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Russell

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[54] **POROUS NOZZLE PROJECTILE BARREL**

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[52] **U.S. Cl.** **89/14.05**; 89/14.3; 89/8

[58] **Field of Search** 89/8, 14.05, 14.3; 42/76.01

[56] **References Cited**

U.S. PATENT DOCUMENTS

3,186,304	6/1965	Biehl	89/7
3,204,527	9/1965	Godfrey et al.	89/8
3,311,020	3/1967	Piacesi et al. .	
3,465,638	9/1969	Canning .	
3,468,216	9/1969	Charpentier	89/8
3,771,414	11/1973	Graham	89/14.05
4,457,206	7/1984	Toulios et al.	89/14.05
4,590,842	5/1986	Goldstein et al.	89/8
4,643,073	2/1987	Johnson	89/14.3
4,658,699	4/1987	Dahm	89/8
5,097,743	3/1992	Hertzberg et al.	89/7
5,131,313	7/1992	Zimmerman	89/8
5,303,633	4/1994	Guthrie et al.	89/8
5,305,677	4/1994	Kleinguenther et al.	89/14.2
5,421,237	6/1995	Naumann	89/8

FOREIGN PATENT DOCUMENTS

324510	2/1935	Italy	89/8
164697	6/1921	United Kingdom	89/8

OTHER PUBLICATIONS

Beeman Precision Airgun Guide, 1995, Edition 19, Beeman Precision Airguns, 5454 Argosy Drive, Huntington Beach, CA 92649 USA p. 21.

John, James E. A., 1984, *Gas Dynamics*, Allyn and Bacon, Inc., Newton, Massachusetts pp. 43–47, 74.

Jones, M. C., 1986, "Shock Simulation and Testing in Weapons Development," *The Journal of Environmental Sciences*, Sep./Oct., vol. 29, p. 17–21.

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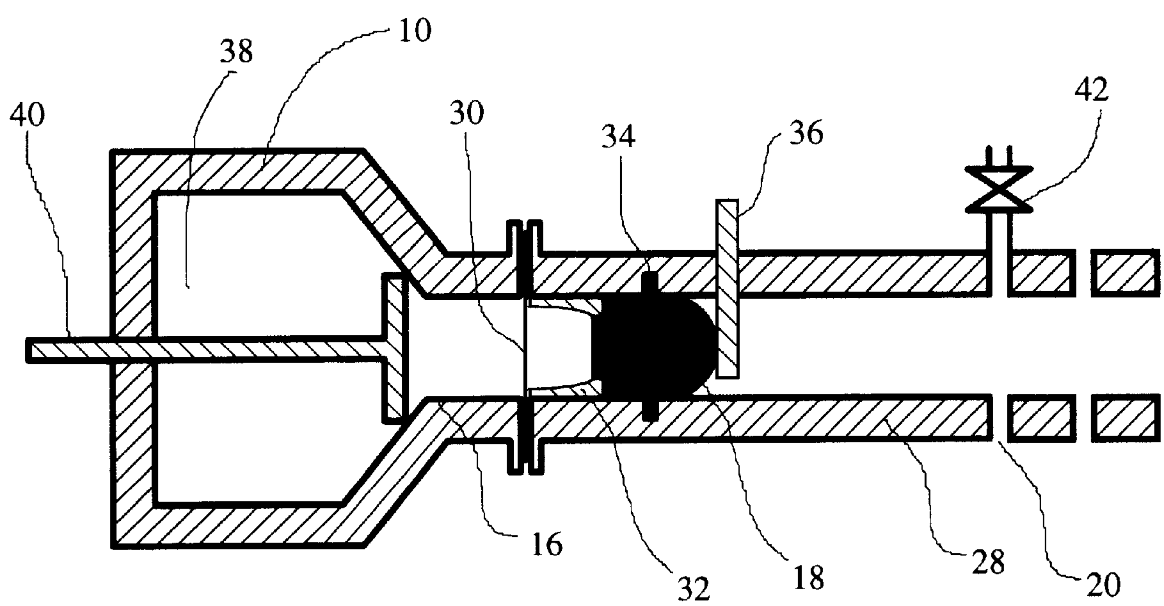
[57] **ABSTRACT**

A porous barrel, projectile passageway, or tube as a type of supersonic nozzle for projectile propulsion therein and method for optimizing projectile velocity therethrough. The porous barrel features a barrel wall containing holes, passageways, or otherwise porous material through the barrel wall that allows gas, fluid, or other matter to exit or move in a direction away from the barrel interior. The flow of gas, fluid, or other matter away from the barrel interior allows gas within the barrel to expand in a direction transverse to the projectile path. The amount of transverse expansion of the gas in the barrel interior can be controlled by the porosity of the barrel wall to cause any desired amount of gas expansion. Transverse expansion allows axial gas velocities within the barrel to exceed the local speed of sound as if the gas had passed through a converging diverging nozzle. In one embodiment, a pressurized gas source supplies a pressure propelling the projectile, and gas outflow from passageways through the barrel wall allows gas within the barrel to obtain supersonic velocities as the projectile accelerates.

