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A 50-CALIBER DEFORMABLE-PISTON GUN FOR LAUNCHING HYPERSONIC FREE-FLIGHT RESEARCH MODELS

By Jack D. Stephenson [1962] 1st Presented at the Aerotheo Range Assoc. 3d Meeting, Moffett Field, Calif., Mar. 22-23, 1963

A 50-caliber deformable-piston gun was put into operation in August 1961 by the Supersonic Free-Flight Branch at Ames. The geometry and general dimensions of this gun are indicated in ~~the first slide~~ figure 1. The overall length of the gun is 50 feet, with a launch-tube length of 12 feet or 288 calibers, and a pump-tube length of 36 feet or 203 diameters. The gun has a tapered section 10 inches (4.7 diam.) in length at the forward end of the pump tube. An interchangeable second tapered section, having a length of 6 inches or 2.8 diameters, has also been constructed. The initial firing of the gun was done with 1-gram (2/3-caliber) polyethylene models. A typical round fired by the gun with a 1-gram model might employ an all-polyethylene piston 6 diameters in length, a powder charge in the neighborhood of 200 grams of IMR 4198, and an initial charge of hydrogen of about 40 psia in the pump tube.

Some details of the high-pressure section are indicated at the bottom of ~~the first slide~~ figure 1. A stainless steel flat disk is used as a break diaphragm with a cruciform scoring at the center. The diaphragm, which petals into a conical indentation at the end of the launch tube, is designed according to recommendations of the Naval Ordnance Laboratory report on high-pressure bursting diaphragms (see ref. 1). Most of the diaphragms used have been designed to break at 20,000 psi.

It is believed that the gun performance has sometimes been adversely affected as a result of leakage of high-pressure hydrogen at the joint shown. The most recent solution to this problem is the use of a machined ring of lexan inserted at the point of leakage, together with a rubber "O" ring, both in the plane of the diaphragm. During firing the lexan is extruded slightly into the space between the parts. This has been successful in sealing the leakage, but it has not been tried at the highest pressures at which it is expected the gun will operate.

The second problem that has occurred in the operation of the gun has been some yielding of material at the breech end of the launch tube. This

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is believed to result from momentum transferred from the decelerating piston to the high-pressure coupling which in turn produces a compression load on the end of the launch-tube components. Troubles from this cause seem to have now been corrected by increasing the area over which the compression stresses are distributed.

The launch tube of this gun consists of a steel liner of 3/4 inch outer diameter, clamped between two grooved blocks forming a 4-inch square cross section, held together by 68 one-inch diameter steel screws. Figure 2 ~~The next slide~~ shows some results of shooting this gun. At the left side of the FIGURE ~~slide~~ the muzzle velocity is plotted against piston weight, for a model weighing 1 gram. The maximum velocity obtained so far is 27,700 ft/sec with a piston weighing 770 grams, which corresponds to a cylinder of polyethylene about 5.7 diameters in length. The pistons are generally cylindrical in shape with a conical hole 4 inches deep in the forward end. On the right side of the figure, ~~slide,~~ the muzzle velocity of the gun is plotted against the projectile weight. The results shown here were obtained while the gun was being operated as a model launcher for aerodynamic tests. The gun has been used in this way since the first of the year, operating at what we consider to be conservative performance levels, so that the current research programs will not be delayed as a result of damage to the gun. Attempts to improve the launching velocities will be made soon when a supply of gun replacement parts will be maintained.

Prior to the start of the proof-testing of this gun, calculations were made to furnish a basis for the selection of various operating parameters. Such parameters include the weight of the piston, the hydrogen-charging pressure, bursting pressure of the break diaphragm, and the velocity of the piston as determined by the powder charge, etc. These calculations are based on a solution which was programmed on the IBM 7090 computer by Mr. John Curtis and a colleague, who were then at the Naval Ordnance Test Center at China Lake. This program has been used at Ames with an application to the proof-testing of a 22-caliber gun developed

in the Hypervelocity Ballistic Range Branch. On the basis of the work with the 22-caliber gun, Mr. Curtis has empirically determined a criterion that can be used to predict the occurrence of damage to the high-pressure region of the gun. According to this criterion, the gun will not be damaged if the calculated pressure produced by piston, while it is being decelerated and deformed, does not exceed 600,000 psi. In the calculations, the piston is assumed to have no internal restraint to its deformation, so that it can be considered to act as a fluid in steady motion. Because of the similarity to pressures occurring in fluids, these pressures are referred to here as the piston hydraulic pressures. The program yields this hydraulic pressure as a function of time as well as the velocity history of the model and the pressure in the propelling gas and the pressures on the base of the model.

