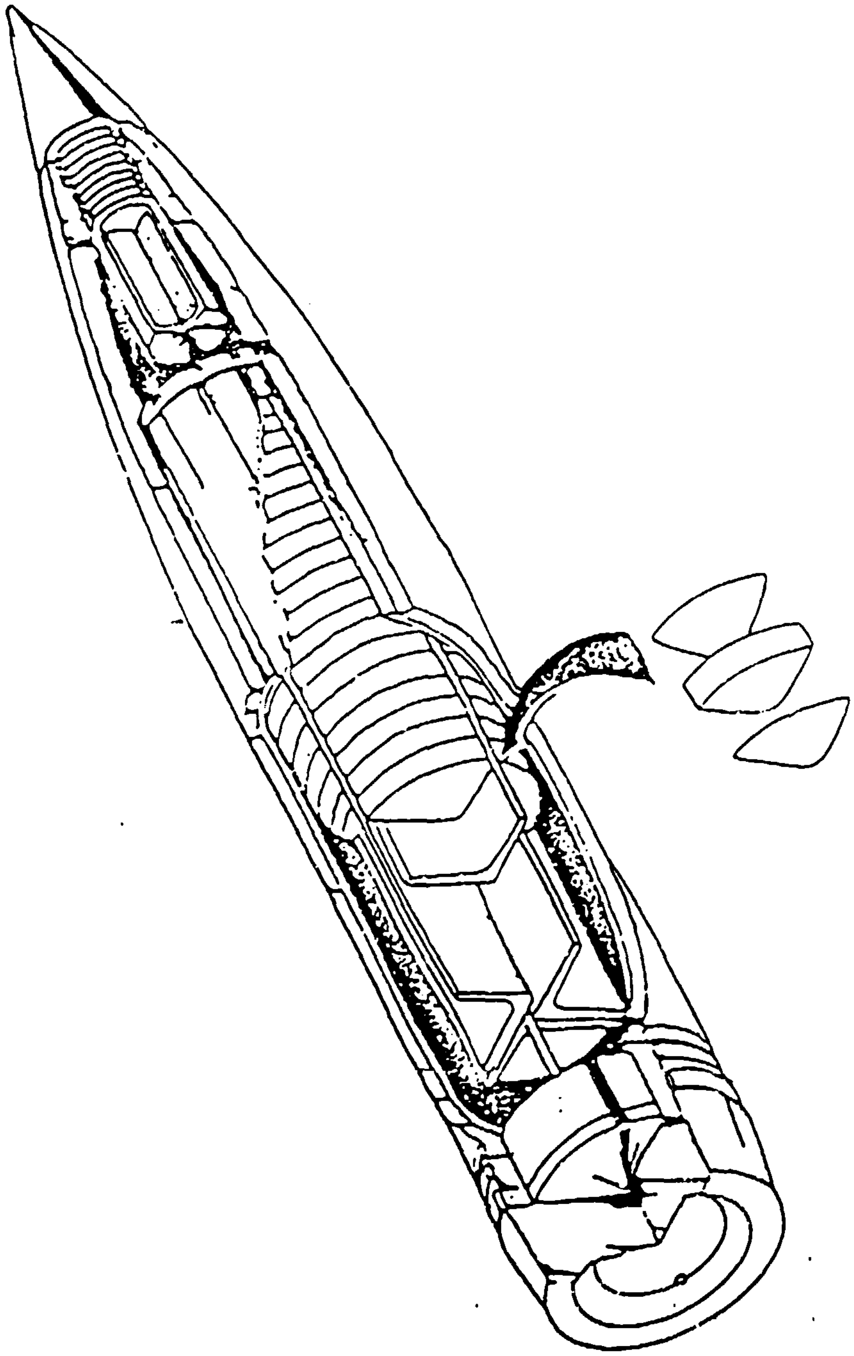

Figure 1. Cut-away view of the MS25.

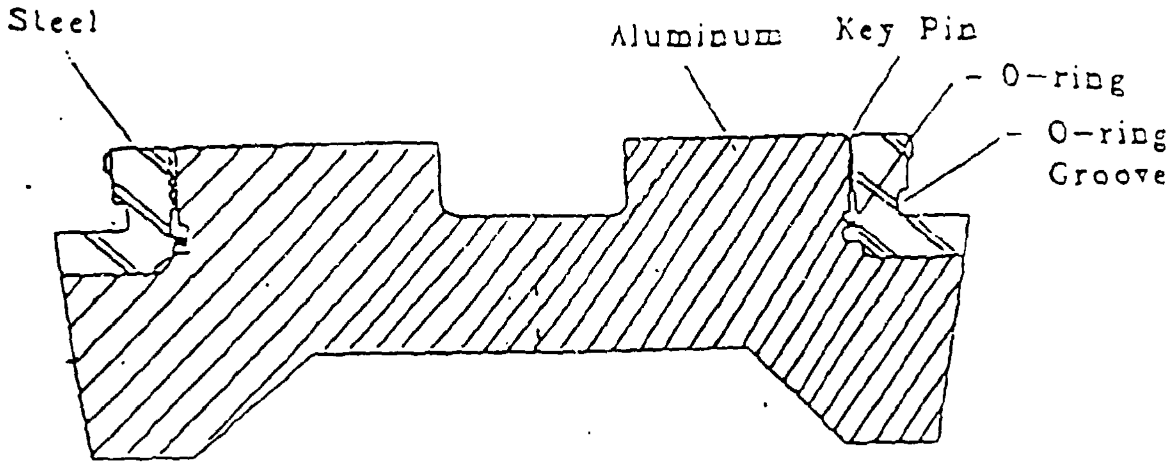

Figure 2a. Section View of Standard Base.

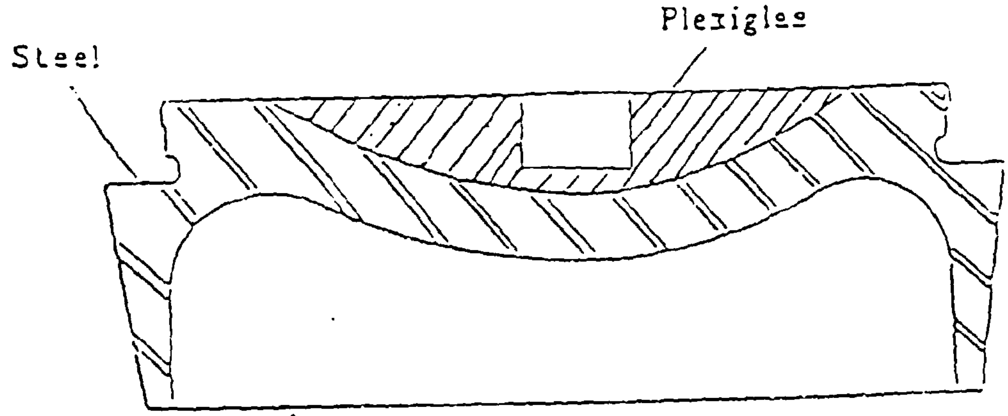

Figure 2b. Section View of PIP Base.

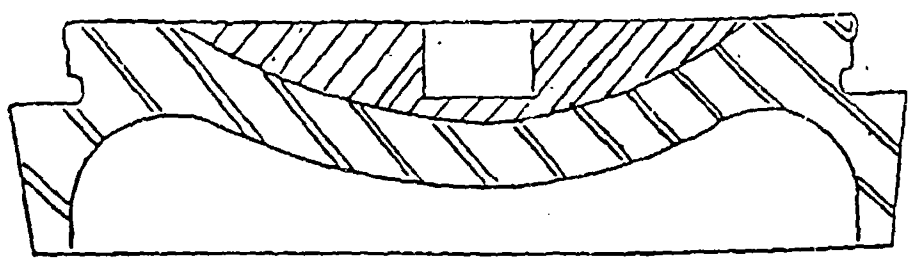

Figure 2c. Section View of Modified Base.

