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MULTIPLE POINT IGNITION IN HARP GUNS

by

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March 1967

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BALLISTIC RESEARCH LABORATORIES
ABERDEEN PROVING GROUND, MARYLAND

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GVBull/CHMurphy/DLyster/sjw
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MULTIPLE POINT IGNITION IN HARP GUNS

ABSTRACT

The usual powder charge in the 16-inch HARP gun can be as long as 12 feet in an even longer chamber. If the charge length is more than 2 feet shorter than the available chamber, the pressure time curve can be significantly improved by dividing this interval into 2 to 4 sub-intervals by use of wooden spacers. An even more dramatic improvement can be achieved by igniting this column of powder at several points. Recently, five point ignition with two squibs in each location has been used in the 119-foot long 16-inch gun at Yuma Proving Ground, Arizona with very good results.

The service charge for a 16-inch gun is 660 pounds of standard 16-inch gun propellant. This charge will launch a 3000-pound projectile at 2800 feet per second, but is too slow burning to launch the standard HARP projectile plus sabot weight of 410 pounds at this velocity. With multiple point ignition, 1275 pounds of this propellant accelerated the HARP projectile to 5900 feet per second and an apogee of 414,000 feet was achieved.

Even better performance can be achieved with multiple point ignition. A WM/M propellant with 0.220 web (920 pounds) allows the HARP projectile to reach 6800 feet per second and an altitude of 540,000 feet while a 0.225 M8M propellant yields a muzzle velocity of 7000 feet per second and a 590,000-foot apogee.

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INTRODUCTION

A basic aim of the HARP program is the use of gun-launched projectiles and gun-boosted rockets to reach extreme altitudes.[1-3*] 5-inch gun-launched projectiles have reached 250,000 feet, 7-inch gun-launched projectiles have exceeded 330,000 feet, while a HARP extended 16-inch gun has reached 590,000 feet with a 185-pound projectile. With the 16-inch gun, very long charge lengths have been used and ratios of charge weight to in-gun projectile weight greater than three were encountered.

The host of ballistic data available on conventional guns along with semi-empirically developed computer programs based on conventional solutions[4] have been used to predict 16-inch HARP gun performance. With the large number of firings used in the program, many variations in propellant loading and ignition techniques were introduced This report has been prepared to correlate the results of numerous HARP firings,[5-7] and to present conclusions based upon them.

THEORY

The model generally used to predict gun performance is that postulated by authors such as Hunt and Hinds.[8] Implicit in this model are the assumptions of a uniform shot start pressure, initial burning on all surfaces, and a pressure distribution at any time which is quasi-dynamic.[4]

The standard method of solution is to determine the amount of energy released by the burning propellant (from thermodynamic characteristics and burning rate), and from this to calculate the space mean gas pressure. Account is taken of the covolume factor in determining the volume available for gas.

Superscript numbers denote references which may be found on page 32.

The motion of the vehicle can be described only if the pressure acting on its base is known, and this pressure is defined by a semi-empirical equation given by Leduc[8] as the ratio

$$\frac{\text{Breech Pressure}}{\text{Base Pressure}} = 1 + \frac{1}{2}\,\frac{\text{Charge Weight}}{\text{Shot Weight}} .$$

The validity of the solution of the ballistic problem will depend critically on the ability of this pressure gradient to describe the true pressure distribution.

HARP GUN SYSTEM

In the HARP application, 16-inch guns are used at their highest operable level with breech pressures running consistently 10 to 20 percent over normal service usage. It is essential to know and control accurately the barrel pressure distribution to prevent over-loading of both the gun structure and the missile structures. In order to reach the high launch velocity requirements of the program, barrel lengths vary from 105 feet for the Highwater gun to 119 feet for the Barbados and Yuma guns. In the work reviewed here, shot weights varied between 400 and 450 pounds, with a maximum velocity of 7000 feet per second. A lighter 250-pound projectile has been fired from the Highwater gun at 8400 feet per second.

A photograph of the Yuma 16-inch gun is shown in Figure 1 with internal geometry sketched in Figure 2. The chamber has been extended some 5 feet into the barrel, beyond the normal seating position. Similar installations at Barbados, West Indies, and Highwater, Quebec, have essentially the same internal geometry. The limiting loading curve of the barrel for the Barbados gun (Mk 2) is shown in Figure 3 along with a typical predicted maximum pressure distribution.

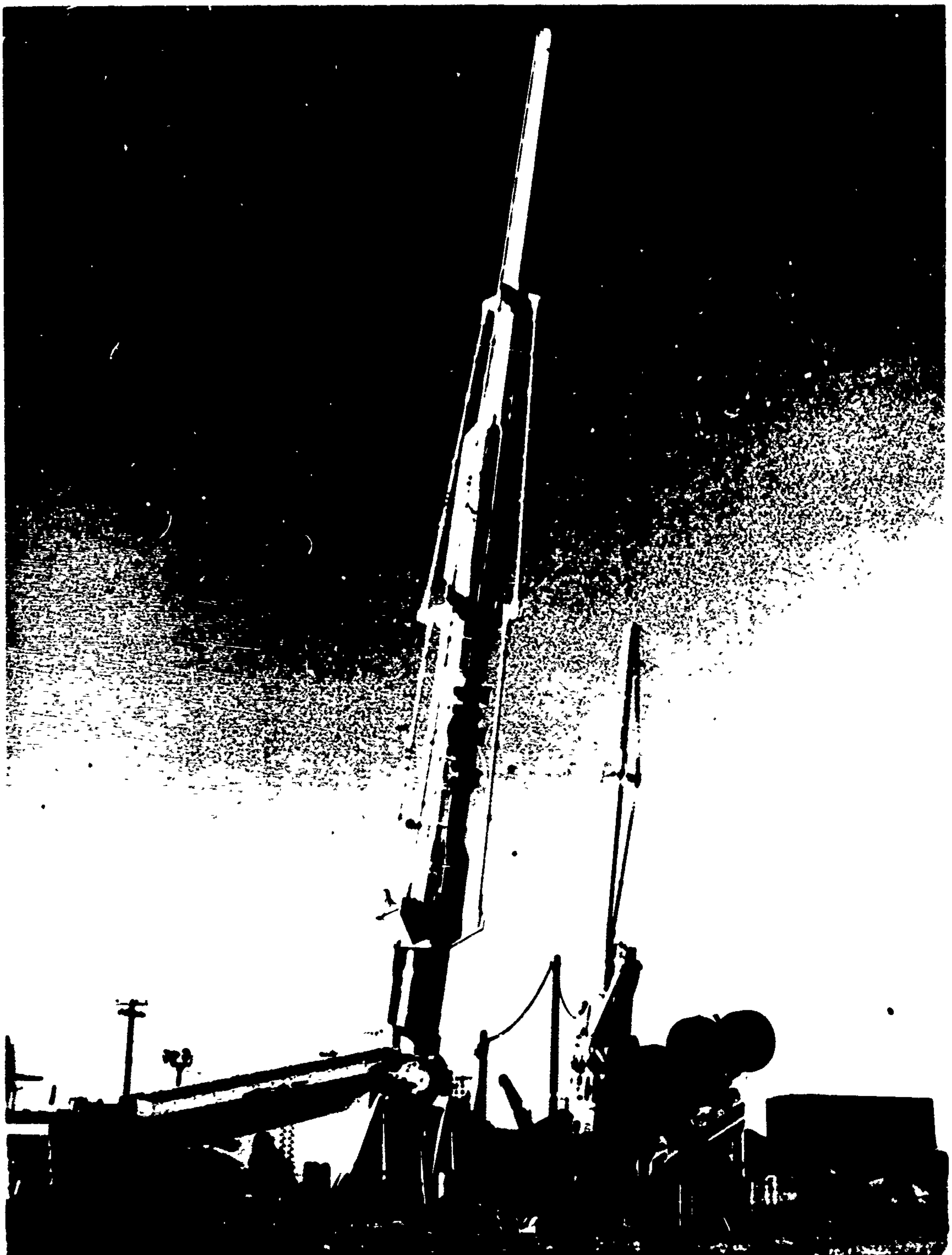
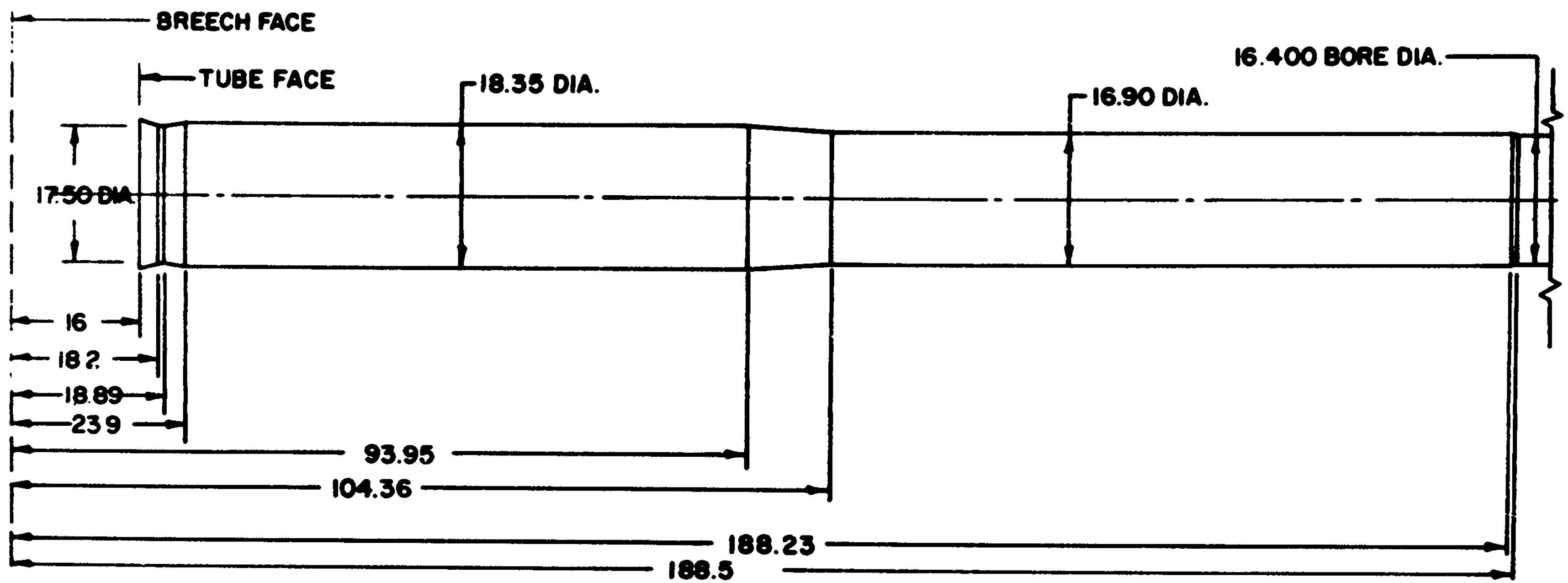


