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Barrel Failure in an Over and Under Shotgun

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Abstract

A 12-gauge over-and-under shotgun experienced a rupture in its lower barrel when firing standard factory ammunition. This incident marked the shotgun's first use in the field, as it had only been test-fired at the factory with regular-pressure shells (not proof loads) prior to this event. The barrel steel split axially ahead of the reinforced chamber, under the polymer fore-end, causing hot gases and plastic debris to violently strike the shooter's left hand, resulting in serious injury. A detailed metallurgical and geometric evaluation of the affected barrel was conducted at an independent third-party laboratory. Chemical analysis confirmed the steel matched SAE 1045 alloy with appropriate hardness for the barrel's intended thickness. Performance testing on a new, identical shotgun using intentionally overloaded shells was also carried out, despite the spent hulls from the incident showing no signs of excessive pressure. The assessment uncovered a distinct manufacturing flaw in the lower barrel, creating a localized weak spot in the barrel wall.

Keywords

Over-and-under shotgun, barrel rupture, factory ammunition, metallurgy, manufacturing defect, forensic engineering

Introduction and Background

The firearm involved in the incident was an imported "value model" over-under shotgun, chambered for 12-gauge, 3-inch shells, featuring 28-inch carbon steel barrels equipped with interchangeable chokes. The shotgun was fitted with polymer furniture. The owner, operating the firearm for the first time during a bird-hunting excursion on open farmland, used factory-loaded 12-gauge steel shot ammunition (predominantly Winchester brand).

On approximately the sixth round fired, which was the first shell discharged through the lower barrel by the owner, a catastrophic failure occurred. The lower barrel ruptured along the left side, resulting in the destruction of the fore-end and severe injury to the shooter's left hand, as depicted in **Figure 1**. Additional evidence available for examination included fragments of the fore-end, the printed owner's manual, three unfired shotgun shells, and five spent shotgun hulls previously fired through the firearm, including the final Winchester shell.

A shotgun barrel functions as a steel open-ended pressure vessel. It comprises a long cylindrical tube designed to channel multiple shots or a single slug, accelerated by combustion gases from the propellant upon cartridge discharge. Unlike rifle and pistol barrels, most shotgun barrels are smoothbore, lacking rifling, except in specialized slug guns. The barrel wall thickness is non-uniform, with the chamber exhibiting the greatest thickness and strength to withstand peak combustion stresses at the breech. The barrel thickness then decreases along the barrel length.

In modern shotguns, fast-burning smokeless propellant, akin to pistol powder, is employed, which combusts rapidly, with peak chamber pressures developed within ~1 to 3 inches of wad and shot travel down the barrel. Bore

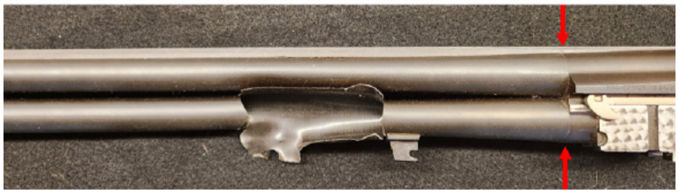

Figure 1
Photo of the ruptured carbon steel lower barrel from the left side; red arrows indicate the chamber region welding point to the thinner and longer barrel segments leading to the muzzle.

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pressure diminishes rapidly past peak manifestation due to increased gas volume from axial projectile movement, adiabatic cooling that is associated with the volume increase, heat transfer to the barrel and shell, and interfacial friction, as illustrated by the representative shotgun barrel pressure trace in **Figure 2** [1]-[4].

The stress distribution within the barrel wall comprises three orthogonal principal components as illustrated in **Figure 3**, expressed in cylindrical coordinates. Isostatic atmospheric pressure is disregarded. The radial compressive stress at the inner wall (σ_r) corresponds identically to the local combustion pressure (p) as measured by the compression gauge. Additionally, axial tensile stress (σ_z) and circumferential hoop tensile stress (σ_θ) are induced.