2 Claims, 1 Drawing Sheet



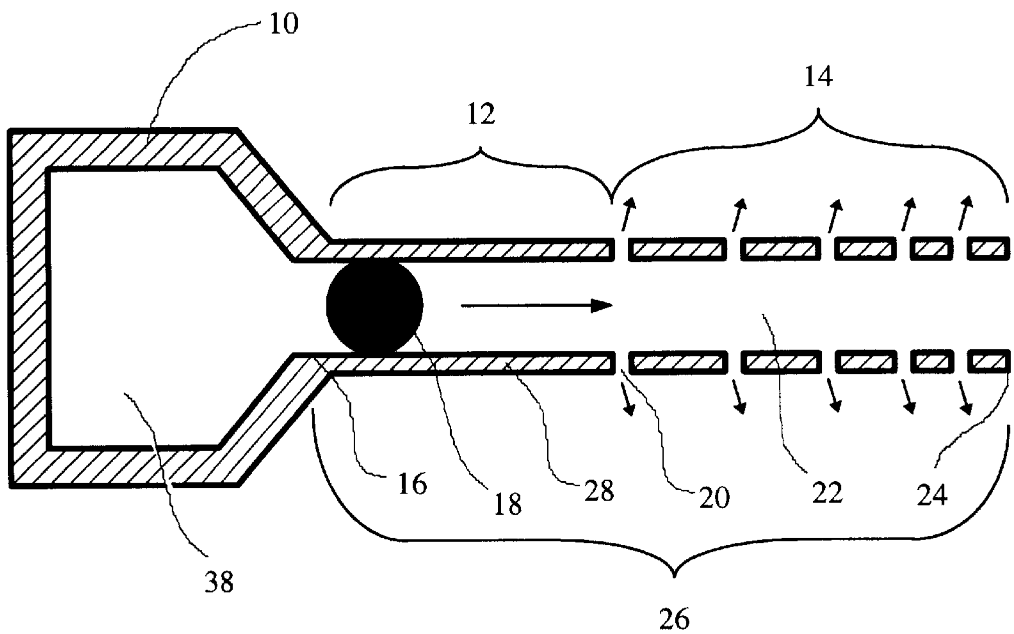


FIG. 1

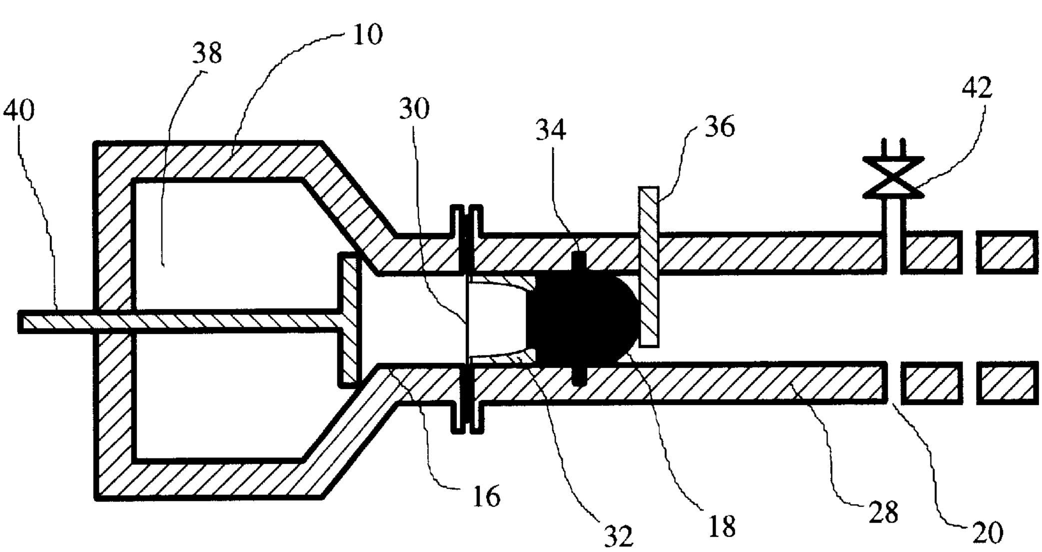


FIG. 2

POROUS NOZZLE PROJECTILE BARREL

FIELD OF THE INVENTION

This invention relates to any form of projectile launcher or gun which utilizes gas, plasma, explosive, or any compressible material to drive or propel a projectile. More particularly, this invention relates to projectile accelerators such as airguns, hypervelocity guns, and high velocity projectile launchers in which it is desired or beneficial to obtain a projectile velocity that is greater than the local speed of sound of the driving gas or compressible substance. This invention also relates to guns and high velocity projectile launchers as mentioned in U.S. Pat. No. 5,303,633.

