Wear and Erosion in Large Caliber Gun Barrels

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PREFACE

"Wear and erosion" is one of several failure mechanisms that can cause large caliber Gun Barrels to be condemned and removed from service. This paper describes the phenomenon, its causes and effects, methods that are used to passively manage it, and steps that are taken to actively mitigate it.

1.0 GUN BARRELS – BACKGROUND

A large caliber Cannon (Figure 1) is a pressure vessel whose primary function is to accurately fire projectiles at high velocities towards a target.

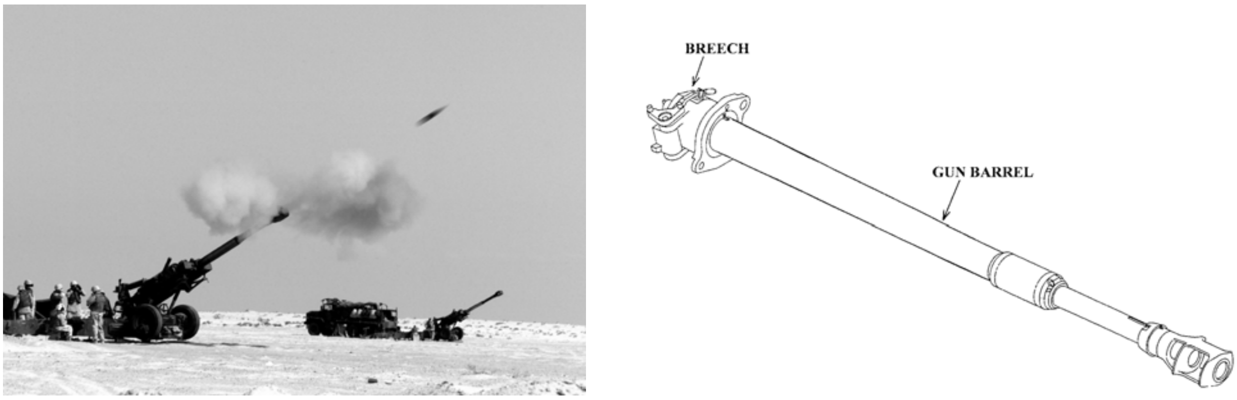

Figure 1: Representative Large Caliber Cannon

At its simplest, a Cannon consists of two major sub-assemblies:

- "Gun Barrel": a long, slender Tube that serves multiple functions such as safely containing high pressure combustion gases and providing a means for aiming/guiding the projectile in the intended direction;
- "Breech": an assembly that seals off the rear of the Gun Barrel during firing, but which can be quickly opened to allow loading of ammunition. It also contains a device used to initiate the combustion process.

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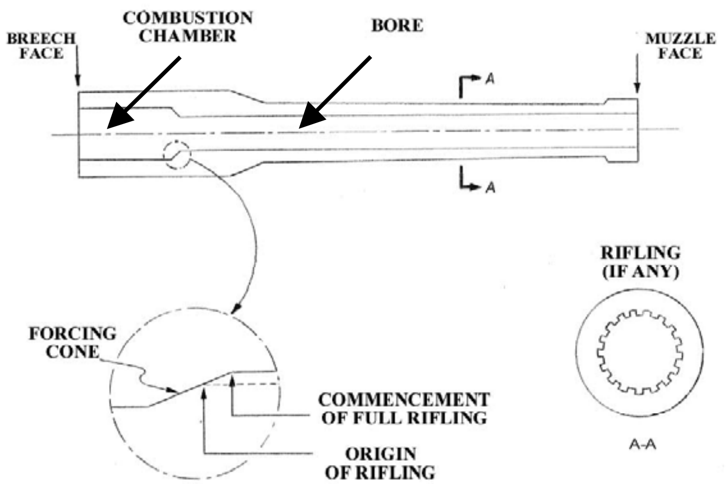
1.1 GUN BARREL INTERNAL GEOMETRY

Internally, a Gun Barrel often features three distinct regions (Figure 2):

- "bore": a long cylindrical hole machined to exacting tolerances for diameter, axial straightness, and surrounding wall thickness;
- "combustion chamber": a much shorter hole at the breech-end of the Gun Barrel that is coaxial with the bore and has a slightly larger diameter. It's shape may be cylindrical, tapered, or both;
- "forcing cone": a short tapered hole that connects the bore and combustion chamber, and is coaxial with both.



(not to scale)

Figure 2: Gun Barrel Internal Geometry

The bores of Gun Barrels fall into two general categories: "smoothbore" and "rifled". As the name implies, the former type has an interior surface that is completely smooth and cylindrical, and the projectiles that are fired from it usually have fins in order to achieve flight stability (similar to an arrow). A rifled bore, on the other hand, contains many so-called "lands and grooves" that give the cross section a castellated appearance (see section A-A in Figure 2 above). These lands and grooves are machined axially, but with a slight twist or helix that causes the projectile to rotate while in-bore (see Figure 9). This rotation continues after muzzle exit, providing gyroscopic flight stability to the projectile.