Experimental evidence indicates that hollow cylinders subjected to excessive internal pressure predominantly — essentially universally — fail due to hoop stress. Failure typically initiates as a near-planar fracture at the inner wall, propagating toward the outer wall with axial and radial progression, resulting in either brittle or ductile surface characteristics. For most shotgun barrels, at axial positions distant from the chamber, the bore radius significantly exceeds the barrel steel thickness, satisfying the condition $r_i > 10t$. In this region, Barlow's hoop stress formula for thin-walled cylinders, given in **Equation 1**, provides sufficient accuracy to evaluate the dominant hoop stress component against the material's tensile yield stress or the designated maximum working tensile stress [5]-[6].

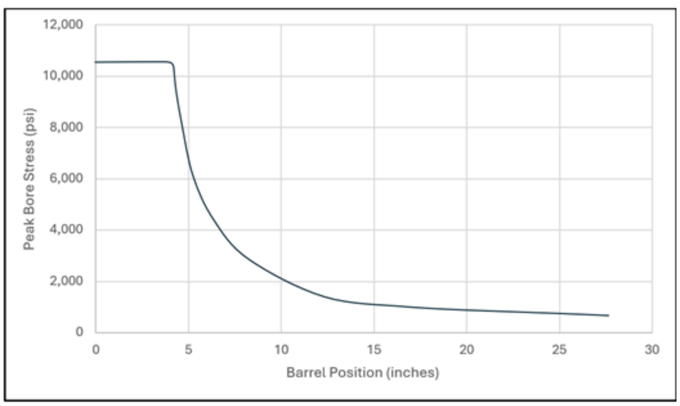

Figure 2
Schematic shape of shotgun barrel maximum bore pressure by axial position.

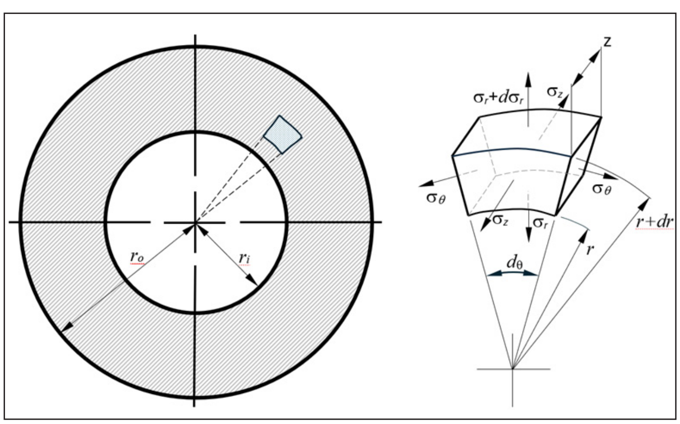

Figure 3
Orthogonal stress components associated with a shotgun barrel cylinder wall describing axial stress σ_z, radial stress σ_r, and hoop stress σ_θ.

Eq. 1: $\sigma_\theta = p * r_i / (r_o - r_i)$
Barlow's equation for pressurized cylinder hoop stress

As a failure criterion, the Barlow equation omits the radial compressive stress on the inner wall and the axial tensile stress, both of which contribute, albeit marginally, to failure in over-pressurized thin-walled cylinders. For internally pressurized cylinders with thicker walls, such as a shotgun barrel where the local condition $r_i < 10t$ is satisfied, the Lamé formulae yield more precise stress analysis results for the maximum stress components at the inner wall surface [7]-[8].

