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IMPROVED MULTIPLE-SHOT GUN FOR USE AS A COMBUSTION STABILITY RATING DEVICE

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SUMMARY

A program was conducted to develop and experimentally evaluate an improved version of a modified machine gun for use as a device for rating the relative combustion stability of various rocket combustors. Following the results of a previous study involving a caliber .30 machine gun, a caliber .50 machine gun was modified in order to extend the charge-size range of the device.

Nitrocellulose charge sizes ranging from 1.004 to 9.720 grams (15.5 to 150.0 grains) were fired at rates up to four shots per second. Shock pressures up to 25 512 kN/m^2 (3700 psid) were measured near the end of a shortened gun barrel. A minimal resistance type of check valve permitted the gun to fire into pressurized regions; back pressures up to 3448 kN/m^2 abs (500 psia) were tested. The final modified assembly was evaluated during combustion stability tests using rocket combustors burning a FLOX-methane propellant combination.

INTRODUCTION

The need for this program resulted from a previous study (ref. 1) in which a caliber .30 light-duty machine gun was modified and successfully used to rate the dynamic combustion stability of several types of rocket combustors. Most commonly, stability rating is accomplished by introducing a series of successively larger, explosively produced pressure disturbances into a stably operating rocket combustor until combustion instability is initiated. The earlier program proved the following important assets of the modified machine gun over other types of explosive rating devices:

(1) The interpretation of the perturbation characteristics, as related to the operating conditions of the gun and combustor, was enhanced because of the constant geometric

relations between gun port, injector element configuration, injector baffles, and pressure transducer locations.

(2) The number of penetrations into the thrust chamber was reduced since all explosively produced perturbations could be introduced through a single port in a combustion chamber wall.

(3) The explosive charges were relatively inexpensive and could be graduated easily in small increments.

(4) The device is more adaptable to use with flight-type rocket combustors than the more usual bomb ring.

The caliber .30 machine gun, however, was limited to an incremented charge-size range from 1.199 to 2.527 grams (18.5 to 39.0 grains) when loaded with DuPont SR4759 nitrocellulose. The gun could be fired at a rate of up to three shots per second. When the modified gun was fired into regions pressurized to 862 kN/m^2 abs (125 psia) or more, malfunctioning of the gun occurred until a check valve was placed at the end of the gun barrel. Because of its design, though, this type of valve greatly attenuated the shock amplitude. Further, shock pressures decay as they propagate down the length of the barrel (ref. 2). By shortening the barrel, higher exhaust shock pressures potentially should have been possible; but, because of the inherent design of the caliber .30 gas-operated gun, this was not feasible.

Thus, a brief study was initiated to develop and experimentally evaluate an improved version of the multiple-shot device. An immediate application of this improved device was to be the stability rating of several rocket combustor configurations which would use a FLOX-methane propellant combination. These combustors would operate at a chamber pressure of 2758 kN/m^2 abs (400 psia) and produce a thrust of 17.79 kN (4000 lbf). The proposed chamber diameter was 0.137 meter (5.39 in.). Because of this small chamber diameter and the inherently high stability of combustion associated with it (ref. 3), it was felt that charge sizes larger than 2.527 grams (39.0 grains) would be required to initiate high-frequency combustion instability.

Accordingly, a caliber .50 heavy-duty machine gun was procured from the U.S. Army along with empty, unprimed cartridges. This report describes in detail the modifications made to the caliber .50 recoil-actuated machine gun in order to convert it to a gas-operated mechanism having a fixed, shortened gun barrel. Modifications made to caliber .50 cartridges in order to extend the range of charge sizes while maintaining efficient release of the explosive energy also are described in detail. Quantitative data obtained during evaluation tests are presented in graphical form for shock pressures as a function of charge size, cartridge type, and barrel length from the explosion.

APPARATUS

A heavy-duty, caliber .50 machine gun was procured from the U.S. Army along with empty caliber .50 cartridges and percussion primers. The cartridges were delivered unprimed and without the percussion primer vent hole drilled. Pneumatic gun chargers were procured from the U.S. Air Force; thus, standard military hardware was used wherever possible. A detailed description of the machine gun and gun chargers is presented in appendix A. Further, a description of the cartridges and primers is presented in appendix B. Technical information bulletins were obtained through the Adjutant General Publication Center as well as at several Army arsenals. Technical discussions were conducted with personnel at the Frankford Army Arsenal. Manual loading of the modified cartridges with percussion primers and specific charge sizes was performed at a local gun shop on contract. The explosive powder used to charge the cartridges had a tubular design and was designated as Dupont SR4759 nitrocellulose.

Tests were conducted with the machine gun bolted to a stand in a test cell (fig. 1). The system used to control firing of the gun is discussed in appendix C. Most tests were made with the gun firing into an open-ended shock tube. Later, the tube was capped and pressurized with nitrogen to simulate the high-pressure environment of a rocket com-
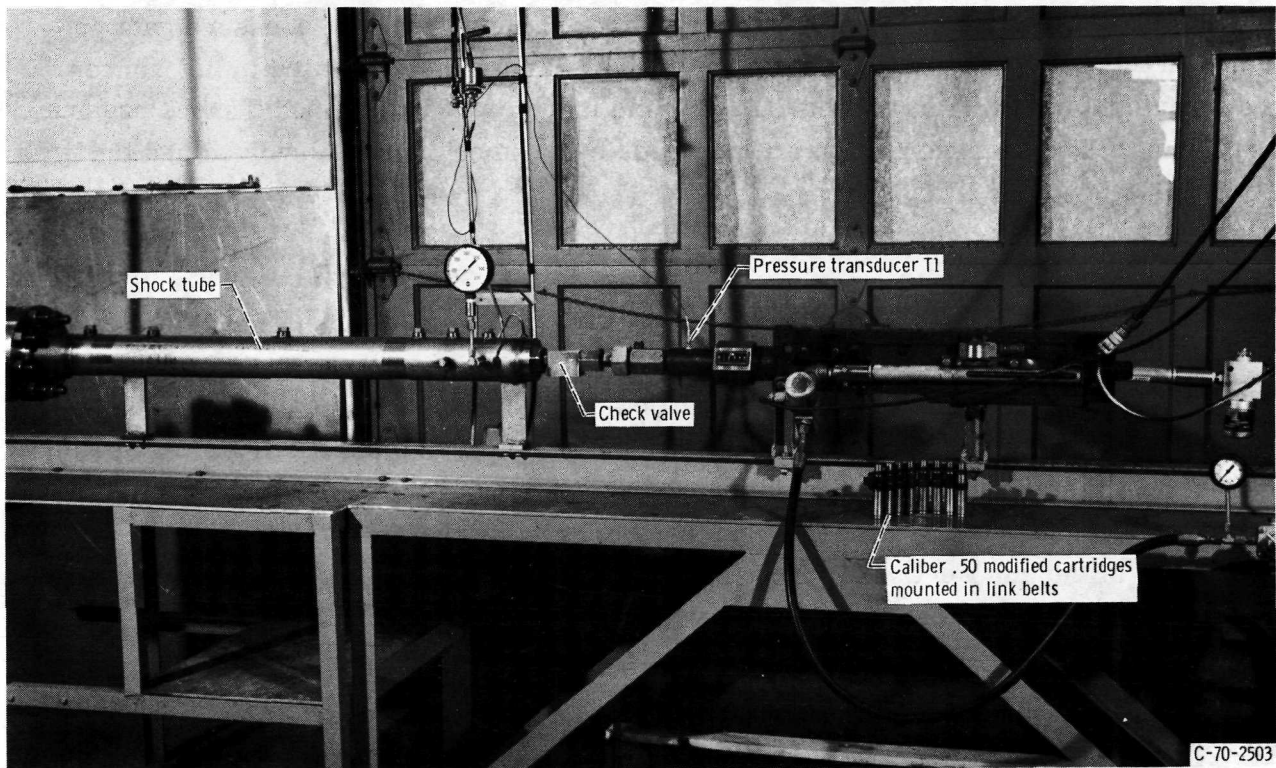

Figure 1. - Caliber .50 modified machine gun connected to shock tube. Both mounted to test stand.

bustion chamber. During such tests, a unique commercially available check valve was used to restrict reverse flow of gas up the barrel. Tests were conducted with pressure transducers located at four axial locations on the gun barrel. For the exact locations, see appendix A, figure 12(d). Transducer T1 was closest to the breech - 0.229 meter (9.00 in.) from the front end of a cartridge placed in the breech. Moving toward the other end of the gun barrel, transducer T2 was at a length of 0.409 meter (16.12 in.), T3 at 0.685 meter (25.89 in.), and T4 at 1.051 meters (41.38 in.) and mounted in the barrel - to - shock-tube adapter. The barrel inside diameter was a constant 0.0127 meter (0.500 in.).

Shock pressure amplitude data were measured by pressure transducers specially designed for use in gun barrels. According to the manufacturers specifications, the piezoelectric transducers could measure pressures up to 275 800 kN/m^2 (40 000 psid) maximum with a rise time of 1.5 microseconds. Applied shock loadings up to 15 000 g's for 1.0 millisecond should have had minimal effect on the output signal of the transducers. Each transducer was flush mounted in the gun barrel wall; no extra mounting adapters were used. Data were recorded on an oscillograph using galvanometers with an undamped natural frequency response up to 8000 hertz. This was the limiting frequency response of the recording system. This method of recording yielded data which were not absolutely correct because of the relatively low-frequency response of the recording system. However, the relative aspects of the data were considered good enough to use for evaluations of the cartridge configurations tested. Thus, the shock pressure data presented in this report have attentuated amplitudes. Equations presented in references 4 and 5 could be used to correct the data and find more exact values of the shock pressure amplitudes. These corrections were not made because of the time involved and the brevity of this study.

