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SONIC RAREFACTION WAVE LOW RECOIL GUN

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A principal challenge faced by the U.S. Army TACOM-ARDEC Benét Laboratories in the design of armaments for lightweight future fighting vehicles with lethality overmatch is mitigating the deleterious effects of large caliber cannon recoil. The sonic RArefaction waVE low recoil guN (RAVEN) is a novel invention to dramatically reduce the gas momentum contribution to recoil with absolutely no reduction in the ballistic efficiency of launch. This technology is being investigated as part of the future combat vehicle armaments program conducted at Picatinny Arsenal, NJ, and Watervliet Arsenal, NY.

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INTRODUCTION

Current interest in future army fighting vehicles is being focused by the joint effort between the U.S. Army and the Defense Advanced Research Projects Agency (DARPA) Tactical Technology Office. The Future Combat System (FCS) program, lead by LTC Marion Van Fosson, is centered on providing air deployable forces with lethality overmatch. The present projection for fielding of such a force would have the first units equipped with future combat vehicles in the 2008 to 2012 timeframe.

Engineering guidance on the vehicle requirements indicates that they will have to be deployable from an airframe such as the C130J—or a future airframe of similar limitations—that imposes fundamental restrictions on size and weight. The limitations are nominally 20,000 kg, and 2.5-m in both height and width with ample length available (over 10-m). Thus, the FCS vehicles will be very lightweight relative to the current M1A series of main battle tanks weighing in at over 60,000 kg. An image of a vehicle that may be made to fit the C130 requirements is depicted in Figure 1. This vehicle, in addition to others including the United Defense Armament Systems type classified M8 armored gun system, was considered for near term fielding of a medium weight brigade.

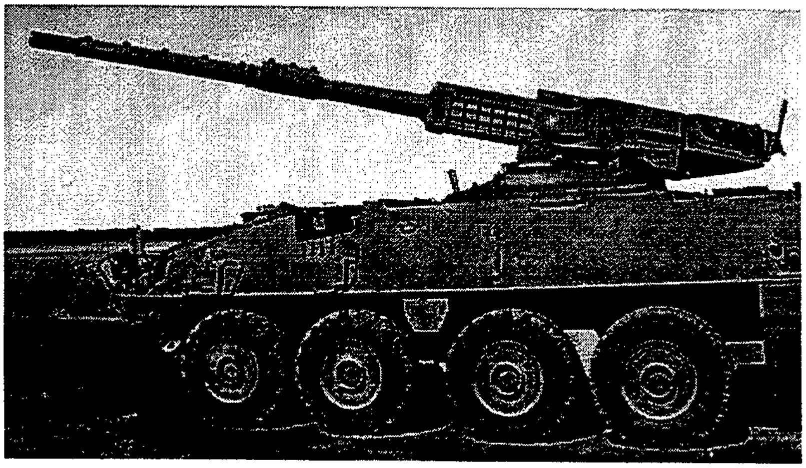

Figure 1. General Dynamics low profile turret assault gun for light armored vehicles.

Armament options for the FCS include:

- Gas guns
- Electromagnetic guns
- Missiles

Each option has its advantages and disadvantages. Using current technology, only gas guns and missile-based armaments are viable for future combat vehicles. Electromagnetic guns will require substantial technological breakthroughs to become a viable weapon system for the future combat vehicle. The Electromagnetic Gun System Program, DAAD17-99-R-9381, is currently fostering such breakthroughs, sponsored by the Army Research Laboratory and led by LTC Buck Tanner.

RECOIL

> *"The firing of a gun gives rise to forces on the vehicle from which the gun is fired. These forces have to be kept not only below a level at which they could cause the vehicle to topple over but also below that causing excessive vehicle motion and crew discomfort,"* (ref 1).

The momentum manifest within a gun system during the firing of the weapon is equal and opposite to sum of the momentum imparted to the projectile launched from the gun and that of the propellant gases subsequently ejected from the gun system. This is true by Newton's third law of motion:

> *"To every action there is always opposed an equal reaction."*

RAVEN achieves its dramatic reduction in the recoil momentum by ejecting much of the propellant gases rearward out of the back of the gun system, thus reducing the combined launch momentum (ref 2). (The launch momentum associated with a given round of ammunition is often termed the "impulse" of the round.[†]) It will be shown that RAVEN has the potential to achieve this dramatic enhancement in recoil momentum without disadvantages associated with traditional recoilless rifle systems whose "*...ammunition is considerably heavier than that of comparable low-pressure or conventional guns,*" (ref 1).

It is important to realize that momentum is a vector quantity and may not be dissipated, as is the case for kinetic energy, which is a scalar quantity. For a traditional gas gun, the launch momentum consists of that imparted to the projectile, and the propellant gases that follow the projectile out of the muzzle.

TRADITIONAL ENGINEERING SOLUTIONS

The first recoil momentum reduction approach to be described will achieve momentum cancellation by ejecting a secondary projectile rearward out of the gun; this is called a Davis gun. The second and third approaches will eject propellant gases out of the rear of the gun; these are termed recoilless guns, the current invention being a variation on this theme. The fourth and final approach will attempt to divert the forward momentum of the propellant gases at the muzzle end of the gun. This mechanism that diverts the propellant gas is called a muzzle brake.

[†] Impulse represents the momentum imparted to the gun system by the launch of the round. It is defined as the integral force over time and has units of force multiplied by time, which is equivalent to mass multiplied by velocity. Unfortunately, impulse has a separate usage to represent an idealized mathematical function whose duration is infinitesimal but whose integral is finite—the Dirac delta function. For common engineering applications of recoil design that do not consider the dynamics during the very brief interior ballistics cycle, both definitions are concurrently applied, leading to confusion when the distinction is not understood.