In this paper, the term "caliber" refers to the diameter of a Gun Barrel's bore. In the specific case of a rifled Barrel, this diameter is measured from the top of one internal land to that on the exact opposite side of the bore.

NOTE: an alternative definition of the word "caliber" is the "total length of the Gun Barrel divided by the diameter of its bore". This gives a rough indication of the overall length-to-diameter (slenderness) ratio of the Barrel. For example, a 155 millimeter (mm) Gun Barrel that is 6045 mm long would be referred to as a 39-caliber Barrel (6045 divided by 155).

1.2 MATING PROJECTILE GEOMETRY

Projectiles fired from large caliber Gun Barrels (Figure 3) are generally cylindrical, with aerodynamically-shaped forward surfaces. The outside diameter is only slightly smaller than that of the bore, providing a snug fit but allowing the projectile to slide in the axial direction within the bore. Most projectiles feature one or more external "bands" towards the rear that are slightly larger than the bore (providing an interference fit), but smaller than the combustion chamber (allowing easy loading). These bands, which consist of different material(s) than the main body of the projectile, serve multiple functions such as providing**:** a consistant loading position for the projectile when one of the bands axially comes to rest against the forcing cone; a repeatable "shot-start force" that momentarily resists forward projectile motion while the combustion process is just beginning; a seal to minimize the escape of combustion gases past the projectile; a bearing surface to help keep the projectile centered while in-bore; and (if the bore is rifled) a means of creating projectile spin for flight stability.

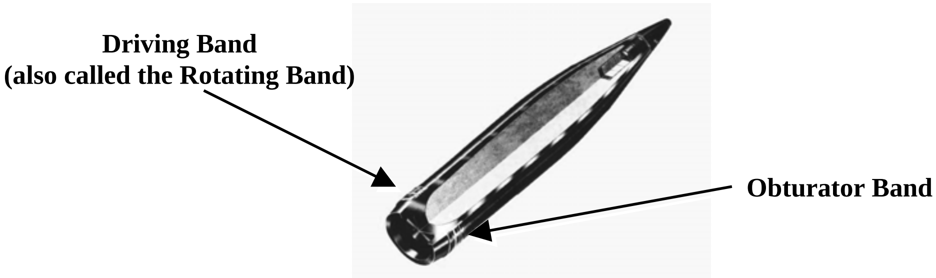
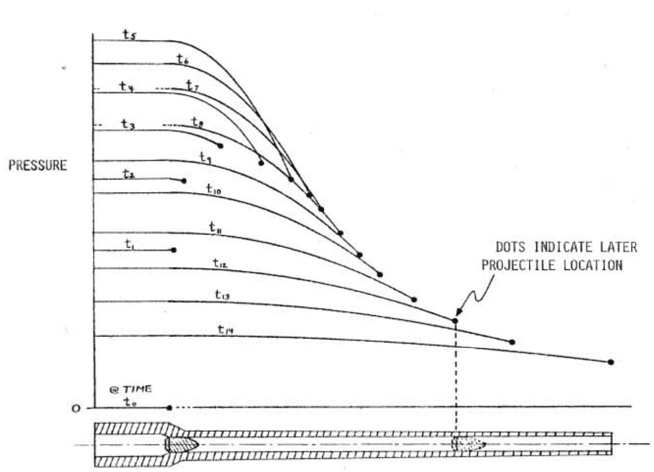


Figure 3: Representative Large Caliber Projectile

1.3 INTERNAL BALLISTIC CYCLE

In preparation for firing the Gun, its breech is opened and a projectile is loaded into the rear of the Barrel, passing through the combustion chamber and entering the bore. Next, a propelling charge is placed in the combustion chamber, to the rear of the loaded projectile. When the propelling charge is ignited by an energetic device in the breech, the propellant burns and produces gaseous products of combustion that have very high pressure and temperatures.



kmFigure 4: Barrel Internal Pressure vs. Projectile Travel

The propellant gases exert a force on the base of the projectile, and after they overcome the "shot-start force" (provided by the driving band), it begins moving forward ("downbore"). Within milliseconds after ignition, the projectile reaches the "muzzle" (the extreme forward end of the Barrel), where it is ejected at high velocity towards its target. The gases that remain in the Barrel are then free to expand in the axial direction, and they follow the projectile out the muzzle. Once they reach atmospheric pressure, the entire internal ballistic cycle can be repeated. Typically a Gun Barrel is able to fire on the order of 10^2 or 10^3 rounds during its lifetime. The thermodynamic cycle for a Gun Barrel firing a projectile can be viewed simply as a single-stroke engine. Figure 4 generically shows the nature of the pressure gradients when the projectile is at various locations in the bore.