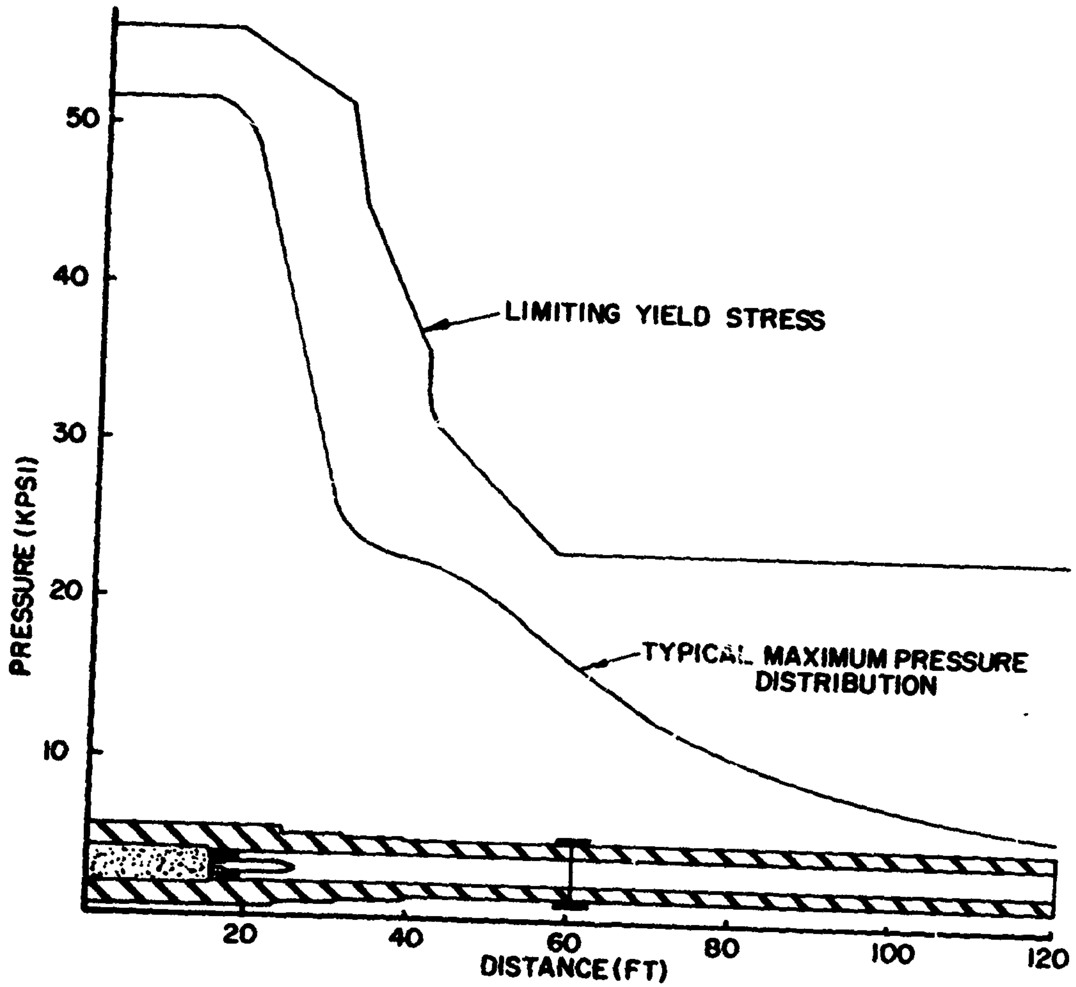
FIGURE 1. 5-INCH AND 16-INCH GUN AT YUMA PROVING GROUND, ARIZONA



TOTAL LENGTH OF GUN FROM BREECH FACE TO MUZZLE IS 119 FT. 4 INS.

CHAMBER OF 16-INCH YPG GUN

FIG. 2



16-INCH GUN LIMITING STRESS AND PRESSURE DISTRIBUTION

FIG 3

For any given powder, the maximum breech pressure and barrel pressure distribution is controlled by varying the burning rate (i.e., by changing web size), charge weight, and charge distribution. In addition, the ignition method can radically alter the pressure histories, particularly for a very long chamber. This report summarizes the progression of ignition techniques from the first HARP 16-inch firings in January 1963 to the present. These firings were made primarily to obtain altitudes over 100 km; ballistic instrumentation was secondary. Current firings use more extensive instrumentation, so that with direct measurement of barrel pressure distribution some of the observations noted herein may be further substantiated in the near future.

RESULTS

Most of the guns were fired with the standard grain geometry shown in Figure 4 but varying web size. Recently, strip propellant has been used to study regressive burning. Powder compositions used have included double-based (NC-NG) solventless propellant (M8M), double base solvent propellants (WM/M), and single base (NC) propellants typified by the U.S. Navy variety known as "pyro" from its pyrocellulose base. Powder characteristics are summarized in Table I.

Table I. Powder Characteristics

Type		M8M	WM/M	PYRO
Density	lbs/in.^{3}	0.0573	0.0575	0.0578
Force Constant	in.-lbs/lb	4,532,000	4,480,000	4,070,000
Isochoric Flame Temperature	^oK	3,400	3,220	2,570
Specific Heat Ratio		1.228	1.24	1.26
Covolume	in.^{3}/lb	27.7	25.5	27.0
Burning Low*	α	1.0	1.05	0.85
[$R = \beta p^\alpha$, in/sec]	β	0.265 x 10^{-3}	0.200 x 10^{-3}	0.560 x 10^{-3}

*Note: Pressure in psi.