Davis Gun

During Word War I, Commander Cleland Davis, U.S. Navy, invented a recoilless gun that fired an ordinance projectile at the target (e.g., a submarine) and a dummy projectile of equal mass to the ordinance projectile. The dummy projectile was made of Vaseline and lead dust and was fired in the opposite direction. See Figure 2. This was achieved using a cannon that was open at both ends, and loaded in the middle (ref 3).

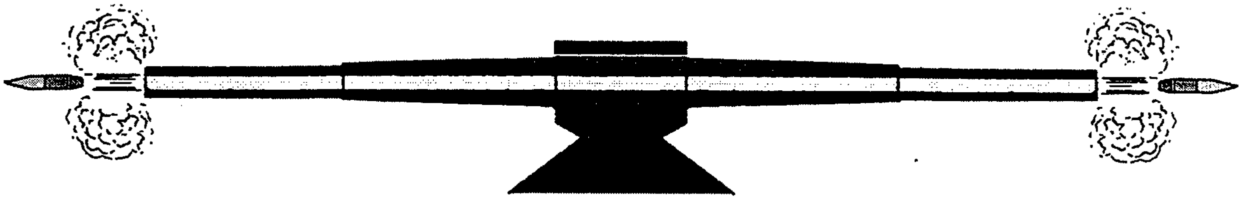

Figure 2. Simplified depiction of a Davis gun firing two projectiles of equal mass.

An attempt was made in 1972 (ref 4) at the Naval Weapons Center, China Lake, CA, to apply a Davis-type gun to the underside of an A-4 aircraft center line as shown in Figure 3. The conclusion of the study was that the recoil mitigation was successful, but diffusion of the muzzle blast would be required to prevent popping of rivets and buckling of the exposed skin material of the aircraft.

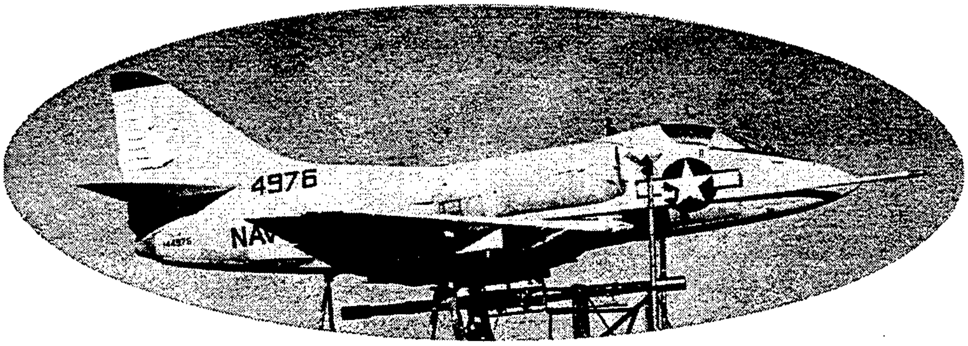

Figure 3. Image of back-to-back M2A2 105-mm howitzer cannons mounted to a Navy A-4.

Problems with a Davis gun include:

- The rearward fired projectile and subsequent muzzle blast constitutes a hazard to friendly forces.
- It is clear that the weight of the double projectile and double charge ammunition is twice that of a conventional gun system with equal firepower.
- The gun is required to contain pressure in both directions, being nominally twice the size in both length and weight of a conventional gun system with equal firepower.

Recoilless Guns

> *"In order to eliminate the need for heavy recoil mechanisms, some guns are built with a nozzle in the breech, so that part of the propellant gas can flow backward and counter-balance the momentum of the projectile and the part of the propellant that moves forward. Such guns are called recoilless guns or recoilless rifles,"* (ref 5).

In the United States, the first reduction to practice of a recoilless gun was hastily—but effectively invented—during World War II by Colonel René R. Studler, at the Research and Development Service of U.S. Army Ordnance, as a means to achieve a lightweight recoilless gun without the weight disadvantages of the Davis-type gun described above. The incredible result of the invention was a shoulder-fired weapon with the accuracy comparable to an M1 rifle that could propel a three-pound (1.36 kg) explosive shell with a muzzle velocity of 1200 feet per second (366 m/s) (ref 3).

A drawing of the U.S. Army M40AD 106-mm recoilless rifle is depicted in Figure 4. In the depiction, the projectile travels to the right, while propellant gases escape to the left after passing through a perforated chamber case shown between the projectile and breech (ref 6). Alternative designs, such as the German LG 42 105-mm recoilless howitzer, used a bursting disk located at the breech to contain the propellant through ignition as opposed to a perforated chamber (ref 7).