Eq. 2: $\sigma_r = -p$
Lamé equation for cylinder radial stress at inner wall

Eq. 3: $\sigma_z = pr_i^2/(r_o^2 - r_i^2)$
Lamé equation for cylinder axial stress at inner wall

Eq. 4: $\sigma_\theta = p\,(r_o^2 + r_i^2)/(r_o^2 - r_i^2)$
Lamé formula for cylinder hoop stress at inner wall

Equations 2 through **4** apply to linear elastic materials, such as steel. For failure assessment, the Lamé hoop stress equation serves as a conservative estimator and can be compared directly to the material's yield stress. Alternatively, the three orthogonal stress components can be combined using either the Tresca shear yield criterion or the von Mises distortion energy criterion, as outlined in **Equations 5** and **6**, where σ_Y represents the uniaxial tensile yield stress of the barrel material, and τ_Y represents the barrel material shear yield stress, which is conservatively approximated as half of the tensile yield stress [9]-[10].

Eq. 5: $\tau_{max} = (\sigma_\theta - \sigma_r)/2 \leq \sigma_Y/2 \leq \tau_Y$
Tresca shear yield criterion

Eq. 6: $\sigma_{max} = 1/\sqrt{2} * \sqrt{(\sigma_r - \sigma_z)^2 + (\sigma_r - \sigma_\theta)^2 + (\sigma_z - \sigma_\theta)^2} \leq \sigma_Y$
von Mises distortion energy criterion

Forensic Engineering Analysis & Candidate Barrel Failure Mechanisms

In the examined shotgun barrel, the stresses induced in the barrel wall by the combustion gases of the propellant surpassed the material's local strength, leading to failure [11]. The injury incurred by the shooter resulted in the forensic investigation detailed in this study. The subsequent analysis focused on three key areas to ascertain whether the barrel wall's inadequate strength or excessive combustion gas pressure caused the failure.

- Shooter — activities and other circumstances
- Ammunition — suitability and peak pressure
- Firearm — design, metallurgy, manufacturing

A technical paper by forensic investigator Stanton O. Berg summarized 33 previously published barrel obstruction tests along with their results, performed by multiple researchers [12]. Berg categorized the experiments into six different obstruction types:

1. Bullet lodged in barrel, deliberate placement
2. Bullet lodged in barrel, squib loading
3. Bullet jacket in barrel
4. Cleaning patch in barrel
5. Sand, earth, or mud in muzzle
6. Water in barrel

The results of discharging a normal pressure cartridge with bullet behind the known obstructions included:

1. No detectable damage to firearm
2. Bullet halts and lodges behind obstruction
3. Barrel burst
4. Barrel circumferentially bulged

Testing conducted by Hatcher [13] on bolt-action rifles demonstrated that excessive cosmoline — a thick, waxy grease used as a rust inhibitor — acted as a bore obstruction and resulted in outcomes ranging from no damage to a split barrel, depending on the quantity of cosmoline present. The National Shooting Sports Foundation [14] confirms similar risks for shotguns, stating, "Excessive lubricating oil or grease in the bore can lead to dangerously elevated pressures, potentially causing the barrel to bulge or rupture upon firing, posing injury risks to the shooter and bystanders."

In the case of the well-used pump action shotgun depicted in **Figures 4** and **5**, the owner reported a barrel rupture during the first discharge of the season. According to him, the barrel contained only a factory-loaded shotgun shell and residual oil from the previous season's final cleaning. A circumferential ring, located away from the chamber and formed incrementally prior to the rupture, served as a diagnostic indicator of overpressure caused by an obstruction. The existing literature does not describe a mechanism whereby the peak combustion pressure from fast-burning nitrocellulose powder propagates down a shotgun bore to induce this failure mode. However, numerous reports document secondary explosive effects from underloaded cartridges with slow-burning nitrocellulose powders [2], [15]-[17].

Figure 4
Ruptured pump-action shotgun barrel due to bore obstruction with wad retention observed at the distal end of the fracture.

Figure 5
Circumferential ring indicative of local gas stress maximum due to a barrel obstruction in the region of the red arrow.

Shooter Evaluation

The individual involved in the incident was an adult male who had purchased the shotgun new from a local retailer. No drugs or alcohol were involved, and the shotgun was being used for legal hunting purposes — not for criminal activity, competitive shooting, or misuse. The incident occurred during the first outing with the shotgun with the failure occurring upon the initial discharge of a cartridge through the lower barrel.