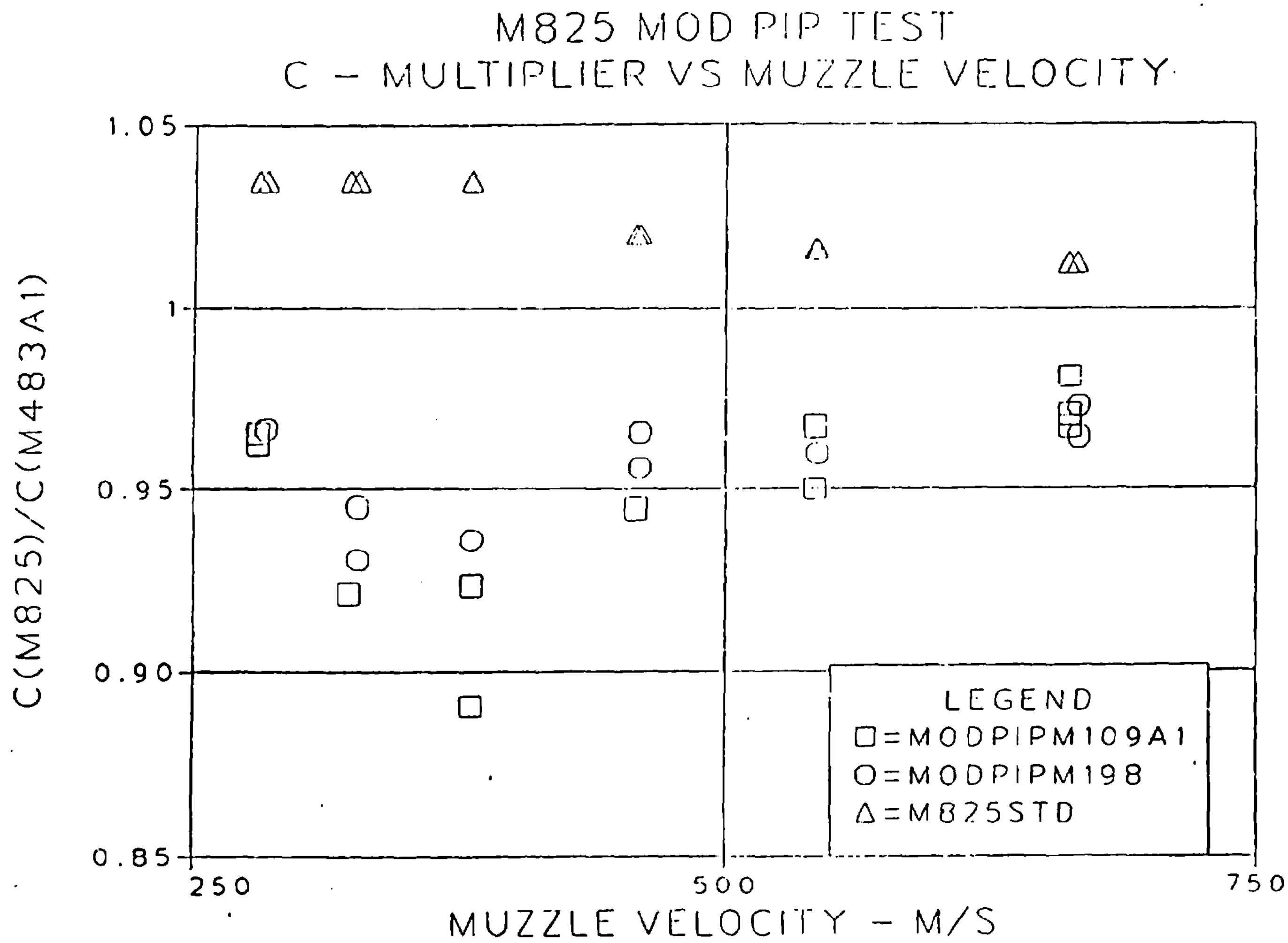

Figure 3. Ballistic coefficient (c) multiplier vs. muzzle velocity.

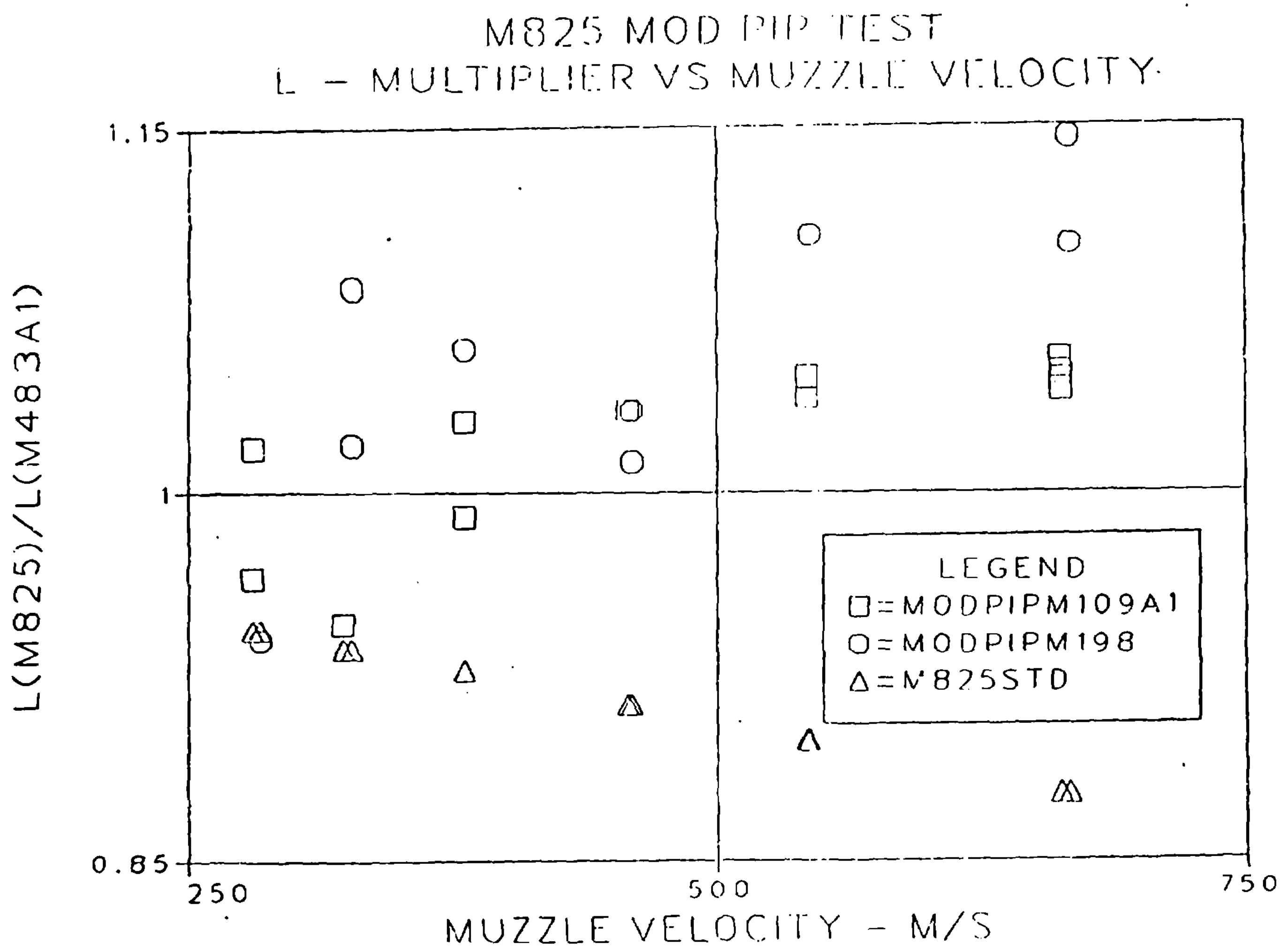

Figure 4. Lift factor (l) multiplier vs. muzzle velocity.

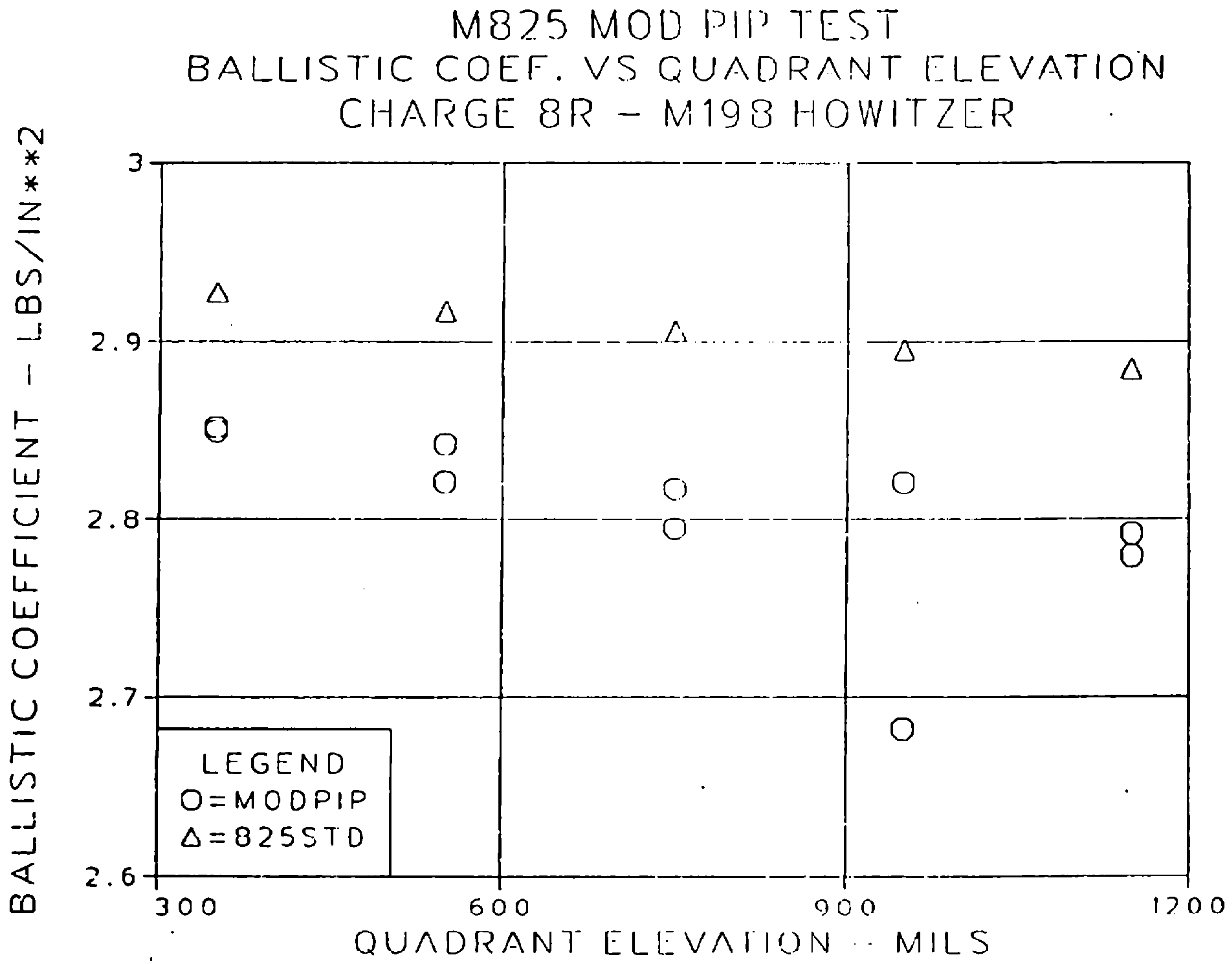

Figure 5. Ballistic coefficient (c) vs. quadrant elevation - charge 8R.