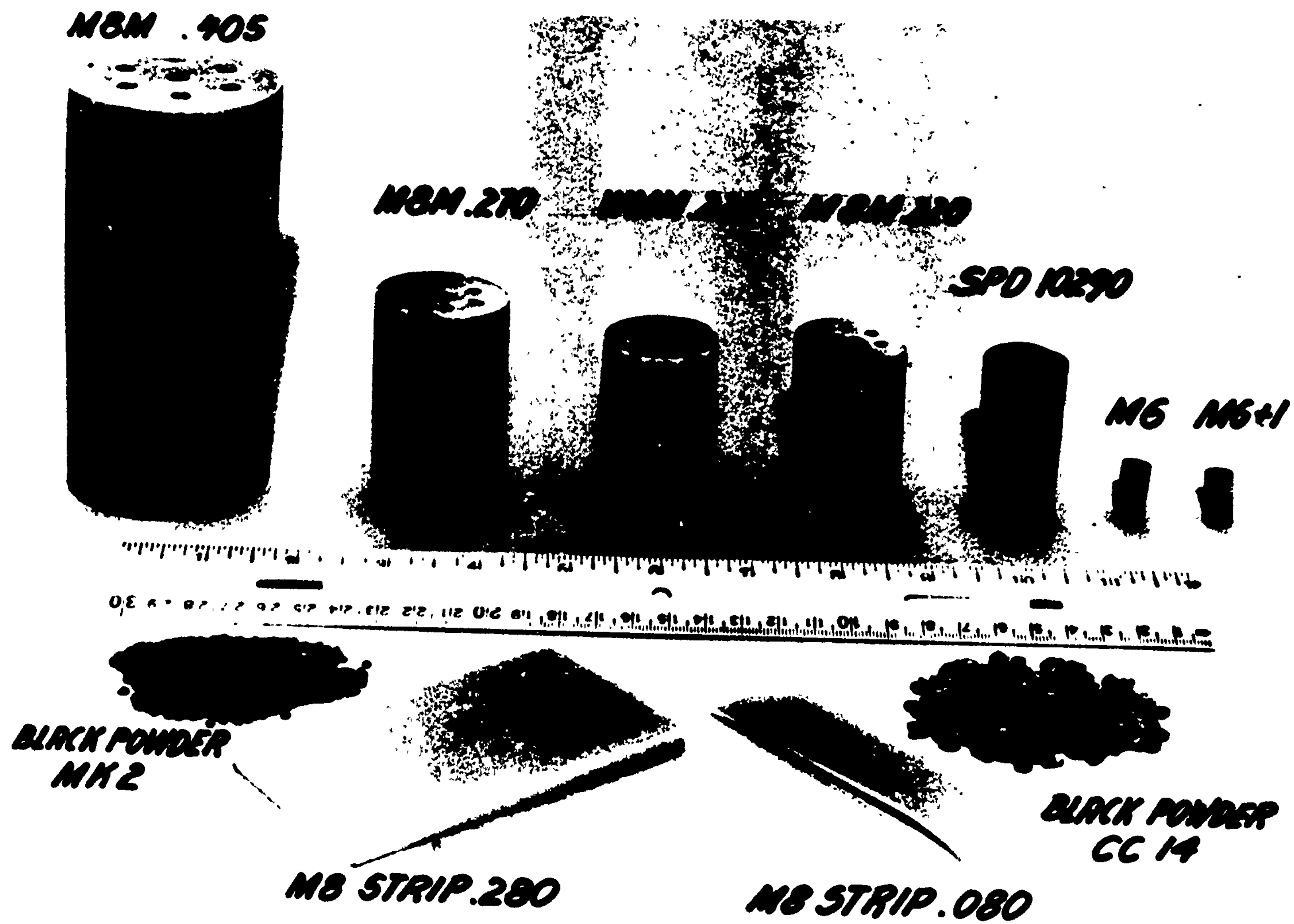


FIGURE 4. STANDARD GRAIN GEOMETRY

Single Point Non-Spaced Charge Results

In early firings (1963-1965), the loading and ignition techniques were essentially those supplied to the HARP program by the Naval Weapons Laboratory (Dahlgren). Ignition was achieved by firing a standard primer into the bags nearest the breech. The powder was bagged in 100-pound units, with 200 to 400 gram-pouches of black powder sewn on each of the bags at the end facing the breech. In addition, the powder was essentially stacked at the breech end as shown in Figure 5.

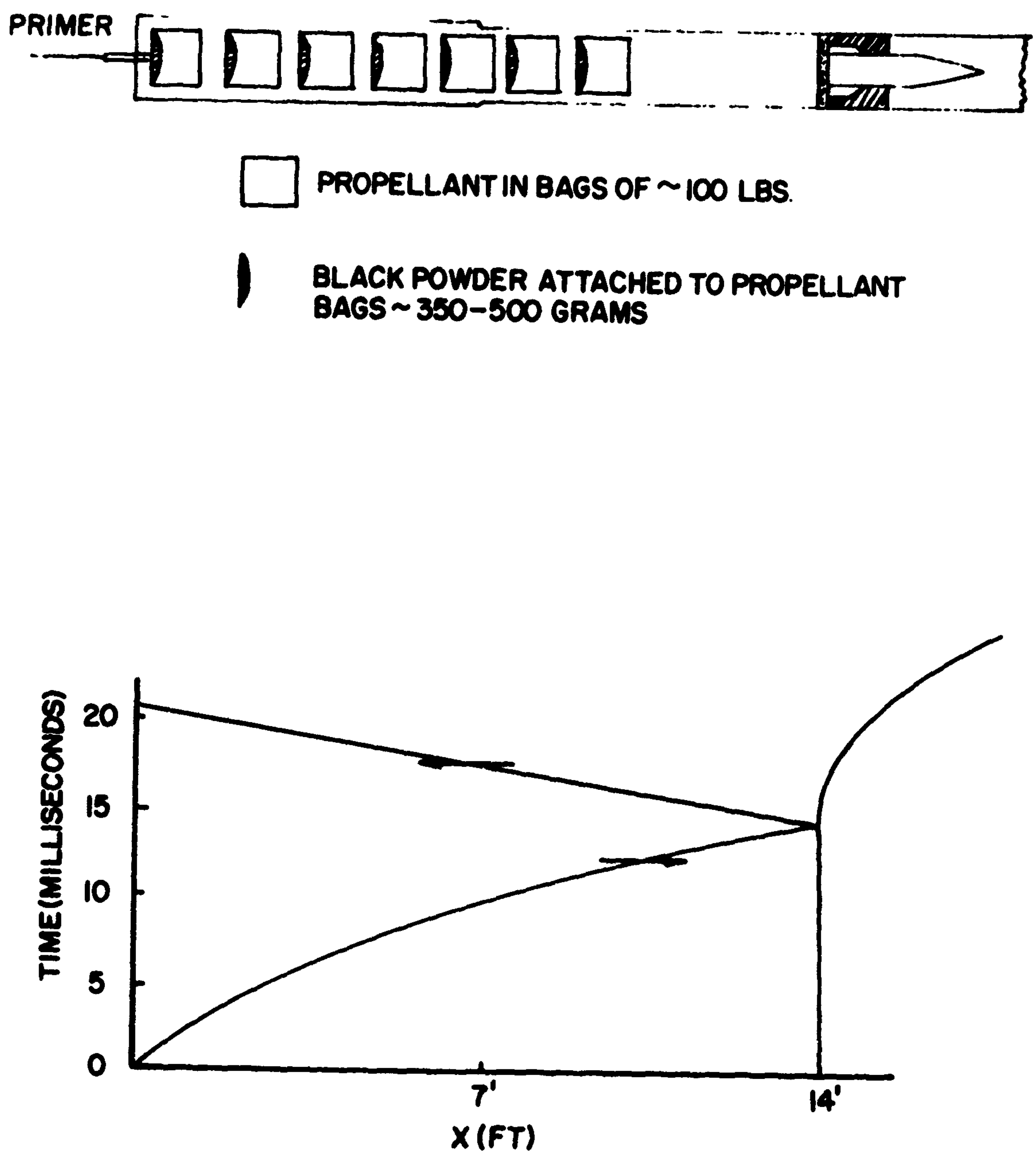
Based on the breech pressure records, the physical model of the combustion process found most plausible for this case is shown in Figure 5. When the primer fires, a burning front is initiated near the breech and propagates in the muzzle direction. A compression wave is generated ahead of the burning front which eventually degenerates into a shock, traverses the air gap between the powder and projectile, then reflects back off the projectile, and recompresses the burning grain. This creates a sharp rise in burning rate and chamber pressure. Typical breech pressure traces are given in Figure 6 covering a range of pressure peaks. The time for the reflected waves to reach the breech was used in postulating this model. Rather poor agreement between experimental peak breech pressure and corresponding theoretical muzzle velocity was noted.

Using this single point ignition system, evidence was observed of grain impact against the shot base. In all cases, this resulted in undesirable impact loadings and, in some cases, in vehicle break-up.