BACKGROUND OF THE INVENTION

Early documentation of compressible gas powered projectile propulsion devices, such as airguns, dates back to around the middle of the 16th century according to Traister, Robert J, 1981, *All About Airguns*, Tab Books Inc., Blueridge Summit, Pa. These ancient airguns were generally military devices used to fire projectiles in the 0.30 to 0.60 caliber size range. They were usually pneumatic, having a pressure cylinder that was manually pressurized. The basic principles used in gas powered guns have changed only slightly over the years.

Gas driven guns now have a wide variety of applications. Low velocity sport airguns are commonly used for target practice, gun training, and for hunting very small game. Airgun competition is now an Olympic sport. Airguns are also used in military and science labs for various purposes. The military uses airguns to launch some types of missiles which have vibration sensitive electronics inside according to Jones, M. C., 1986, "Shock Simulation and Testing in Weapons Development," *The Journal of Environmental Sciences*, September/October, Vol. 29, pp. 17–21. Gas powered guns are also used in various types of field weapons. Airguns typically operate with low vibration compared to explosive driven guns. Gas powered guns also are typically more controllable than explosive powered guns. Hypervelocity guns are similar to airguns, but usually use explosives and high temperature light gases which have a high speed of sound to achieve much higher velocities.

Airguns today are generally low powered and low velocity compared to guns which use explosives or high temperature light gases to drive the projectile. The most significant factor in the low velocity limitation of airguns and low temperature compressible gas powered guns is the speed of sound in the driving gas that propels the projectile. Hypervelocity guns that use explosives, hot gasses, light gasses, plasma, and other gas like propellants are also limited by the same principle. For example, compressible gas equations for a gas in steady state, isentropic flow show that gas traveling from a high pressure reservoir at rest, to a low pressure reservoir, through a constant area or narrowing passageway, cannot exceed the velocity of the local speed of sound. The assumption of isentropic flow is common practice for many airgun designers. Using a hydraulic analogy of an airgun shows that even though an airgun is an unsteady device, the sonic limitation still applies.

Efforts to minimize the effect of the sonic velocity limitation have led to developments such as "light gas guns" disclosed in U.S. Pat. No. 3,186,304 and mentioned in U.S. Pat. No. 5,303,633. Light gasses, such as hydrogen, have high speed of sound and increase the attainable sonic velocity. For example, the speed of sound in hydrogen is about 4 times faster than the speed of sound in air at the same temperature.

Raising the temperature of the driving gas is another way to reduce the effect of the sonic velocity limit. Raising the temperature of a gas raises the speed of sound in the gas. Several methods that raise the temperature of the propellant gas immediately before firing a gun are used today. For example, in U.S. Pat. No. 3,311,020 a conventional piston compresses the propellant gas immediately before firing the gun raising the temperature very high. In U.S. Pat. No. 3,465,638 an explosion compresses the driving gas chamber increasing the temperature of the driving gas and thus raises its speed of sound. Many similar methods of adding heat to the driving gas have been used to raise the speed of sound of the driving gas; however, they are all nonetheless limited by the sonic limitation.

Similarly, U.S. Pat. No. 4,658,699 discloses a wave gun that uses an explosive to propel a piston which compresses the driving gas chamber. Rapid acceleration of the piston creates shock waves ahead of the piston which raise the pressure and temperature of the driving gas. This gun is also mentioned in U.S. Pat. No. 5,303,633 which attempts to improve upon the above mentioned technology. Again, the gas upstream from the projectile is limited by the sonic limitation.

U.S. Pat. No. 5,303,633 discloses a "shock compression jet gun" that implements a shaped charge, compressible gas, and converging-diverging nozzle to drive a projectile through a barrel. The explosive shaped charge provides high pressure and temperature gas upon detonation. Then the high temperature and pressure exhaust gasses accelerate through a converging-diverging supersonic nozzle. Upon exiting the nozzle, the supersonic driving gasses, preceded by an abrupt normal shock, hit the projectile. The normal shock rebounds from the projectile leaving higher temperature and pressure subsonic gas immediately behind the projectile. This high temperature gas immediately behind the projectile remains limited to sonic velocities as the projectile travels through the barrel.