PROCEDURE

The caliber .50 machine gun was modified in successive steps and experimentally tested without cartridges following each step. Each of these tests simply consisted of cycling only the reloading mechanism of the gun and observing the performance. Since high-pressure pneumatic cylinders were used to activate the mechanism, control and observations of the gun were made from a remote location. After the modified gun was operating as desired, further tests were conducted using standard military blank cartridges. The next step was to fire each cartridge design in the gun and evaluate the results by visual inspection of the spent cartridges and by comparing measured shock pressure amplitudes against a reference design. In this study, the reference design was an unmodified standard cartridge filled with nitrocellulose charge sizes ranging from 1.004

to 9.720 grams (15.5 to 150.0 grains). Finally, the best cartridge configurations were fired in rapid succession using an electrical-mechanical firing system. The firing rate was progressively increased until the reloading mechanism malfunctioned.

The evaluation tests were conducted with the modified machine gun barrel rigidly secured to one end of a shock tube. The opposite end of the shock tube was fitted with a removable cap. The primary purpose of this tube was to simulate the high-pressure environment of a combustion chamber. This was done by capping the shock tube and pressurizing it with nitrogen. Because of the type of evaluation tests, however, most tests were made with the tube uncapped; that is, the gun barrel exhausted to atmospheric pressure within the tube. In this configuration, the tube served no useful purpose except to support the gun barrel and help contain any of the solid products of explosion (cartridge sealing plugs) or unburned powder.

Performance of the modified machine gun when fired into pressurized regions was evaluated first by firing the gun into the shock tube pressurized with nitrogen. A unique type of check valve, having a spherically shaped poppet and minimal restriction to flow, was used between the end of the gun barrel and the shock tube.

The final test of performance was made by firing the gun into an operating rocket combustor burning a FLOX-methane propellant combination. The chamber pressure was 2758 kN/m^2 abs (400 psia) and charge sizes up to 9.072 grams (140.0 grains) were fired.

RESULTS AND DISCUSSION

In this section the modifications made to a caliber .50 machine gun and cartridges in order to convert both to use as a combustion stability rating device are discussed first. The experimental results from the evaluation tests are then presented and discussed.

While a detailed description of each modification is important, it is secondary to the importance of reporting and discussing the results of experimental evaluations of the modifications. Consequently, to minimize the possibility of diverting the reader's attention from the primary results of this program, a brief discussion of the major modifications will be presented here; a detailed description of, and reason for, each modification are presented in the appendixes. The modifications to the machine gun mechanism are discussed in detail in appendix A, while modifications to the cartridge are discussed in appendix B. Further, a cursory description of the firing control circuit is presented in appendix C.

Gun Modifications

For application as a combustion stability rating device, several drawbacks existed

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in the gun as delivered. One was the long barrel, which made the gun unwieldy and exhausted shock pressures which would be lower than desired (ref. 2). Another serious drawback was the fact that the barrel moved along its longitudinal axis during the recoil phase of operation. This presented problems in effecting a seal between the barrel and wall of a combustion chamber. Finally, the rate of fire was inherently related to the recoil mechanism and, as such, was not variable.

To make the caliber .50 machine gun adaptable to specific requirements as a rating device, the following major modifications were made to the gun:

(1) The movable gun barrel was fixed rigidly relative to the receiver or main body of the gun. This conversion was effected by decoupling the barrel from the reloading assembly and fixing it to the receiver by using a special adapter.

(2) The recoil type of mechanism for reloading was converted to a gas-operated mechanism. This change was effected after the barrel was decoupled from the reloading assembly. Two pneumatic cylinders were connected to the reloading mechanism. By operating the cylinders in opposite directions, cycling of the reloading mechanism was made possible. Solenoid valves controlled helium gas flow to these cylinders. Thus, the rate of fire of the gun was controlled by the rate of opening and closing of these valves. A specially designed electrical pulse generator was used to control the sequencing of the valves.

(3) The gun barrel was shortened by cutting off an arbitrary length of 0.721 meter (28.375 in.) from the original 1.143-meter (45-in.) barrel. The barrel end opposite the breech was threaded to accept an adapter for connection to a combustion chamber wall.

Cartridge Modifications

The simplest way to vary the size of the explosive charge is to use standard brass cartridges, which are obtained readily from the U.S. Army, and load each cartridge with varying amounts of powder. However, the density of loading (defined here as the mass of charge per total fillable volume within the cartridge) is quite important for uniform ignition of the explosive (ref. 2). Thus, to extend the range of charge sizes while retaining efficient release of the explosive energy, three internal configurations were used with the standard cartridge (external) design. With 10 charge-size increments for each cartridge configuration, the range of charge sizes varied from 1.004 to 9.720 grams (15.5 to 150.0 grains), figure 2, of DuPont SR4759 nitrocellulose - the same type of explosive powder as was used in the earlier study (ref. 1). A series designation was assigned to three charge-size ranges, regardless of cartridge configuration, as shown in figure 2. Series A was for the charge-size range of 1.004 to 2.754 grams (15.5 to 42.5 grains); series B was for the range from 2.916 to 5.832 grams (45.0 to 90.0 grains); and series C was for the
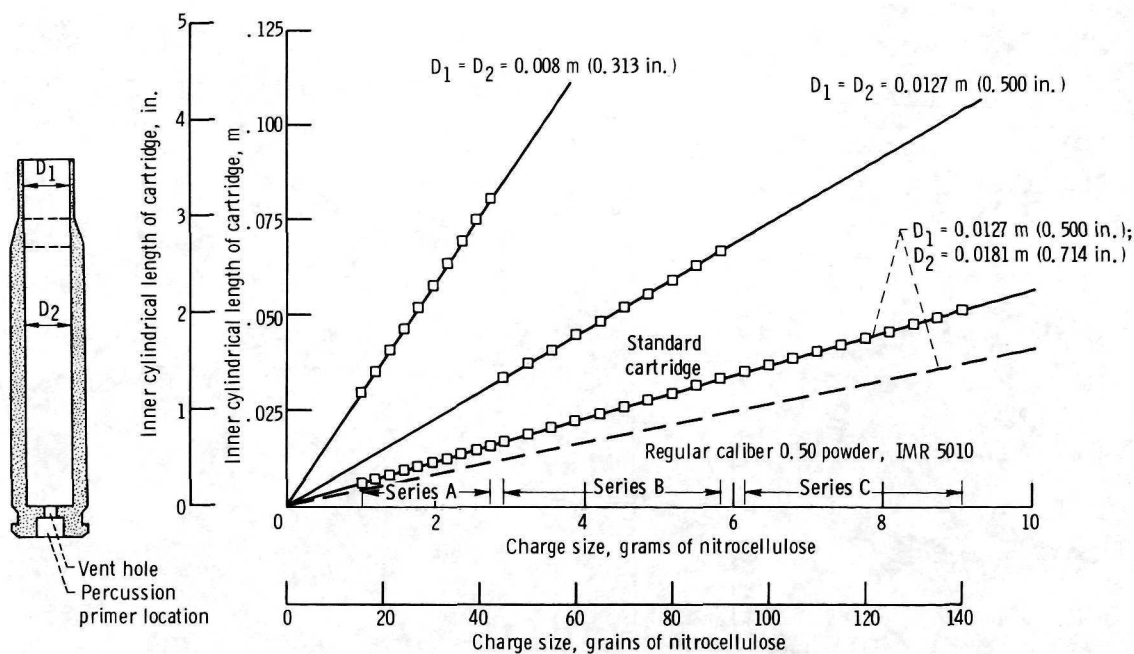
Figure 2. - Design map for modified caliber .50 cartridges containing DuPont SR 4759 powder.

range 6.156 to 9.072 grams (95.0 to 140.0 (or larger) grains). In all configurations, the explosive powder was poured into the cartridge cavity with no further material used to constrain the charge against the percussion primer located in the base of the cartridge. A detailed description of modifications to the cartridges is presented in appendix B.

Experimental Evaluations

To establish a basis for comparison of the efficiency of releasing the explosive energy from each cartridge configuration, standard brass cartridges were loaded with nitrocellulose charge sizes ranging from 1.004 to 9.720 grams (15.5 to 150.0 grains). An indication of the efficiency of explosion was provided by the strength of the resultant shock wave. Test results from firing each charge into a nonpressurized environment and measuring the resultant shock pressure amplitudes or differentials are shown in figure 3. Shock pressures shown are for transducer T1, where the highest pressures were measured. Shock pressures from 283 to 25 512 kN/m^2 (41 to 3700 psid) were measured. A relation between charge sizes and shock pressure amplitudes as plotted on a logarithmic scale is linear down to a charge size of about 2.171 grams (33.5 grains). It seems that charge sizes below 2.171 grams (33.5 grains) of nitrocellulose exhibit a different mode of chemical reaction because of the very low loading densities. In fact, upon inspection
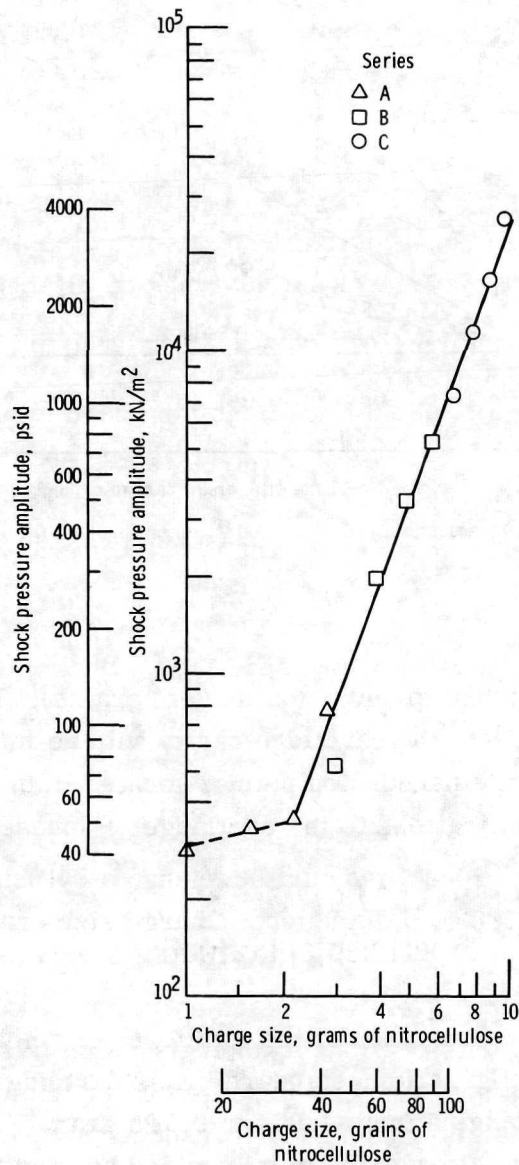
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Figure 3. – Shock pressure amplitude as function of charge size for standard brass cartridges fired into a nonpressurized environment. Transducer T1 (located 0.229 m (9.00 in.) from front end of cartridge).