Single Point, Spaced Charge

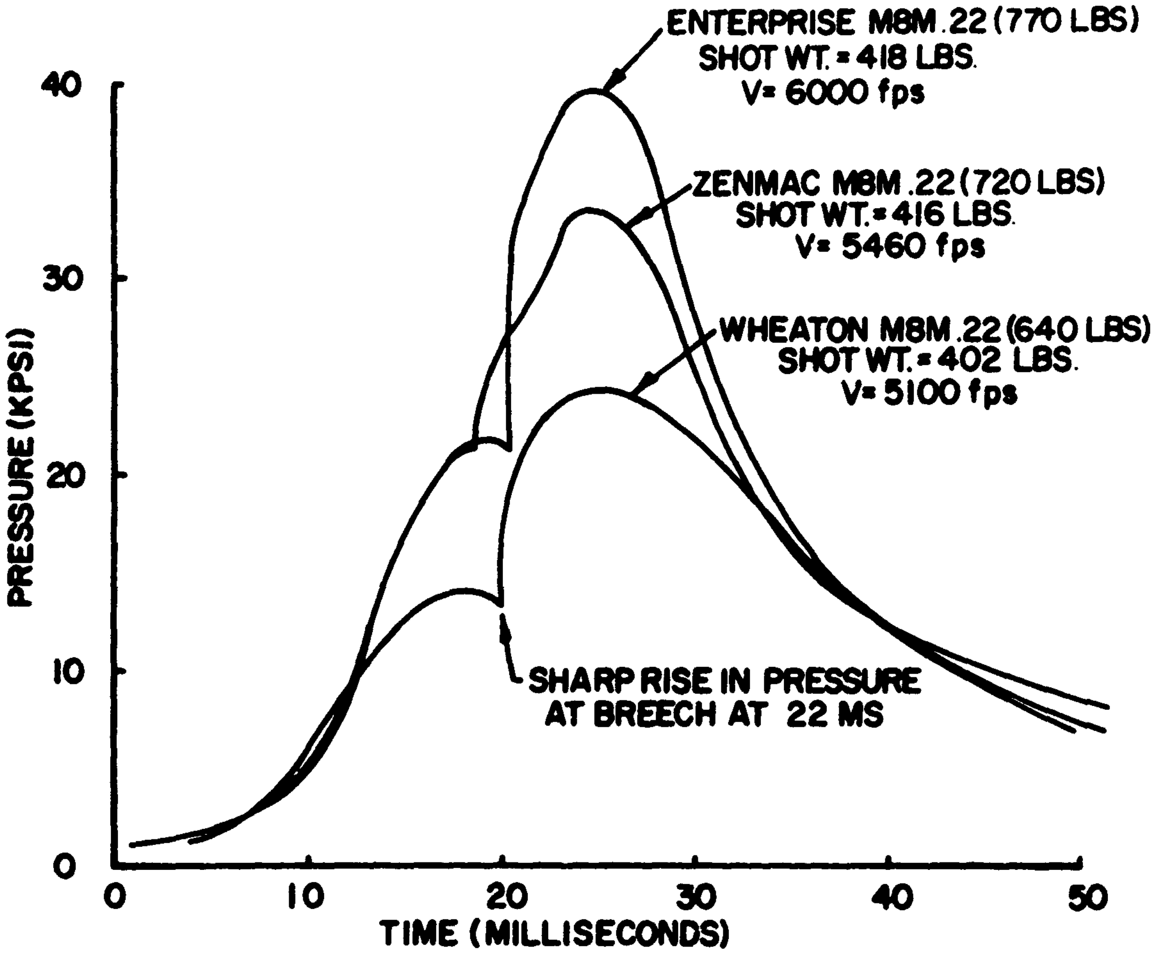
The non-spaced charge results were explained on the basis of shock formation and reflection across the air gap between powder and projectile. If this explanation is valid, the double hump in the pressure trace should be eliminated by uniformly spacing the charge in the chamber, as shown in Figure 7.

A typical pressure trace is shown in Figure 7, where it may be noted that a smooth profile is obtained in comparison with the double-peaked traces previously attained. It is also evident that a



STANDARD IGNITION 16-INCH GUN

FIG. 5



BREECH PRESSURE HISTORIES
(PRIOR TO NOVEMBER, 1965)

FIG. 6

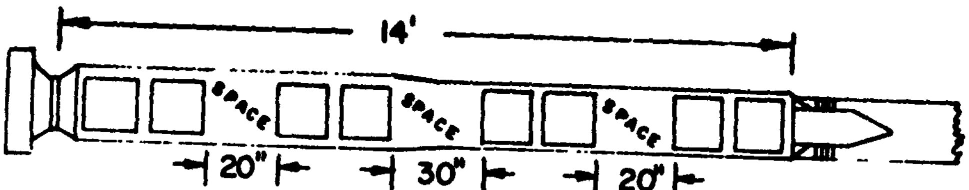
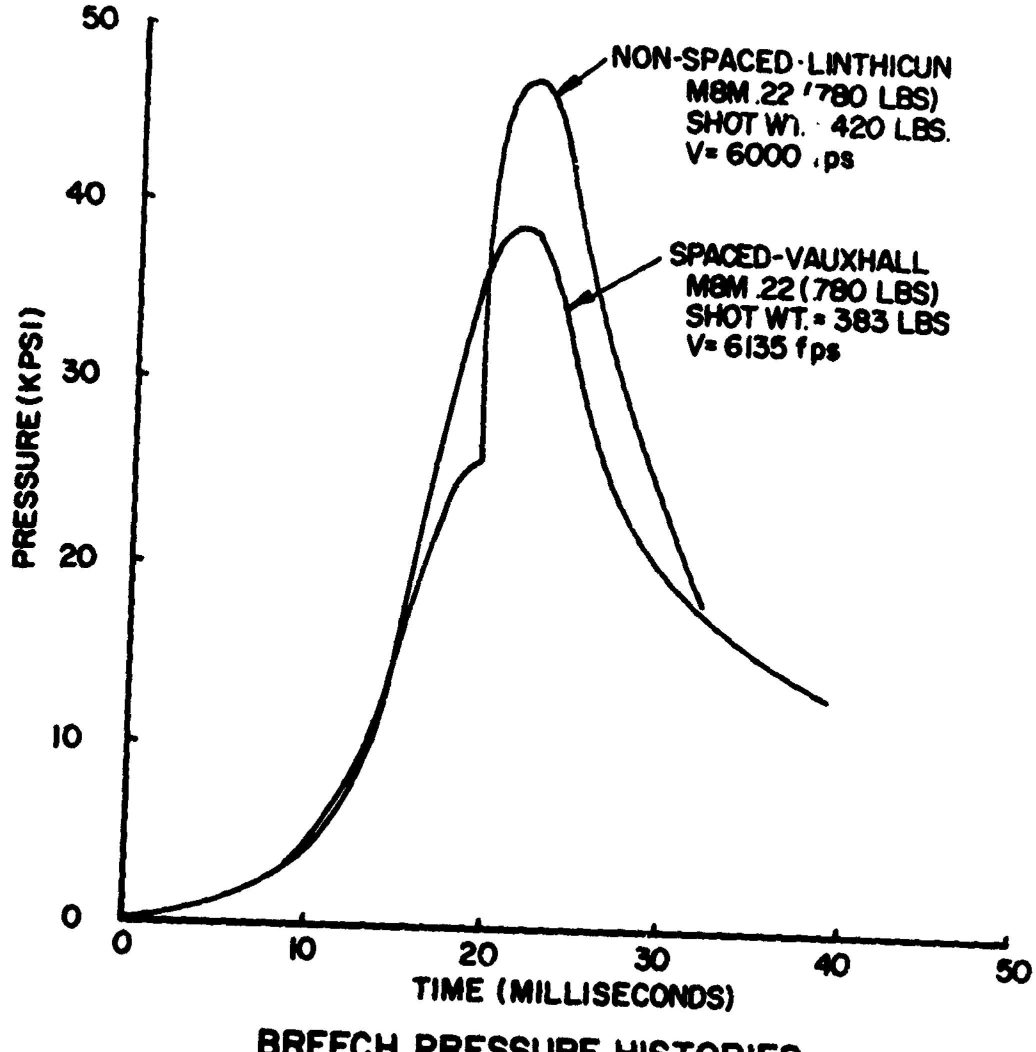


DIAGRAM OF SPACED CHARGE



BREECH PRESSURE HISTORIES
SPACED AND NON-SPACED CHARGES

FIG. 7

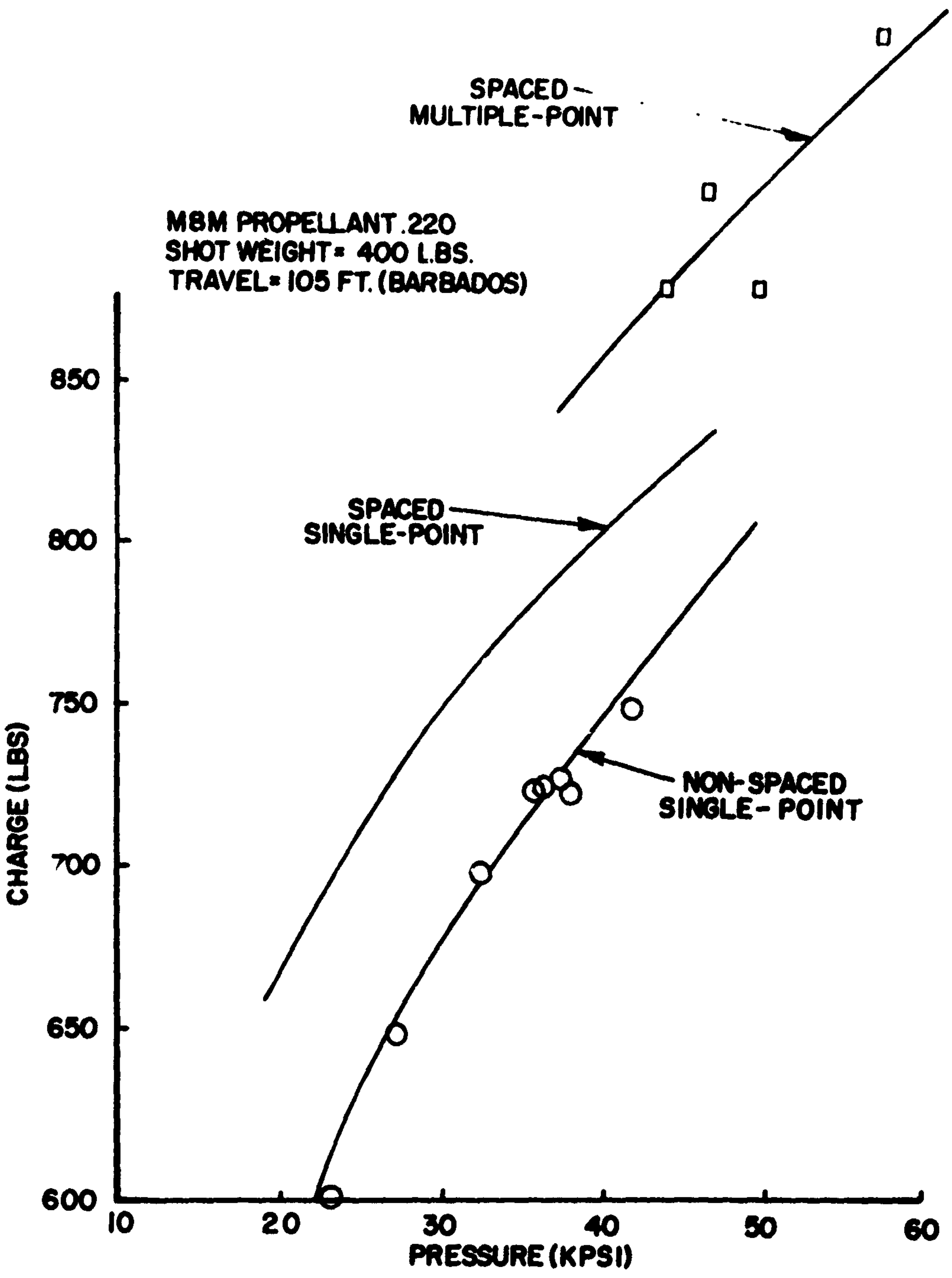
considerable reduction in maximum pressure occurs for the same charge. In Figures 8 and 9, peak breech pressure is shown against charge weight and muzzle velocity for this case. The non-spaced data are also shown for comparison, and it may be noted that spacing has reduced the peak breech pressure, but that the pressure versus muzzle velocity relation is about the same. It should be noted that the charge and velocity data for the spaced charge system were collected for a different web size propellant (M8M 0.270 instead of M8M 0.220). In theory, the fact that the lower burning rate for 0.270 allows a larger charge to be used should result in a higher velocity pressure relationship (dotted curve in Figure 9). Because of the limited amount of data available for M8M 0.220, there is no direct comparison, but it is expected that the difference would be indicated.

