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Reduction of 40-mm Muzzle Blast and Flash for AC-130 Gunship

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Muzzle devices for reducing the blast and flash levels received by the AC-130 gunship were investigated. A noise suppressor design decreased the blast levels only minimally while the flash level increased compared to the standard flash hider. Extension tubes with 6-inch and 8-inch exit diameters were also tried with no better results. A flash hider with an 8-inch exit diameter brought the flash levels down to new lows but the peak overpressure levels on the airplane were not improved. Finally, a 22-inch barrel extension was tried. The use of a barrel extension resulted in decreased levels of flash and reduced peak overpressures at all microphones except one positioned in the most forward position.

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1. INTRODUCTION

The U.S. Air Force is developing an improved gunship, the AC-130U, with enhanced capabilities, such as an increased stand-off range. The envisioned higher performance capabilities necessitate the development of ammunition with greater velocity and more energy. The 40-mm PGU-31/B APFSDS round was a candidate for development and production, but it had some potential drawbacks. The prototype round, when fired from the Bofors L60 40-mm cannon mounted on the gunship, increases the blast loads on the airplane and also increases the occurrence and intensity of flashing. Theory and experiment show that the higher projectile velocity and muzzle exit pressure result in larger loadings to the external surfaces of the gunship (Baur 1986; Fansler and Schmidt 1983; Heaps et al. 1985; Fansler 1985). Furthermore, the pressure pulse induced by secondary flash that is directed to the rear may be greater than the pressure pulse generated by the primary wave. Therefore, secondary flash must be suppressed not only to decrease detection probability but also to decrease blast loadings.

Much work has been expended on propellant design to inhibit flashing, increase accuracy, and promote extractability and reloading of the rounds. Muzzle devices can be used to further reduce flash and blast problems. The current muzzle device mounted on the L60 40-mm barrel is designed to inhibit flashing and is a cone-type flash hider with an exit diameter of 5-inches. Cpt. Jeffrey Palumbo of Eglin Air Force Base has designed an improved flash hider with an exit diameter of 9-inches, which not only reduces flash but also increases the gun recoil distance. Although the PGU-31/B round is a high velocity round, the resultant cannon recoil travel is smaller than for the PGU-9 round, which works optimally with the gun.

Flash hiders are only one of many kinds of devices that can be used to solve flash and blast problems. Devices may be specially designed to reduce the peak energy efflux from the gun, redirect the blast away from vulnerable surfaces, reshape the gun exhaust plume, or process the propellant gas so that cooler gas exits with less likelihood of flashing. Some muzzle devices may perform more than one of these functions. Mufflers can certainly reduce the blast field peak overpressures and, when large enough in terms of muffler-to-bore-volume ratio, can also inhibit flash (Fansler et al. 1989; Fansler et al. 1990; Fansler et al. 1992). A large muffler not only reduces the peak energy efflux but also facilitates the transfer of heat from the exiting gases to itself, which produces the added benefit of reducing the gas temperature. Another candidate device is the oversized tube extension. The gunship is equipped with a $105 - mm$ howitzer that mounts a muzzle device consisting of a large tube that displaces the exit propellant flow farther away from the fuselage of the gunship. Its effect upon the gun's propensity to flash is not known.

The goal of the present work is to determine what type of muzzle devices and hardware will reduce blast loadings and flashing.

2. STUDIES AND TESTS OF FLASH HIDERS, MUFFLERS, AND OTHER MUZZLE DEVICES

2.1 Design and Fabrication of Devices Restrictions are presently placed on the firing directions for the L60 40-mm cannon when used with the present ammunition. If the cannon is fired above a certain elevation, the muzzle blast may harm the wing flaps. The prototype round will have even greater muzzle blast peak overpressure levels in all directions. Therefore, a muzzle device is required that will reduce the peak overpressures and impulses to acceptable levels. For a given muzzle device, the higher the peak energy efflux from the device, the higher the peak overpressure and impulse. The free field blast strength increases approximately as the square root of the product of the exit muzzle pressure and the projectile velocity (Fansler and Schmidt 1983, Fansler et al. 1993). The peak overpressure also increases slowly with an increase of the exit flow Mach number.