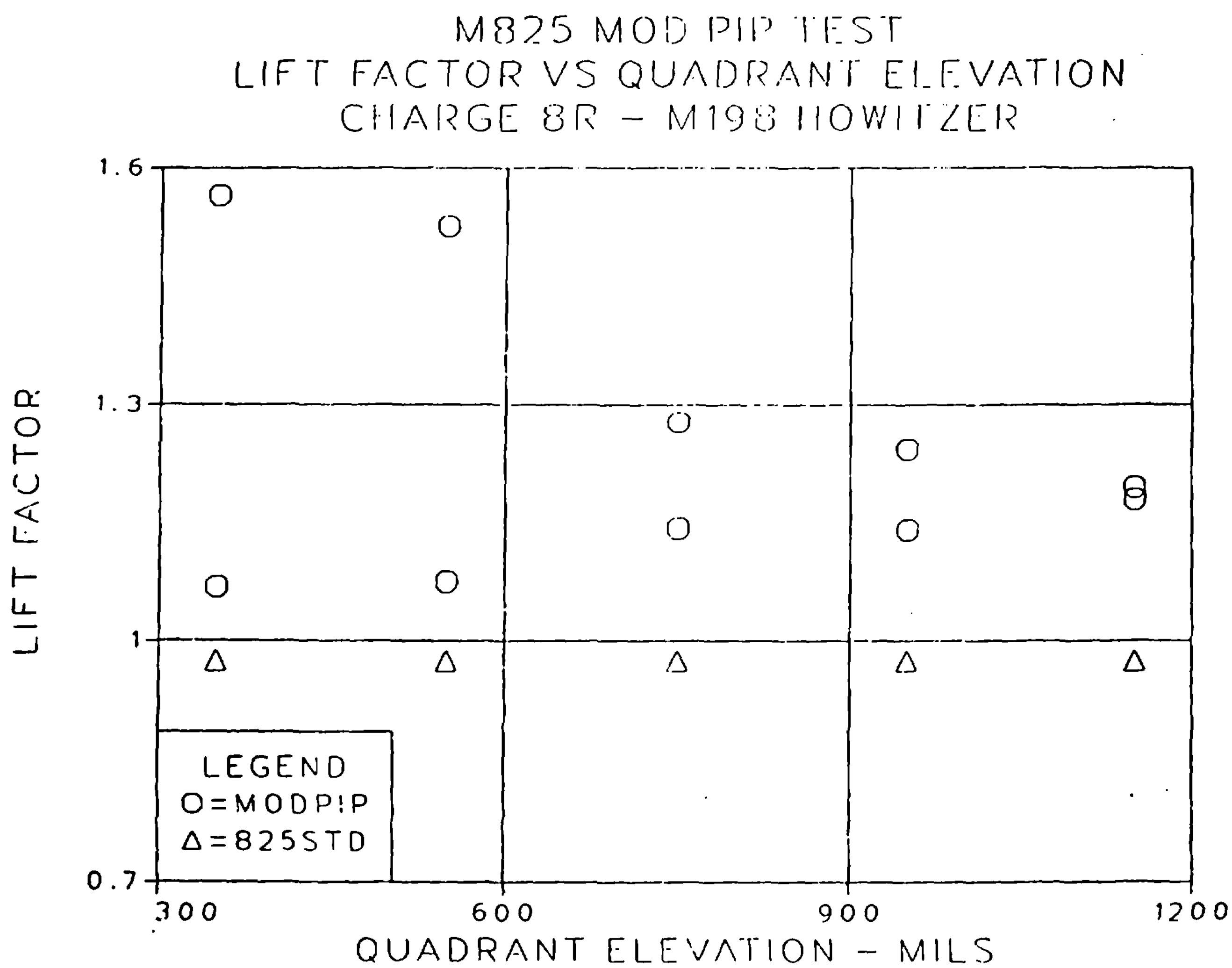

Figure 6. Lift factor (l) vs. quadrant elevation - 8R.

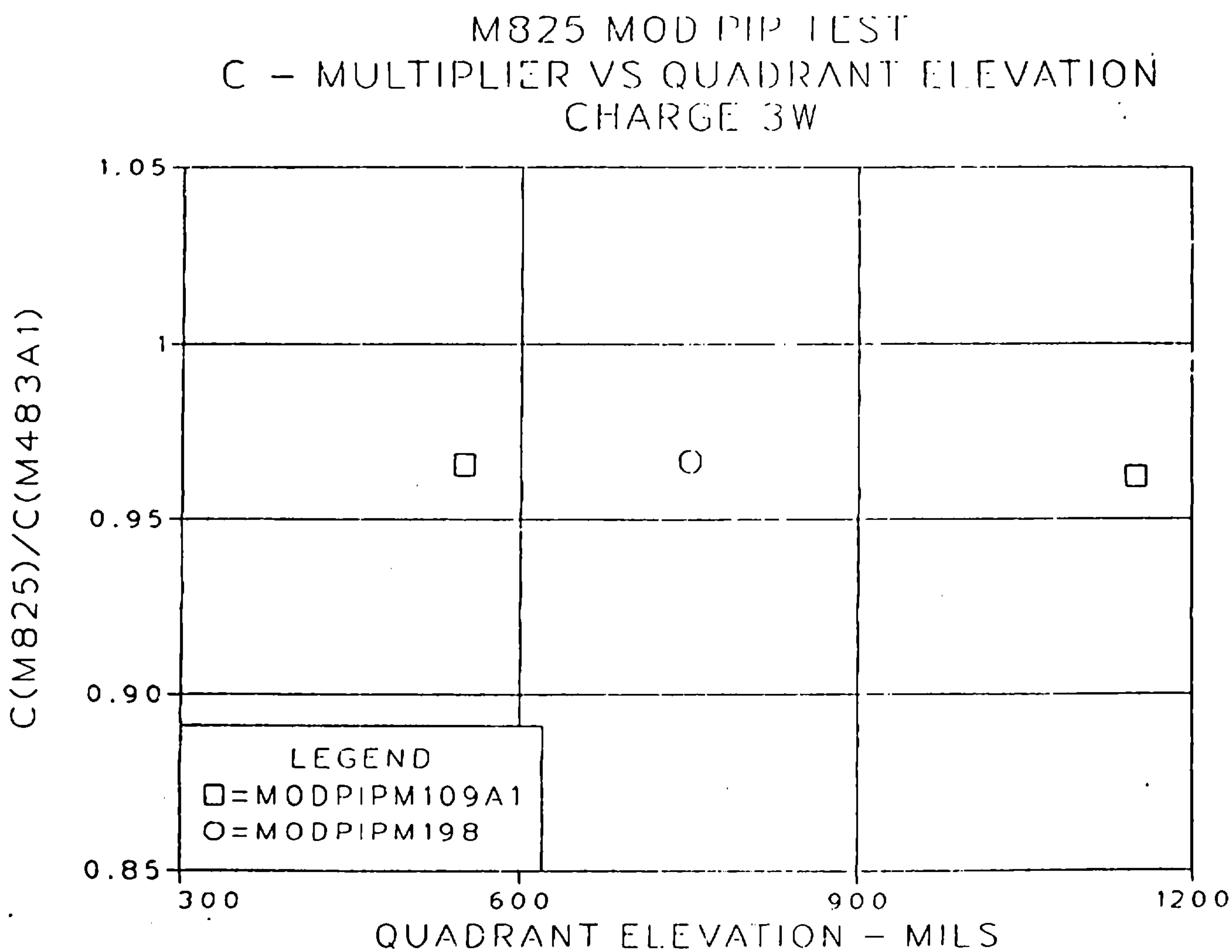

Figure 7. Ballistic coefficient (c) multiplier vs. quadrant elevation - charge 3W.