The above mentioned gun types are dynamic devices, and the sonic limitation as applied to them should be clarified. Upon firing a gas powered gun, local flow properties such as Mach number, temperature, and pressure will vary with time and position within the gun because firing a gun is an unsteady process. Under some circumstances, the projectile velocity could be greater than the local speed of sound of the gas immediately behind the projectile in the above mentioned gun types. For example, if the gas temperature behind the projectile decreases as the projectile travels, the local speed of sound in the gas behind the projectile may lower to a value that is less than the velocity of the projectile. However, in this example, the projectile never exceeds the maximum local speed of sound attained in the driving gas immediately behind the projectile along its pathway through the barrel. Therefore, without the use of some type of supersonic projectile barrel, as herein described, the projectile velocity cannot exceed the maximum transient sonic velocity of the driving gas behind the projectile.

In the case of the "shock compression jet gun" in U.S. Pat. No. 5,303,633, the velocity of the projectile is also limited by the local speed of sound immediately behind the projectile. Combustion gasses may attain a supersonic velocity after passing through the converging-diverging nozzle. However, supersonic explosion gasses hitting the projectile will cause a normal shock to rebound from the projectile. Once a normal shock rebounds from the projectile, the gas immediately behind the projectile is high temperature and pressure, but is subsonic, and travels the same velocity that the projectile travels. The temperature rise after the shock wave from the driving gas hits the projectile will increase he speed of sound in the gas immediately behind the projectile to higher values. This increased temperature raises the limiting speed of sound. However, this method is also limited by the speed of sound in the driving gas as mentioned and clarified above.

U.S. Pat. No. 4,590,842 discloses a "Method of and Apparatus for Accelerating a Projectile" that places multiple supersonic plasma spray nozzles along the projectile barrel that spray supersonic plasma through the barrel wall and against the back of the projectile as it passes each nozzle. FIG. **2** in this patent depicts supersonic plasma spray from the nozzle impacting the back side of the moving projectile which causes the supersonic plasma to slow down and create shock waves. This patent explains that the barrel is designed to fit loosely around the projectile at locations where projectile velocity is high to minimize friction. This loose barrel to projectile fit allows high pressure plasma from the back of the projectile to escape into the region in front of the projectile through the annular gap between the barrel and projectile. Apertures, or vents, may be placed in the barrel wall downstream from a plasma spray nozzle to vent plasma gasses that accumulate in front of the projectile. In this design, the projectile may reach speeds that are greater than the speed of sound of the driving gas because of the multiple impacts of supersonic driving gas against the projectile accelerating the projectile in multiple stages along its path through the barrel.

The above patent, U.S. Pat. No. 4,590,842, discloses that the purpose of the apertures, or vents, is to remove high pressure plasma that had accumulated in front of the projectile. The patent never indicates or claims that the apertures are designed to vent or control the gas behind the projectile. The patent also recommends a preferred size of aperture having a cross sectional area equal to approximately twice the barrel, or projectile, cross sectional area.

With the exception of the design disclosed in U.S. Pat. No. 4,590,842, the problem in all the above types of guns which use any type of compressible gas to accelerate the projectile is that the attainable projectile velocity is restricted by the speed of sound in the driving gas or gasses behind the projectile. Projectile velocity in the design disclosed in U.S. Pat. No. 4,590,842 is not limited by the speed of sound in the driving gas because of its modular supersonic plasma jets that repeatedly impact the projectile as it travels along the length of the barrel. The present invention allows driving gas propelling the projectile and the projectile itself to reach supersonic velocities without the complexity and cost of methods such as the one disclosed in U.S. Pat. No. 4,590,842.

SUMMARY OF THE INVENTION

A purpose of the present invention is to eliminate the sonic velocity limitation of gas driven guns which propel a projectile through a barrel or tube, thereby increasing the attainable projectile velocity. Another purpose of the present invention is to provide a method of controlling the local Mach number of the driving gasses along their travel through any variety of projectile barrel or tube. The driving gasses can be pressurized gas, explosive combustion products, or any gas like substance.

The present invention comprises using a barrel or projectile launch tube which has holes, vents, passageways, or other means of porosity through the barrel wall which allow gas to exit or enter the barrel interior through the barrel wall. Gas exiting from the barrel interior through barrel wall passageways allows gas within the barrel interior to expand transverse to the direction of projectile motion. This transverse expansion of the gas in the barrel interior has the same effect on gas flow that a diverging nozzle has on gas flow. Gas in the barrel interior can accelerate to supersonic velocities if gas traveling at Mach 1 or faster passes through a porous barrel that allows gas to exit from the barrel interior through barrel wall passageways. Gas within the barrel will slow down if gas traveling less than Mach 1 passes through a porous barrel that allows gas to exit the barrel interior through barrel wall passageways. Gas entering the barrel interior through passageways causes subsonic gas in the barrel interior to accelerate, and causes supersonic gas in the barrel interior to decelerate.