Effective muzzle devices must reduce the peak energy efflux from the weapon or rearrange the focus of the blast forward away from the fuselage and the wing. In an effort to increase the distance of the origin of the blast away from the fuselage and to decrease the peak energy efflux from the device, the concept of using a large diameter long tube to channel the flow was explored. The flow through the oversized tube extension for the 40-mm L60 barrel was modeled using the Godunov muzzle blast code (Widhopf, Buell, and Schmidt 1982). The peak energy efflux was calculated and the peak overpressure was obtained relative to that obtained with a bare muzzle. This calculated relative peak overpressure versus the extender length is shown in Figure 1. These results assume that no additions to the blast wave are made by secondary flash.

The graph's ordinate value is the ratio of peak overpressure for the extension tube to the peak overpressure for the bare muzzle. These values are for the same location relative to the exit plane of the muzzle or device, as the case may be. The calculations were obtained for a 5 caliber diameter extension tube, which is approximately the size of the oversized extension tube that was tested and is discussed later in this report. The polar distribution of the peak overpressure may change because the extension tube may change the exit flow characteristics, but for simplicity, we assume no change in the distribution pattern. The front-to-back peak overpressure ratios should actually increase with higher supersonic flows and lower exit pressures (Fansler et al. 1993). Although the blast wave strength declines only slowly with length, the origin of the blast is moved farther away from the fuselage. The resultant peak overpressure fields would improve the environment for the fuselage. The combination might be beneficial.

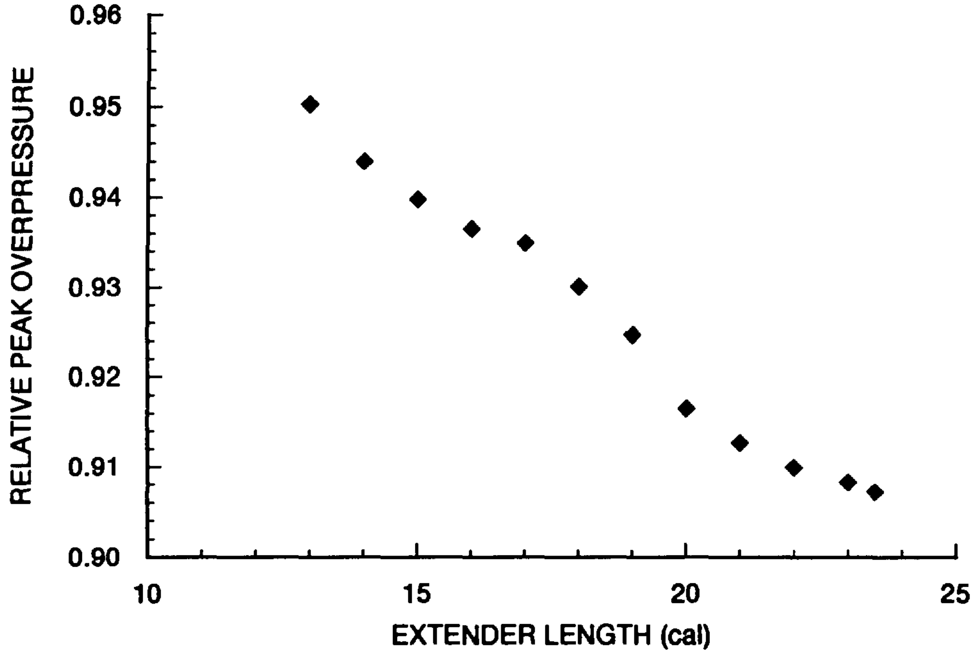

Figure 1. Peak Overpressure Attenuation; Peak Overpressure Relative to that from Muzzle.

Two oversized extension tubes were designed and fabricated. Figure 2 shows the smaller oversized extender tube, which is approximately 6-inches in diameter.