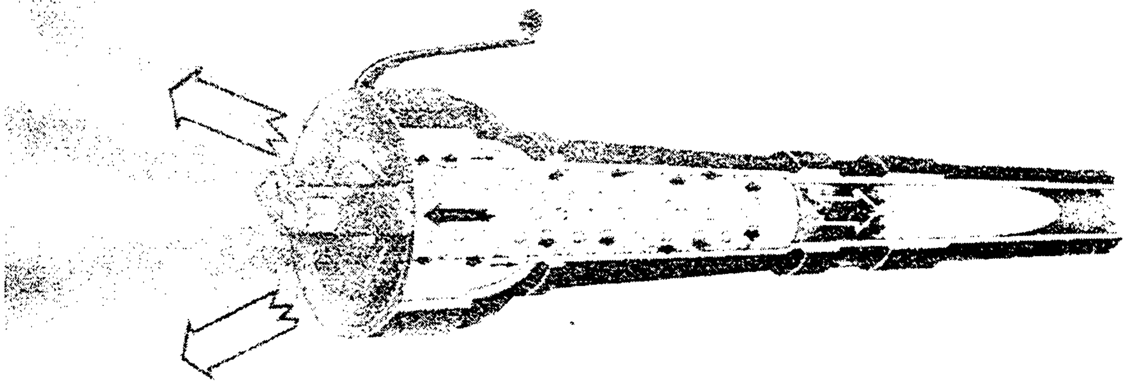

Figure 4. Recoilless rifle depicting propellant gases escaping to the rear while the projectile is propelled forward.

Problems with recoilless rifles include:

- Poor ignition characteristics of propellant within the open chamber system of a traditional recoilless gun system are evident (ref 8). (Actually, an impregnated paper liner inside the case is used to contain chamber pressure during shot start (ref 3). However, the paper is not fully effective in its purpose.)
- There is ejection of unburned propellant through the nozzle, clearly wasting the chemical energy contained within (ref 8).

- Because of the inefficient interior ballistics: "R*ecoilless guns require at least twice as much propellant as conventional guns of similar performance and their ammunition is, therefore, bulky and heavy,*" (ref 9). The inefficiency is caused primarily by the substantial application of chemical energy, released during combustion, to the rearward kinetic energy of the propellant gases vented through the nozzle.
- Most recoilless gun systems require a perforated cartridge to contain the propellant while it burns. The perforated cartridge adds to the cost and weight of the ammunition.
- "*Their back-blast constitutes a hazard to (their) own troops and makes them conspicuous when they fire,*" (ref 9).

Front Orifice Recoilless Rifle

The Frigidaire Division of the General Motors Corporation, in collaboration with the Armour Research Foundation, developed a particularly clever variation of the recoilless gun system known as the "front orifice recoilless rifle" in the early 1950s (ref 8).

A schematic of the concept is shown in Figure 5. This approach enables the ignition process to occur in a closed chamber, thus eliminating the poor ignition characteristics and reducing the ejection of unburned propellant. Accordingly, the efficiency is superior to that of a conventional recoilless gun system.

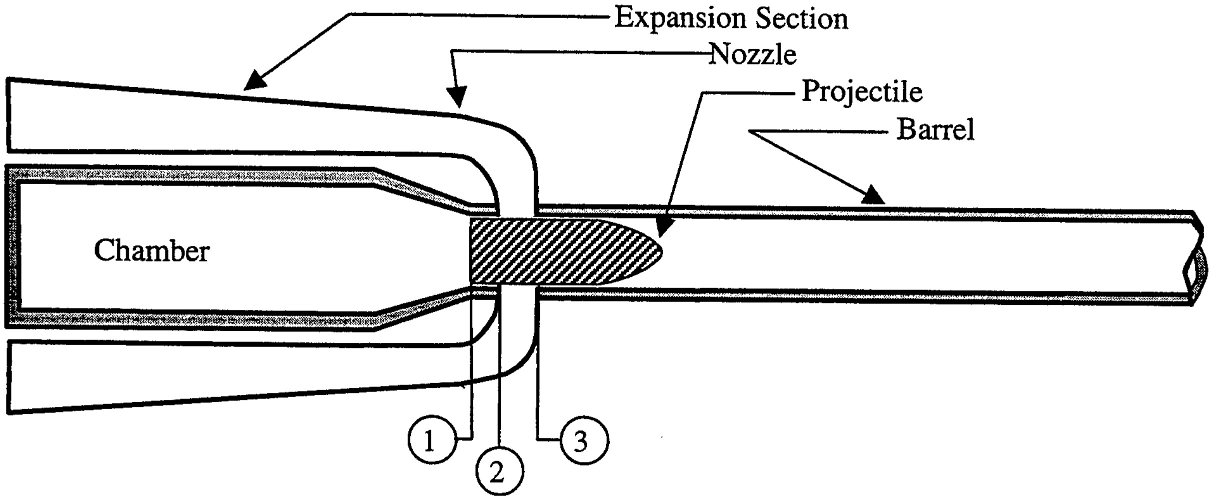

Figure 5. Diagram showing the principles involved in the "front orifice" type recoilless rifle.

The operation of the gun system shown in Figure 5 is as follows (ref 8):

- "During projectile travel from 1 to 2, the rifle behaves as a conventional (closed breech) weapon."
- "During the travel from 2 to 3, the entrances to the nozzles are opened gradually and the rifle is partially recoil compensated."

- "During the travel beyond 3, the ports are completely open, and the thrust developed by the nozzles is greater than the pressure force applied to the base of the projectile, hence compensating for the unbalances occurring during states 1 and 2."

Problems with a front orifice recoilless rifle include:

- The propellant gases escaping rearward must be ducted a substantial distance, from the orifice location along the bore, to the rear of the weapon. This adds to system weight and complexity (ref 10).
- The orifice reduces the propellant gas pressure behind the projectile after the orifice is enabled and throughout the remaining duration of the ballistic cycle. This reduces the energy applied to the propulsion of the projectile.
- The front orifice recoilless rifle suffers the same disadvantages as a recoilless gun (limited chamber pressure, ammunition weight, and back-blast, respectively) albeit to a lesser extent than a traditional recoilless gun.
- The initial imbalance in recoil loads requires a flexible and therefore heavier and more complicated mount to accommodate the initial rearward motion of the gun system prior to the uncovering of the orifices and their recoil mitigation effect.