1.4 GUN BARREL MODES OF FAILURE

Gun Barrels have several potential modes of failure:

- If the maximum pressure developed in the combustion chamber or bore exceeds the elastic strength pressure of the Gun Barrel at any axial location, "***permanent bore expansion***" can result.

- In extreme cases, very high pressures can cause the Barrel walls to rupture. If the Barrel material is brittle, the Gun Barrel can catastrophically "***burst*".** If the material is more ductile, "***gas leakage***" will occur, a far more preferable outcome than bursting.

- Even at somewhat lower pressures, micro-cracks can form on the surfaces of the combustion chamber, forcing cone, and/or bore due to the firing environment. Over many hundreds or thousands of firing cycles, these can grow, coalesce, and eventually break through the Barrel wall by a process known as "***fatigue***".

- Finally, unacceptable loss of material can occur on the forcing cone or bore that is caused either by the action of the hot gases passing over them at high velocity (a process called "***erosion***" which typically has thermal, chemical and/or mechanical bore degradation components) and/or by the projectile moving through the bore and interacting with the Barrel walls (a process known as "***wear*",** which only has a mechanical bore degradation component).

The likelihood of permanent bore expansion, bursting, and gas leakage can be mitigated by proper Gun Barrel design practices. Fatigue is characterized by means of rigorous testing (a combination of firing and lab simulations), the results of which are used to statistically determine the Barrel's "fatigue life". Even though wear and erosion have separate causes, they are sometimes referred to simply as "wear" in large caliber Gun Barrels. To maximize safety, the practice is almost always to design the Barrel so that its "wear life" is less than its "fatigue life".

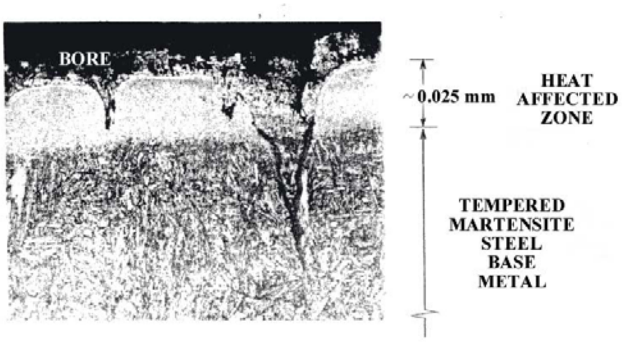
1.5 GUN BARREL MATERIAL

In general, modern Gun Barrels are manufactured from low alloy steel forgings. Steel has been found to be an excellent material for this application due to its balanced combination of high elastic yield strength, surface hardness, ductility/fracture toughness, modulus of elasticity, and melting point. These properties enable the resulting Gun Barrel to be resistant to all of the potential failure modes described above. However, the desire for ever-increasing performance characteristics of weapon systems in recent years has required that Guns operate at higher pressures, as well as increased firing rates and durations. Further, the trend has been to utilize more energetic propellants that have higher flame temperatures and rates of bore degradation. Designers of Gun Barrels are under constant pressure to reduce weight, resulting in thinner walls, reduced thermal heat sink, and higher Barrel operating temperatures. All of the above tend to increase the rates of wear and erosion inside the Gun Barrel, despite gun steel's excellent combination of properties.

2.0 PRIMARY CAUSES OF GUN BARREL WEAR AND EROSION

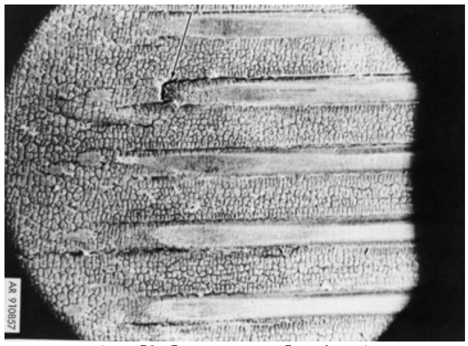
2.1 Erosion

In most advanced Gun Barrels, the bore material exposed to hot combustion gases can undergo significant thermal, chemical, and/or mechanical degradation. An unprotected steel bore is fully exposed to these hot gases, and this can result in so-called "heat affected zones" (thermally altered layers) at and below the bore surface; see Figure 5. This in turn leads to "heat checking" (which has an alligator skin appearance; see Figure 6) and cracking of the bore surface, both of which increase with continued firing. In addition, thermo-chemical firing damage is caused by hot gas-induced degradation of the fully exposed steel bore, leading to gas-wash erosion.