One potential, though improbable, user error that could have contributed to the overpressure event is the inadvertent insertion of a 20-gauge shotgun shell into the chamber prior to the destructive shot; this barrel contamination would have acted as a barrel obstruction [18]-[19]. To investigate this possibility, a dummy 20-gauge shell was inserted into the lower barrel, and its farthest forward position was recorded. The 20-gauge test shell passed easily through the 12-gauge chamber but was halted by its rim at the forcing cone downstream of the chamber. The face of the 20-gauge dummy shell was positioned 3.4 inches from the breech face, whereas the approximate initiation point of the barrel fracture was approximately 7 inches from the breech face, as shown in **Figure 6** (where the barrel set is depicted inverted from its standard over-under configuration for clarity). Thus, this inadvertent improper ammunition substitution explanation was discarded.

Bore diameter measurements for the upper and lower barrels were obtained using a three-point internal diameter gauge with results tabulated in **Figure 7**.

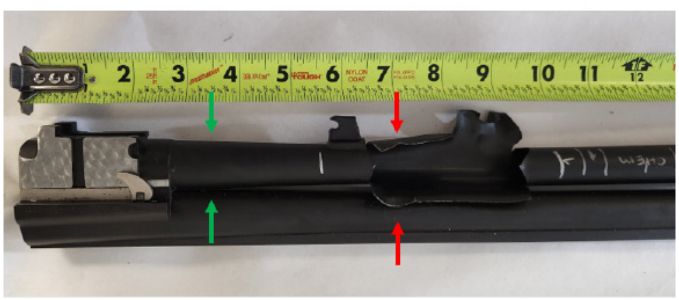

Figure 6
Close-up photo of the inverted barrel pair; green arrows mark the lodging point of the rimmed base of the 20-gauge test round, while red arrows indicate the approximate location of fracture initiation.

As recorded in the table, the inner diameter of the upper barrel is slightly smaller than that of the lower barrel. This design variation may stem from factors such as recoil management, weight distribution, balance considerations, or a perceptual effect influencing the subjective comparison of the top and bottom barrel sizes.

No credible failure causation could be attributed to the shooter in this case. The shooter did not manufacture the firearm, had no opportunity to neglect its maintenance due to the incident occurring during its first use, used ammunition that was appropriate for the firearm and not self-manufactured, and there was no evidence indicating the presence of an obstruction during the discharge.

Incident Ammunition Inspection and Analysis

A standard initial step in investigating a ruptured firearm barrel is to determine whether hand-loaded ammunition was used. Manufacturers predictably void warranties for damage associated with hand-loaded ammunition. Hand-loading is typically associated with high-volume competition shooters or long-range shooters — neither of which applies to this case. However, reloading of expended shotgun hulls is a known practice, supported by commercially available equipment for small-volume operations. "Most blown-up handguns and rifles are caused by improper hand loads. Shotgun ammunition, on the other hand, is not nearly so frequently handloaded" [18]. In this investigation, no evidence was found to suggest that the shell responsible for the rupture of the lower barrel was hand-loaded.

The cardboard box for the incident ammunition involved had been marked with the production lot number on the inner surface of a closing tab. However, this packaging was not preserved by the owner, leaving no lot number information available for the forensic investigation. An online search of the manufacturer's website and the Consumer Product Safety Commission's database revealed no

	Barrel Bore Internal Diameter Measurement at Position Past Breech Face (inches)											
Position	**1 – 3**	**4**	**5**	**6**	**6.5**	**7**	**8**	**9**	**10.5**	**11**	**12**	**13**
Upper	Chamber	0.728	0.727	0.728	0.728	0.728	0.725	Dent	Dent	0.728	0.728	0.728
Lower		0.735	0.735	0.736	0.734	RUPTURED			0.734	0.735	0.735	0.735