Muzzle Brakes

Firing impulses can be reduced considerably by the use of muzzle brakes, which deflect the gases flowing out of the muzzle, thus redirecting a substantial portion of the gas momentum. The efficiency of muzzle brakes has generally been between 30 and 40%, with exceptional muzzle brakes achieving efficiencies as high as 70% (ref 1). In this context, the muzzle brake efficiently is defined as the percentage reduction in the kinetic energy imparted to the freely recoiling gun system mass. An image of a current technology, perforated muzzle brake is shown in Figure 6.

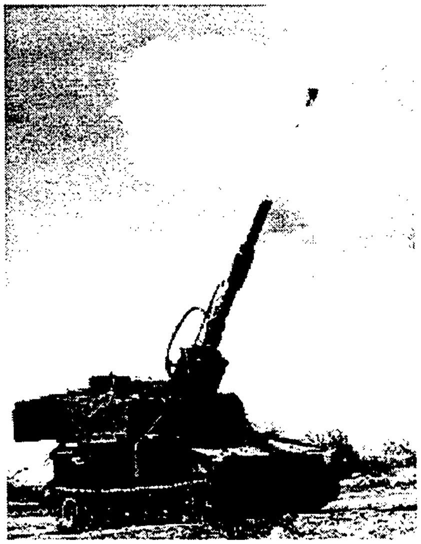

Figure 6. Image of a 155-mm XM 297 artillery cannon with integral perforated muzzle brake firing from a prototype Crusader platform.

Problems with muzzle brakes include:

- "*The deleterious effect that the muzzle blast has on the crew, particularly excessive overpressure. Air disturbances or propellant gas moving at high velocity, loud noise, and heat can be disconcerting if not outright injurious,*" (ref 12).
- Muzzle brake blast stirs up debris, entraining solid objects in the air. "*...the resulting obscuration is a primary objection (for direct fire guns),*" (ref 12). It is important to note that this obscuration occurs between the gunner's sight and the enemy target being engaged.
- "*The added weight of the muzzle brake further burdens the elevating mechanism,*" (ref 12). For stabilized cannons subject to environmental disturbances, such as a tank firing on the move, this additional weight could substantially increase dispersion.
- A column of high velocity gas is allowed to follow the projectile straight out of the muzzle brake unimpeded.

SONIC RAREFACTION WAVE GUN (ref 2)

A method of ejecting substantial propellant gas out the rear of a gun system, without having any effect whatsoever upon the interior ballistics that propel the projectile forward has been achieved by implementation of a robust valve at the rear of the gun chamber that enables the venting of propellant gases while the round is still in-bore.

Rarefaction Wave

The effectiveness of the method is greatly enhanced by the limiting speed of the rarefaction wave that may travel forward down the bore toward the base of the moving projectile. A substantial delay time between "uncorking" the back of the gun breech and communication of this forward means that the interior ballistic pressure driving the projectile is fundamentally unaware that the back of the gun is open. The wave cannot travel faster than sonic speed in addition to the local velocity of the gases.[†]

Chamber Valve

Such a chamber valve is most similar to the burst disk method of containing propellant gas pressures through shot start pressure (ref 5). These disks were designed to contain the propellant gas pressure somewhat past shot-start (the point at which the projectile begins to move). The advantage is that delays in the venting of the chamber decrease the percentage of propellant grains that are ejected prior to being completely burnt. However, burst disks by their nature fail upon reaching a maximum pressure limit. Venting of the chamber cannot be delayed beyond the peak pressure, which occurs very early in the travel of the projectile.

[†] An ever so slight effect may be discernible that is caused by the radiant heat transfer within the gas column and travels at the speed of light. Thus, the cooler gas behind the rarefaction wave will not return as much radiant heat forward through the wave and into the gases propelling the projectile as would occur if the rarefaction wave were not present (ref 11).

Analogy may also be drawn to the front orifice recoilless rifle as depicted in Figure 4. In this type of gun, the venting of the chamber may be delayed indefinitely. In fact, the distinction between the front orifice recoilless and muzzle brake becomes blurred as the orifice is moved toward the muzzle. However, even though the venting of the chamber may be delayed indefinitely, the fact that the rear of the projectile uncovers the exhaust port implies that there is no delay in communication of this forward. Thus, the propulsion of the projectile is immediately compromised.

A Hybrid Davis and Front Orifice Gun

A robust means of achieving a breech valve is to combine the Davis gun concept of Figure 2 with the front orifice recoilless concept of Figure 5. This results in a hybrid Davis and front orifice recoilless gun concept in Figure 7. If the rearward facing dummy projectile of the Davis gun were to uncover an orifice and allow the chamber to be vented through nozzles facing to the rear, substantial forward thrust would be produced to accelerate the cannon forward. This venting of the chamber would immediately decrease the pressure acting on the dummy projectile of the Davis gun, while a substantial time delay would be incurred before the rarefaction wave front could reach the base of the ordnance projectile. What remains is to address the issues of the forward thrust imparted to the cannon, and the discharge of the dummy projectile.