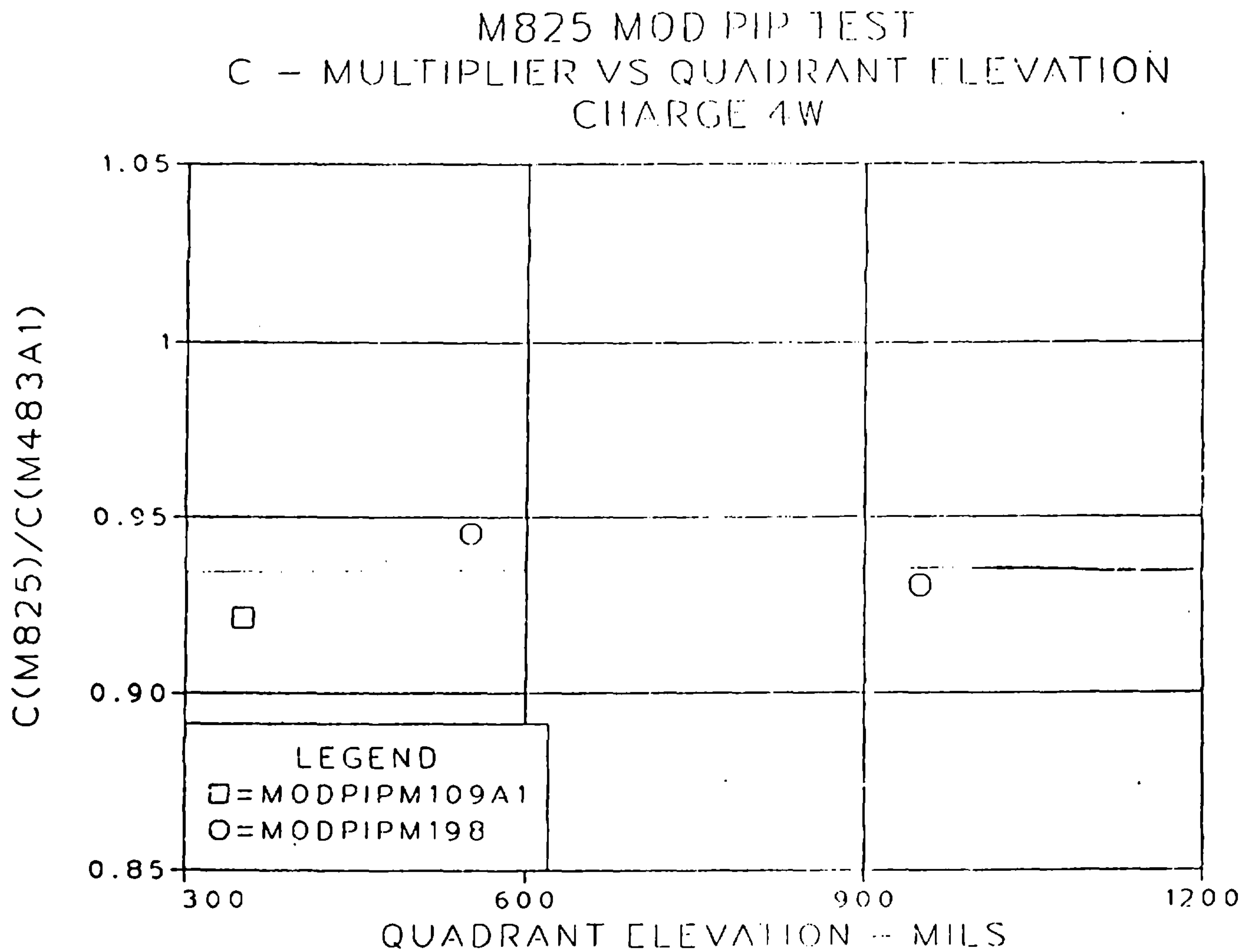

Figure 8. Ballistic coefficient (c) multiplier vs. quadrant elevation - charge 4W.

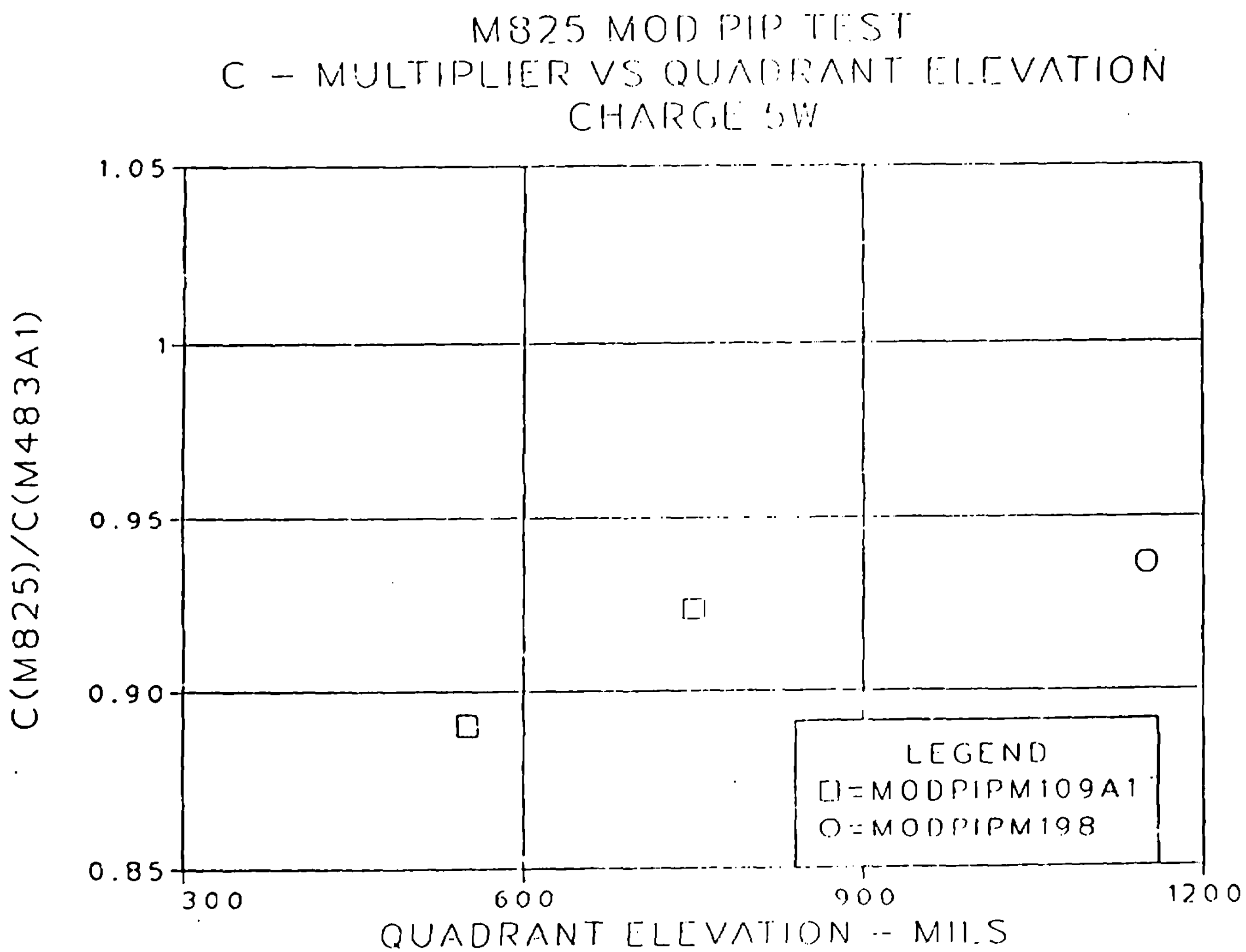

Figure 9. Ballistic coefficient (c) multiplier vs. quadrant elevation - charge 5W.

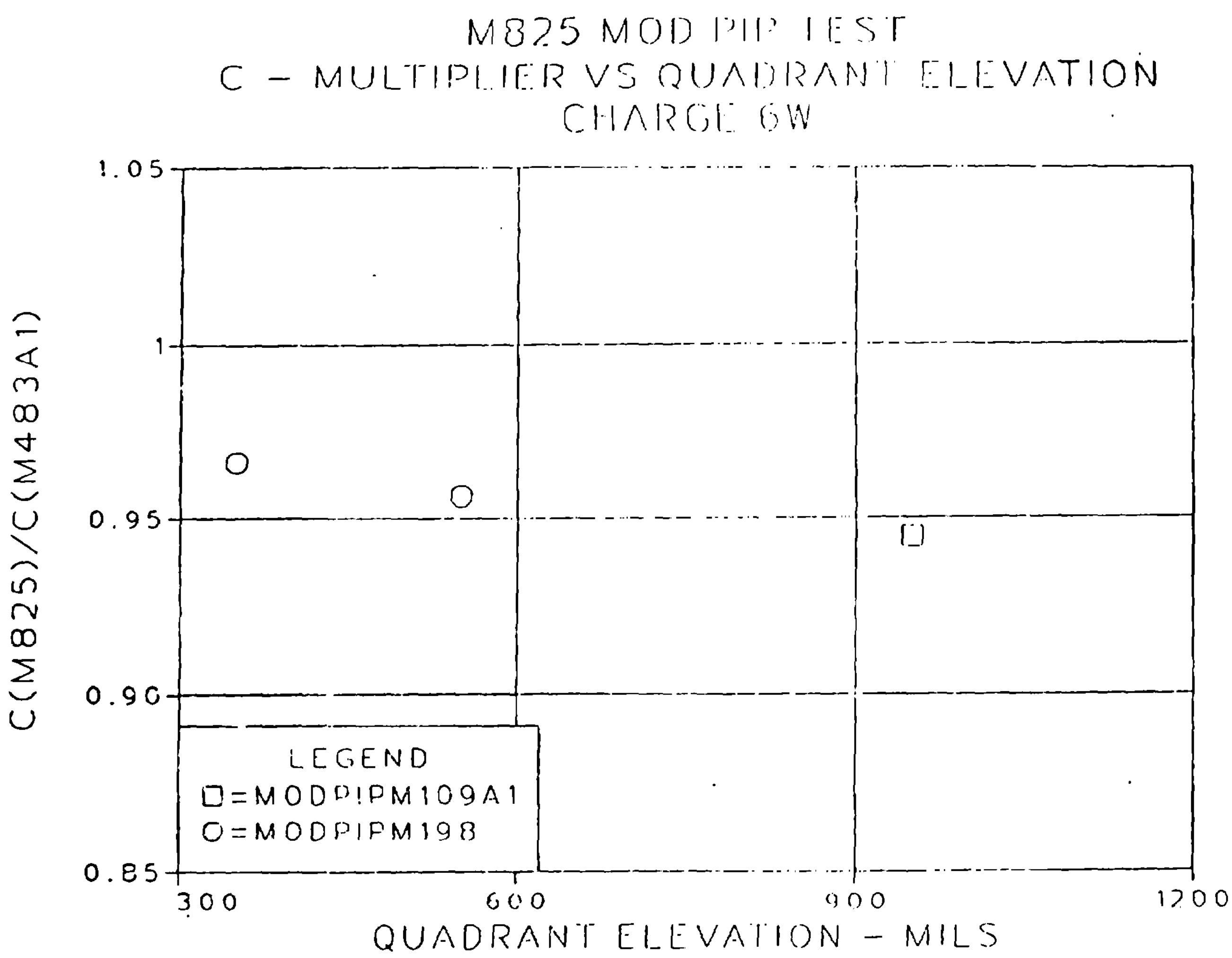

Figure 10. Ballistic coefficient (c) multiplier vs. quadrant elevation - charge 6W.