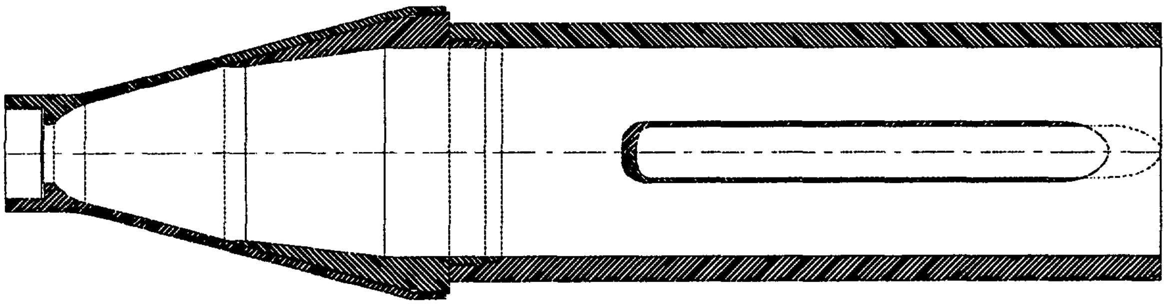

Figure 2. The Small Extender, Designed to Translate the Blast Away from the Airplane

The 6-inch cylinder was slotted on opposite sides to reduce the blast in the plane perpendicular to the plane of the slots. These slots can be oriented to reduce blast loads on the wing flaps or other vulnerable areas of the plane. The slots might also act in a manner similar to a bar suppressor (Engineering Design Handbook, AMCP 706-251 1968). For this configuration, it was not practical to design the slots with the length recommended in the Engineering Design Handbook (1968). Figure 3 shows the large extender tube which has an inside diameter of approximately 8-inches. To advance further as candidates, these particular configurations must create a reduction of the flash as well as a reduction in blast loads to the airplane flaps forward and above the gun.

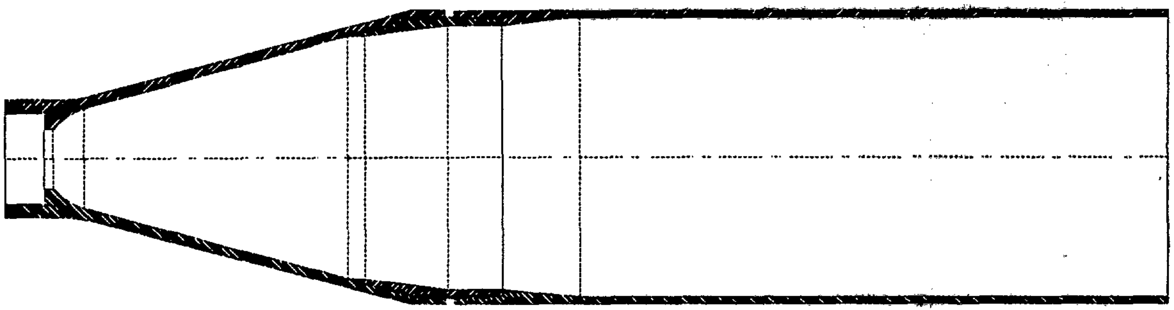

Figure 3. The Large Extender, Designed to Translate the Blast Away from the Airplane

When the tube and joining adapter piece are removed, the resulting component can be used as a flash hider. The flash hider can also reduce the blast load to the fuselage of the plane by shifting the origin of the blast forward. The shock wave also becomes stronger in front of the gun relative to locations in back of the gun. The device has an 8-inch inside diameter, expands from an ogive geometry to a cone shape, and then changes to a cylindrical shape at the exit of the design. No flow code was used to design the nozzle to reduce shocks; Shope (1992) partially calculated the flow, but this was after the flash hider and cylinder extensions had already been designed, fabricated, and tested. The standard flash hider for the L60 cannon is a 5-inch cone type. The Eglin group had recently designed and tested flash hiders with 9-inch and 10-inch exit diameters.