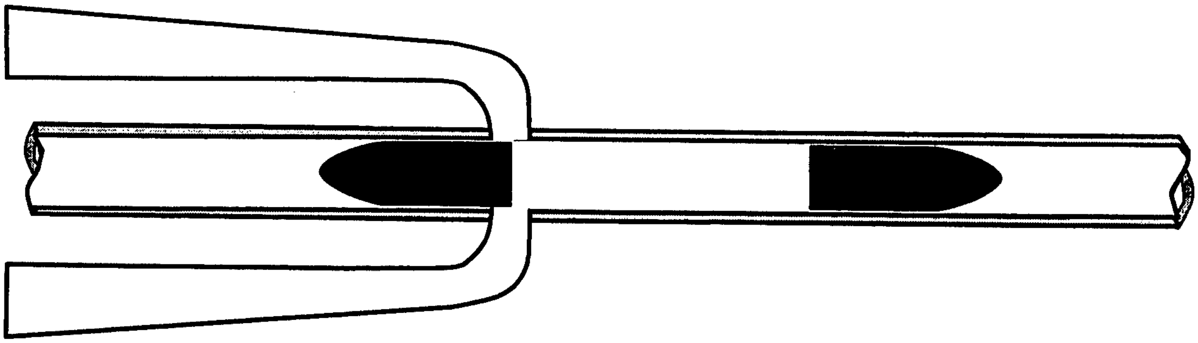

Figure 7. Hybrid Davis and front orifice recoilless gun concept.

Inertial Breech

A more pragmatic means of achieving the desired effect is to increase the mass of the dummy projectile, until it becomes of the same order of the recoiling mass of a traditional cannon. Once this is achieved, it may be seen that a recoil system designed to decelerate (i.e., "catch") the dummy projectile would be similar in size and volume to one dedicated to the deceleration of a traditional canon. Such a dummy projectile may be termed an "inertial breech" (ref 13). Those familiar with small arms may see the similarity between this concept and the behavior of a straight blow-back mechanism common to pocket automatic pistols (ref 3).

Using an inertial breech, the rear orifice may be uncovered to vent the chamber during the launch of the ordnance projectile in analogy with the uncovering of the exhaust ports of a two-stroke engine by its piston. The timing of the venting may be controlled by:

- The location of the rear orifice
- The starting position (and velocity if any) of the inertial breech
- The mass of the inertial breech
- The effect of any external loads applied to the inertial breech

SYSTEM CONCEPT 1

Using an inertial breech, RAVEN may be achieved by allowing the inertial breech to freely recoil within the cannon barrel prior to venting the chamber. Once the inertial breech has uncovered the rear orifice, a recoil system (shock isolator) connecting the inertial breech to the cannon barrel may bring the relative motion of the breech to rest. While the inertial breech pulls rearward on the cannon barrel, the forward thrust developed by the release and expansion of the propellant gases out of the chamber and through a de Laval nozzle will provide forward thrust to the cannon barrel. Although it is conceivable, it is not anticipated that the two forces will cancel, so a gun mount, and secondary recoil system to extract any remaining recoil momentum from the cannon will be required.

The principal disadvantage of the concept depicted in Figure 8 is that the kinetic energy imparted to the inertial breech will be substantial, and grow ever larger with decreased inertial breech mass. It is also undesirable to require two recoil systems, one for the inertial breech, and one for the cannon to abate whatever recoil momentum is not cancelled by the nozzle thrust.

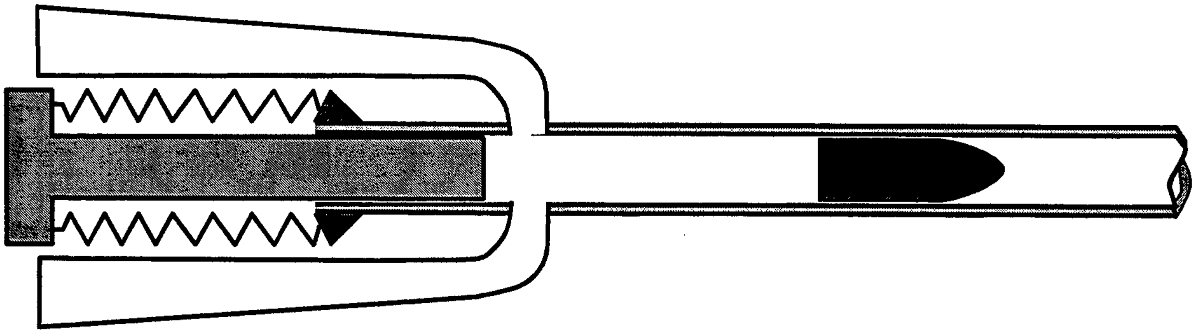

Figure 8. Inertial breech rear orifice low recoil gun.

SYSTEM CONCEPT 2

An alternative to Concept 1 would be to integrate the nozzle within the recoiling inertial breech; see Figure 9. Using this approach, the cannon barrel will remain truly recoilless, and therefore eliminate the need for the cannon recoil and slide-mount. The thrust developed by the nozzle would be applied directly to the recoiling mass of the inertial breech, thus reducing its kinetic energy, and easing the burdens of the recoil system required to abate any momentum remaining after thrust. This will facilitate the application of a light inertial breech and eliminate the need for two recoil isolation systems.

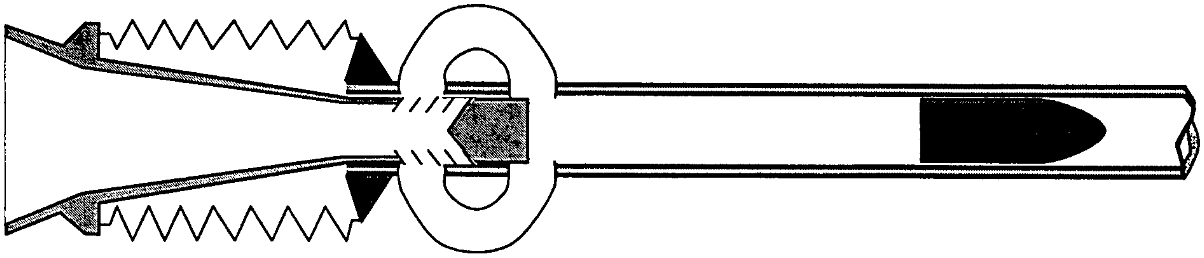

Figure 9. Integral nozzle/inertial breech rear orifice low recoil gun.