(axial view)

Figure 5: Heat Affected Zone with Cracking



(radial / normal view)

Figure 6: Heat Checking

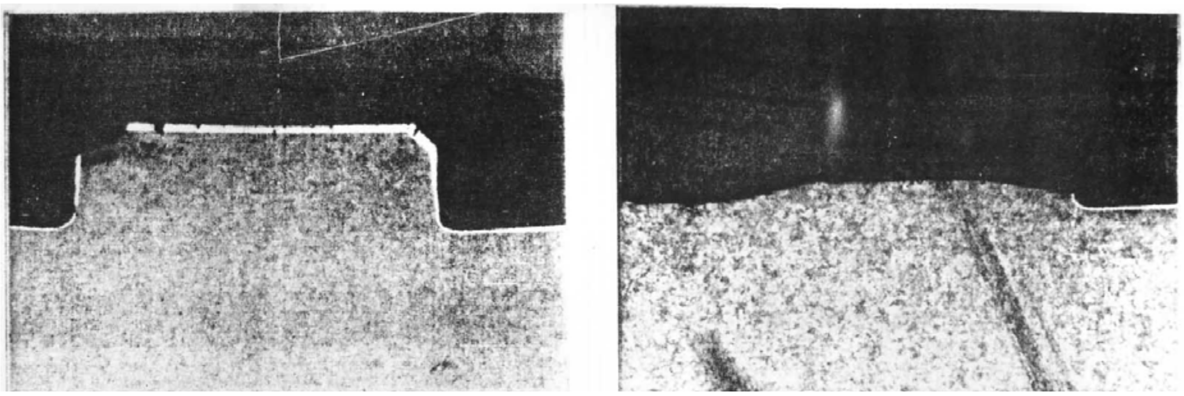
The bores of some very-high performance Guns are provided with a protective coating (see paragraph 6.3.2), and if it becomes damaged, the steel becomes partially exposed to the hot gases through cracks and pits in the coating. General erosion mechanisms for these coated, advanced Gun Barrels also include thermal, chemical, and/or mechanical components. As with an unprotected bore, thermal damage can cause heat affected zones at and below any exposed substrate, leading to heat check cracking and platelet micro-cracking of the bore coating and steel. Continued firing leads to bore coating shrinkage and heat check crack widening. Thermochemical firing damage to the steel bore is caused by hot gas-induced degradation of the partially exposed interface between the coating and substrate. This causes an accelerated erosion rate leading to micro-pit formation and abrupt spalling, chipping, and stripping of the protective coating.

2.2 Wear

Wear is a mechanical effect that is the result of interaction between the Gun Barrel and the projectile as the latter traverses the bore. For example:

- If propellant gases escape past the rear band(s), they can create a sideward thrust on the projectile. This, coupled with the projectile's axial velocity and friction, can cause wear of the projectile ("side body engraving"), the Gun Barrel, or both.

- For rifled Gun Barrels, if the projectile's axial center of gravity (c.g.) is offset from its center of rotation (c.r.), it can whirl or precess while moving downbore, causing some of the rifling lands to wear selectively ("spiral wear") towards the muzzle end of the Barrel (see Figure 7 and Figure 12).



Chromium-plated rifling land at 12 o'clock position

Worn land at 6 o'clock position on opposite side of bore.

Figure 7: Spiral Wear

- One of the bands towards the rear of the projectile is the so-called "rotating band" or "driving band", and it is generally made from a softer material than either the projectile body or Gun Barrel. During loading and the initial stages of combustion, the driving band forcibly engraves into the Barrel's rifling grooves. As the ballistic cycle continues, the driving band maintains an interference fit that exerts a radial force on the bore. This can contribute to wear as the projectile traverses the Gun Barrel, especially if the bore material has been thermally-damaged.

3.0 OBSERVATION AND MEASUREMENT OF WEAR AND EROSION

A variety of instruments are available to either observe or measure wear and erosion in large caliber Gun Barrels:

3.1 Borescope

A photograph of a Borescope is shown at Figure 8:

Figure 8: Borescope

It is basically a long, thin pipe containing suitable lights, lenses, and mirrors that allows an inspector to look closely at the bore surface over its entire length. The inspector typically describes his observations in writing, but a capability is sometimes provided to also record the visual images permanently on videotape.

The borescope's output is often qualitative since depth of the wear/erosion cannot be ascertained. Despite this limitation, an experienced inspector can make a meaningful determination of the Barrel's condition and suitability for continued use. Figure 9 shows a Borescope view for a newer rifled Barrel, and Figure 10 shows one for an unplated Barrel that has been fired many times.

Figure 9: Borescope View of a New Rifled Barrel

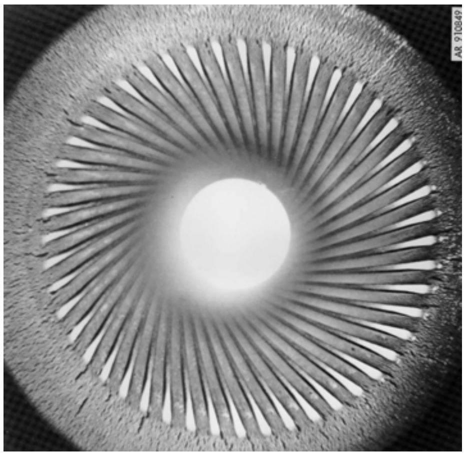


Figure 10: Borescope View of a Worn Rifled Barrel

Note the significant heat-checking ("alligator skin" pattern) of the worn Barrel. In Figure 11, the inspector has installed a mirror that permits viewing at right angles to the bore. Again, heat checking is clearly visible, which can contribute to both wear/erosion and fatigue.