Visual examination of recovered sabot base plates showed that the problem of powder grain impacts still existed and some poor missile flights were observed.

Multiple Point, Spaced Charge

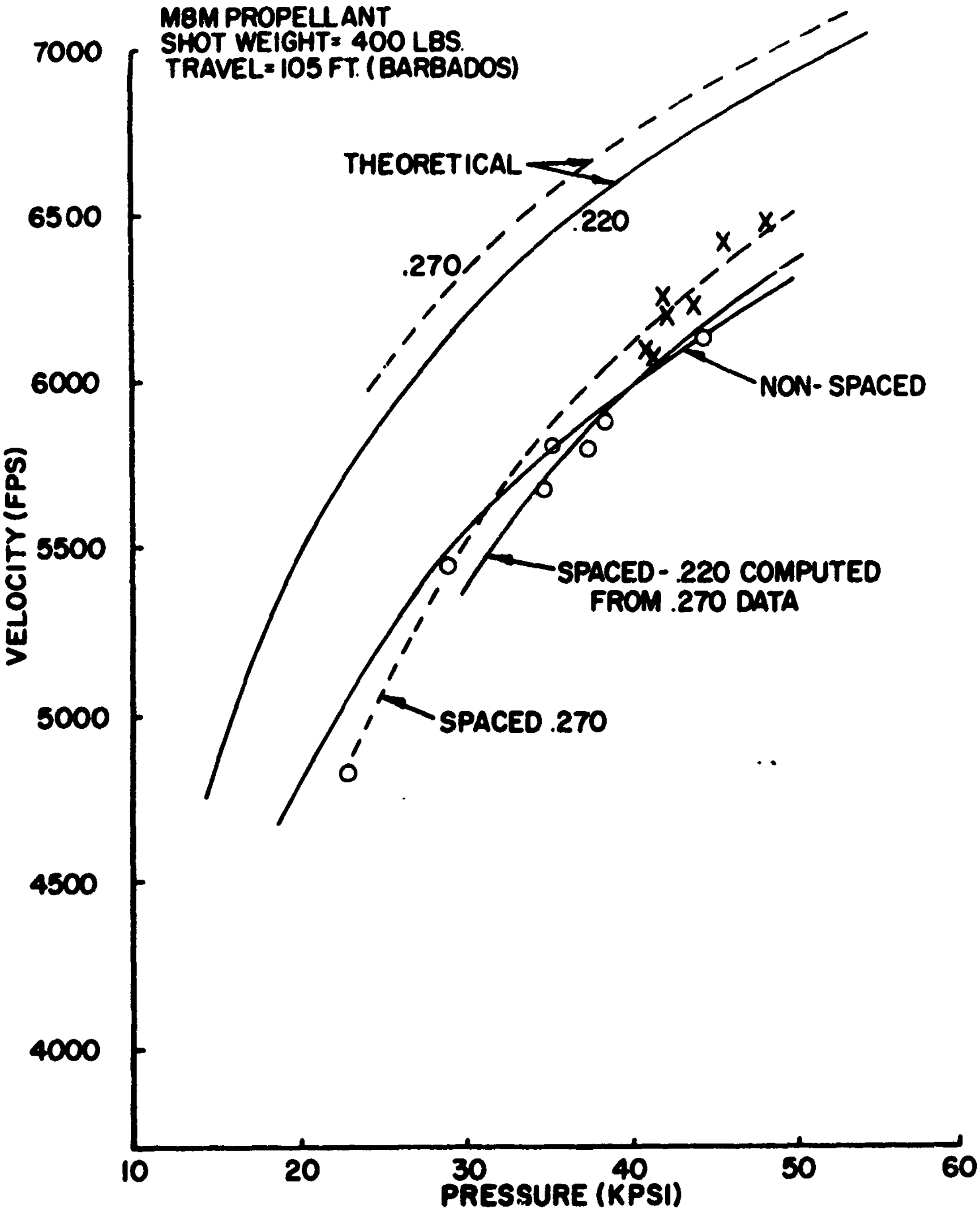
In order to provide more uniform ignition, electrically fired squibs (C. I. L. Pyrotechnic) were sewn into the black powder bags on five of the charges shown in Figure 10. Two squibs were placed at each ignition point to minimize the spread in squib firing time. By maintaining a voltage between 60 and 100 volts (current 5 amperes), variation in squib firing times was found to be within 1/2 millisecond.

The first tests of the multipoint ignition system were with the surplus 16-inch Naval propellant (pyro). Previous attempts to use this propellant with the very light HARP projectiles (415-pound saboted subcaliber vehicles instead of the 2800-pound Naval projectile) had failed to provide peak pressures over 20,000 psi. As can be seen from Figure 11, multipoint ignition allowed us to reach 50,000 psi with very smooth pressure curves. For the higher pressure shots, shear lips were placed on the sabot base plates to hold the shot until a breech pressure of 10,000 psi was reached. The success of multipoint ignition with pyro