ANALYSIS

Wave Front Propagation

Interior ballistic computations using NOVA (ref 14) analysis of a closed-breech gun contain sufficient information to accurately assess the propagation of the wave front that would be released by venting the chamber. Thus, the earliest point at which the breech may be vented without reduction in projectile propulsion can be computed.

The propagation of the rarefaction wave may be computed using a backward difference scheme from muzzle exit that propagates the wave rearward in time and space. The wave velocity may be computed by the addition of the local sound speed within the propellant gas column in addition to its down-bore velocity

The results of this analysis are plotted in Figure 10 for three gun systems. The top plot is for the 25-mm M242 chain gun firing an M919 round. The middle plot is for the M256 Abrams tank gun firing the current state-of-the-art M829A2 "Silver Bullet" round. The bottom plot is for the 155-mm XM297 integral mid-wall cooled cannon under development for the Crusader program. This last gun is shown firing in Figure 6.

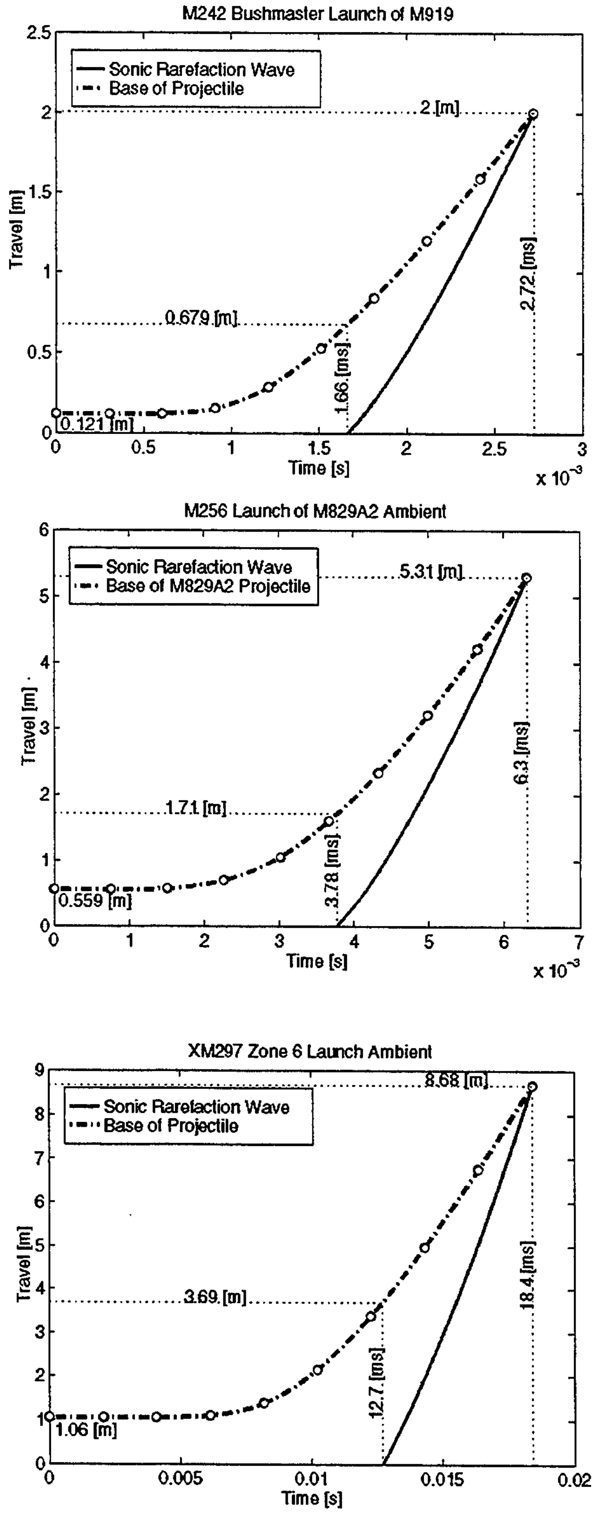

Figure 10. Rarefaction wave propagation and projectile position versus time for a 25-mm, 120-mm, and 155-mm gun, respectively, from top to bottom.

In all cases, the sonic velocity hovered near 1000 m/s, while the local velocity of the gas column followed a nearly linear ramp from zero to the muzzle velocity of the round in space and time. The sonic velocity and local gas velocity contributions to the rarefaction wave speed are shown in Figure 11 for the 120-mm example shown in Figure 10.

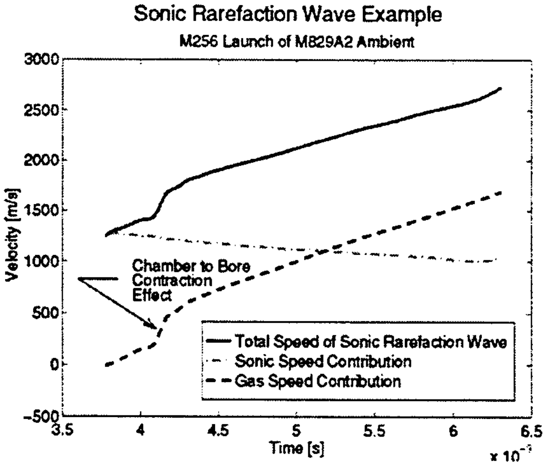

Figure 11. Velocity contributions to the rarefaction wave for the M256 example.