Figure 7
Measurements of bore diameter for the shotgun barrels involved in the incident.

evidence of recalls for ammunition of this make and load characteristics, either recently or historically. Exemplar ammunition of the same design remains in production, and two boxes were purchased for analysis. Multiple rounds, randomly selected from boxes bearing identical lot numbers, were disassembled to document their construction, as shown in **Figure 8**. The primer was left intact within the brass base. For reassembly of the round of **Figure 8**, the smokeless propellant would first be poured back into the empty hull, settling at the base near the primer flash hole. The white wad would then be positioned above the propellant. The shot would be loaded into the blue cup, and both components would be inserted into the red hull, which would subsequently be crimped at the end to form a star-shaped closure.

The exemplar rounds have the following mass characteristics, based upon an average of four deconstructed shells:

1.	Empty hull with primer	136.6 grains
2.	Smokeless propellant	30.9 grains
3.	White plastic wad disk	13.9 grains
4.	Blue polymer cup	38.0 grains
5.	Steel shot	543.3 grains
6.	**Total**	**762.6 grains**

Figure 8
Components of an exemplar 12-gauge shotgun round displaying decrimped plastic and brass hull, smokeless flake propellant, polymer wad, polymer shot cup, and steel shot.

The total mass of the solid ejecta is 595 grains, equivalent to 0.085 lb or 1.36 oz. The average shot mass was measured at 1.24 oz, closely aligning with the nominal 1.25 oz load indicated on the retail ammunition packaging.

No significant evidence of excessive pressure was observed on the breech face of the receiver of the incident break-action shotgun. The expended shell, which was discharged and resulted in the rupture of the lower barrel, showed no clear signs of overpressure markings. Such markings on a brass casing may include an ejector mark on the base or a flattened or cratered primer. Soot around the primer pocket generally indicates gas leakage due to a loose primer pocket rather than overpressure. As noted by Naramore, "Primers are of very little value in estimating [cartridge] pressures" [20]. For thoroughness, bore ash swabs were collected from the upper and lower chambers and at the site of the barrel rupture. These combustion product samples were preserved but not subjected to further analysis.

Shotgun Inspection, Testing, and Analysis

The owner's manual claimed that the incident shotgun was subjected to "proof testing" prior to shipment, utilizing "standard factory-loaded ammunition." Typically, proof testing entails the use of higher-than-standard pressure cartridges to validate a barrel's construction, encompassing its geometry and metallurgical properties. (See 21 for standard and proof load peak bore pressures for 12-gauge shotgun rounds of various types.)

Successful proof testing is frequently indicated by stamped or engraved pictograms on the barrel, action, or both. The absence of such markings on the incident firearm suggests that the manufacturer's assertion of "proof testing" in the owner's manual may be misleading. A more precise description would be that the firearm underwent successful functions testing before being shipped to the distributor. Inspection of two exemplar shotguns of the same make and model, performed by swabbing their bores with clean cotton patches, detected ash residue, consistent with these firearms being functions-tested at the factory using standard-pressure 12-gauge ammunition.

To evaluate the durability of the incident shotgun design, one of the two sample shotguns acquired for this study was tested with a double propellant charge, mirroring the destructive event outlined by Lee [22]. A single round with a double propellant charge was created by combining components from two disassembled shotgun rounds. Due to space constraints, the test round's hull could not accommodate both the doubled propellant and all the original shot, as factory rounds lack extra space or compressible parts.

Consequently, the quantity of shot was diminished, yet the polymer case mouth still failed to form the neat star crimp seen in the original rounds. Such a visibly imperfect and underweight round is unlikely to leave a modern ammunition factory. The test was conducted by remotely firing the double-propellant round from the lower barrel of the sample shotgun in an open area, using a fixture and trigger lanyard for safety. The shotgun fired without issue, showing no cracks, bulges, dimensional changes in the barrel, or damage to other components. **Figure 9** juxtaposes the primers of the incident round and the double-propellant round. Notably, the incident primer appears flatter than the double-propellant round's primer, supporting Naramore's [20] view that primer shape analysis is unreliable. These rounds likely came from different production lots. While both used type 209 shotgun Boxer primers, their designs may not be identical.