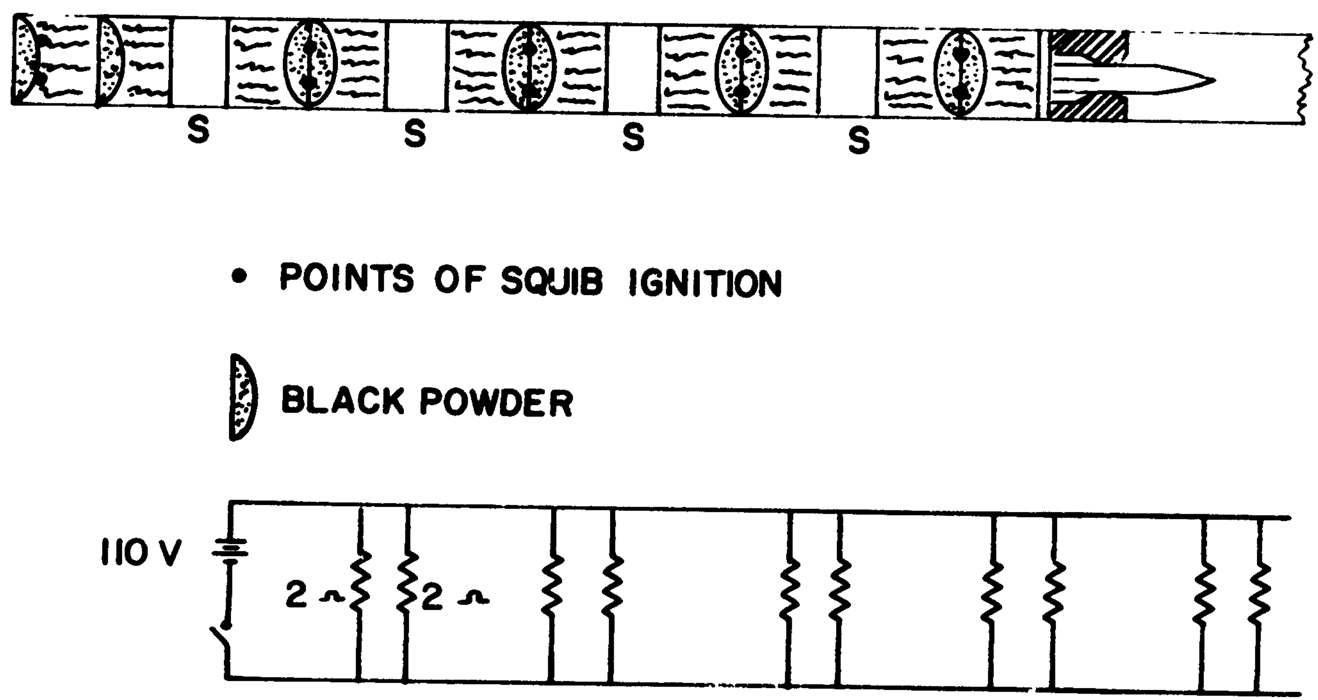
CHARGE vs PRESSURE

FIG. 8



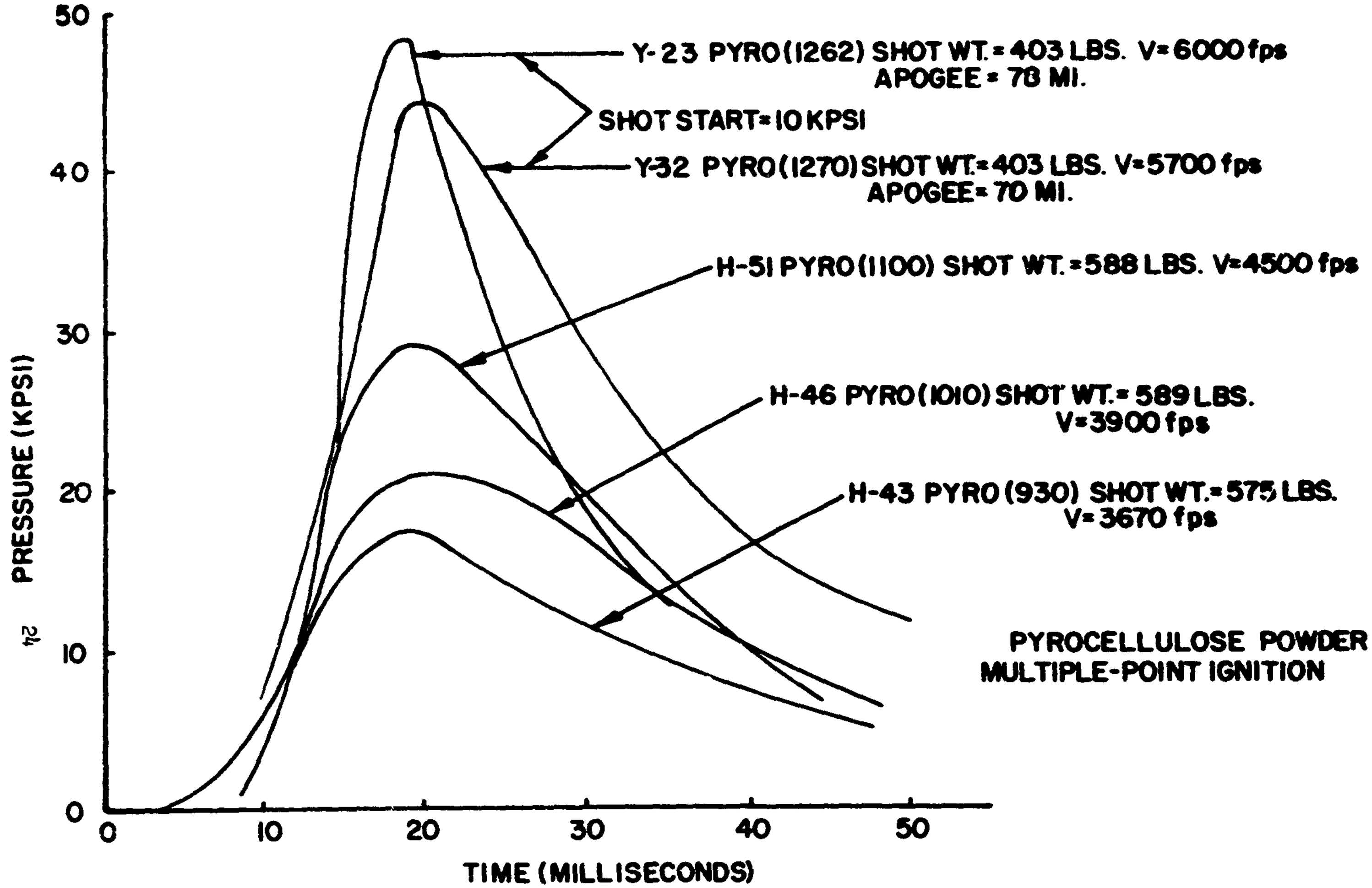
VELOCITY vs PRESSURE

FIG. 9



MULTIPLE-POINT IGNITION

FIG. 10



PRESSURE-TIME CURVES

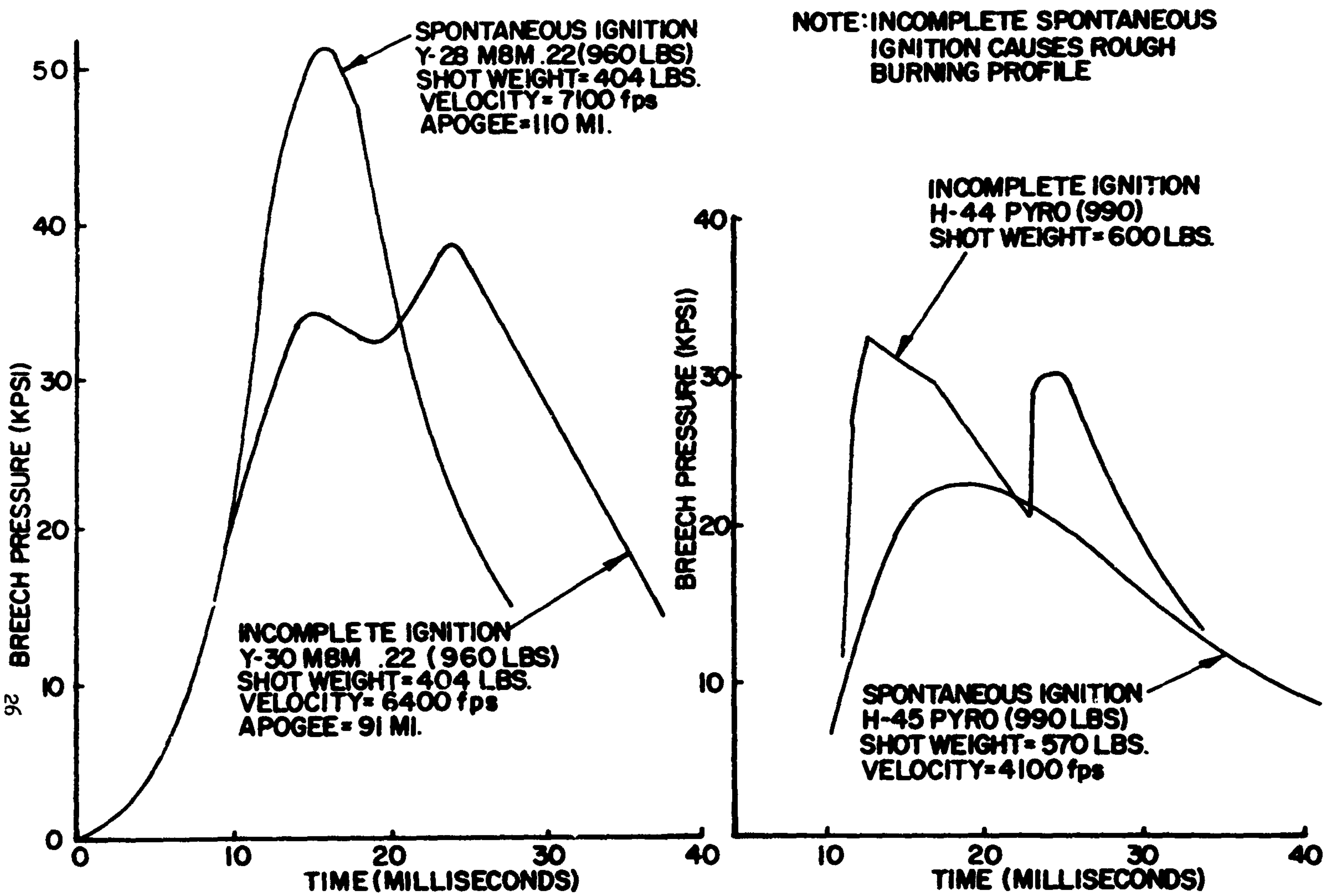
FIG. 11

allows the use of this surplus propellant for sounding missions up to 77 miles. It is interesting that the pyro charges for this use have been as large as 1300 pounds while the service charge for the standard 16-inch projectile is 660 pounds. Figure 12 shows rough pressure profiles resulting from malfunctioning of some ignition points. In the early stages of the experimental studies on ignition, the number of ignition points was increased from two to four, and then to five with two squibs per point for redundancy. It was found that this greatly increased the reliability of the ignition system, and pressure traces as shown in Figure 12 were nearly eliminated. In one instance, however, this method of redundancy failed, and the cause could only be traced to the non-functioning of one or several ignition points.