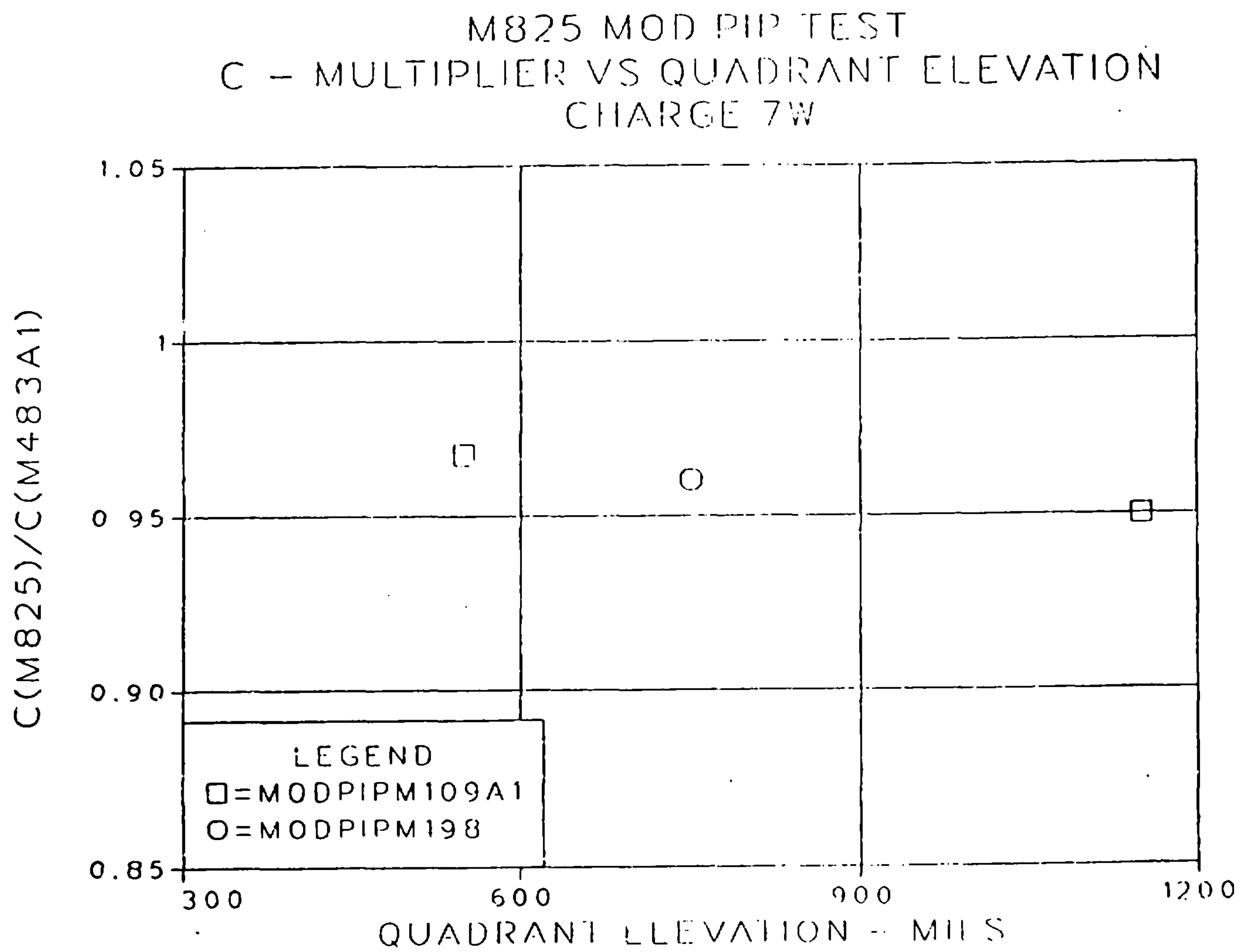

Figure 11. Ballistic coefficient (c) multiplier vs. quadrant elevation - charge 7W.

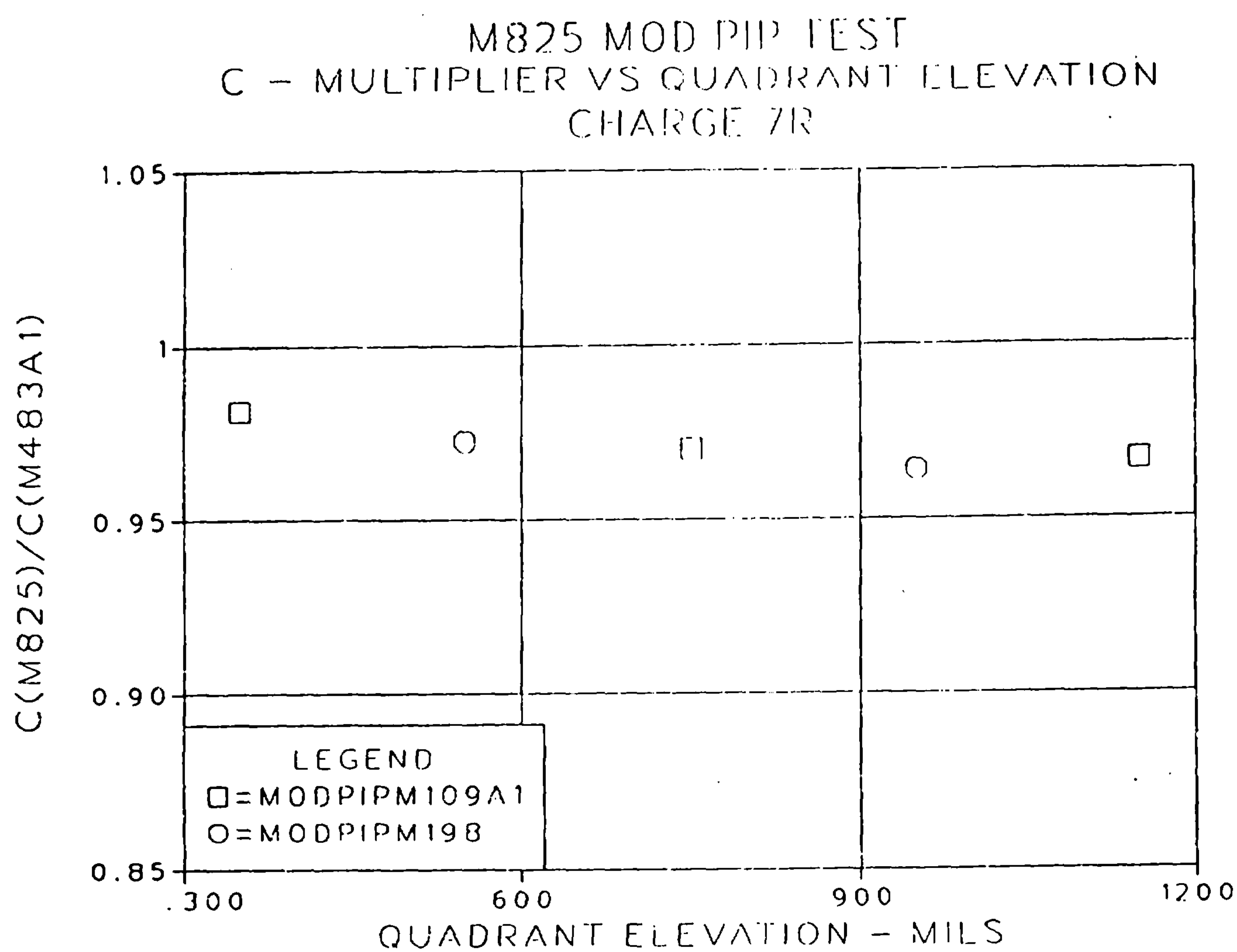

Figure 12. Ballistic coefficient (c) multiplier vs. quadrant elevation - charge 7R.