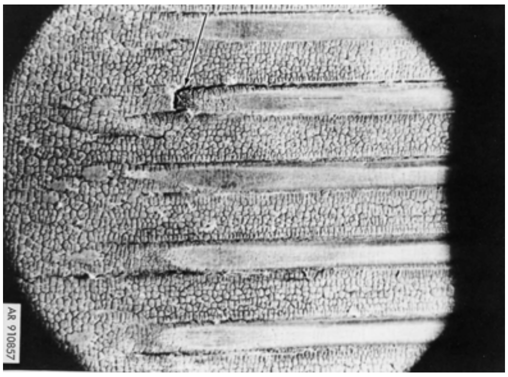


Figure 11: Borescope View Normal to the Bore

3.2 Pullover Gage

This is a field measurement device that is capable of making a bore diameter measurement at a single axial location. It is long enough to be inserted into the rear of the Barrel, passing through the combustion chamber to a specified axial location in the bore. It is essentially an inside calliper, and the inspector (usually a Soldier in the field) pulls a lever until the measurement surfaces touch the top and bottom of the bore or rifling. The inspector then writes this diameter reading on a "record card" that accompanies the Barrel throughout its service life.

3.3 Stargage

This is a measurement device that is most frequently used in the Gun Barrel factory (for acceptance after manufacturing) or at the Proving Ground (either for acceptance after initial proof firings or to measure wear and erosion during developmental tests). It is as long as the entire Gun Barrel, enabling diametral measurements to be taken at any axial location in the bore. Also an inside calliper, a stargage can be inserted into the bore from either the breech end or the muzzle end in accordance with local practices. For a smoothbore Barrel, all measurements are typically made with the contact pins oriented vertically (top-to-bottom) over the entire bore length; then the process is repeated with the pins aligned horizontally (side-to-side). For a rifled Barrel, the measurements can be made either by maintaining vertical or horizontal alignment for the entire length of the bore (same as for a smoothbore) or by following the twist of a specific pair of rifling lands. Either practice is acceptable, but once selected it is important to maintain the same procedure throughout the Barrel's life. After these diameter measurements have been recorded for many axial locations, the results are graphed as a function of distance from the breech face of the tube. A generic example is shown at Figure 12.

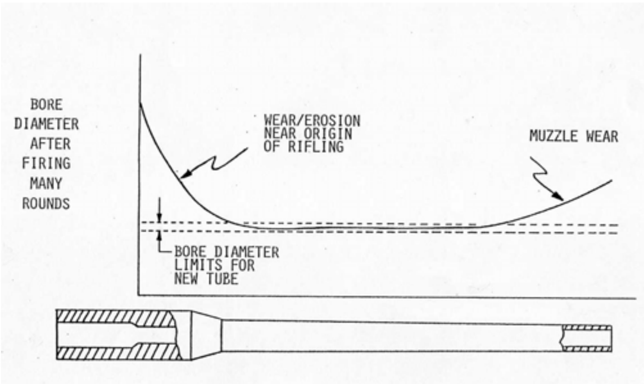


Figure 12: Generic Tube Wear Chart

3.4 Optical Bore-Mapping Systems

Each of the above inspection methods has its own set of benefits and drawbacks, but none gives a complete visualization (qualitative *and* quantitative) of the bore's condition. For this reason, bore-mapping systems have been developed that are capable of making optical (usually laser) measurements of the entire bore, then quantitatively displaying the bore condition using advanced imaging techniques.

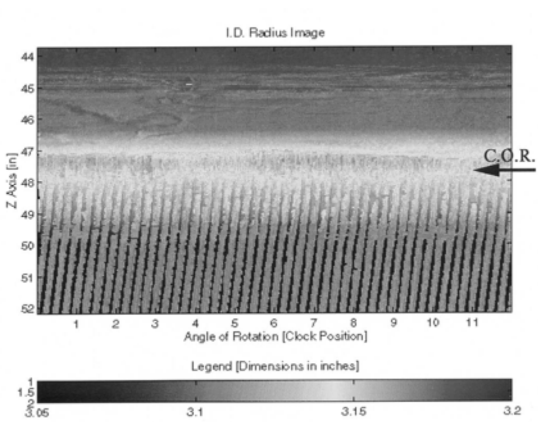


Figure 13: Representative Bore-Mapping Output

Figure 13, for example, shows a partial view of a rifled bore, forcing cone, and combustion chamber. Note that the imaging computer has artificially "unrolled" the Barrel from its usual cylindrical shape into a flat plane for easier observation. Optical bore-mapping systems have the added benefit of being able to capture all data permanently on digital media. This technique provides a holistic understanding of the wear and erosion pattern inside the Barrel.