In Figure 13, breech pressure profiles are compared for the same charge weight with the different distribution and ignition systems. The top two subfigures compare spaced and unspaced charges of the same weight for two different powders and the bottom two compare single point and spaced multipoint ignition for M8M powder. In the first multipoint comparison, a non-spaced single point ignition pressure profile is plotted with a profile for multipoint ignition of the same charge weight. The second comparison involves spaced charges yielding the same peak pressure for the two ignition systems.

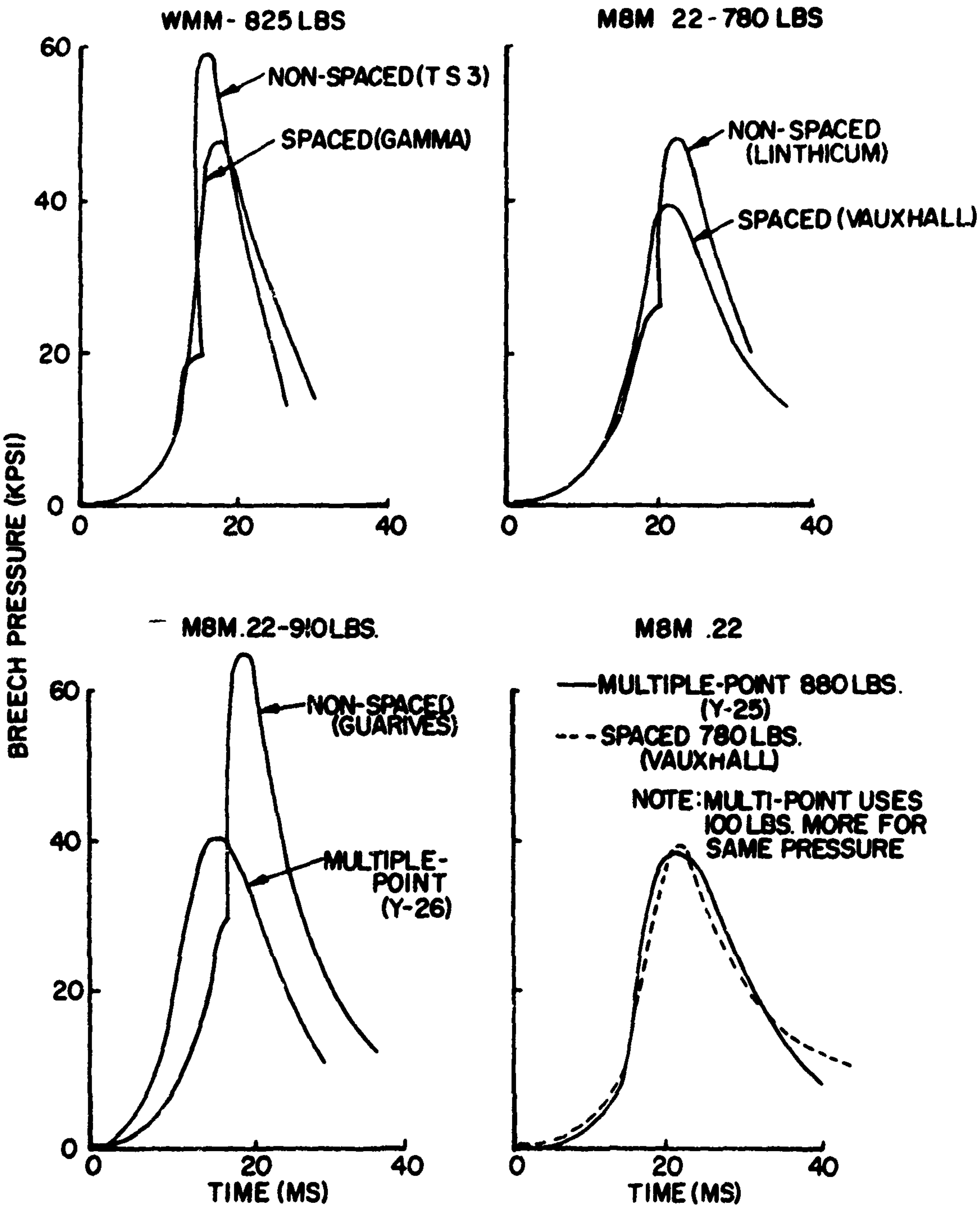
In Figure 14, the muzzle velocity is plotted as a function of breech pressure for the Navy powder and compared with theory. Very good agreement may be noted. Figure 15 shows similar results for M8M and WM/M powders, and indicates the improvement in velocity over the single point case. In Figure 16, breech pressure histories from theory and experiment are compared for several representative cases.

The theoretical model is based on the supposition that velocity is proportional to the area under the breech pressure-time curve (Leduc gradient). An analysis of any one of the pressure histories in Figure 16 shows that the area under the experimental curve is considerably less than that under the theoretical curve. Integration of the experimental breech pressure curve, using the Leduc distribution, yields