of the spent cartridges and gun mechanism following each firing of the smaller charge sizes, some unburned powder was found. This probably explains why, in figure 3, the curve deviates at the low charge sizes from that at the higher charge sizes. For charge sizes larger than 2.171 grams (33.5 grains), the curve in figure 3 has a slope which indicates that the shock pressure amplitude is proportional to the cube of the charge size.

Two configurations of cartridges were tested with fillers to reduce the internal volume and thus increase the loading density (see appendix B, table I). The first had a cylindrical internal geometry of constant 0.008-meter (0.313-in.) diameter. Charge sizes ranged from 1.004 to 2.754 grams (15.5 to 42.5 grains) of nitrocellulose and, thus, were designated as series A cartridges. This corresponded to the range possible with caliber .30 cartridges as reported in reference 1. Four types of filler were used to change the cartridge volume compared to that of a standard brass cartridge. Two of the fillers (Cerro-bend and Rigidex), when in a molten state, could be poured into standard brass cartridges. This was more economical than machining cartridges from solid stock - the method used for the solid brass and solid aluminum fillers. The filler types are further discussed in appendix B. Experimental results of firing each charge size into a nonpressurized environment and measuring the resultant shock pressure amplitudes are shown in figure 4 for three of the fillers. Pressures shown were measured at transducer location T1. At any charge size, a distinct difference is apparent for each type of filler. The highest shock pressure amplitudes were measured when the solid brass design was used, followed by Cerro-bend and then Rigidex. For comparison, part of the curve from figure 3 is shown as a dashed line. It is apparent that decreasing the fillable internal volume of a standard brass cartridge (i.e., larger loading densities) yields a significantly increased shock pressure amplitude for comparable charge sizes.

The second configuration of modified cartridges had a cylindrical internal geometry of constant 0.0127-meter (0.500-in.) diameter. Charge sizes ranged from 2.916 to 5.832 grams (45.0 to 90.0 grains) of nitrocellulose and, thus, were designated as series B cartridges. Four types of filler were used. Further description may be found in appendix B. Experimental results of firing each charge size into a nonpressurized environment are shown in figure 5, which is a logarithmic scale plot of shock pressure amplitude as a function of charge size measured at transducer location T1. With this configuration, no significant difference is apparent between filler types of solid brass, Cerro-bend, Rigidex, and solid aluminum. A comparison of the mean value of the shock pressure amplitudes with the superimposed line from figure 3 again shows that decreasing the internal volume of a standard brass cartridge yields higher shock pressures. Also, the difference in shock pressure amplitudes between the modified cartridge and standard brass cartridges is smaller for series B than for series A cartridges.

Several plausible reasons exist for the shock pressure differences among the filler types tested. One reason could be the difference in the elasticity of each filler and the
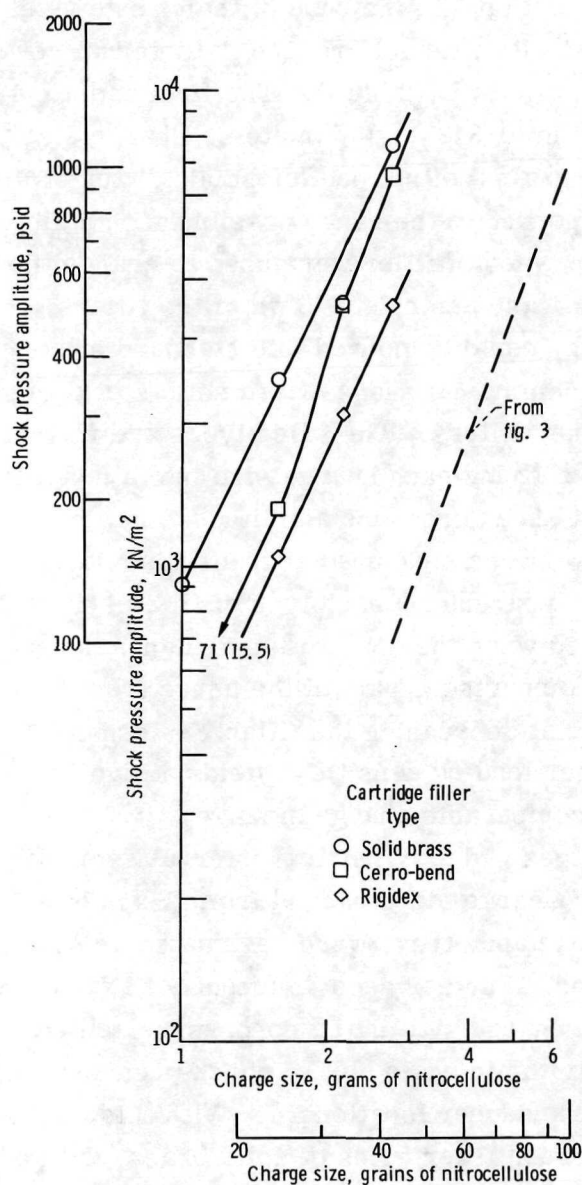
Figure 4. - Shock pressure amplitude as function of charge size for series A charge sizes fired into nonpressurized environment. Transducer T1.
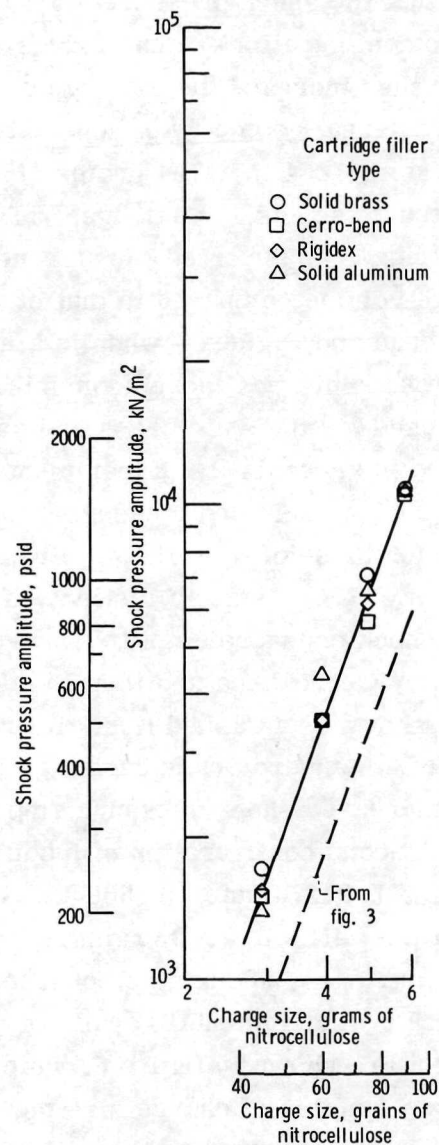

Figure 5. - Shock pressure amplitude as function of charge size for series B charge sizes fired into nonpressurized environment. Transducer T1.

mechanical absorption of some of the explosive energy. Another reason could be the differences in the heat capacities of each filler and the thermal losses of some of the explosive energy. In any event, a loss of some of the energy released during reaction of the explosive powder would show up as a lower shock pressure amplitude.

In subsequent tests where each of the filler types was fired in rapid succession by the modified machine gun, only the solid brass cartridges held up very well. The Rigidex filler occasionally cracked and emitted a small solid piece of the filler, while the Cerro-bend filler tended to ablate, with the metal being deposited on parts of the breech. After approximately nine cartridges were fired rapidly, jamming of the next cartridge occurred in the breech. Consequently, solid brass cartridges were considered best for machine gun use.

Although the data shown in figures 3 to 5 were obtained at pressure transducer location T1, data were obtained also at locations T2, T3, and T4 (see appendix A, fig. 12(d)). In figure 6 is presented a representative sample of such data; again, the gun fired into a nonpressurized environment. The data are plotted on logarithmic scale paper for a wide range of charge sizes and cartridge configurations. From figure 6, it is evident that the shock pressure amplitude decays as it travels down the gun barrel. On the average, the curves have a slope which indicates that the shock pressure amplitude is approximately proportional to the reciprocal of the square root of the distance from the source of explosion. Thus, by shortening the barrel length, the shock is exhausted at a higher pressure amplitude. Accordingly, a 0.721-meter (28.375-in.) section was removed from the caliber .50 gun barrel end. The resultant configuration is shown in appendix A, fig. 12(c). Only transducer location T1 remained on the barrel. Finally, by comparing curves of constant charge size (e.g., in fig. 6, curves b and c, e and g, or f and i), it is evident again that an increase in shock pressure amplitude results if the loading density is increased.

The experimentally determined relations between the shock pressure and the charge size, as well as the shock pressure and the barrel distance from the source of explosion, in the absence of a projectile, could not be verified by the work of others. A possible reason for this is that interior ballistics is not an exact science, and, as such, the development of formulas and equations requires certain assumptions which possibly depend on specific characteristics of a gun or explosive powder (ref. 2).