From the plots of Figure 10, it is clear that a sonic rarefaction wave low recoil gun can vent propellant gases out long before shot exit. This is in sharp contrast to the only viable alternative, the muzzle brake:

> *"Unfortunately, the muzzle brake does not perform while the projectile is still in the bore. The recoiling parts almost reach their full momentum during this time, thus consigning the function of the brake to the analogous role of a corrective rather than a preventative performer,"* (ref 12).

Thrust Estimation

Estimates of the thrust reductions possible from venting the breech prior to shot ejection were made using a quasi one-dimensional approach. The interior ballistic solution was obtained from an interior ballistic code such as NOVA (ref 14) and used as the initial conditions for the analysis. The propellant gas was assumed to behave as calorically perfect and obey the Noble-Able equation of state. No chemical reactions were modeled; additionally, there was no dispersed second phase such as unburned propellant particles.

The flow was assumed to process isentropically for this initial investigation. Later efforts will focus on the bore heating, friction, and two-dimensional effects. Van Leer's flux vector splitting method was used to solve the Euler equations in a time-marching method.

The present study was conducted by using a baseline case of a closed breech. The recoil impulse was calculated until the blow-down had continued to a point where further calculation produced negligible impulse. This baseline calculation of recoil impulse was compared to the recoil impulse values accepted in the gun community as a validation of this method of calculating the recoil impulse. Once this baseline case was validated, the vented breech calculations were run.

The vented breech calculations were conducted assuming a nozzle with a throat area equal to the chamber area and fitted with a diverging nozzle designed to expand the gas to Mach 5. These calculations proceeded with a closed breech until the breech opening time was reached. The breech vents were assumed to open gradually over a period of 50 time steps. The thrust from the breech nozzle was calculated and subtracted from the projectile and muzzle thrust to yield the overall system thrust and recoil impulse.

To validate the method used here, the calculated closed-breech recoil impulse was compared to the accepted value for the 120-mm M256 gun firing the M829A2 projectile. The accepted value of the total impulse for this gun/ammunition combination is 35.6 kN-s. The calculations predicted a value of 35.9 kN-s as shown in Table 1. Since the calculations were within 1% of the accepted value, the method is considered validated and the vented breech calculations can be made.

Table 1. Recoil Impulse (kN-s)

	Muzzle Impulse	Breech Impulse	Total Impulse	Delta
Baseline	35.6	0	35.6	-
Vent	18.0	-9.06	8.94	-75%

The calculations made with a vented breech fitted with a Mach 5 nozzle yielded a total recoil impulse of 8.94 kN-s, a 75% reduction as shown in Table 1. This represents 66% of the propellant mass being expelled through the breech nozzle and the remaining 34% out the muzzle. Since the breech nozzle is fitted with a diverging portion and the muzzle behaves as a sonic nozzle, the momentum recovered from the breech is higher than what one might expect by looking at the mass expelled.

ADVANTAGES

Recoil Momentum Reduction

The sonic rarefaction wave low recoil gun dramatically reduces recoil energy manifest as reduced kinetic energy of recoiling gun parts. Complete elimination of recoil energy may be possible. This reduces the imposition of recoil momentum and energy upon mobile weapon platforms such as aircraft, spacecraft, and fighting vehicles.

Reduced Gun System Weight

Although efforts have been made to reduce the weight of recoiling gun system components such as the cannon barrel, breech, and breech ring using novel construction methods and materials, these efforts result in new problems manifest as recoil challenges. Gun mass is largely dictated by the need to control the kinetic energy of recoil. It may be shown that the trunnion pull of a traditional recoiling gun is inversely proportional to the recoiling mass when all other design parameters are held constant (ref 15). This relationship between recoiling mass and recoil energy has severely limited the evolution of composite cannon components from proving ground demonstrators to fielded weapons.

Reduced Heat Transfer to Cannon

Exhausting propellant gases out of the gun bore prior to shot exit will substantially reduce the net heat transfer to the gun barrel by reducing the time of exposure and temperature of the gases in contact with the bore of the gun. Also, for much of the cannon bore, the speed of the propellant gases will be reduced, thus decreasing the scouring of the boundary layer adding further reduction in the drivers of heat transfer.

Reduced heat transfer to the gun barrel will enhance thermal management of the system and reduce the need for radial conduction of heat from the bore through the barrel to the surface. (Thermal effects have been a challenge to the application of fiber-based composites to gun barrels.)

Favorable Nozzle Location

By its location at the rear of the gun, the method better enables the use of nozzles of sufficient surface area to efficiently allow adiabatic expansion of the high-energy propellant gases. Also, as is the case for muzzle brakes, the additional weight of the nozzle will reduce recoil energy as long as the nozzle is coupled to the recoil gun parts. Finally, location of the nozzle weight to the rear of the trunnions will favorably affect the balance of the gun system.

Efficient nozzle design, that enables greater adiabatic expansion of the propellant gases, may better incorporate flash, smoke, and noise suppression than would be possible with traditional recoilless rifles. This would be aided by avoiding gross under-expansion of the nozzle design.