A metallurgical analysis was conducted at a commercial laboratory to examine the barrel's properties. The barrel was marked for sampling and then sectioned using a diamond saw, as shown in **Figure 10**. The upper barrel exhibits significant compression deformation, resulting from the impact of hot combustion gases during the rupture of the lower barrel.

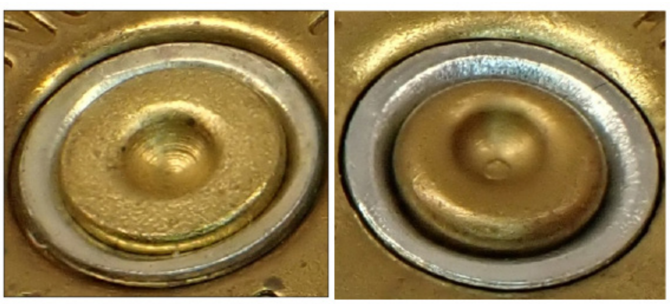

Figure 9
Primers of two shotgun shells; ruptured barrel final round at left, double-propellant exemplar test round at right.

Figure 10
Segments of the lower barrel post diamond sawing and the deformed area of the upper barrel.

Once cut free, the fracture surface was analyzed using a scanning electron microscope, as shown in **Figure 11**. The examination revealed a ductile fracture surface without undesirable features such as porosity, inclusions, or laps.

A barrel segment underwent optical emission spectroscopy (OES) to analyze its composition [23], as shown in **Figure 12**. The elemental fractions are consistent with SAE 1045 carbon steel [24].

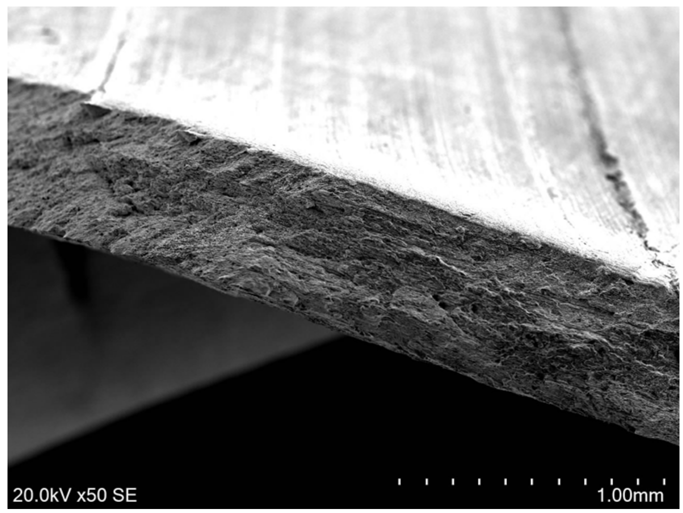

Figure 11
Scanning electron microscope image of fracture surface of the ~0.020" barrel local wall thickness with bore interior surface visible showing circumferential machining marks.

Element	Sample Chemistry (Wt %)	SAE Grade 1045 Chemistry (Wt. %)
Carbon	0.47	0.43 - 0.50
Manganese	0.61	0.60 – 0.90
Silicon	Silicon	Silicon
Phosphorous	0.025	0.04 Max
Sulfur	0.012	0.05 Max
Iron	Balance	Balance
Aluminum	0.02	Trace
Chromium	0.03	Trace
Cobalt	<0.01	Trace
Copper	0.03	Trace
Molybdenum	<0.01	Trace
Nickel	0.01	Trace
Niobium	<0.01	Trace
Titanium	<0.01	Trace
Vanadium	<0.02	Trace

Figure 12
Results of optical emission spectroscopy elemental analysis of the incident barrel.