A muffler device was also designed and developed for this project as an alternate way to solve the blast and flash problems. Because of the L60's large bore size, a muffler with a large interior-volume-to-gun-volume ratio (30 bore volumes) is not permitted. Larger mufflers than the present noise attenuator might permit vibrations to accumulate, which would affect the accuracy. A larger muffler that protruded into the air stream around the gunship could also cause undesirable vibrations because of vortex shedding. The present muffler was designed with an interior volume-to-bore-volume ratio approaching three. For comparison, the successful muffler designed for the 25-mm cannon had an interior volume-to-bore-volume ratio approaching 10. Figure 4 is a sketch of the basic design.

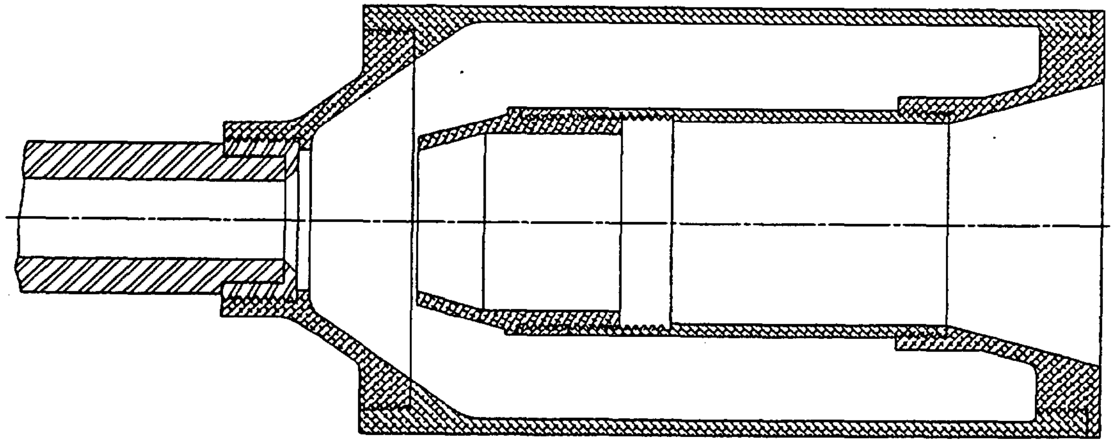

Figure 4. The Muffler Design for 40-mm Cannon

The suppressor was configured with two different axial positions for the exit cone. The exit cone is the component nearest the muzzle through which the projectile must pass. The exit cone design critically affects the performance of the suppressor. The exit cone diameter and the cone angle must be large enough to avoid interfering with the sabots that are separating from the sub-projectile because of centrifugal forces. Yet, the entrance diameter of the exit cone must also be small enough at a given distance from the gun muzzle to capture most of the propellant gas issuing from the muzzle. As the distance between the cone exit and the muzzle increases, the diameter of the exit cone and suppressant device must be made larger. To aid in the design of the exit cone, a method of characteristics code (Love et al. 1959) was used to calculate jet flow at the appropriate muzzle pressure. Figure 5 shows the free jet streamlines for a steady jet with a jet exit pressure of 600 atmospheres. The streamlines are shown that enclose 0.1, 0.3, 0.5, 0.7, and 0.9 of the mass flow within. The streamline nearest the axis corresponds to the enclosure of 10% of the total mass flow. From these results, the exit nozzle was designed to be placed 2.0 inches, 2.5 inches, 3.0 inches, and 3.5 inches from the muzzle. If the exit nozzle is placed approximately 2 calibers (3.1 inches) away and the diameter of the exit cone is 2.8 inches (corresponds to an ordinate value of 0.89 calibers), it can be determined that only about 0.3 of the mass flow would be passed. Since the peak overpressure around the gun varies approximately as the square root of the peak energy efflux, the peak overpressure would be reduced to approximately half that experienced without the suppressor.