In this invention, porosity using any type of passageway or duct through a gun barrel wall can be placed strategically along the barrel to control pressure and Mach number of gas within the barrel along the projectile pathway. In general, adding gas exit passageways through the barrel wall at locations where subsonic gas velocity would otherwise be expected in the barrel interior as the projectile passes will reduce the driving gas pressure, velocity, and Mach number. Adding gas exit passageways through the barrel wall where sonic or supersonic gas is traveling through the barrel interior can increase the velocity and Mach number of gas in the barrel interior. Adding gas entrance passageways through the barrel wall which add gas to the barrel interior has the opposite effect. Adding gas entrance passageways through the barrel wall accelerates subsonic flow and decelerates supersonic flow through the barrel interior. Without a method of allowing gas to expand transverse to the flow direction the projectile and driving gasses could not continue to accelerate once sonic velocity is reached.

In the case of adding passageways through a barrel wall at a location where sonic or supersonic projectile and driving gas velocity is expected in the barrel interior, gas exiting from the barrel interior through passageways may cause driving gas to accelerate faster than the projectile. This accelerating driving gas can cause shock waves to develop behind the projectile which may reduce the driving gas velocity immediately behind the projectile to subsonic. The pressure of this subsonic gas may be higher than the pressure of the supersonic gas, but its local sonic velocity may be slower than the projectile which could prevent additional acceleration of the supersonic projectile. A conclusion from the above considerations is that the design of the gas exit flow profile, and thus barrel porosity, is important, and a method to facilitate design of one is provided hereinbelow.

In a preferred embodiment, passageways through a barrel wall are disposed along the barrel to maximize the projectile velocity for a gas driven gun. The driving gas source is in effect a chamber or reservoir containing high pressure gas. The pressure chamber is connected to a barrel, or projectile tube, by a passageway. The internal diameter of this passageway is preferably narrowing such that the most narrow location between the gas chamber and barrel is the barrel itself. However, it may be acceptable for this passageway to have a narrower internal cross sectional area than the barrel. The barrel has a constant internal cross sectional area matching the projectile shape. The muzzle of the barrel, where the projectile will exit the barrel, opposite from the pressure chamber, is open ended. A projectile is placed in the breech of the barrel near the end that is connected to the pressure chamber. Upon firing the gun, either the projectile is held sealing the barrel and released with the full chamber pressure behind it, or gas is released from the pressure chamber to come in contact with the projectile. Passageways through the barrel wall begin here the projectile and driving gas immediately behind the projectile obtain Mach 1 after the gun is triggered. From that location along the barrel and continuing to the muzzle end of the barrel, passageways through the barrel wall are disposed along the barrel to cause a local gas mass flow out through the barrel wall that will maintain a gas velocity immediately behind the projectile that is equal to the projectile velocity as it accelerates through the barrel. Barrel wall porosity can be varied by incorporating passageways through the barrel wall of various size and spacing along the barrel or using other types of porous material disposed along the barrel wall. The sonic limitation is thereby overcome, and gas immediately behind the projectile, and the projectile itself obtain increasingly accelerating supersonic speed. A method to achieve such optimization of the propulsion process is described hereinbelow.

The porous nozzle projectile barrel of the present invention offers the simplicity of conventional gun technology but eliminates the sonic driving gas limitation and thereby improves the performance of existing conventional guns. Further, the ease of modifying conventional guns of nearly any type to implement a porous nozzle projectile barrel provides easy incorporation into nearly all current gun applications. The passageways through the barrel wall have an additional benefit of allowing gas in front of the projectile to escape from the barrel interior through barrel wall passageways.

Furthermore, the porous nozzle projectile barrel may be used with any type of propellant that provides or produces pressurized gas to drive a projectile through a barrel. The propellant may include gun powder or other explosives commonly used in rifles today. The propellant or driving gas source may also include plasma, chemical reaction products, or any substance that has physical properties similar to a gas.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will be more fully understood from the detailed description given hereinbelow and the accompanying drawings which are given by way of illustration only, and thus are not limitative of the present invention, and wherein:

FIG. **1** shows a cross sectional view of one embodiment of the porous nozzle projectile barrel with a gas pressure chamber and projectile shown at rest before firing the gun.

FIG. **2** shows projectile firing, sealing, pressure release, and trigger mechanisms that could be used in various combinations to allow pressurized driving gas to cause projectile acceleration upon firing a gun.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. **1** shows one embodiment of a porous nozzle projectile barrel **26** with passageways such as passageway **20** through the wall of barrel **26**. Barrel **26** is a barrel, tube, or any type of passageway through which projectile **18** may travel. Barrel **26** may be straight or curved in any shape and have any cross sectional area shape. Barrel **26** preferably contains porous region **14** extending from the location of first passageway **20** to muzzle **24** end where projectile **18** exits barrel **26**. Barrel **26** preferably contains solid region **12** between breech **16** and location of first passageway **20**. Barrel **26** contains at least one porous region **14** at any location along barrel **26**.