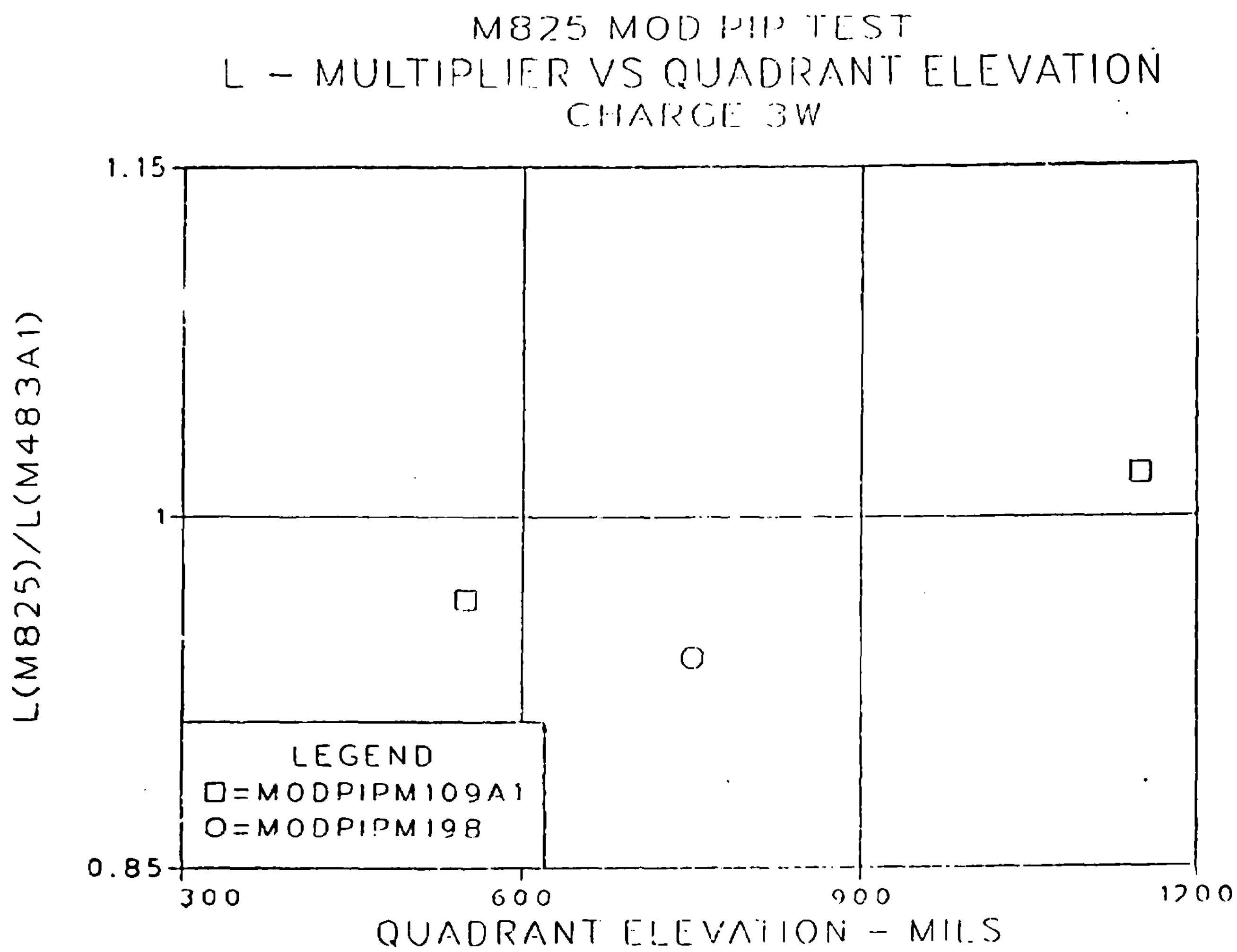

Figure 13. Lift factor (l) multiplier vs. quadrant elevation - charge 3W.

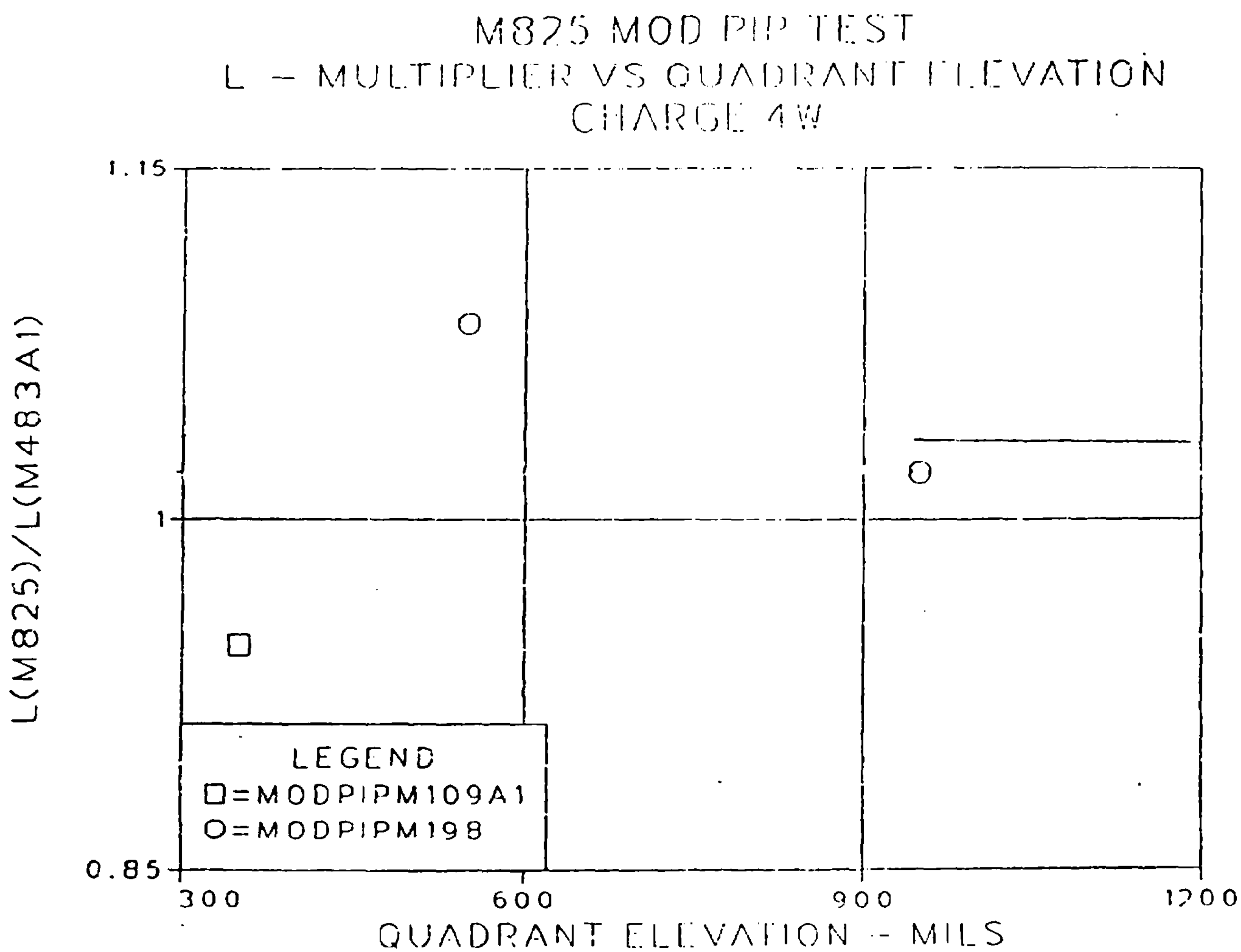

Figure 14. Lift factor (l) multiplier vs. quadrant elevation - charge 4W.