4.0 EFFECTS OF GUN BARREL WEAR AND EROSION

Several potential failure modes for Gun Barrels were outlined earlier in paragraph 1.4. The first four (permanent bore deformation, gas leakage, bursting, and fatigue) must be avoided since they pose a potentially catastrophic threat to the gun crew and weapon system, as well as nearby personnel and equipment. Wear and erosion is a more subtle (and perhaps tolerable) mode of failure since it usually produces effects that have a gradual onset/progression and can for a time be compensated for. Some of these effects are:

- Lowers muzzle velocity (decreases the projectile's firing distance and/or terminal effectiveness);
- Causes inaccuracy (increases distance between intended aim-point and projectile impact-point);
- Increases dispersion (causes greater variation of projectile impact-points within a firing group);
- Produces unstable projectile flight (causes projectile to approach or strike the target incorrectly)
- Impairs proper fuze functioning (triggers at the improper time or not at all);
- Damages other sensitive projectile components (e.g., electronics, sensors, and guidance systems);
- Aggravates projectile driving band erosion and side-body engraving;
- Instigates surface defects in the bore and combustion chamber (hastens Barrel fatigue failure).

Although these effects are not usually hazardous to the crew operating the Gun, some can clearly be dangerous to friendly personnel who are located downrange or near the intended target. Equally importantly, if the intended target cannot be incapacitated, it remains a battlefield threat that is able to return fire. And finally, the need to replace a large caliber Gun Barrel in the field represents a significant life cycle cost on the order of 10^5 Dollars/Euros for each occurrence. For all these reasons, research and development personnel devote significant effort not only to manage wear and erosion of Barrels in the field, but also to mitigate this phenomenon in the first place.

5.0 MANAGING WEAR AND EROSION IN GUN BARRELS

Although wear and erosion is not a desirable phenomenon, the fact is that it initiates with the very first round that is fired from a large caliber Gun Barrel; further, it continues progressively to the end of the Barrel's useful life. Despite that inevitability, the effects of wear and erosion are often not intolerable until many rounds are fired (except in extremely high-performance Guns), and in many cases steps can be taken to compensate for its presence.

5.1 Wear Testing and Life Assessment

During the development cycle, large caliber Guns are subjected to a wide array of testing under various conditions to assure that**:** performance requirements have been achieved; the Gun is safe for the crew to operate; and RAM-D (Reliability, Availability, Maintainability – Durability) goals have been met. One of these is the so-called "Barrel Wear Test", which is described in detail in International Test Operations Procedure (ITOP) 3-2-829, "Cannon Safety Test". Although testing can be tailored, it is usually required that a minimum of two new Barrels be fired to the end of their useful lives. This must be done in accordance with a test sequence consisting of alternating groups of "control rounds" (in which service rounds are fired and ballistic performance measurements are made) and "expenditure rounds" (in which rounds are fired principally to induce firing damage, with minimal data being taken). These alternating groups are repeated until firing damage to the bore degrades performance of the control rounds, making one or more of the effects cited in paragraph 4.0 intolerable. At the conclusion of the Wear Test, a correlation is sought that links increased wear with decreased firing performance/function. Once derived, this provides two important pieces of information:

- the wear and erosion failure mode of the tube, and
- a simple metric that can be used to indicate when the Barrel must be condemned and replaced in the field.

The latter metric is normally a maximum bore diameter measured at a specific axial position using a pullover gage (ref. Paragraph 3.1). For example, Figure 14 shows some representative metrics for field replacement of U.S. Army 155mm artillery Barrels. These values are published in each Gun's field manuals for use by maintenance and logistics personnel. As an example, when the bore diameter of the M199 Cannon increases from 155mm to 157.480mm, the Barrel must be replaced. Failure to do so will cause the onset of one or more of the effects outlined in paragraph 4.0.

CANNON *(Overall System)*	**AXIAL DISTANCE FROM REAR FACE OF TUBE (mm)**	**BORE DIAMETER AT CONDEMNATION (mm)**
155mm M199 Cannon *(M198 Towed Howitzer)*	1060.45	157.480
155mm M284 Cannon *(M109A6 Paladin Self-Propelled Howitzer)*	1060.45	157.607
155mm M776 Cannon *(M777 Lightweight Towed Howitzer)*	1060.45	157.353

Figure 14: Representative 155mm Artillery Barrel Condemnation Criteria

5.2 Equivalent Full Charges (EFCs)

Normally, the metric for determining whether a Gun Barrel must be condemned is a (increased) diameter measurement as described in the previous paragraph; however, the requirement that is often specified by Users for Gun Barrel wear life is the "number of EFCs fired". To explain this concept, most Guns are capable of firing an array of ammunition, and not all of these create the same firing damage per round fired. The round (i.e., combination of projectile and propelling charge) that produces the most firing damage is assigned an EFC value of "1". Other round combinations are assigned lesser values, and a round that creates no firing damage at all would have an EFC of "0". The assignment of EFCs to the various round types can be problematic since extensive (i.e., expensive) testing could be required in order to make those determinations. In lieu of that, the use of predictive wear and erosion computer models and/or firing simulations represent cost-effective, alternative methodologies for estimating these values.