During some of the evaluation tests of the machine gun mechanism, standard brass blank cartridges were fired. These blanks had a different type of explosive powder, packing, and technique for sealing the neck when compared with the modified cartridge configurations. Consequently, no direct comparison in explosive potential, between the blank and modified cartridges, could be made based on charge size alone. However, a relative comparison between the cartridges would be desirable. Data obtained at transducer location T1 for the standard brass blanks fired into a nonpressurized environment
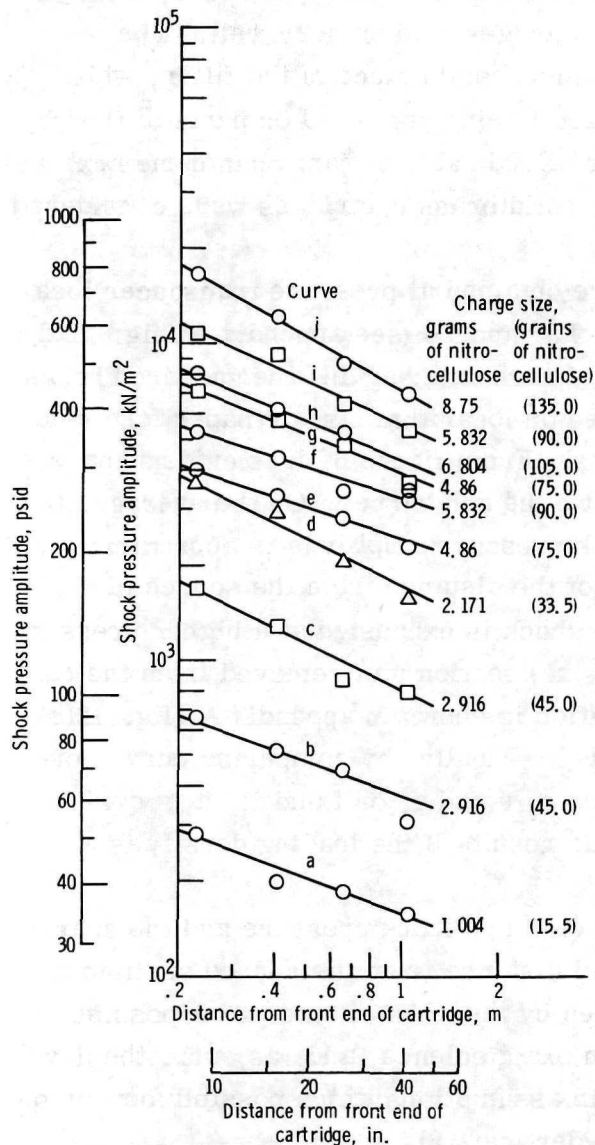
Figure 6 (left)

Shock pressure amplitude, psid

Shock pressure amplitude, kN/m²

10^5

1000
800
600

400

200

10^3

100
80

60

40

30

10^2

Curve

j
i
h
g
f
e
d

c

b

a

	Charge size,	
	grams of nitro-cellulose	(grains of nitro-cellulose)
	8.75	(135.0)
	5.832	(90.0)
	6.804	(105.0)
	4.86	(75.0)
	5.832	(90.0)
	4.86	(75.0)
	2.171	(33.5)
	2.916	(45.0)
	2.916	(45.0)
	1.004	(15.5)

.2   .4   .6 .8 1   2

Distance from front end of cartridge, m

10   20   40 60

Distance from front end of cartridge, in.

Figure 6. - Shock pressure amplitude as function of distance from front end of cartridge fired into nonpressurized environment.

Figure 7 (right)

○   Standard brass blank; primer plus 46 grains black powder

△   Standard brass cartridge; primer only; open end

□   Glued in place
◇   Press fitted (normal procedure) } Standard brass cartridge; primer only; capped end

— — Mean value lines from fig. 6 (standard brass cartridge data for charge sizes shown for comparison)

	Charge size,	
	grams of nitrocellulose	(grains of nitrocellulose)
	6.804	(105.0)
	5.832	(90.0)
	2.916	(45.0)
	1.004	(15.5)

10^4

Shock pressure amplitude, psid

Shock pressure amplitude, kN/m²

1000
800

600

400

200

10^3

100
80

60

40

20

10^2

3

2
2

.2   .4   .6 .8 1   2

Distance from front end of cartridge, m

8 10   20   40
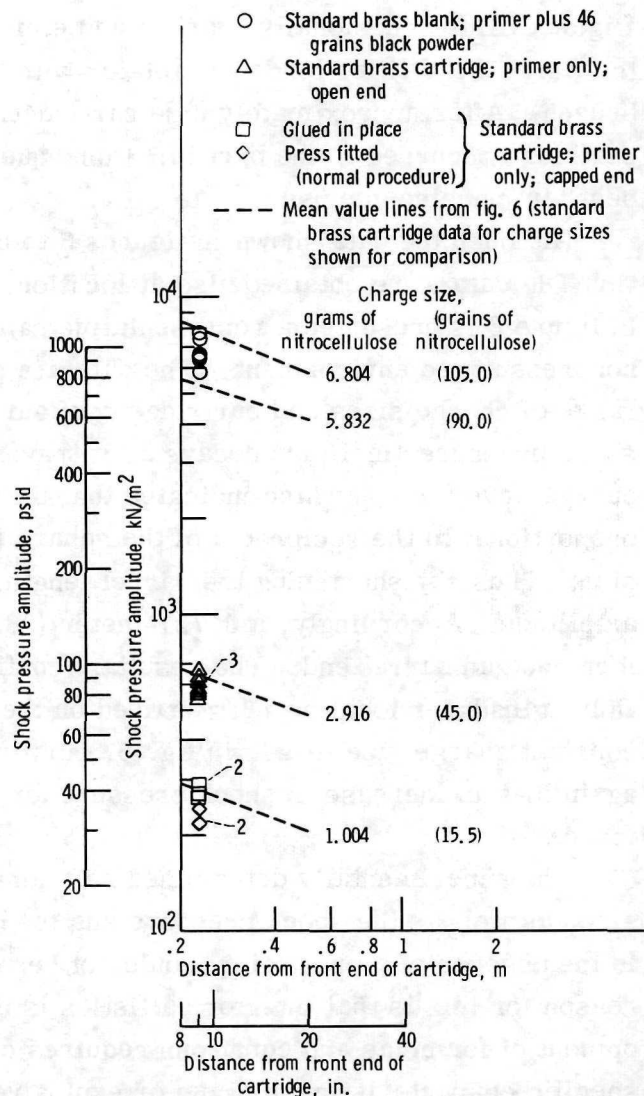
Distance from front end of cartridge, in.

Figure 7. - Shock pressure amplitude as function of distance from front end of cartridge fired into nonpressurized environment.

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are presented in figure 7. For comparison with data from the modified cartridges, several curves from figure 6 are superimposed on figure 7. It may be concluded that the standard brass blanks have a resultant shock pressure differential comparable to that resulting from firing a standard brass cartridge charged with 5.832 to 6.804 grams (90.0 to 105.0 grains) of nitrocellulose. This does not imply that a charge size of 2.981 grams (46.0 grains) of black powder is just as powerful as twice as much nitrocellulose, for cartridge packing and sealing are important and must be taken into account.

Also presented in figure 7 are data taken at location T1 for standard brass cartridges charged only with percussion primers. As shown in figure 7, with an open cartridge neck (that is, no seal) the percussion primer produced a shock comparable to that produced by a 2.916-gram (45.0-grain) charge in a standard brass cartridge. However, when a primer-only charged cartridge was fitted with a tapered, polyethylene plug (the normal procedure used for the modified cartridges), the resultant shock was comparable to only a 1.004-gram (15.5-grain) nitrocellulose charge in a standard brass cartridge. The method used to hold the plug, press fitted or glued in place, had little effect on the resultant shock wave amplitude. The data indicate the amount of explosive energy lost in the deformation of the cartridge sealing plug. Also, because the capped cartridge with only the primer yields the same resultant shock amplitude as that with 1.004 grams (15.5 grains) of charge, it seems that the 1.004 grams (15.5 grains) of nitrocellulose is not being burned. This seemed to be the case since much unburned powder was found in the gun barrel after tests with very small charge sizes in the standard brass cartridges. This fact perhaps accounts for the unusual behavior of charge sizes lower than 2.171 grams (33.5 grains), which are presented in figure 3.

Reverse Flow Restriction

Previous experience with the modified caliber .30 machine gun (ref. 1) verified the need for restricting gas backflow up the gun barrel when the barrel was attached to a high-pressure source - such as a rocket combustion chamber. Because of its simplicity in design and relatively fast response time, a check valve seemed best suited for the task of restricting the flow to one direction. The check valve used in reference 1 was activated by an axial displacement of a cylindrical poppet. Modification of this valve by decreasing the poppet weight (ref. 1) resulted in the passage of larger shock pressures. The blunt end of the poppet, however, absorbed much of the shock wave energy, with the remaining energy flowing around the poppet and out the end of the valve. The exhausted shock, as a consequence, was greatly attenuated.