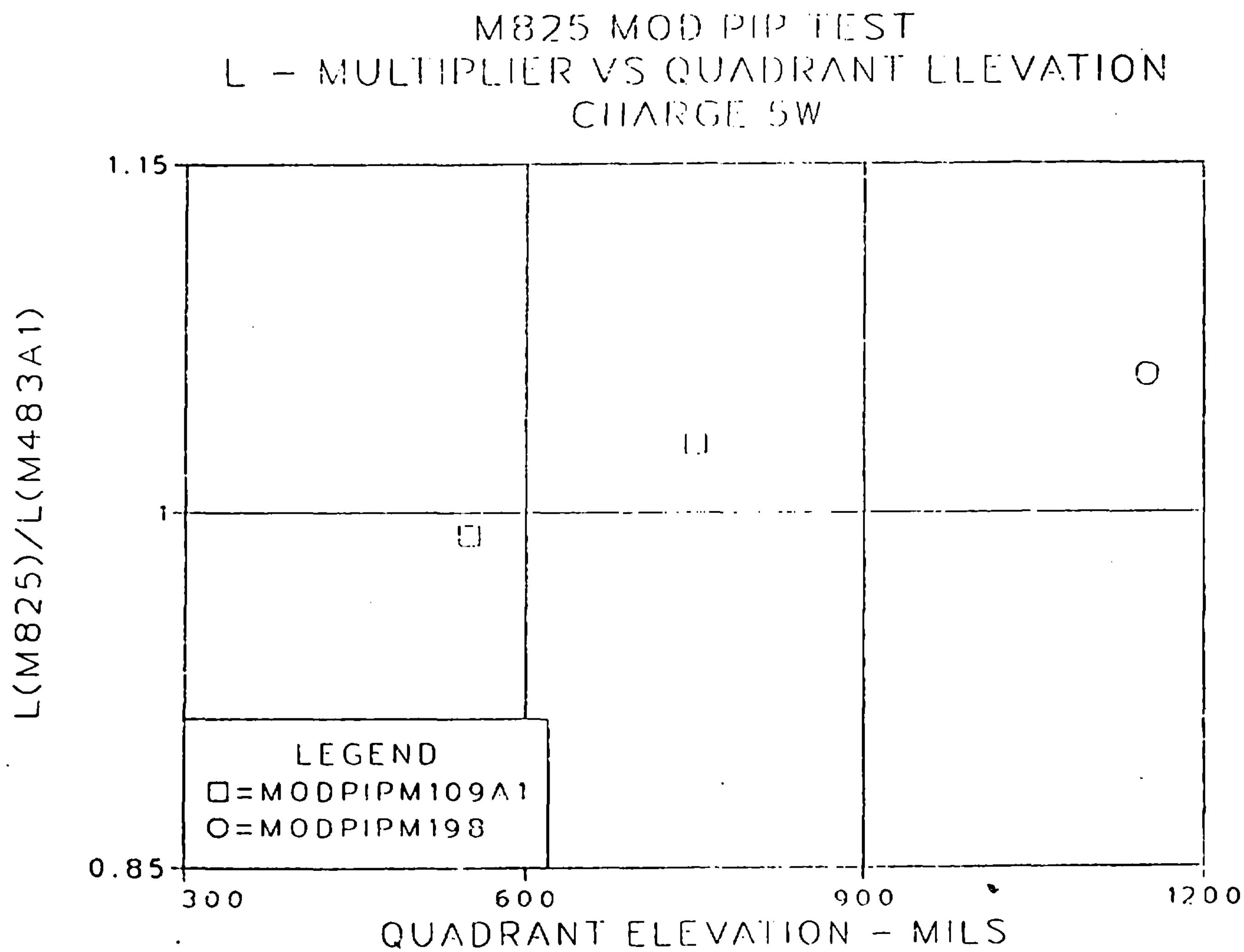

Figure 15. Lift factor (l) multiplier vs. quadrant elevation - charge 5W.

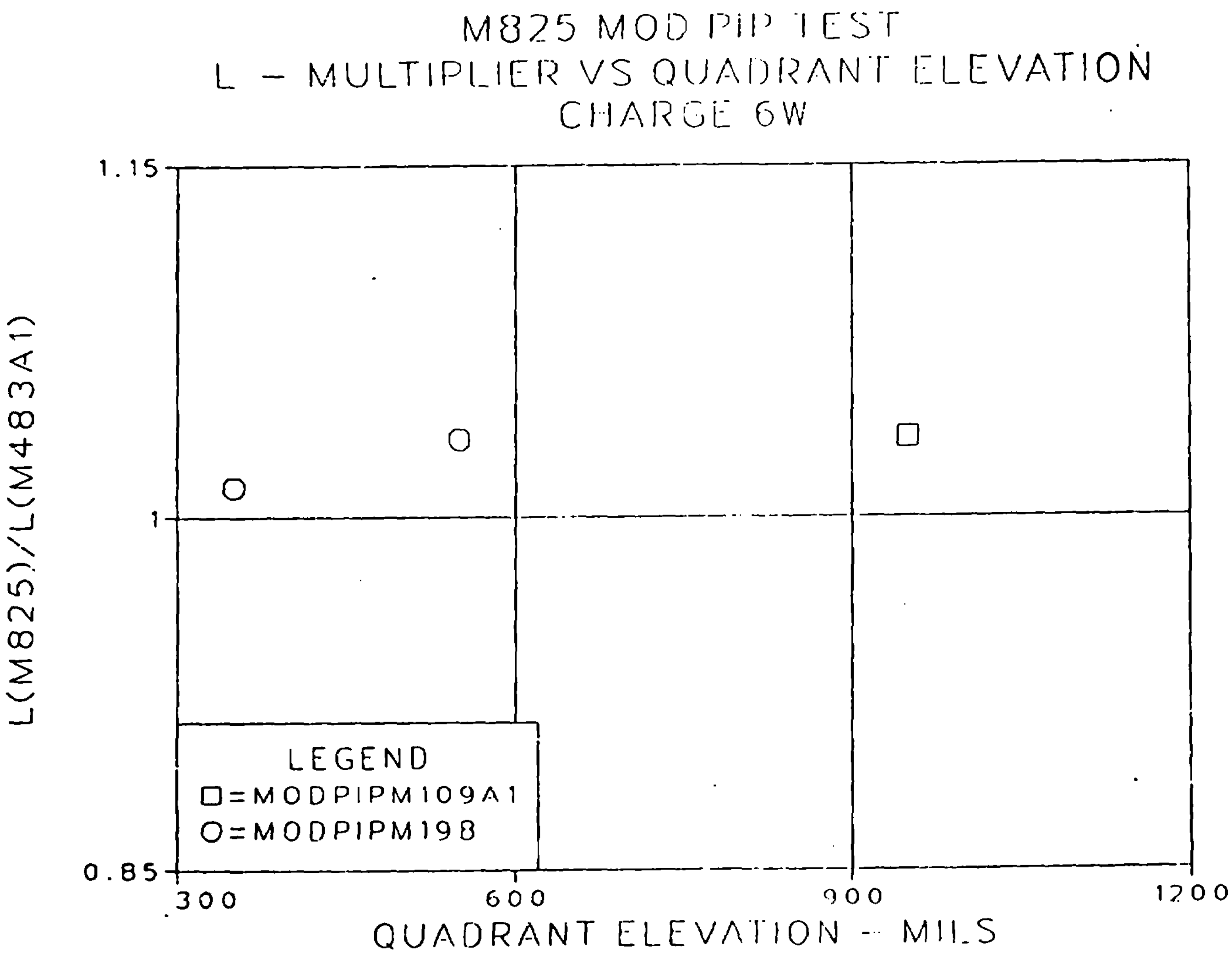

Figure 16. Lift factor (l) multiplier vs. quadrant elevation - charge 6W.

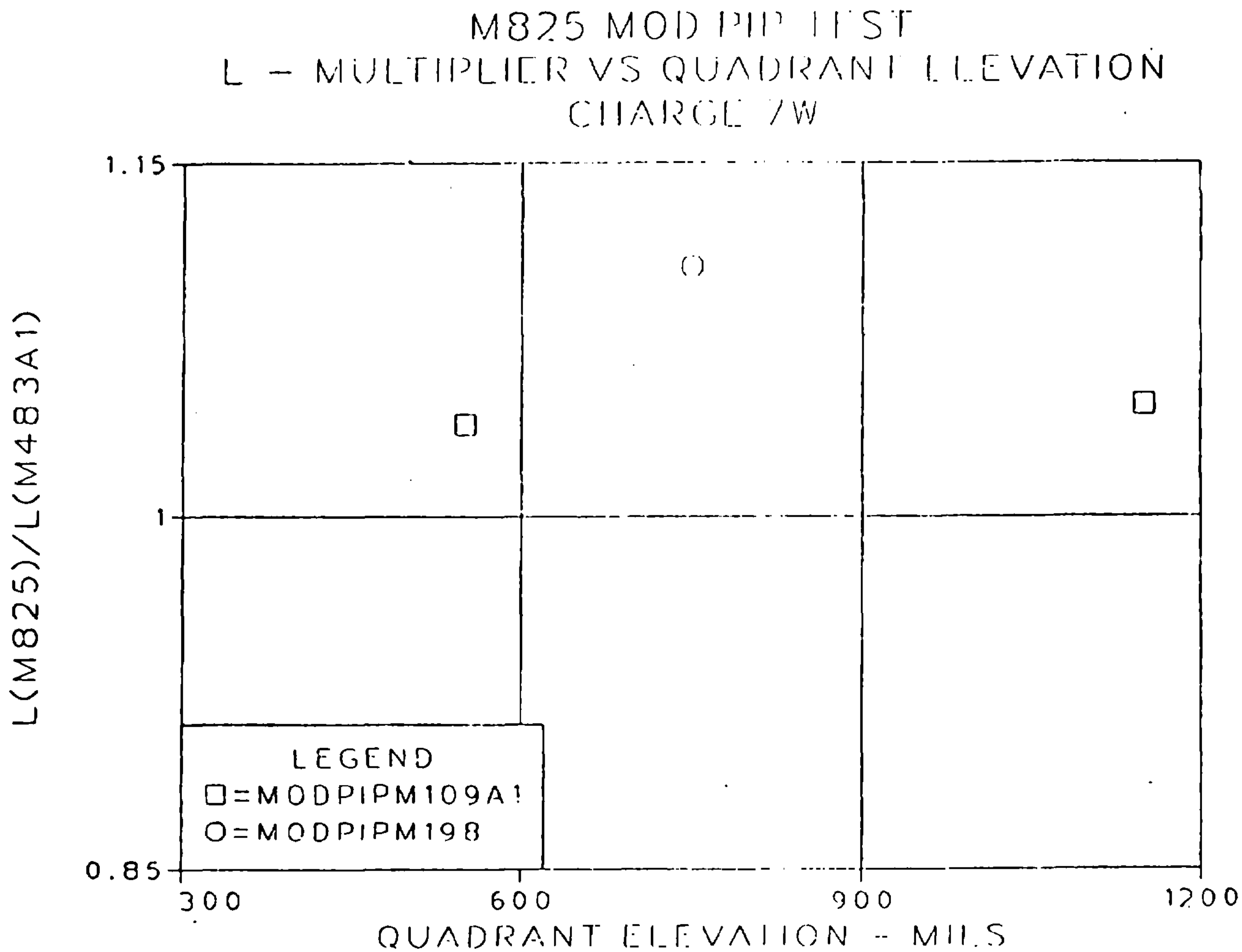

Figure 17. Lift factor (l) multiplier vs. quadrant elevation - charge 7W.