Figure 3 ~~The next slide~~ shows the results of the calculations applied to the 50-caliber gun. At the top of the figure ~~slide~~ on the left, the launching velocity is plotted against the velocity of the piston for two hydrogen-charging pressures, 31 and 42 psia. The piston velocity here is that occurring at the time the burst diaphragm breaks. Ordinarily, at this time the front of the piston is a short distance from the start of the tapered section. At the center of this figure ~~slide~~ is shown the maximum hydraulic pressure in the tapered section. It is seen that for the conditions considered here the pressures are always well below the 600,000 psi level, although at somewhat higher piston velocities than those shown, this pressure would probably be exceeded. At the bottom of the figure ~~slide~~, the maximum pressure on the base of the model during launch is shown as a function of the piston velocity. It is seen that the pressures remained relatively low. The effects of changing the hydrogen-charging pressure are small, both pressures giving the same muzzle velocity at a piston speed of 3400 ft/sec. For the calculations shown here the gun had a tapered section 10 inches long. The effect of changing from this to a 6-inch tapered section is indicated on the right side of the figure ~~slide~~. Again, the muzzle velocity is shown at the top, the maximum piston hydraulic

pressure in the center, and the maximum pressure on the base of the model at the bottom of the ~~slide~~ figure. It is seen that there is not a large effect on the muzzle velocity; however, the hydraulic pressure and the pressure at the base of the model have both been increased considerably.

In ~~the next slide~~ Figure 4 the effect of changing the weight of the piston is shown. The piston weights of 700, 1000, and 2000 grams are indicated, corresponding respectively to equivalent lengths of polyethylene cylinders of 5.14, 7.35, and 14.7 diameters. The ~~slide~~ figure shows that there is a large effect of these increases in piston weight on the computed muzzle velocity and on the hydraulic pressure and the maximum pressure on the model base. For the 2000-gram piston, the maximum hydraulic pressure exceeded the 600,000 psi limitation at a speed of about 1750 ft/sec. These calculations indicated that use of a lighter-weight piston at a higher piston speed would be conservative with regard to pressure loads. Consequently, this combination has been used for the preliminary test-firing of the gun.

~~The next slide~~ Figure 5 shows the calculated effects of changing the weight of the projectile. The launching velocity shown at the top indicates that the increase in the weight from 1 to 4 grams and 8 grams has a large effect on the muzzle velocity, as would be expected. The effect on the hydraulic pressure at the tapered section of the gun was not large, but the maximum base pressure on the model increased considerably with projectile weight. These calculations were based upon a piston weight of a thousand grams and a hydrogen-charging pressure of 42 psia. These combinations of conditions are not optimum for the projectile weights shown. More complete studies of the gun performance with heavy models are in progress.

In ~~the next slide~~ figure 6 a comparison is made of the results of these calculations with measured performance of the gun. Here again in the upper part of the ~~slide~~ figure, the muzzle velocity is plotted as a function of the piston velocity. For the calculations, piston weights of 700 and 1000 grams were assumed. The gun was fired with pistons weighing

770 grams and 840 grams. The horizontal lines, each of which represents one shot fired from the gun, are used because the piston speeds were not accurately determined. An effort was made to measure the speed of the pistons using a type of instrumentation employed successfully on a smaller-caliber gun. This instrumentation consisted of applying strain gages at two longitudinal locations on the outside of the pump tube to measure stress due to internal pressure. With the smaller gun, an oscilloscope record showed clearly the times when the piston passed the two strain-gage locations. However, in the case of the 50-caliber gun, the internal pressures were too small, and the effects of vibrations produced by the powder burning and by the piston motion were so large that the signal could not be interpreted to furnish the velocity information. Obviously, the piston velocities can be measured by removing the launch tube and firing the pistons past instrumented measuring stations. This has not been done for this gun, however, except with much heavier pistons than the ones indicated here.

Summarizing our experience with the operation of the 50-caliber gun, we have seen from the calculations that the maximum pressures at the base of the model are predicted to be relatively low for model-launching velocities up to and above 25,000 ft/sec. It is believed that the gun does function in practice so as to realize these low or moderate pressures on the model, while providing the observed high velocities. This is evidenced by our experience in launching saboted models. In a recent series of firings, with a model and sabot combination weighing 1.9 grams, the gun has been consistently launching aluminum models at velocities in excess of 23,000 ft/sec.

Reference

1. Rast, J. J.: The Design of Flat-Scored High-Pressure Diaphragms for Use in Shock Tunnels and Gas Guns. Ballistics Research Report 29, U. S. Naval Ordnance Laboratory, White Oak, Md. Jan. 1961.