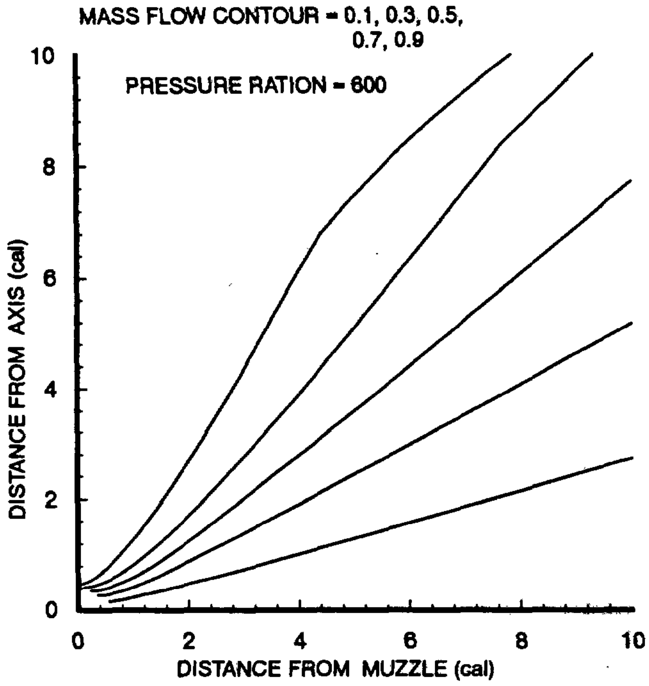

Figure 5. Free Jet Streamlines in Muzzle Blast for 40-mm Cannon

2.2 Experimental Setup for Test at Eglin The devices just described were tested at Eglin Air Force Base from June 2 through June 3, 1992. Gauges were placed at angles and distances that in some instances corresponded to positions that would be near or on a fuselage or the wing tank of the aircraft. The light levels produced by secondary flash were monitored once a suitable degree of darkness was achieved. The units for these light levels are not known but given as numbers for comparison.

2.3 Results and Discussion of Flash Hider and Tube Devices. For each given test condition, two or three shots were fired through each device. Some of the test conditions were repeated later at night to obtain the light production from flashing. The first part of the test occurred at or near ambient temperature conditions. Table 1 shows these results.

The 8-inch (20.3 cm) flash-hider, discussed earlier, reduced the flash by a factor of two when compared to the best current design, the 9-inch (22.8 cm) Eglin cone flash-hider. Possibly an optimum diameter between 5 inches (12.7 cm) and 9 inches (22.8 cm) may exist. Alternatively, the diverging section of the Eglin flash hider may need an added section shaped to reconverge the flow, as occurs for the 8-inch (20.3 cm) flash hider.

Both extension devices produced more flash than either the 8-inch flash hider or the

Table 1. Device Tests at Ambient Conditions

Device	Peak Overpressures (psi)							Luminance
	15° 427 in.	30° 144 in.	45° 197 in.	90° 118 in.	135° 39 in.	135° 118 in.	165° 39 in.	
Std Hider	2.08	14.4	2.11	1.01	1.01	0.41	0.75	0.26
6 in. Hider	2.57	16.2	2.08	–	1.08	0.43	1.20	1.82
8 in. Hider	1.67	16.2	2.20	0.88	0.80	0.38	0.90	0.06
9 in. Hider	2.02	16.5	2.25	0.89	1.60	0.42	1.48	0.11
Nonslotted	1.86	19.4	2.31	0.73	1.42	0.51	1.05	1.22
Slotted	1.69	16.4	2.06	0.74	1.35	0.46	0.97	2.54
Supp w/1.5 in.	1.42	15.3	1.97	0.64	0.73	0.51	0.72	0.43
Supp w/1.0 in.	1.42	14.3	1.92	0.56	0.70	0.36	0.74	2.03

standard flash hider. Perhaps the flashing process is accelerated by the hot shock layer of air and propellant gas that precedes the quasi-steady jet flow. The air and propellant gas may be turbulently mixed while traveling through the length of the tube. The calculations of Shope (1992) indicate that significant shocks occur in the 8-inch flash hider. These shocks result not only in the gas temperature being increased over the isentropic case but also in the generation of shock induced turbulence. A nozzle shape based on Shope's calculated contour, which produces isentropic flow, might yield much less flash when combined with the oversized extension tubes used here.

The suppressor was tested with two different spacing rings that varied the distance from the muzzle to the exit cone. The spacing of 1 inch and 1.5 inches corresponds respectively to a distance of 2.5 inches and 2.0 inches from the muzzle. The blast suppressor produced the least amount of secondary flash when the entrance to the exit cone was closest to the muzzle. The amount of secondary flash varied from shot to shot and was comparable to, but somewhat higher than the flash from the standard flash hider.