Reduced Muzzle Blast Obscuration

The muzzle blast (see Reference 12, chapter 2, for a description of muzzle blast) that follows the round out of the gun barrel may be dramatically reduced. (This is the column of propellant gases that follows the projectile out of the bore and even speeds past it for a brief distance immediately following muzzle exit.) This may be achieved by timing the sonic rarefaction wave to coincide with projectile exit from the muzzle. Reduction in muzzle blast will reduce obscuration that results from the raising of dust by muzzle blast (ref 12).

Favorable Blast Discharge Location

Muzzle blast signature will be dramatically reduced. While it is anticipated that the signature of the gases discharged out the rear nozzle may be substantial, the turret lies between this blast and the targeted threat system that the gun is engaging. Thus, the gun turret itself will reduce the observability of the back-blast. This is in sharp contrast to the muzzle blast of a traditional gun system that prominently displays its signature to the targeted enemy in front of the turret.

Unlike a muzzle brake, which directs shock waves back at the vehicle, the shock waves exhausted out the back of RAVEN by the nozzle will travel away from the vehicle, thereby reducing the deleterious effects of blast upon externally mounted vehicle components such as active protection systems, antennae, lights, and infrared receivers.

Closed-Breech Operation Mode

The gun system may be designed to automatically operate in closed-breech mode when firing low-impulse rounds. This is achieved by designing the actuation method for the chamber valve to be a function of the impulse imparted to the recoiling gun mass, such that the valve at the rear of the gun is not opened without sufficient impulse. Under such closed-breech operation, a traditional recoil system will function to absorb the low-recoil energy imposed upon the gun system by the low-impulse round.

Closed-breech operation for low-impulse rounds may be of particular advantage in a military operations in urban terrain (MOUT) environment where the back-blast associated with recoilless operation could result in unacceptable danger to nearby civilians, friendly troops, and civil structures. (Consult Reference 16 for a lay discussion of the MOUT environment.) Serendipitously, during such MOUT operations, the extended range armor penetration requirements of many munitions intended for open terrain may be dramatically reduced, thus reducing the impulse associated with rounds that would be fired in MOUT operations and thereby eliminating the need to vent propellant gases rearward.

DISADVANTAGES

Cannon Mechanism Complication

There is no doubt that the incorporation of a chamber valve within a high-performance cannon will complicate the design. Most notable among the design challenges will be the engineering of a robust seal, to provide closed-breech operation prior to the release of the rarefaction wave. It is anticipated that a direct mechanical coupling of the valve operation to the chamber pressure of the gun will be critical to ensure reliable operation under any interior ballistic load. Candidate approaches include the inertial breech gun as depicted in Figures 9 and 10 and down-bore gas actuation as used by machine guns such as the Benét-Mercie (ref 3). Detonated rupture disks that will withstand peak pressure, but be caused to fail at a predetermined time are also worthy of consideration.

Back-Blast

Although the point has been made that the energy of the propellant gases released out the back of the gun will be comparable to the energy released out the muzzle of a traditional cannon, back-blast constitutes a real concern for organic infantry, noncombatants, and nearby material.

A rule-of-thumb for the back-blast from a recoilless rifle is, "*For a given nozzle-breech configuration, equal peak over-pressures occur at points whose distances to the nozzle are the inverse ratio of the cube root of the charge weights,*" (ref 17). Using this as a rough guide, the back-blast danger zone from 20 kg of propellant from a current tank gun round that expelled two-thirds of the propellant rearward would compare to the danger zone for an M27 105-mm recoilless rifle firing a round with 3.6 kg of propellant, with a 55% increase in the 25-m rearward zone of the M27 (ref 10) to 37-m. This equates favorably with respect to current TOW missile back-blast. (Consult References 18 and 19 to compare the danger zones of fielded recoilless rifles and TOW missile systems.)

It is also worthy to note that because of the initial closed-breech operation, and subsequent behavior of the rarefaction wave propagation through the two-phase forward oriented flow of solid propellant grains entrained in the propellant gas column, few if any solid particles will be ejected out the nozzle. This should substantially reduce the danger zone.

> "*The most important single injuring factor (in the danger area) is the missile effect of unburned propellant expelled at high velocity,*" (ref 10).

This assessment was based on experimental investigations of such blasts on goats (ref 20).

Back-blast is also a challenge for muzzle brakes, the only viable alternative technology to reduce recoil momentum. A critical design requirement for any muzzle brake is to meet the standards of MILSTD-1474D, "Noise Limits for Army Materiel," (ref 21). The focus on auditory damage is consistent with the recoilless rifle danger zone finding that sound pressure level was the principal danger factor remaining if unburned propellant projectiles were eliminated through design (ref 10).

NOZZLE EXHAUST LOCATION

Clearly, any gun that vents propellant gases out the back must be integrated such that the propellant gas exhaust may proceed unimpeded rearward. The most direct means to accommodate this requirement is to use a pedestal mount, external gun. (See section 16.7 of Ogorkiewicz [ref 1] for elaboration on external-mounted guns.) The 105-mm M68 cannon integration with the eight-wheeled light armored vehicle of Figure 1 is an excellent example of a pedestal mount.

An alternative approach is to provide for a turret that rotates in both azimuth and elevation. Such a turret is termed an oscillating turret, such as the French AMX 13 tank (Figure 12) with an oscillating turret. Further information is contained in Reference 9.

Figure 12. Prototype of French AMX 13 tank with oscillating turret.

CONCLUSIONS

RAVEN constitutes a new approach to the mitigation of gun recoil, and radically departs from the traditional application of muzzle brakes, while avoiding many of the pitfalls of recoilless rifles. Such technology may prove critical to the in-field success of future lightweight fighting vehicles of current interest to the United States Army.

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