In modifying the caliber .50 machine gun to fire into high-pressure regions, a unique, commercially available type of stainless-steel check valve was selected. A sec-
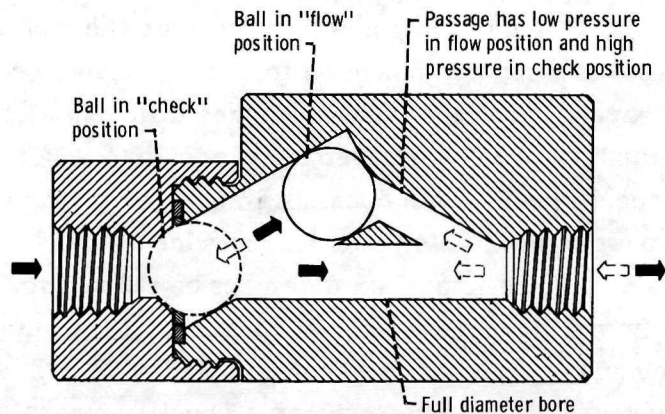
Figure 8. – Check valve. Sectioned view shows principle of operation.

tional drawing of the valve is shown in figure 8. As shown, the solid ball poppet is spherical in shape, having a diameter of 0.019 meter (0.75 in.). Of greatest importance is the minimal-restriction-to-flow feature of the valve when it is activated. The ball poppet, when activated, moved off to one side and allowed a straight-through passage of the gas flow. Although the poppet still absorbed some of the shock energy, the amount of attentuation would be expected to be less than that for other check valve designs. Figure 9 is a comparison of shock pressure amplitudes as measured before and after the check valve. The comparison shows, first, the amount of attentuation of the shock amplitudes caused by the check valve to be about 172 kN/m^2 (25 psid). This takes into account the normal pressure decay down the gun barrel. Although the pressure loss caused by the check valve was relatively small, larger losses might occur with the check valve positioned closer to the charge. Second, as shown in figure 9, there was a pressure buildup behind the check valve which overcame the spring force of the bolt group and caused the group to open the breech prematurely when large charge sizes were fired with the check valve located at the end of the shortened barrel. A solution to this problem is mentioned at the end of this section. And third, figure 9 shows that higher shock pressures are measured downstream of the check valve as the shock tube pressurization level is increased.

In general, the check valve operated very well. The gun was fired successfully into the shock tube pressurized up to 3448 kN/m^2 abs (500 psia) with nitrogen. Because of the high shock pressures, some permanent deformation occurred in the check valve body near the section where the poppet is seated in the flow position, but valve sealing areas held up well. Only after many firings did the accumulated carbon deposits on the sealing areas cause slight leaking. Also, repeated firings with large charge sizes caused a slight amount of cracking in the poppet material. This cracking was corrected by using a new 0.019-meter (0.75-in.) diameter spherical poppet made of stainless steel having a
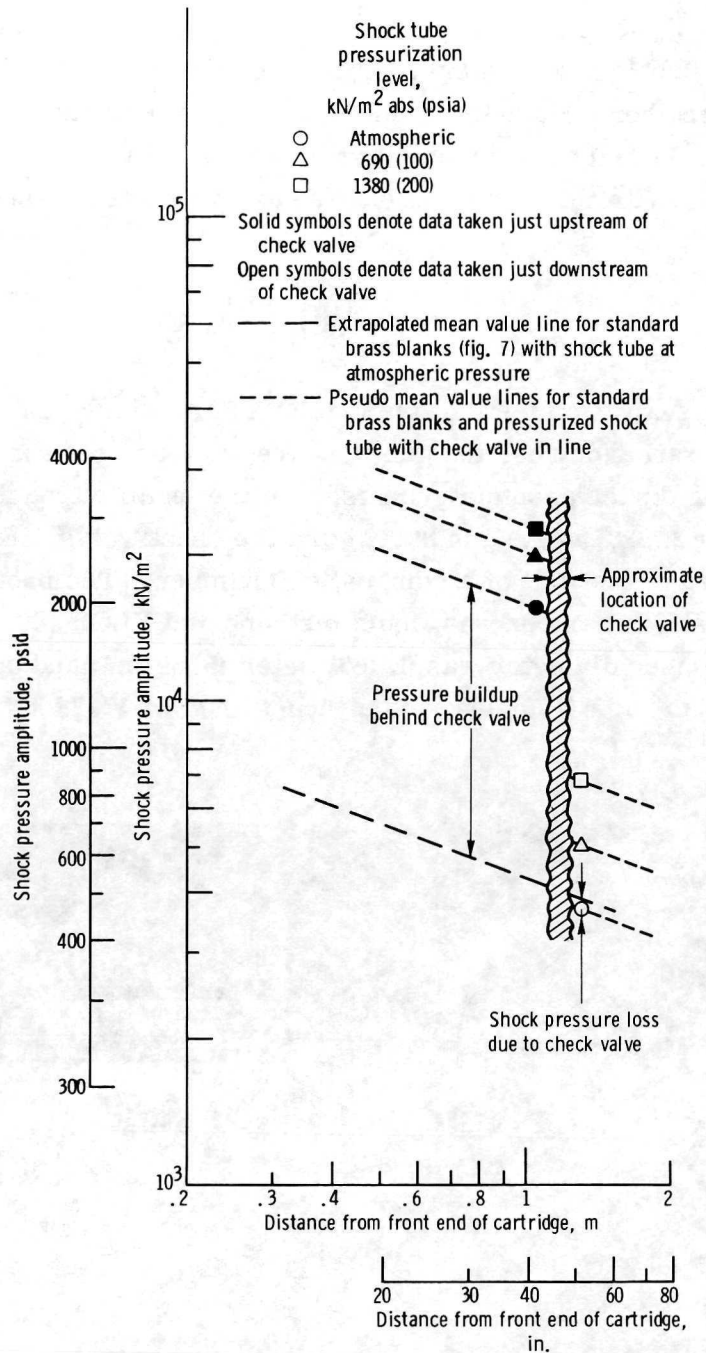
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Figure 9. – Shock pressure amplitude as function of distance from front end of cartridge for machine gun barrel fitted with check valve at end. Data for standard brass blanks.

Rockwell "C" hardness of 58, which compares with the previous value of 24. As for valve compatability with the machine gun mechanism, the only problem which occurred was a "blowback" phenomenon when large charge sizes were fired with the check valve positioned at the end of the shortened barrel. This phenomenon, in which the bolt group prematurely began to retract before breech pressure had decayed sufficiently, was eliminated by installing another pneumatic cylinder in a reverse position on the gun receiver (see appendix A, fig. 14). Thus, the bolt group was controlled at all times by the two pneumatic cylinders. With this arrangement, up to four shots per second were obtained.

Combustion Rating Tests

To complete the evaluation tests of the caliber .50 machine gun modified to be a combustion stability rating device, the gun was fired into an operating rocket combustion chamber. The rating device assembly consisted of the modified machine gun complete with the 0.721-meter (28.375-in.) gun barrel and the check valve. Figure 10 shows the rating device attached to the wall of a combustion chamber. The propellant combination burned in the combustion chamber was liquid methane and FLOX (86.2 percent fluorine by weight). The chamber diameter was 0.137 meter (5.39 in.) and operated at a nominal pressure of 2758 kN/m^2 abs (400 psia) and a thrust level of 17.79 kN (4000 lbf). In one
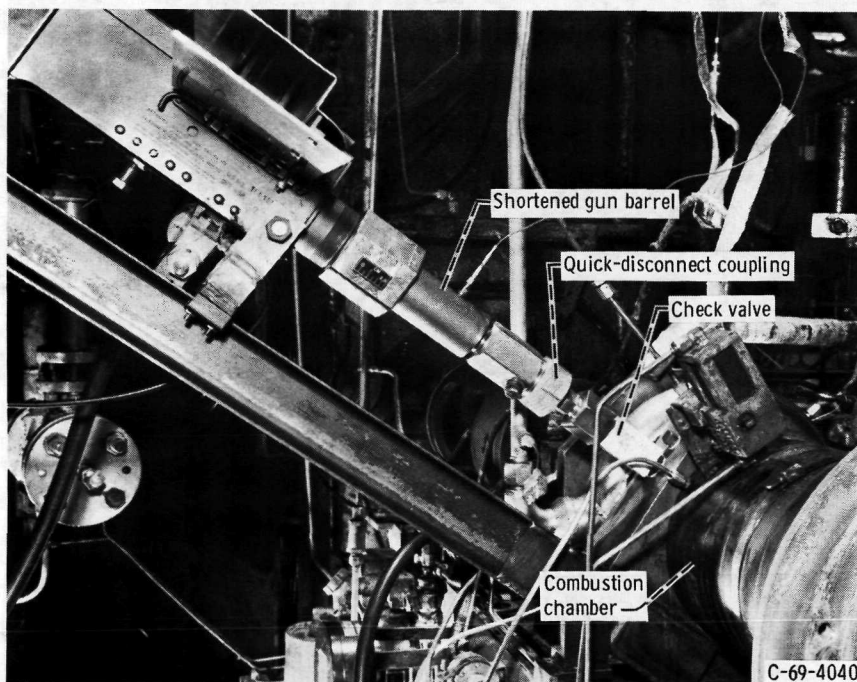

Figure 10. - Modified caliber .50 machine gun attached to a rocket combustion chamber.

test, a series of five increasingly larger charge sizes (2.916, 3.564, 4.212, 4.860, and 5.508 grams (45.0, 55.0, 65.0, 75.0, and 85.0 grains) of nitrocellulose) were fired into a combustor having a fuel-on-oxidizer triplet injector configuration. The first tangential mode of high-frequency combustion instability was initiated at a charge size of 4.860 grams (75.0 grains). Other tests were conducted using gaseous methane and FLOX. Charge sizes up to 9.072 grams (140.0 grains) were fired into the combustor but damped out.

Concluding Remarks

Although the caliber .50 machine gun was modified specifically to be a combustion stability rating device, the gun seems to have application for other uses. For example, explosively driven shock tubes could be equipped with this device and operated at a somewhat faster rate since recharging would be automatic. Another use would be as a high-pressure generating device for use in metal-forming trades (ref. 6). Here, because of the ease in varying the strength of the shock pressure by changing charge sizes, a metal workpiece could be formed by starting at low charge sizes and progressively increasing them until the workpiece is completely formed. One must remember, however, that because of the explosive nature of the shock, carbon deposition onto the workpiece from the products of explosion must be taken into account.