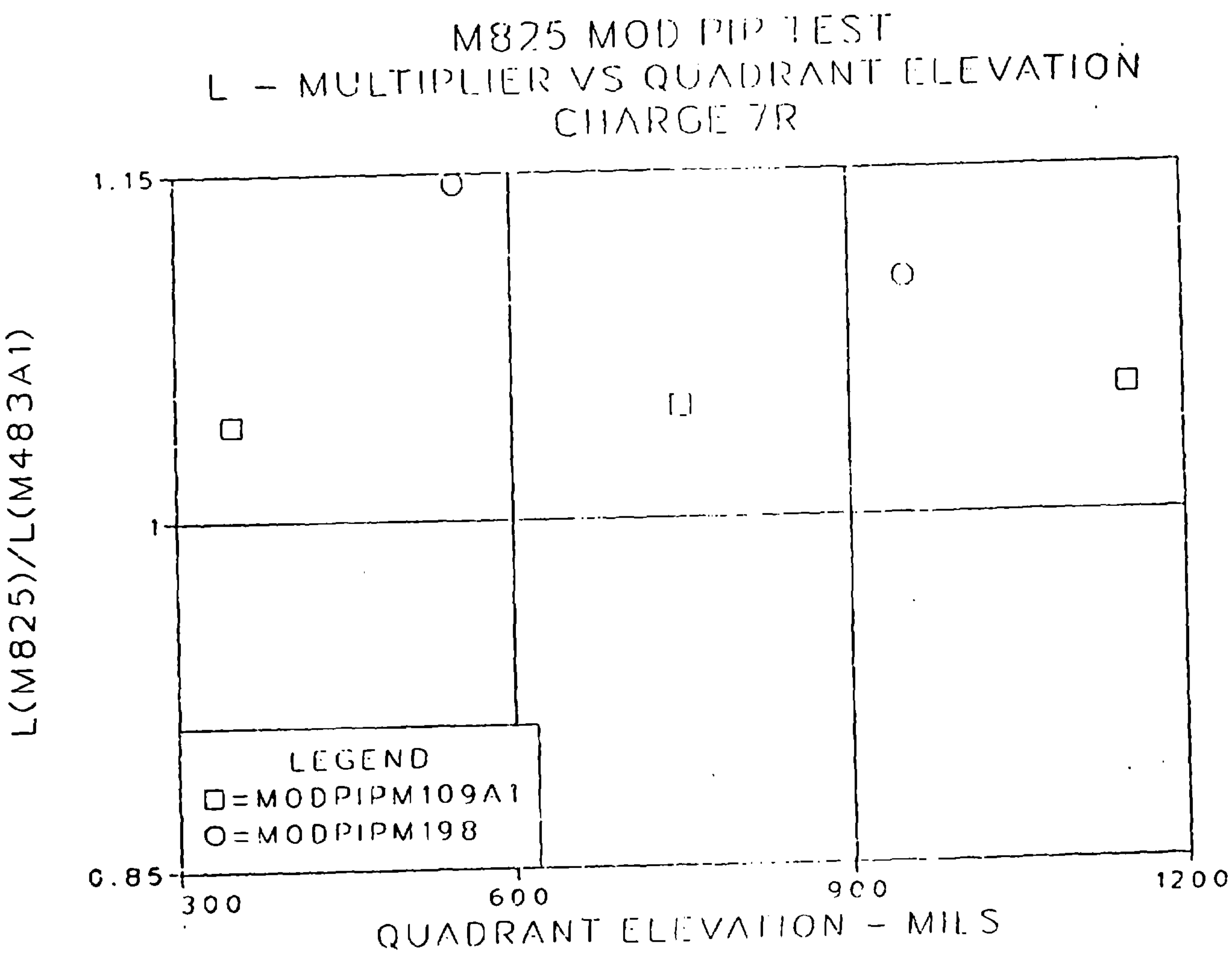

Figure 18. Lift factor (l) multiplier vs. quadrant elevation - charge 7R.

Table 1. Average Physical Characteristics of M825 Projectile Designs

Projectile Type	Standard	PIP	MOD/PIP
Base Type	Standard	1/4 Cal	1/6 Cal
Diameter (mm)	154.78	154.78	154.76
Mass (kg)	46.53	46.70	46.19
Axial Moment of Inertia ($kg - m^2$)	0.168	0.170	0.168
Transverse Moment of Inertia ($kg - m^2$)	1.85	1.86	1.81
Center Gravity - Base (m)	0.331	0.332	0.313
L/D (Length to Diameter Ratio)	5.790	5.792	5.705

Table 2. Standard Muzzle Velocity (m/s) and Probable Error in Muzzle Velocity (m/s) Comparisons for M825 with Modified PIP Base

MUZZLE VELOCITY

		STANDARD		PROBABLE ERROR	
CHARGE	n	M825	M483A1	M825	M483A1
		M109A1 HOWITZER			
3W	2	280.3	280.5	.68	1.19
4W	1	322.8	322.9	.52	.38
5W	2	380.3	379.1	.84	.63
6W	1	457.7	457.6	.94	.54
7W	2	542.3	543.2	.56	.48
7R	3	662.3	663.8	.71	1.01
		M198 HOWITZER			
3W	1	283.8	280.1	2.34	2.42
4W	2	326.8	323.4	2.46	1.21
5W	1	380.3	377.2	2.27	1.37
6W	2	459.7	457.9	2.19	1.02
7W	1	543.4	543.5	.87	1.29
7R	2	666.3	666.8	1.13	.90
8R	10	796.2			

NOTE 1 : CORRECTED TO STANDARD WEIGHT OF 103.5 LBS.
NOTE 2 : n DENOTES NUMBER OF OCCASIONS;
EACH OCCASION CONSISTS OF A 5 ROUND GROUP
NOTE 3 : ABOVE DATA DERIVED FROM M825 MODIFIED PIP TEST

Table 3. Standard Muzzle Velocity (m/s) Comparisons for M825 with Standard Base

CHARGE	MUZZLE VELOCITY STANDARD M825	M483A1
	M109A1 HOWITZER	
3W	294.9	294.9
4W	334.8	334.8
5W	385.9	385.9
6W	461.6	461.6
7W	546.8	546.8
7R	659.0	659.0
	M198 HOWITZER	
3W	285.2	285.2
4W	326.5	326.5
5W	381.3	381.3
6W	460.7	460.7
7W	546.2	546.2
7R	660.0	660.0
8R	803.0	

NOTE 1 : CORRECTED TO STANDARD WEIGHT OF 103.5 LBS.
NOTE 2 : ABOVE DATA DERIVED FROM FCI-155-AN-A DOCUMENTS

Table 4. Example of Ballistic Similitude Comparison

Ballistic Coefficient (Range)

Charge	QE	Difference of plotted point from constant line (Figure 8)	Partial from reduced data	Difference dx	PE-TABLE G FT-155-AN-1
	mils	%	dx/dc (m/%)	meters	meters
4W	350	1.19	7.9	9.4	20
4W	550	1.11	5.5	6.1	27
4W	950	.40	6.9	2.8	29

Lift Factor (Deflection)

Charge	QE	Difference of plotted point from constant line (Figure 14)	Partial from reduced data	Difference dz	PE-TABLE G FT-155-AN-1
	mils		dz/dl (m/1)	meters	meters
4W	350	.075	34.8	2.6	3
4W	550	.045	82.8	3.7	4
4W	950	.015	225.9	3.4	6

Table 5. Precision Probable Error Comparisons of M825 Projectile Designs with M483A1 Projectile

CHARGE	HOWITZER	QE	RANGE PE_R M483A1	RANGE PE_R M825 MOD PIP BASE	RANGE PE_R M825 STAN. BASE	DEFLECTION PE_D M483A1	DEFLECTION PE_D M825 MOD PIP BASE	DEFLECTION PE_D M825 STAN. BASE
3W	M109A1	550	41.5	25.1	29	2.5	2.6	3
3W	M198	750	98.6	96.3	32	4.6	6.4	5
3W	M109A1	1150	44.1	23.3	25	6.8	2.7	6
4W	M109A1	350	9.3	23.2	20	5.0	5.9	3
4W	M198	550	30.1	97.0	27	4.0	4.1	4
4W	M198	950	84.7	69.2	29	6.6	5.2	6
5W	M109A1	550	14.4	23.7	23	12.1	5.6	4
5W	M109A1	750	16.7	34.6	26	.6	4.0	5
5W	M198	1150	27.4	49.5	22	9.0	7.3	7
6W	M198	350	32.7	61.9	14	2.1	6.2	3
6W	M198	550	50.4	52.0	19	8.7	5.5	5
6W	M109A1	950	14.5	35.9	20	8.2	7.8	7
7W	M109A1	550	12.3	25.2	18	13.9	18.8	7
7W	M198	750	20.1	30.7	21	.8	4.1	10
7W	M109A1	1150	2.3	11.7	19	6.4	4.8	12
7R	M109A1	350	36.0	25.9	28	6.6	7.2	7
7R	M198	550	46.9	36.3	33	6.4	1.9	10
7R	M109A1	750	66.1	32.4	38	14.5	15.9	14
7R	M198	950	49.9	30.1	40	13.7	7.2	15
7R	M109A1	1150	58.3	23.9	34	20.3	27.7	17

NOTE 1 : QE measured in mils; PE_R and PE_D measured in meters.
NOTE 2 : PE values for M825 standard base projectile come from FT 155-AN-1.
NOTE 3 : PE values for M825 modified PIP base projectile and M483A1 projectile come from M825 MOD PIP Test.

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