In summary, only the 8-inch flash hider reduced flash more than the standard flash hider; unfortunately, the peak overpressure levels were not significantly reduced. The flashing levels for all the other muzzle devices were higher than the Eglin 9-inch flash hider, and the peak overpressure levels were comparable. There are clearly no winners among these muzzle candidate devices. In the next section, other options for reducing blasts and flash are discussed.

3. STUDIES AND TESTS OF BARREL EXTENSIONS

From interior ballistics, it is known that as the barrel length increases, the efflux propellant gas can expand farther to become cooler and less dense before exiting. With cooler exiting propellant gas, the likelihood of flash decreases. The less dense propellant gas flow reduces the peak energy deposition rate and thereby reduces the peak overpressure levels. Moreover, the origin of the blast is displaced away from the fuselage, resulting in lower peak overpressure levels in most instances. As a bonus, the projectile velocity is increased. The prototype ammunition's high velocity and high energy are extremely attractive; unfortunately, the recoil distance declines to a less than optimal value. With the longer barrel, greater momentum is imparted, and the recoil travel may be restored to a more optimal value. These potential advantages led us to explore the actual performance of a longer barrel.

3.1 Design and Fabrication of Barrel Extensions Calculations showed that a barrel approximately 2 feet longer than the L60 barrel would improve the performance in almost all ways, including increasing the recoil travel distance for the barrel. Because an unworn L60 barrel was not available, an L70 barrel was obtained that could be converted into two extensions. The L70 barrel has a gain twist and is a squeeze bore. Figure 6 shows the cutoff sections threaded and ready for assembly.

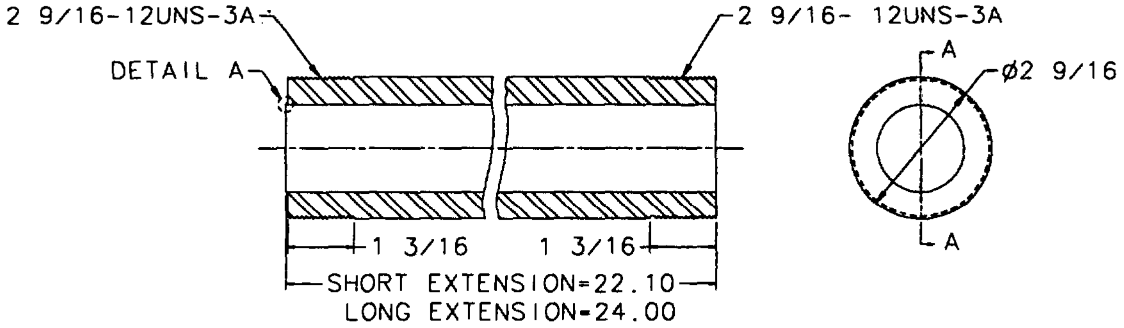

Figure 6. The Section of the L70 Barrel Threaded and Ready for Assembly

The L70 barrel was cut at a location where the the twist rate was approximately the same as the exit twist rate for the L60 barrel. The L70 barrel was then cut 2 feet farther back to yield another section. The long rear cutoff section, when mounted, would decelerate the spin rate whereas the short front cutoff section obtained between the first cut and muzzle would continue to accelerate the spin. Since the L70 barrel is a squeeze bore, the short section would compress the round in transit, while mounting the long section would decompress the traversing round. The short section of the L70 barrel was selected and fitted onto the L60 barrel so that the grooves and lands aligned and there would be no abrupt transition. The L70 section nearest the muzzle was attached to the L60 barrel as shown in Figure 7.