The gun was fired at a rate of up to four shots per second in this study. This was the limiting rate because of the type and design of pneumatic cylinders and actuation valves used. As stated in reference 7, however, the gun has a rated repetition rate of up to nine shots per second. With better or optimally designed pneumatic cylinders and valves, the higher firing rate should be feasible when a gas reloading mode of operation is used.

The shock pressure amplitude attenuation and response time of the check valve possibly could be reduced by using a lighter weight poppet. For instance, Viton-A is a light-weight elastic material which could be used in normal shock tube work, while hollow balls developed for bearing applications seem promising for rocket engine use.

SUMMARY OF RESULTS

Evaluation of a caliber .50 modified machine gun for use as a device for rating the relative combustion stability of various rocket combustors produced the following results:

1. A caliber .50 machine gun was modified to be a multiple-shot, explosive shock wave generating device. Charge sizes varied from 1.004 to 9.720 grams (15.5 to 150.0

grains) of nitrocellulose. The rate of repetition was up to four shots per second. The device was fired into regions pressurized up to 3448 kN/m^2 abs (500 psia). It was used successfully to rate the combustion stability of an operating rocket combustor.

2. Decreasing cartridge internal volumes for charge sizes from 1.004 to 5.832 grams (15.5 to 90.0 grains) of nitrocellulose resulted in higher shock pressure amplitudes when compared with data for standard military cartridges. The type of inert filler used to decrease the volume of standard caliber .50 cartridges had an appreciable effect on the shock amplitudes only in the charge-size range from 1.004 to 2.754 grams (15.5 to 42.5 grains).

3. Shock pressure amplitudes increased approximately with the charge size cubed and decreased approximately with the reciprocal of the square root of the distance from the explosion.

Lewis Research Center,
    National Aeronautics and Space Administration,
        Cleveland, Ohio, January 24, 1973,
            502-24.

APPENDIX A

MODIFICATIONS TO MACHINE GUN MECHANISM

The caliber .50 machine gun used in this study was a Browning M2, heavy-barrel, turret type which is normally used on the M48 tank. The gun is an air-cooled, recoil-operated, alternate-feed, automatic weapon which seemingly can take much abuse in a wide variety of combat situations. Cartridges are fed to the gun by a link-belt. The gun has a weight of 38.102 kilograms (84 lbm), a length of 1.654 meters (65.13 in.), and a cyclic rate of fire between 450 to 550 rounds per minute (about 7 to 9 rounds/sec). A detailed description of the gun, its parts, and its maintenance is given in references 7 and 8.

For application as a rocket combustion stability rating device, several major drawbacks existed in the gun as delivered. One was the long gun barrel (1.143 m, or 45 in.), which made the gun unwieldy, especially when we tried to connect it to a rocket combustor. Also, due to the long barrel, the exhausted shock pressures would be expected to be lower than those with a shorter barrel (ref. 2). Another drawback was the fact that the barrel moved along its axis during the recoil phase of operation. This presented problems in effecting a seal between the barrel and wall of a combustion chamber. And finally, the rate of fire was inherently related to the recoil mechanism and, as such, was not variable. Exhausting at high shock pressures and a variable rate of fire were considered necessary features for a combustion stability rating device.

To make the caliber .50 machine gun adaptable to specific requirements as a rating device, a series of modifications were made to the gun. A detailed description of each modification is given in the following paragraphs.

To prepare the machine gun for part modifications, several accessories were immediately removed from the gun, since they seemingly served no useful purpose for this study. As shown in figures 11(a) and (b), the removed items included the barrel support, shim and bushing; the trigger lever, manual charger (M10), driving spring rod assembly, helical compression spring, and spring guide from the barrel buffer group; and the electrical solenoid and solenoid trigger located on the back plate group.

The first major modification to the gun was to convert the reloading mechanism from a recoil type of actuation to a type which did not require the barrel to move relative to the rest of the gun. A gas-operated mode of reloading was decided on. To effect the change, the gun barrel was decoupled from the barrel extension group by removing the threads and flutes at the breech end of the barrel, see figure 12(a). Then the barrel was fixed to the main body of the gun by machining threads onto the barrel (fig. 12(b)) and screwing the barrel into a special adapter which then was screwed into the receiver of the gun (fig. 12(c)). This rigidly fixed the barrel relative to the receiver. The opposite
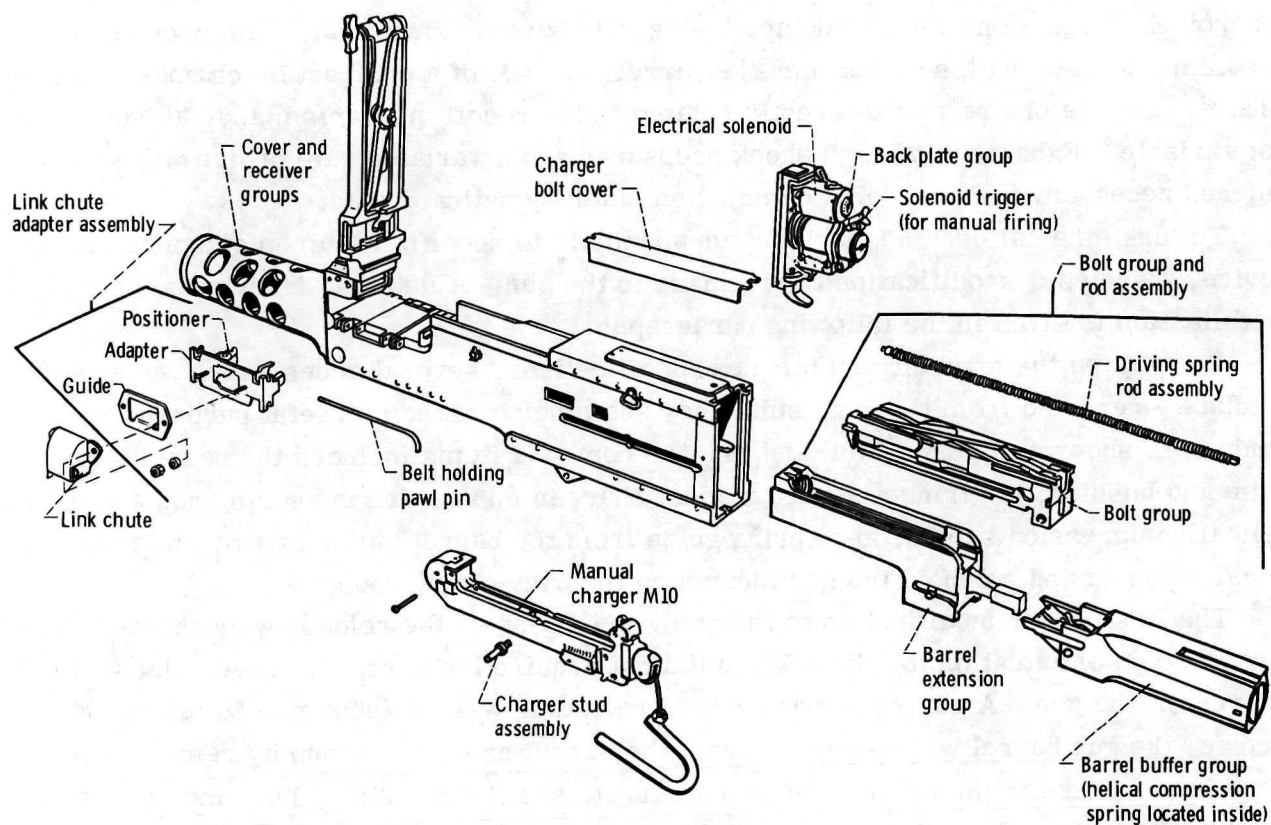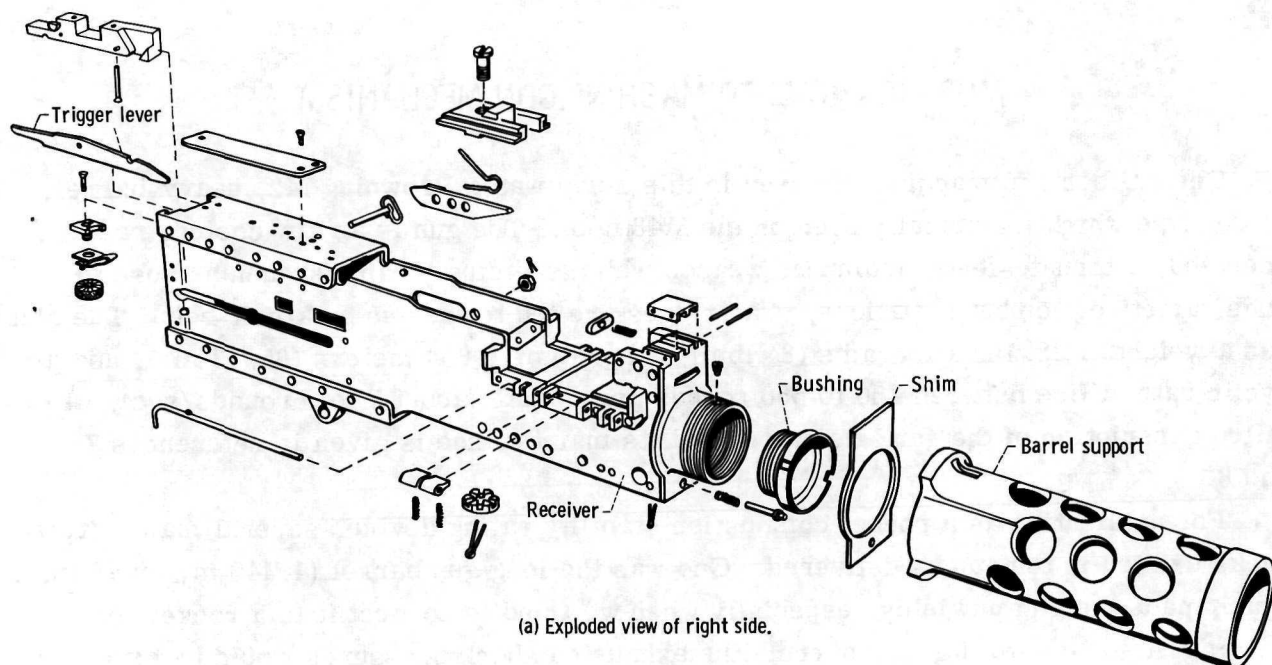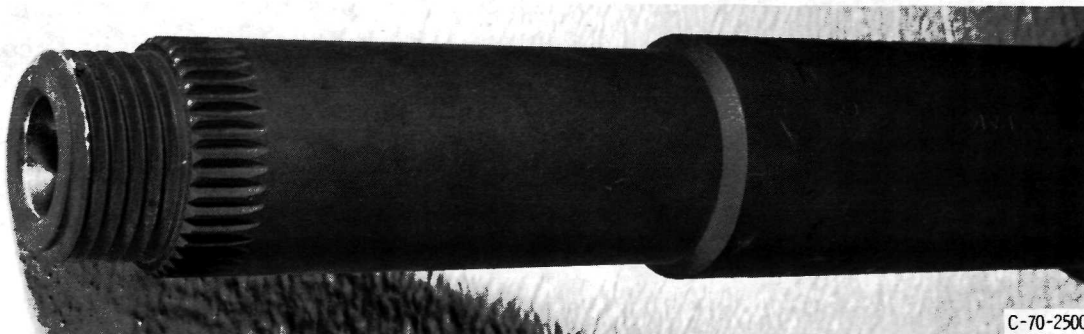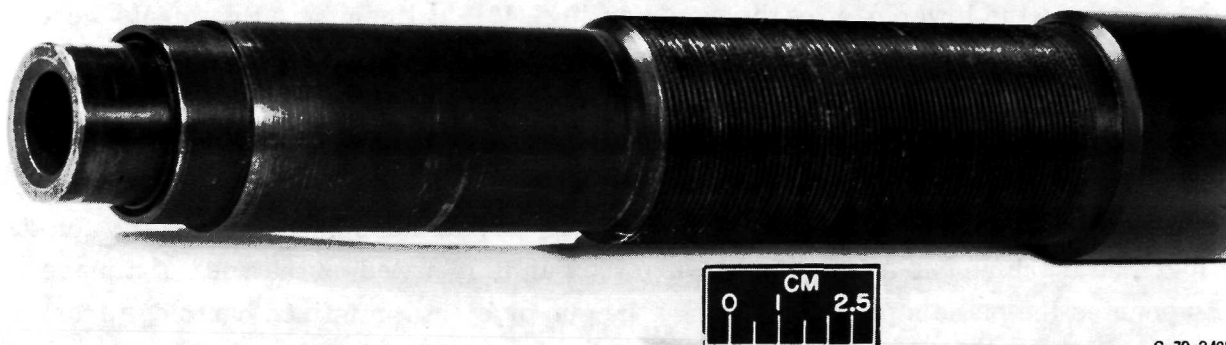
(a) Exploded view of right side.