As an example of how to actually count EFCs, assume that a given Barrel is capable of firing three different round types: Round A (EFC = 1); Round B (EFC = 0.75); and Round C (EFC = 0.25). If 1000 of each round type is fired, then the Barrel is said to have sustained [(1000*1.00) + (1000*0.75) + (1000*0.25) =] 2000 EFCs. If it had previously been determined (perhaps from developmental Tube Wear Tests) that this type of Barrel has an estimated wear life of 2250 EFCs, a logistician would observe that this specific Barrel is approaching 90% of its useful life. Plans would be made to order a replacement Barrel within the time an additional [2250 – 2000 =] 250 EFCs are expected to be fired. It is important to remember, however, that the decision regarding when to actually condemn the Barrel would be based on its measured bore diameter (see paragraph 5.1), not the number of EFCs fired.

6.0 MITIGATING WEAR AND EROSION IN GUN BARRELS

The techniques mentioned in previous sections describe methods of living with wear and erosion. Fundamentally, however, it is an undesirable phenomenon that over time degrades a large caliber Gun Barrel's performance and function. Eventually, the effects become intolerable, and the Barrel must be replaced, a logistics and life cycle cost burden. There are several strategies that can be used to mitigate wear and erosion in the first place, some of which are described below. The degree to which any of these are deployed depends on many factors, the most important being an assessment of the benefits versus change in life cycle costs.

6.1 Propelling Charge Strategies

6.1.1 Propellant Flame Temperature

Since erosion is a thermally instigated phenomenon, it is not surprising that reducing the propellant's flame temperature will provide a significant reduction in wear and erosion. Unfortunately, the propellant's specific energy is almost always a direct function of its flame temperature, so lowering the latter typically results in a degradation of performance----specifically muzzle velocity. For many systems, this strategy is therefore not a desirable option.

6.1.2 Wear-Reducing Additives

An alternative is to place a quantity of wear-reducing additive (e.g., titanium dioxide, talc, silicone, or a mixture of these) within the structure of the propelling charge, usually at its forward periphery. When the propelling charge is fired, this additive is dispensed onto the inside surfaces of the Gun Barrel and/or into the adjacent boundary layer of the propellant gases. This has the effect of reducing the amount of heat passing into the Barrel walls, the result being lower bore temperatures and reduced erosion. Both are highly desirable outcomes, so this strategy is commonly employed.

6.1.3 Propellant Chemistry

The chemistry of the propellant gas's constituents can also have an effect on a Barrel's wear and erosion life. For example, hydrogen is known to embrittle some alloys, which can contribute to early microcracking and removal of material. Carbon atoms can diffuse into the Barrel material's lattice structure, degrading its properties and helping to establish unfavorable local residual stresses. It is usually difficult to avoid these chemical or metallurgical interactions by modifying the propellant itself.

6.2 Projectile Strategies

6.2.1 Symmetry

In a rifled tube, the projectile's rotational velocity near the muzzle can be on the order of 10^4 revolutions per minute (rpm). At these levels, even a slight radial difference between the projectile's center of gravity (c.g.) and center of rotation (c.r.) can result in whirl or precession, both of which increase the interactive radial force between the projectile and barrel wall. For this reason, minimizing the distance between of the projectile's c.g. and c.r. is always beneficial, although additional manufacturing costs may result.

6.2.2 Driving Band

One of the bands at the rear of a spin-stabilized projectile is called a "rotating band" or "driving band". Its material must be soft enough to enable it to engrave into the rifling, yet robust enough to resist wearing away during transit down the Barrel. The frictional forces imparted by the Barrel, combined with the inbore velocity of the projectile, can be significant enough to cause excessive melting of the driving band surfaces. As described earlier, this can result in leakage of the propellant gases, increased offset of the projectile's c.r. from its c.g., and generally degraded projectile performance. If necessary, it is possible to replace the driving bands of fielded projectiles by substituting materials having a higher melting point and/or increased durability; however, it is usually far less costly to employ this strategy during initial projectile development.

6.2.3 Obturator Band

Another band at the rear of many projectiles is called an "obturator band", and its primary purpose is to seal off the propellant gases, preventing them from escaping alongside or ahead of the projectile. Recent advanced obturator band designs have enhanced this capability and have also provided a beneficial centering effect (see paragraph 6.2.2). The result has been a reduced tendency for the projectile to cause downbore wear.