Two barrel specimens were cut and sectioned — one perpendicular and one parallel to the axial plane. They were encased in polymer for metallographic examination. Both were ground, polished, and etched, revealing a hypoeutectoid microstructure of pearlite grains within a ferrite matrix. Hardness was assessed using a diamond Vickers indenter in the perpendicular specimen with findings presented in **Figure 13**. These measurements were taken midway between the barrel bore and exterior and evenly distributed angularly with ~72° of separation between hardness indentations.

Measured Barrel Hardness (Vickers, HV)
242
242
247
236
239
Avg 241.2

Figure 13
Barrel hardness measurements using a Vickers micro-indenter on plane cut perpendicular to the bore axis.

The hardness measurements showed a maximum-to-minimum range of 11 HV, which is not remarkable. The measured hardness is equivalent to 22 HRC (Rockwell C), 99 HRB (Rockwell B), and 233 HB (Brinell). This suggests a yield strength of the 1045 steel barrel of approximately 105,000 psi or 720 MPa.

Cutting the barrel downstream from the fracture exposed the critical defect responsible for the barrel rupture. The barrel was incorrectly bored using a damaged or misaligned reamer or gun drill, resulting in uneven wall thickness. The right side of the barrel was visibly thicker than the left side due to a collinearity machining error. This produced a region near the chamber with abnormally high local tensile wall stress during firing. The defect is visually evident in the mounted specimen shown in **Figure 14**, which gives the local thickness of the barrel in the text boxes. This specimen is the short cylindrical specimen nearest the rupture in **Figure 10** marked with a rightward-facing arrow.

Caliper measurements of the barrel thickness near the fracture were recorded, with a representative measurement shown in **Figure 15**. The wall thickness, as thin as cardstock paper, was uniform across several inches of the ruptured area.

For thoroughness, a calculation of the barrel's strength and localized bore stress was conducted. Since the ammunition manufacturer does not disclose pressure trace data, the bore pressure at the approximate failure point during discharge was estimated using representative barrel bore pressure values from Butler [3], as tabulated in **Figure 16**.

At a barrel position where the load had traveled 4 inches, the distance from the breech face was 7 inches with a wall thickness of ~0.015 inches. According to data shown in **Figure 16**, the bore pressure at the point of rupture

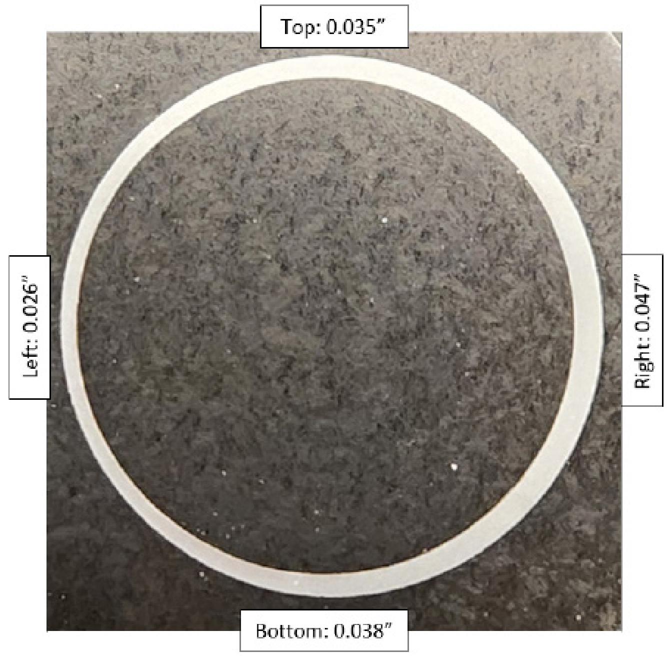

Figure 14
The polished and mounted barrel cross-section sample was taken forward of the rupture, documenting an improperly bored interior wall.