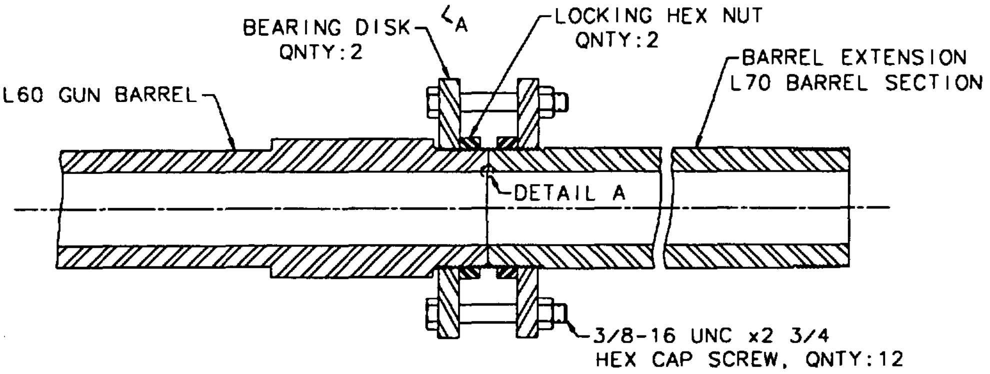

Figure 7. Drawing of Section Attached and Assembled on L60 Barrel

The test was conducted at the Army Research Laboratory (ARL) Transonic Range, Aberdeen Proving Ground, MD. Four different configurations were tested and compared for blast overpressure levels and flashing:

- Barrel extension with standard flash hider.
- Barrel extension with 9-inch Eglin flash hider.
- Regular barrel with standard flash hider.
- Regular barrel with 9-inch Eglin flash hider.

Pressure data were obtained with transducers at the positions that were used for prior tests. The flash was recorded using both a high speed camera with color film and a TV camera. Muzzle velocity was also obtained. Three shots each were fired with the barrel extension for both flash hiders,and because of an ammunition shortage, only two shots each were fired for the regular barrel configurations.

3.2 Extension Barrel Results and Discussion Table 2 summarizes both the peak overpressure and visual results. The average values of these results for each configuration are given here. The "visible frames" under the visual category shows the number of frames that could be seen on the high speed film. The flash size is obtained by measuring the maximum image size on the film and multiplying the size by a factor that depends on the focal length of the camera and location of the camera relative to muzzle. The use of the extension consistently reduces the flash for both flash hiders. The larger flash hider reduces the flash further for both the regular barrel and the barrel equipped with the extension.

Table 2. Extension and Flash Hider Tests

Configuration	Peak Overpressures (psi)							Visual	
	15° 427 in.	30° 144 in.	45° 197 in.	90° 118 in.	135° 39 in.	135° 118 in.	165° 39 in.	Visible Frames	Size (ins)
Ext./5 in. hider	2.80	13.9	2.69	1.61	0.50	0.16	0.37	7	190
Ext./9 in. Hider	2.90	14.1	3.09	1.35	0.38	0.13	0.31	2	110
5 in. Hider	2.88	14.9	2.95	2.08	0.74	0.46	0.50	7	240
9 in. Hider	2.78	14.9	3.47	2.09	0.99	0.48	0.78	5	160

A comparison of the average values of peak overpressures with and without the extension barrel is shown in Figure 8.