6.3 Gun Barrel Strategies

6.3.1 Base Material

The alloy steel bores of many large caliber Gun Barrels are left as-machined except for the application of a cleaning/lubricating oil that is applied to retard corrosion. Only the combustion chambers and forcing cones are electroplated with protective High Contractile (HC) Chromium, also mainly for corrosion resistance. The use of higher-strength steel may provide increased resistance to wear, largely due to its increased hardness compared with that of the projectile body which is also often made of steel. Fortunately, the trend for modern high-performance Barrels is towards this type of material.

6.3.2 Bore Coatings

The bores of some very-high-performance Guns like the twin U.S. 120mm M256 and German 120mm L44 Tank Guns are also plated with HC Chromium, enabling them to achieve a viable wear and erosion life. In general, Chromium is a reasonably effective protective coating due to its higher melting point compared with the underlying steel (1850^{o}C versus 1430^{o}C) and also its resistance to changing phase (lattice structure) as steel does when heated sufficiently. The applied thickness of HC Chromium is typically on the order of 1 to 2 x10^{-1} mm, which is the radial distance over which the most severe thermal gradients are present in the Barrel wall after firing. Chromium has the added benefit of being corrosion resistant, and it serves to protect the underlying steel from chemical attack that can degrade the steel properties and surfaces. Unfortunately, HC Chromium tends to be somewhat brittle, and it contains an array of microcracks as a result of its environmentally-unfriendly immersion plating process. These microcracks can allow the propellant gases to infiltrate the otherwise-protective coating, undermining its integrity and attacking the steel. Low Contraction (LC) Chromium is an alternative coating that can be applied using a more environmentally-friendly Vessel Plating process. It has been shown to be more ductile with significantly fewer microcracks, and it can maintain its integrity (adhesion and cohesion) at greater coating thicknesses than HC Chromium. As the pressure and muzzle velocity requirements for modern Gun Barrels become more demanding, however, Chromium's performance becomes increasingly marginal. Research is being performed to evaluate other coating materials such as Tantalum, a refractory metal with a melting point of 2990^{o}C. Processes for applying this material, including Cylindrical Magnetron Sputtering and Explosive Bonding, are being evaluated for integrity, producibility, and cost-effectiveness.

6.3.3 Rifling Twist

At a given axial velocity, the greater the rifling twist (number of turns per axial length) the greater the tangential force the Barrel applies to rotationally accelerate the projectile. This increased force can contribute to wear of the projectile driving band, which in turn instigates projectile side body engraving and downbore Barrel wear. Rifling strategies to reduce these effects include reducing the twist (as long as gyroscopic stabilization can still be achieved) and progressive rifling (rifling twist is varied to minimize the peak circumferential forces).

7.0 SUMMARY

Wear and erosion is one of several failure mechanisms that can cause large caliber Gun Barrels to be condemned and removed from service, resulting in logistic and life cycle cost burdens. The negative performance and functional effects that it produces are usually progressive in nature and can be managed for much of the Barrel's useful "wear life". However, modern high-performance Guns are producing more aggressive wear and erosion environments that must be not only passively managed, but actively mitigated. Approaching this problem from a system perspective, there are several strategies for accomplishing this that include the propelling charge, projectile, and Gun Barrel. Deciding which (if any) of these mitigating strategies to deploy for a given system is generally a matter of balancing the expected benefit (number of additional rounds that can be fired before the Barrel must be condemned) versus the change in life cycle cost.

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AVT-109
Specialist Meeting on the Control and Reduction of Wear in Military Platforms

Summary of Discussion Sessions

The following presents a summary of the discussion of papers presented in the various sessions of the workshop. Only questions where the authors provided transcripts of their answers are reported.

Session 3 – Modelling of Wear and Erosion
Chair: Dr. Daniel Chaumette, Dassault Aviation, France

Paper MP-AVT-109-16

Dr. Prakash Patnaik, NRC-IAR, Canada

Q. Chromium plating involves hydrogen embrittlement. Does tantalum deposition involve any hydrogen contamination?

Dr. R. Hasenbien, TACOM,ARDEC, USA

A. Yes, but this is removed after electro-deposition by a thermal baking process.

Dr. Prakash Patnaik, NRC-IAR, Canada

Q. Tantalum does not have adequate oxidation protection. Any comments?

Dr. R. Hasenbien, TACOM-ARDEC, USA

A. No comment right now. We are currently fabricating a 1m long tantalum coated liner and will be test firing it. I hope to be able to answer the question after firing trials are conducted.

Dr. Prakash Patnaik, NRC-IAR, Canada

Q. Does the propellant gas have any sulphur or H_2S content?

Dr. R. Hasenbien, TACOM-ARDEC, USA

A. No. The main constituents are nitrogen, oxygen, hydrogen and carbon (see also paper NP-AVT-109-15).