(b) Exploded view of left side.

Figure 11. – Caliber . 50 machine gun. (From ref. 8.)

(a) Gun barrel at breech end, showing threads and flutes.

C-70-2500

CM
0   1   2.5

C-70-2495

(b) Gun barrel at breech end, showing sections where threads and flutes were removed and new threads machined for conversion to a fixed-barrel mode of operation.

Quick-disconnect coupling

Barrel - to - shock-tube adapter

Shortened barrel

Barrel - to - receiver adapter section

C-70-2501
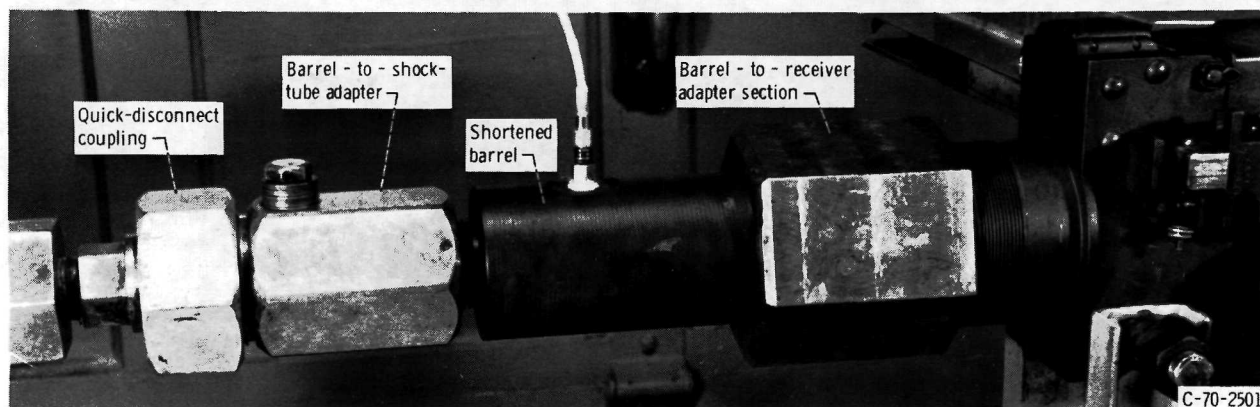
(c) Caliber .50 machine gun with barrel - to - receiver adapter section.

Pressure transducer locations, m (in.):

|← 0.299 (9.00) →|T1|← 0.180 (7.12) →|T2|← 0.249 (9.77) →|T3|← 0.393 (15.49) →|T4

Front end of cartridge location in breech

Barrel - to - shock-tube adapter location

C-70-2497
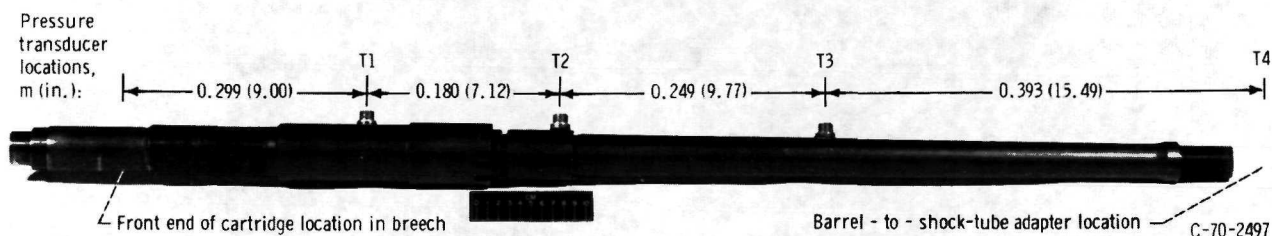
(d) Transducer locations along caliber .50 machine gun barrel.

Figure 12. - Modifications to machine gun mechanism.

end of the barrel was threaded to accept an adapter for connection to a shock tube or combustion chamber. For the first series of tests, in which various cartridge configurations were evaluated, holes were drilled and tapped in the barrel wall at three axial locations for installation of pressure transducers. Transducer locations are shown in figure 12(d). Following the cartridge evaluation tests, the barrel length was shortened by removing a 0.721-meter (28.375-in.) section from the end and machining new threads for the shock tube adapter.

Because of the decoupling of the barrel and barrel extension group and the tolerances involved, a slight misalinement occurred in the reloading mechanism which resulted in firing pin breakage. A solution to this problem was to add a small supporting section of channel iron to the lower part of the receiver (fig. 13). Alinement adjustments were made by a bolt which changed the level of the channel iron which, in turn, changed the relative position between the barrel and the barrel extension group.

The bolt group (fig. 11), which reloads the cartridges, was powered by two identical pneumatic gun chargers. These chargers were procured from the U.S. Air Force and are designated as model MAU-1/A. The gun chargers are designed specifically for the caliber .50 machine gun and are used when the gun is mounted on the wing of a plane. This enables the plane's pilot to recharge the gun or eject a misfired cartridge from a remote position. For this study, the charger operation was modified to control the rate of fire of the modified gun. Further, to ensure that the cartridge stays in the breech
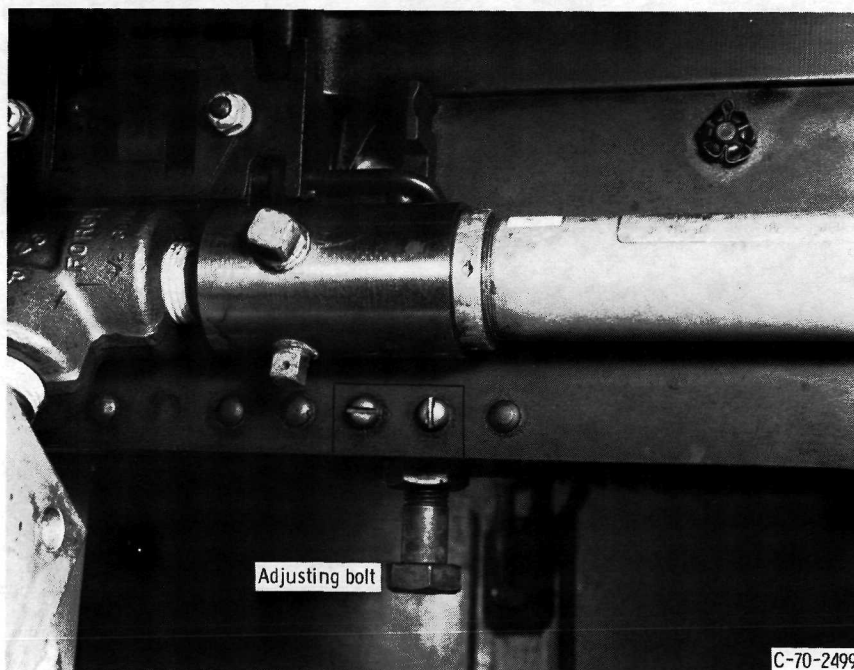