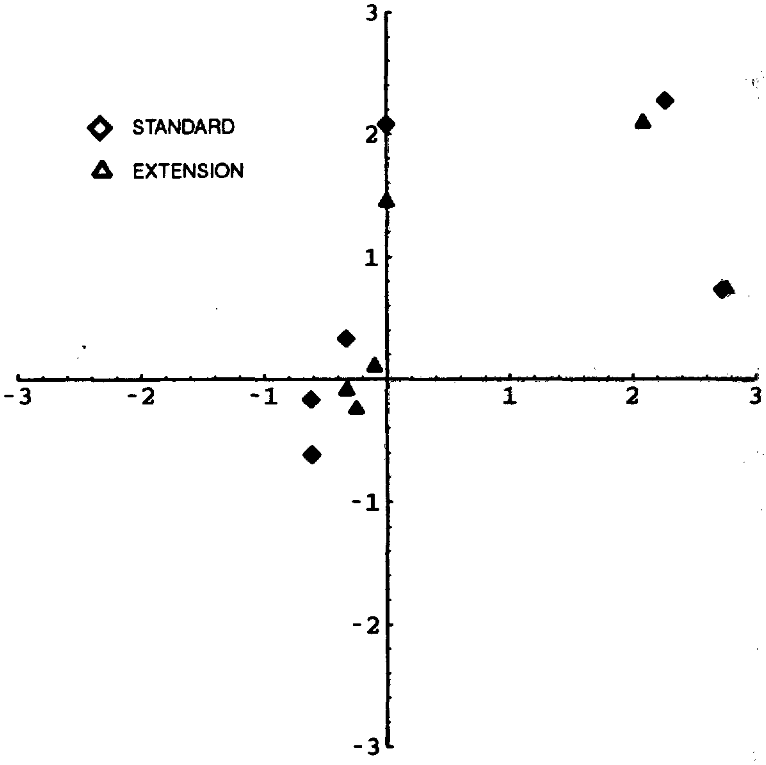

Figure 8. Polar Plot of Peak Overpressures (psi); Comparison of Standard with Extension.

This polar plot of the peak overpressures has the x-axis aligned along the gun axis. The data points to the right-hand side near the x-axis correspond to the peak overpressure value 15° from the boreline and 427 inches away. The peak overpressures are lower with the barrel extension except for the 15°, 427-inch position. Thus, the use of barrel extensions generally improve the flash and peak overpressure performance. The muzzle velocities were also increased by approximately 60 m/s with the use of the barrel extension. The recoil travel was only marginally increased, but only a small difference can be important when extraction occurs most of the time but not all of the time.

The overpressure plots for the transducers behind the barrel showed higher peaks occurring a few milliseconds after the first peak. However, the peak location varied little from shot to shot, which indicates that these higher peaks are reflections from the ground and nearby equipment. Although secondary flash-induced blast may have occurred, a study of the flash-induced blast was not included because these reflections would make such analysis difficult. A different experimental setup is needed to study flash induced blast.

4. SUMMARY AND CONCLUSIONS

In this investigation to reduce flash and blast overpressure levels for the 40-mm Bofors cannon with the L60 barrel, mufflers and oversized tube extension devices were first tried. Muffler devices can produce the desired attenuation if they can be designed with a large enough muffer-volume-to-gun-bore-volume ratio (Fansler et al. 1989; Fansler et al. 1990; Fansler et al. 1992). Unfortunately, the muffler for the 40-mm Bofors cannon had a volume ratio of only 3 and could not have been made much bigger without compromising the gun's performance. The muffler-volume-to-bore-volume ratio of ten for the successful 25-mm muffler devices could not be approached for the L60 40-mm cannon. With the small muffler volume for the L60 cannon, the shock processes that raise the temperature of the propellant gasses and promote secondary flash dominate other processes that inhibit flashing. With sufficient muffler volume, burning of propellant in the muffler may occur but the residence time in the muffler coupled with favorable flow patterns inside and outside the muffler inhibit secondary flash. In this application, the low muffler volume led to enhanced flashing and unacceptably high peak overpressures.

Likewise, the use of oversized tube extension devices yielded unsuccessful results. It was thought that the use of a tube mounted on the end of a flash hider would still act as a flash hider with the origin of the blast being placed farther from the fuselage. Furthermore, the blast level might even be reduced because of the increased length of the tube. The observed higher blast levels may have resulted from propellant gasses passing through an inward moving shock that reheats the propellant gas. This heated propellant gas could mix with the air at the turbulent propellant gas-air interface and promote favorable conditions for burning. Also, calculations show significant recompression shocks occurring in the vicinity of the cone portion of the tube extension device. These recompression shocks promote secondary flash by generating vortical flow and heating the propellant gas.

An extension section was attached to the L60 barrel to create a longer barrel. The 22-inch extension barrel exhibited reduced flash when both the regular 5-inch flash hider and the Eglin 8-inch flash hider were used. The extension barrel also reduced blast peak overpressure, except at the forward position nearest the boreline. These results agree with predictions from an ARL model. The use of a longer barrel would give improved performance, but the design and manufacturing costs may be prohibitive.

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