Projectile **18** is preferably placed near breech **16**. Projectile **18** is any object or matter that can be made to travel through barrel **26**. Gas chamber **10** is connected to the end of barrel **26** at breech **16**. Gas chamber **10** contains driving gas **38** which is used to propel projectile **18** through barrel **26**.

Porous region **14** of barrel **26** preferably contains at least one passageway **20** or other effective porosity extending partially or completely through barrel wall **28** that allows gas to flow out from or into barrel interior **22**. Other effective passageways **20**, or porosity, may include porous material, hollow cavities opening to barrel interior **22** of barrel **26**, holes through barrel wall **28**, or tubes connected through barrel wall **28**. Valve **42** in communication with porous region **14** or passageway **20** may be used to control flow through porous region **14**. It is preferable for the interior wall of barrel **26** to be smooth, especially where supersonic driving gas **38** velocities are expected.

Solid region **12** of barrel **26** is preferably a solid tube with strength sufficient to hold driving gas **38** pressures. Breech **16** is connected to gas chamber **10**, a passageway (not shown) leading to gas chamber **10**, or a gas pressure source. Barrel **26** may be straight, curved, or formed in any shape that allows gas to flow therethrough. The cross sectional area of barrel **26** and projectile **18** may be of any shape that allows projectile **18** to pass through barrel **26** when a force is applied to projectile **18**. Rupture disk **30** (FIG. **2**) may be placed between gas chamber **10** and projectile **18** to rupture at a desired pressure in gas chamber **10**. However, it is preferable to use other types of driving gas **38** release mechanisms that result in having no obstruction between driving gas **38** and projectile **18**. A few examples of said driving gas release mechanisms that have no obstruction between driving gas **38** and projectile **18** are included hereinbelow.

Barrel **26** contains at least one porous region **14** and any number of solid regions **12** anywhere between breech **16** and muzzle **24**. Barrel **26** porosity allows control of driving gas **38** pressure immediately behind projectile **18** and acceleration of projectile **18** along barrel **26**. Injecting gas into barrel **26** through passageways **20** behind projectile **18** when the velocity of projectile **18** is subsonic increases driving gas **38** pressure immediately behind projectile **18** and can accelerate projectile **18** to sonic velocity quicker than without injecting gas. Placing passageways **20** allowing gas to exit from barrel interior **22** behind projectile **18** when projectile **18** is sonic or supersonic can accelerate projectile **18** and driving gas **38** immediately behind projectile **18** to supersonic velocities.

Various mechanisms may be used to initiate or facilitate projectile **18** acceleration. In the preferred embodiment, projectile **18** is placed in barrel **26** toward breech **16**, or aft end of barrel **26**. Projectile **18** may include obturating band **32** (FIG. **2**) to maintain a seal between projectile **18** and barrel **26**. Projectile **18** may also be held in place by a mechanical release **36** (FIG. **2**) that releases projectile **18** at a desired time. Projectile **18** or surrounding barrel wall **28** may contain rupture rim **34** (FIG. **2**) that seals between barrel **26** and projectile **18** and ruptures at a desired pressure in gas chamber **10**. The rear end of projectile **18** may also include a shock absorbing device (not shown). Inlet valve **40** can be opened to release driving gas **38** so that it communicates with rupture disk **30** or projectile **18**. A preferred embodiment may include but is not limited to the above mechanisms.

Gas chamber **10** contains a volume that holds driving gas **38** that propels projectile **18** through barrel **26**. Gas chamber **10** is preferably a sufficiently large volume to maintain a relatively constant pressure as projectile **18** travels through barrel **26**. Gas chamber **10** may be pressurized using an external gas reservoir (not shown). One example of an external gas reservoir is a SCUBA tank used to fill the gas chamber of the Beeman Mako airgun made by Beeman Precision Airguns, 5454 Argosy Drive, Huntington Beach, Calif. 92649 USA. Explosives (not shown) may also pressurize gas chamber **10**. Driving gas **38** includes but is not limited to pressurized gasses such as hydrogen, air, nitrogen, carbon dioxide, or helium. Other suitable driving gasses include but are not limited to gasses formed from chemical reactions, explosives, gun powder, explosion products, plasma, or compressible substances that behave like a gas.