Adjusting bolt

C-70-2499

Figure 13. – Portion of gun receiver, showing location of channel iron and adjusting bolt.
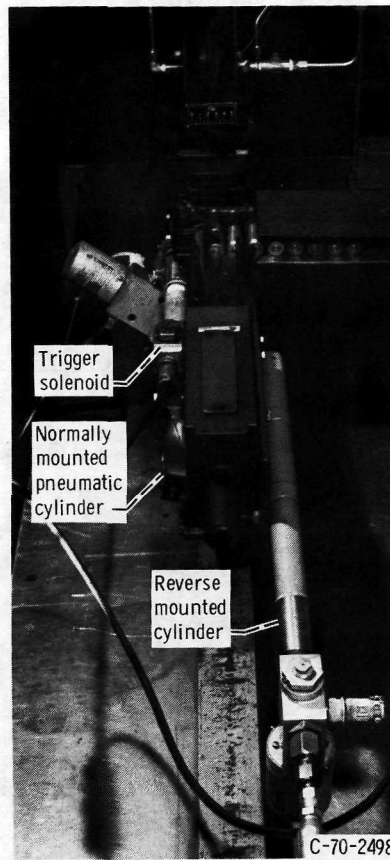
Figure 14. - Pneumatic gun chargers shown mounted to gun receiver.

when the barrel "sees" high pressure - such as in a rocket combustor, a second pneumatic gun charger was installed in a reverse position on the side opposite the first charger (fig. 14). Helium was used as the working fluid in the pneumatic cylinders. Due to its low molecular weight, faster cyclic rates were possible with helium as compared to, say, nitrogen. Low cylinder pressures permitted a faster firing rate. But, the pressure had to be high enough to keep a cartridge sealed in the breech during firing. Generally, 2413-kN/m^2 abs (350-psia) cylinder pressure worked best. Twin solenoid-operated valves were used to control helium flow to the cylinders. They were set up so that one was normally open when the other was normally closed. The flow areas of large valves permitted fast firing rates but had an inherently slower response time than smaller and lighter valves. Line valves 0.0127 meter (0.500 in.) in diameter seemed to be a good compromise.

A separate electrical solenoid, which came mounted on the gun chargers, was used to trigger the firing pin. The solenoid trigger assembly, as well as the solenoid valves, operated on 28 volts dc. All electrical components were sequenced by a separate firing controller described in appendix C.

APPENDIX B

MODIFICATIONS TO CARTRIDGES

Caliber .50 cartridges and percussion primers were procured from the U.S. Army. The M33 cartridges were delivered empty, unprimed, unvented, and without mouth waterproofing. Being unvented, that is, not having a 0.0035-meter (0.128-in.) diameter percussion primer vent hole (which allows passage of the primer flame to the propellant powder) drilled into the base, permitted a molten inert filler to be poured into the top of each cartridge without running out of the base. Upon solidification of the filler, holes of either 0.008- or 0.0127-meter (0.313- or 0.500-in.) diameter were drilled from the top of the cartridge to the beginning of the base. Then the vent holes were drilled.

Four types of fillers were tried. Molten fillers were Rigidex and Cerro-bend and were used to modify standard military brass cartridges. Both fillers normally are found in machine or fabrication shops and are easy to work with. In addition, about 60 cartridges were machined mainly from solid brass, while a few were from aluminum stock. Again, holes of either 0.008- or 0.0127-meter (0.313- or 0.500-in.) diameter were drilled.

The modified cartridges were sent to a contracted local gun shop for loading. Standard caliber .50 percussion primers (number 50M) were press-fitted into the cartridge bases; no waterproofing seal was used. Nitrocellulose (DuPont SR4759) charge sizes varying from 1.004 to 9.720 grams (15.5 to 150.0 grains) were loaded into the primed cartridges in accordance with a code which was stamped into the base of each cartridge. Loading was specified to be ±0.0324 grams (±0.50 grains) of explosive. No extra filler was used to compact the explosive powder against the cartridge base. To seal the nitrocellulose in the cartridge, tapered polyethylene plugs were press fitted into the top of each cartridge hole, as shown in table I.

A complete compilation of all the types of cartridge configurations is shown in table I. Three basic cartridge designs are shown along with the charge loading density at each of the charge sizes. Again, loading density is defined here as the mass of charge per total fillable volume within the cartridge.

TABLE I. - CARTRIDGE CONFIGURATION DATA

		Shell configuration		
				Tapered poly-urethane molded plug press fitted in place
Internal diameter, m (in.)		0.008 (0.313)	0.0127 (0.500)	Variable
Nominal fillable volume of shell, cm^3 (in.^{3})		4.051 (0.2472)	10.135 (0.6185)	18.232 (1.1126)
Design range of charge sizes for each configuration, grams (grains) of nitrocellulose		1.004 to 2.754 (15.5 to 42.5)	2.916 to 5.832 (45.0 to 90.0)	6.156 to 9.072 (95.0 to 140.0)
Number of charge increments in each range		10	10	10
Charge-size change per increment, grams (grains)		0.194 (3)	0.324 (5)	0.324 (5)
Shell types tested:				
Standard brass without filler		No	No	Yes
Standard brass with filler:				
Cerro-bend		Yes	Yes	No
Rigidex		Yes	Yes	No
Solid brass		Yes	Yes	No
Solid aluminum		No	Yes	No

Loading density (ratio of mass of charge to total fillable volume within cartridge)											
grams	grains	g/cm^3	grains/in.^{3}	grams	grains	g/cm^3	grains/in.^{3}	grams	grains	g/cm^3	grains/in.^{3}
1.004	15.5	0.248	62.70	2.916	45.0	0.288	72.76	6.156	95.0	0.338	85.39
1.199	18.5	.296	74.84	3.240	50.0	.320	80.84	6.480	100.0	.355	89.88
1.393	21.5	.344	86.97	3.564	55.0	.352	88.92	6.804	105.0	.373	94.37
1.588	24.5	.392	99.11	3.888	60.0	.384	97.01	7.128	110.0	.391	98.87
1.782	27.5	.440	111.25	4.212	65.0	.416	105.09	7.452	115.0	.409	103.36
1.976	30.5	.488	123.38	4.536	70.0	.448	113.18	7.776	120.0	.427	107.86
2.171	33.5	.536	135.52	4.860	75.0	.480	121.26	8.100	125.0	.444	112.35
2.365	36.5	.584	147.65	5.184	80.0	.511	129.35	8.424	130.0	.462	116.84
2.560	39.5	.632	159.79	5.508	85.0	.543	137.43	8.748	135.0	.480	121.34
2.754	42.5	.680	171.93	5.832	90.0	.575	145.51	9.072	140.0	.498	125.83

APPENDIX C

FIRING SYSTEM

The system used to fire the caliber .50 modified machine gun consisted of (1) an electrical solenoid to actuate the firing pin and (2) solenoid valves to control helium gas which energized the pneumatic gun chargers described in appendix A. A trigger solenoid, which came mounted to the gun charger assembly, is shown in figure 14. The firing pin assembly is located in the bolt group shown in figure 11(b). A 28-volt dc signal actuated the trigger solenoid. With the trigger solenoid energized, the gun could be fired automatically by controlling the gas flow to the gun chargers. This was accomplished by rapidly opening and closing the twin solenoid valves. The electrical signal used to control this pulsing was generated by a dual variable-cycle timer shown schematically in figure 15. The basic part of the timer is an astable multivibrator circuit designed to allow a rate of fire within the limits of the gun. The output of the timer is a duty cycle of variable pulse-on, pulse-off times; it has a pulse-on amplitude of 28 volts dc. Generally, the on-off times were equal, with the duty cycle having a period of 0.25 second.

Figure 15. - Electrical schematic of circuit for dual variable-cycle timer used to control rate of fire of modified caliber .50 machine gun. On and off periods adjustable by 10- and 100-kΩ potentiometers on front panel. Time range switch (S1): number 1, 0.01 to 0.1 second; number 2, 0.1 to 1 second; number 3, 1 to 10 seconds. Gain adjustment about 7 to 100 percent - located on top chassis; for 28-volt solenoid valve, about 0.07 to 1 volt. Current limiter adjustment - 0 to 1.2 ampere - set at 1.0 ampere. 1N2974B diodes to limit inductive transient of valve to 30 volts to prevent damage to 2N1540 transistor.

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REFERENCES

1. Sokolowski, Daniel E.; Vincent, David W.; and Conrad, E. William: Characterization of Pressure Perturbations Induced in a Rocket Combustor by a Machine Gun. NASA TN D-5214, 1969.

2. Hayes, Thomas J., ed.: Elements of Ordnance. John Wiley & Sons, Inc., 1938.

3. Priem, Richard J.: Combustion Process Influence on Stability. Chem. Eng. Progr. Symp. Ser., vol. 62, no. 61, 1966, pp. 103-112.

4. Crocker, M. J.; and Sutherland, L. C.: Instrumentation Requirements for Measurement of Sonic Boom and Blast Waves - A Theoretical Study. J. Sound Vib., vol. 7, no. 3, May 1968, pp. 351-370.

5. Millman, Jacob; and Taub, Herbert: Pulse and Digital Circuits. McGraw-Hill Book Co., Inc., 1956.

6. Rinehart, John S.; and Pearson, John: Explosive Working of Metals. Macmillan Co., 1963.

7. Anon.: Technical Manual TM 9-1005-213-10, Headquarters, Department of the Army, July 1968.

8. Anon.: Technical Manual TM 9-1005-213-25, Headquarters, Department of the Army, July 1968.

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