Figure 15
Barrel thickness measurement at the region of rupture propagation.

Representative 12-gauge Barrel Bore Pressures [Butler, 1973]					
Page	12 Gauge Load	Load Travel / Pressure	Load Travel / Pressure	Load Travel / Pressure	Load Travel / Pressure
203	XPERT 3-1-4	0.65 inches 11,018 PSI	4.91 inches 3,479 PSI	6.05 inches 2,899 PSI	7.25 inches 2,406 PSI
218	Super Speed 3 ¾-1-1 1/4 -6	0.38 inches 11,416 PSI	5.02 inches 4,636 PSI	6.17 inches 3,882 PSI	7.37 inches 3,268 PSI
221	Mag. Mark V 4 ½ - 1 ½ - 2	0.39 inches 12,512 PSI	5.05 inches 4,336 PSI	6.15 inches 3,742 PSI	7.30 inches 3,188 PSI

Figure 16
Pressure data for 12-gauge shotgun loads, giving peak bore pressure as a function of shot position in the barrel.

initiation can conservatively be estimated at 4,000 psi, and it could be higher when considering the steep pressure curve slope illustrated in **Figure 1**. The inner radius of the lower barrel at this location was 0.367 inches — over 24 times the barrel thickness — making Barlow's formula for hoop stress appropriate and simplified as Equation 7:

Eq. 7: $\sigma_{\hat{\theta}} = 4{,}000 \text{ psi} * 0.367'' / 0.015'' \approx 98{,}000 \text{ psi}$

This estimated hoop stress minimum at the time of discharge as given in **Equation 7** is very close to the calculated yield stress of the barrel's SAE 1045 steel, 105,000 psi. This estimated yield stress of 105 ksi is based upon the measured barrel material hardness and represents yielding at a quasi-static strain rate. Discharge of a firearm produces strain rates significantly above quasi-static, which is reliably expected to increase the yield stress of the carbon steel alloy 1045 as it is a strain-rate sensitive material. This strain rate strengthening is countered by geometric weakening due to the roughly machined bore of the incident shotgun, which manifests as stress concentrations. The balance between the strengthening and weakening aspects of the barrel was beyond the scope of this investigation.

As a further check of this forensic analysis, the C.I.P. standard regarding Material Quality and Wall Thickness of Barrel and Chamber of Small Arms (Recommendation) was consulted [25]. The C.I.P. is a SAAMI-affiliated organization for European manufacturers and importers. This standard indicates that for 12-gauge shotguns with barrels manufactured from Category 1 steel (200-249 HB hardness, perlite + ferrite microstructure), at 200 mm = 7.9" past the breech face, the minimum wall thickness of the barrel is 1.90 mm = 0.075". At the 7.9" position of the incident barrel, the wall thickness on the mis-bored left side measured 0.015", 20% of the C.I.P. safety recommendation.

Summary and Conclusions

The investigation examined three potential causes of the barrel rupture: shooter error, ammunition defects, or weapon deficiencies. No evidence of shooter error or ammunition irregularities was found. The rupture mechanism was clear — a defectively thin barrel at the point of rupture initiation due to a drilling or reaming error.

During function testing using a standard pressure round at the factory prior to shipment, the lower barrel of the incident shotgun probably bulged without bursting. This initial deformation, of unknown extent, could have signaled a defect but was concealed by the polymer handguard, making it undetectable to the user. Since the shotgun failed on its second normal-pressure discharge, the defective barrel could likely have been identified at the factory using high-pressure "proof" rounds, which would have either caused a rupture on this first shot or created a noticeable ring. Prior to proof testing at the factory, there would be reason to not install the polymer handguard. After a nominally successful proof-load discharge, the technician could simply visually inspect the barrel pair and/or run a hand down the barrel, checking for any irregularity. A substantially bulged barrel would also make installation of the tight-fitting polymer fore-end difficult.

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