Barrel Porosity Optimization Method

In another embodiment of the invention, passageways **20** through barrel wall **28** can be disposed along barrel **26** to achieve an optimized driving gas **38** pressure profile along the path of projectile **18** as it travels through barrel **26**. The primary driving gas **38** pressure of interest is the pressure of driving gas **38** immediately behind projectile **18** as projectile **18** travels through barrel **26**. There are many methods to generate and analyze preferred embodiments including finite element methods, finite volume methods, Euler Equation schemes, water analogies, and others. The following is a method to optimize placement of passageways **20** along barrel **26** for the embodiment shown in FIG. **1** to obtain highest projectile **18** muzzle **24** velocity. This analytical model assumes isentropic, locally steady, driving gas **38** flow. Although this model is idealized, it is accurate and useful for preliminary design of an embodiment of a porous nozzle projectile barrel because it shows the limit of achievable gun performance and allows optimization of design parameters through parametric sensitivity analysis.

Knowing driving gas **38** pressure applied to projectile **18** using isentropic gas flow equations, the acceleration of projectile **18** can be obtained from Newton's law, F=ma. This leads to an iterative method to determine an optimal projectile **18** velocity profile along its path through barrel **26**. This optimal velocity profile is equivalent to projectile **18** traveling through a supersonic nozzle designed to exactly conform the velocity of driving gas **38** to the velocity of projectile **18** at every location along the path of projectile **18** through barrel **26**. Knowing the optimal projectile velocity profile, the required local driving gas **38** mass flux through barrel **26** can be obtained from isentropic equations. Knowing the local mass flux profile through barrel **26**, the local mass flux that must exit barrel **26** through each passageway **20** can be determined. Porosity of the barrel wall can be arranged to achieve this mass flux that must exit through barrel porosity.

Driving gas **38** mass flow rate increases in barrel **26** until Mach 1 is reached. After Mach 1 is reached, any further increase in driving gas **38** velocity requires driving gas **38** expansion transverse to the gas flow direction. Since steady gas flow is limited to Mach 1 in a typical constant area gun barrel, porous region **14** allowing gas outflow is used to allow transverse expansion of driving gas **38**. This allows driving gas **38** to achieve supersonic flow as if it had passed through a diverging nozzle. Assuming the gas flow is isentropic, a porous nozzle projectile barrel **26** can be designed and optimized using isentropic compressible gas flow relations as given in the following successive sections.

Variable Definitions

A = barrel 26 internal cross sectional area (m^2)
C = gas flow coefficient through passageway 20
D = passageway 20 diameter (m)
k = driving gas 38 specific heat ratio
L = barrel 26 length (m)
m = projectile 18 mass (kg)
m_b = driving gas 38 mass flux through barrel 26 immediately behind projectile 18 (kg/s)
m_h = sonic gas mass flux through passageway 20 (kg/s)
M = local driving gas 38 mach number
P = local driving gas 38 pressure (N/m^2)
P_t = stagnation pressure (gas chamber 10 pressure) (N/m^2)
R = driving gas 38 constant J/(Kg ° K.)
Δt = time increment (s)
T = local driving gas 38 temperature (° K.)
T_t = stagnation temperature (gas chamber 10 temperature) (° K.)
V = projectile 18 velocity or local driving gas 38 velocity (m/s)
V_1 = projectile 18 velocity at beginning of computational time increment, Δt, (m/s)
V_2 = projectile 18 velocity at end of computational time increment, Δt, (m/s)
X = projectile 18 position (distance from initial rest position) (m)

Method

Rearranging isentropic gas equations gives the following relations:

$$T = T_t - \frac{(k-1)V^2}{2kR} \tag{1}$$

$$M = \frac{V}{\sqrt{kRT}} \tag{2}$$

$$P = P_t\left(1 + \frac{(k-1)}{2}M^2\right)^{\left(\frac{k}{1-k}\right)} \tag{3}$$

Equations are from John, James E. A., 1984, *Gas Dynamics*, Allyn and Bacon, Inc., Newton, Mass.

The following steps are used to optimize porosity of barrel **26**. Projectile **18** starts from rest at position X=0 m, near breech **16**. Porosity begins at first passageway **20** and continues to muzzle **24**. Porosity begins where projectile **18** and driving gas **38** velocity equal Mach 1. Friction between barrel **26** and projectile **18** is neglected here for simplicity, although it may be accounted for by subtracting the frictional force from the term PA in step 4 below. Assuming driving gas **38** velocity at the location of projectile **18** equals the velocity of projectile **18**, the following steps can be iterated with time to determine the optimum projectile **18** velocity profile at every X position along barrel **26**:

1. Calculate temperature, T, of driving gas **38** at projectile **18** assuming the local driving gas **38** velocity equals the instantaneous velocity of projectile **18**, V, using Eq. (1).
2. Calculate local Mach number, M, of driving gas **38** at projectile **18** using Eq. (2).
3. Calculate local pressure, P, of driving gas **38** at projectile **18** using Eq. (3).
4. Calculate new projectile **18** velocity, V_2, after time increment, Δ t, using

$$V_2 = V_1 + \left(\frac{PA}{m}\right)\Delta t.$$

5. Integrate the average velocity, V, of projectile **18** with respect to time to determine the new position, X, of projectile **18** after time increment, Δ t .