H140503

GUN ASSEMBLY AND HIGH PRESSURE COUPLING

LAUNCH TUBE BORE
PUMP TUBE BORE 2.125 IN

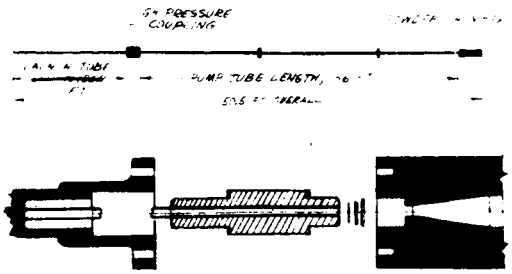

Fig. 1.

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EXPERIMENTAL GUN PERFORMANCE RESULTS

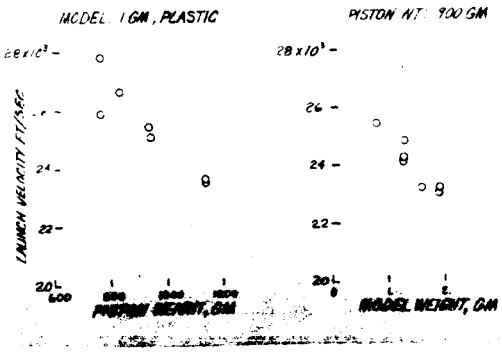

Figure 2

Fig. 3

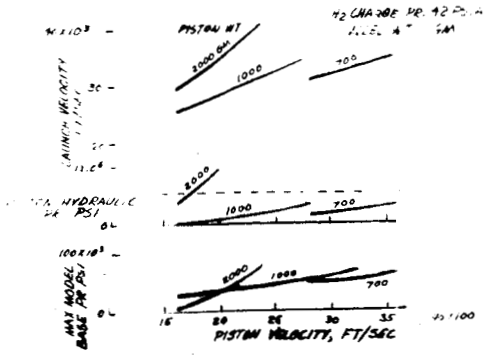
CALCULATED GUN PERFORMANCE
EFFECTS OF PISTON WEIGHT
PISTON WT
2000 GM
1000
700
2000
1000
700
2000
1000
700
15
20
25
30
35
PISTON VELOCITY, FT/SEC

Fig. 4

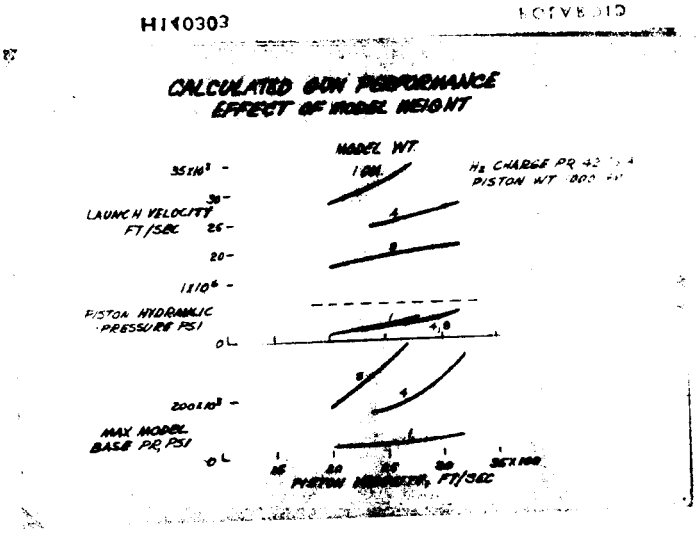
CALCULATED GUN PERFORMANCE
EFFECT OF MODEL WEIGHT
MODEL WT.
1 GM.
LAUNCH VELOCITY FT/SEC
PISTON HYDRAULIC PRESSURE PSI
MAX MODEL BASE PR. PSI
PISTON VELOCITY, FT/SEC

Fig. 5

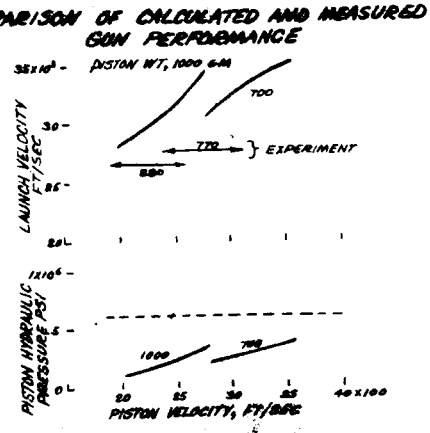
COMPARISON OF CALCULATED AND MEASURED
GUN PERFORMANCE
PISTON WT, 1000 GM
700
EXPERIMENT
LAUNCH VELOCITY FT/SEC
PISTON HYDRAULIC PRESSURE PSI
1000
700
PISTON VELOCITY, FT/SEC

Fig. 6