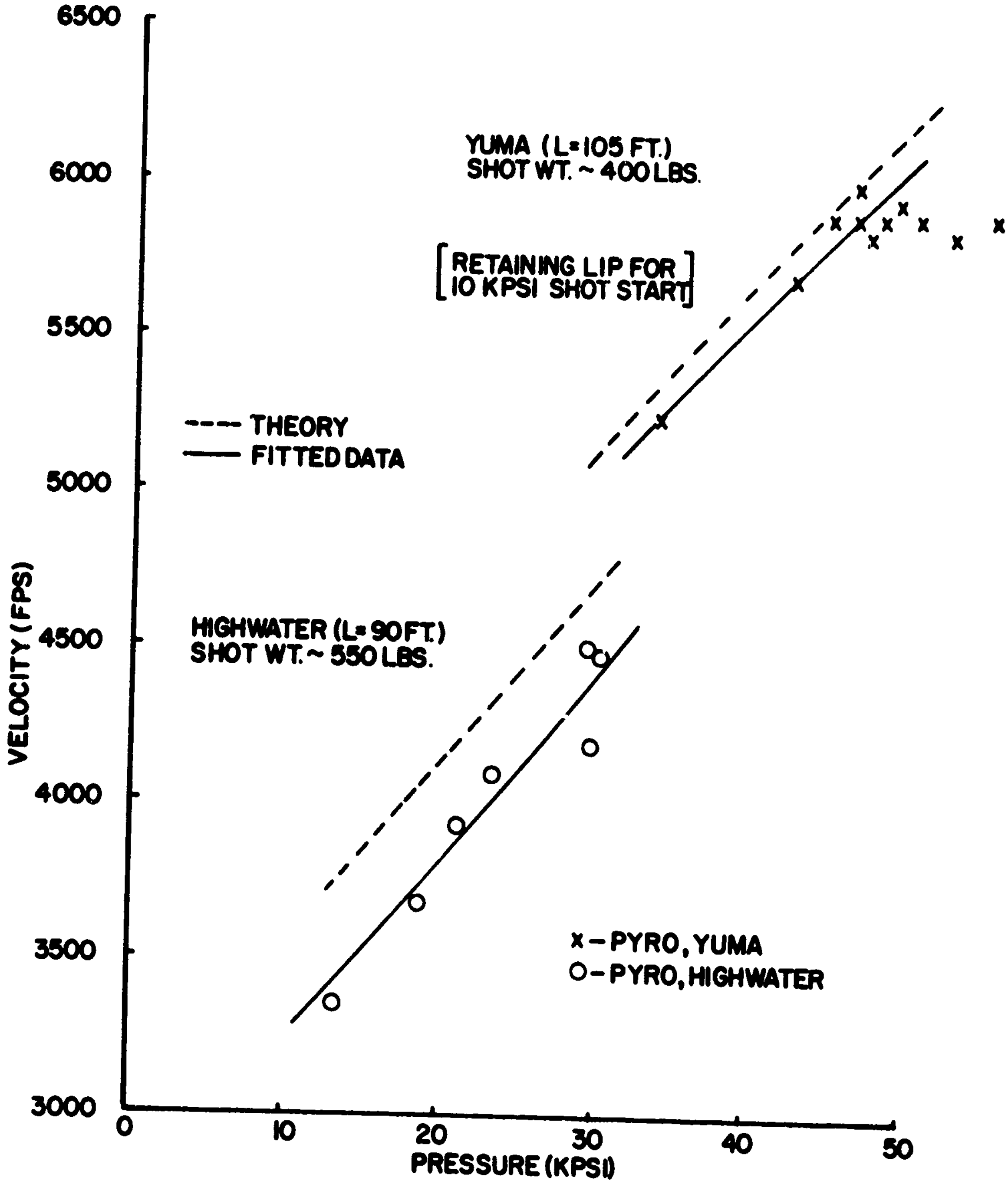
MULTIPLE-POINT IGNITION

FIG. 12



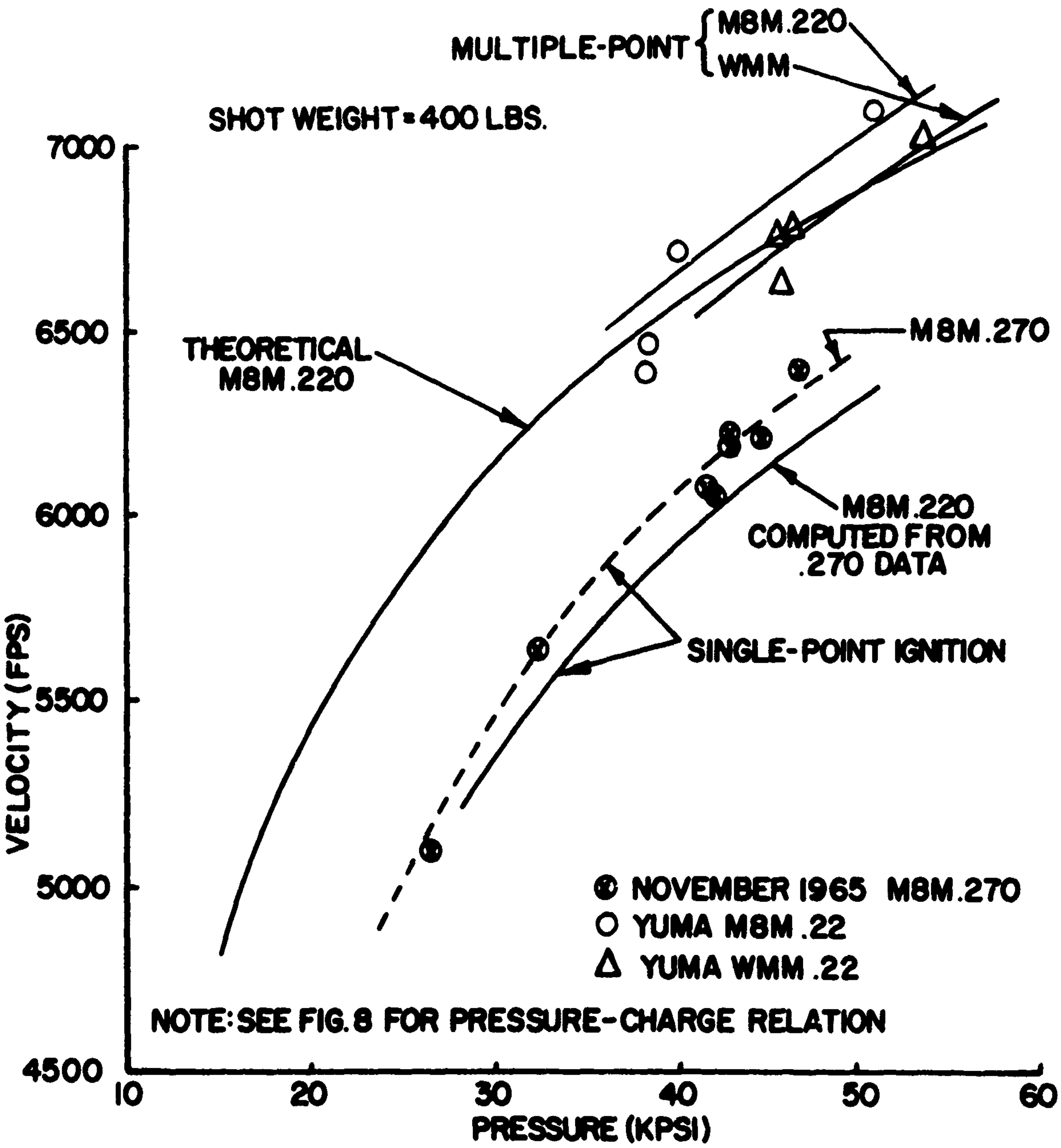
SUMMARY OF BREECH PRESSURE PROFILES

FIG. 13



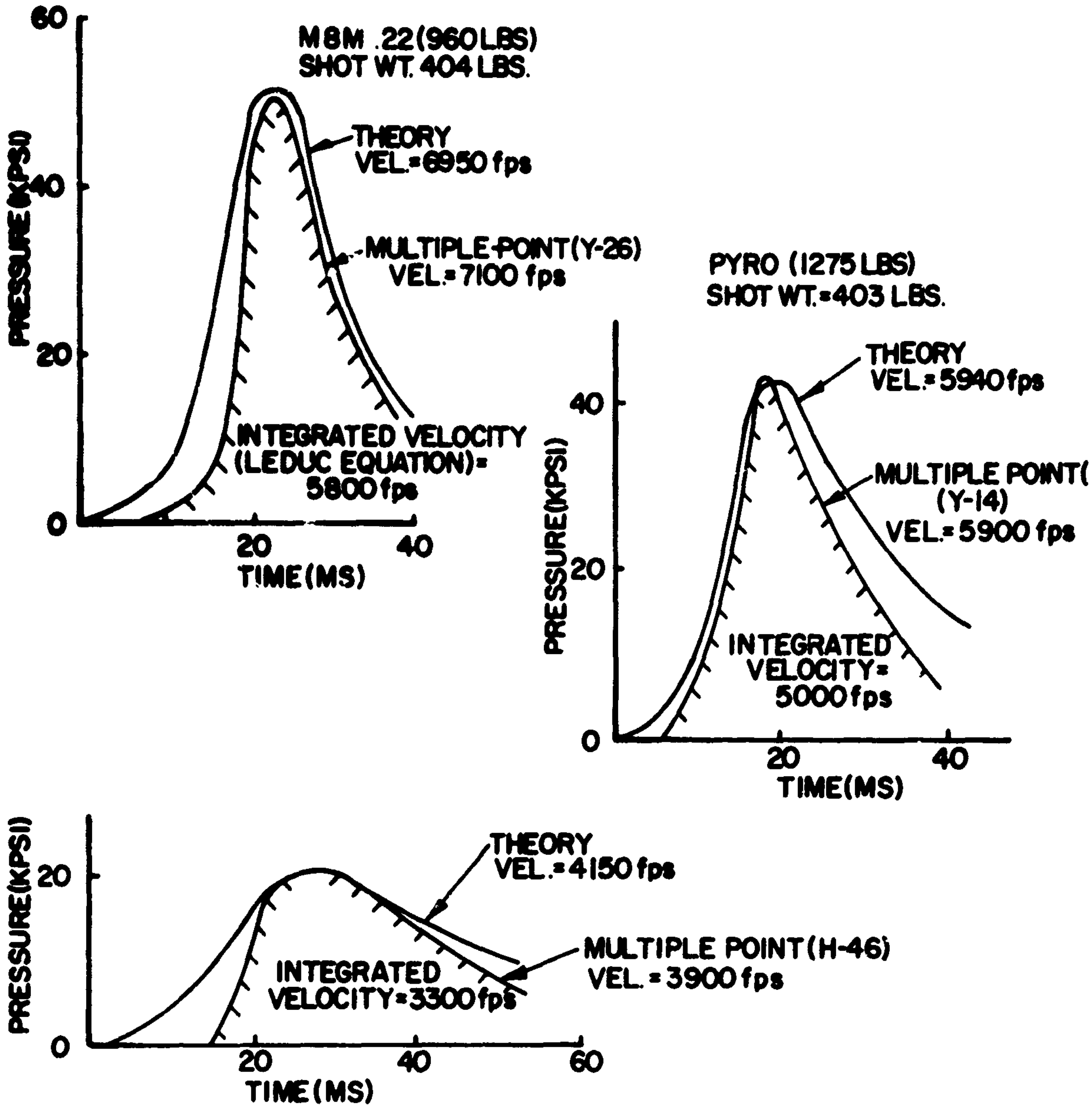
MULTIPLE-POINT IGNITION RESULTS
VELOCITY vs PRESSURE

FIG. 14



MULTIPLE-POINT RESULTS COMPARED WITH THEORY
VELOCITY vs PRESSURE

FIG. 15



BREECH PRESSURE PROFILES
MULTIPLE-POINT AND THEORY

FIG. 16

muzzle velocities in the order of 15 to 20 percent lower than the corresponding theory. However, the results show that muzzle velocities are usually greater than expected. Thus, the experimental velocities imply a barrel pressure distribution somewhat higher than the theory predicts.

The spaced charge multiple point ignition system was found to result in considerable improvement in vehicle launch reliability. Missiles previously encountering structural problems at muzzle velocities of 6400 feet per second were launched at velocities over 7000 feet per second using this system.

CONCLUDING DISCUSSION

These studies have emphasized the requirement for good ignition, particularly in the case of the long chamber used in the HARP program. The applicability of the theory is limited and since barrel pressure distribution is critical in vehicle design, improvements are required. Currently, pressure histories are being taken along the barrel and will be used to improve the analytical predictions.

ACKNOWLEDGMENTS

The work and the studies involved over the past three years to evolve a suitable technique for the utilization of high performance guns has required the continuing efforts of all those on the HARP staff. Dr. G. J. Gallagher of the University of the West Indies in Barbados has provided exceptional assistance and it was primarily through his insight and suggestion that many of the innovations have been made.

This work was jointly supported by the Canadian Department of Defense Productions and the U.S. Army.

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