6. Calculate optimal driving gas **38** mass flux through barrel **26** at projectile **18** using the relation

$$\dot{m}_b = \frac{PAV}{RT}.$$

7. After projectile **18** and driving gas **38** reach Mach 1, the local mass outflow per barrel length required to cause optimal supersonic gas outflow through porous region **14** may be determined as

$$-\frac{\Delta \dot{m}_b}{\Delta X}.$$

The difference in axial mass flux, $\dot{m}_b$, between any two points along porous region **14** of barrel **26** gives optimal gas outflow that must leave through passageway **20** such as a hole or other means of barrel porosity.

8. Eq. (4) can be used to determine mass outflow, $\dot{m}_h$, from passageway **20** (such as a hole, orifice, or pore) through barrel wall **28** with a given passageway **20** diameter, D. Eq. (4) can be used with the above steps to provide passageway **20** size and spacing for an optimum design. It may be desired to solve Eq. (4) for passageway **20** diameter, D, since optimal mass outflow, $\dot{m}_h$, can be determined from step **7** in the above procedure. Eq. (4) should be solved for D to determine each passageway **20** diameter to give optimum mass outflow if passageway **20** spacing is predetermined. If passageway **20** size is predetermined, use Eq. (4) to determine the mass outflow, $\dot{m}_h$, through passageway **20** and space passageways **20** along porous region **14** according to the optimal mass outflow found in step **7**.

$$\dot{m}_h = C\left(\frac{P}{RT}\right)\left(\frac{\pi D^2}{4}\right)\sqrt{kRT} \tag{4}$$

From John, James E. A., 1984, *Gas Dynamics*, Allyn and Bacon, Inc., Newton, Mass.

Steps 1 through 5 are repeated for each time increment, Δ t, to predict optimal projectile **18** velocity profile and driving gas **38** properties behind projectile **18** at every position along barrel **26**. Steps 6 and 7 are used to determine the required mass outflow through passageways **20** that allows optimal transverse expansion of driving gas **38** within barrel **26** and causes optimal projectile **18** velocity. Knowing the optimal mass outflow along porous region **14**, step **8** can be used to determine proper passageway **20** size and spacing along barrel **26**. The flow coefficient, C, in Eq. (4), is generally a constant based on the efficiency of gas flow through passageways **20** through barrel wall **28**. The flow coefficient, C, should be determined by experiment for a specific passageway **20** type to obtain best accuracy in the above calculation. Experiments may show that the flow coefficient, C, may vary with local driving gas **38** velocity along barrel **26**. Methods such as using an effective passageway **20** diameter may be used if passageway **20** is not a circular hole.

While there have been described and illustrated several specific embodiments of the invention, it will be clear that variations in the details of the embodiments specifically illustrated and described may be made without departing from the true spirit of the invention as defined in the appended claims.

What is claimed is:

1. A nozzle projectile barrel comprising a barrel wall extending from a breech end to a muzzle end and defining a main projectile passageway of constant cross section for the passage of a projectile driven by a driving gas therethrough,

said barrel wall having a plurality of longitudinally spaced apart transverse passageways therethrough positioned in a region of the barrel between a point where the driving gas immediately behind the projectile achieves local Mach 1 and the muzzle end of the barrel wall so that a local gas mass flow from the main projectile passageway through the longitudinally spaced apart transverse passageways causes supersonic driving gas flow relative to the speed of sound in said driving gas within said nozzle projectile barrel,

wherein at least one of said transverse passageways has at least one control mechanism allowing adjustment of the gas mass flow out of the main projectile passageway.

2. A method for disposing at least one barrel wall passageway along a nozzle projectile barrel to maximize projectile velocity comprising the steps of:

a) Calculating driving gas temperature immediately behind said projectiles, assuming the velocity of said driving gas is equal to the velocity of said projectile;

b) Calculating local Mach number of said driving gas immediately behind said projectile;

c) Calculating local pressure of said driving gas immediately behind said projectile;

d) Calculating new velocity of said projectile after a selected time increment;

e) Integrating projectile velocity with respect to time to determine projectile position after said time increment;

f) Calculating optimal driving gas mass flux through said barrel immediately behind said projectile;

g) Repeating steps a through f for each said time increment along the pathway of said projectile through a length of said barrel;

h) Calculating gas outflow that must exit from the barrel interior through at least one barrel wall passageway between any two barrel locations disposed from the position in said barrel where said driving gas obtains Mach 1 to the muzzle end of said barrel;

i) Determining the size of said passageway through said barrel wall that results in said gas outflow between said barrel locations found in step h; and

j) Disposing at least one said passageway along said barrel between said barrel locations for optimization of said nozzle projectile barrel.

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