Saunsbury & Co., Solicitors

Crown v. Joseph Beatham
Harrow Crown Court - 17/7/00

Engineering Report
July 2000

Prepared	Checked
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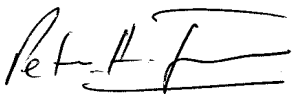
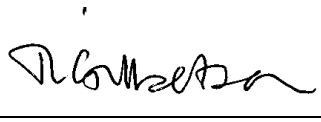
Signed: 	*Signed:* 
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1 Introduction

I have been instructed to inspect and test one of a series of modified .22 rim-fire rifles in connection with Crown v. Joseph Beatham (Harrow Crown Court, 17 July 2000) by Saunsbury & Co., Solicitors.

I received the rifle on 5 July 2000 and I completed my inspection and tests on 7 July 2000.

This report presents the results of these tests and includes comments as requested on other aspects of the above case.

2 Author's qualifications and experience

I am 46 years old, a Chartered Engineer, with an MA degree from Oxford University in Engineering Science. I am a member of the Institution of Civil Engineers, a member of the Society for Underwater Technology, and I am qualified by the Health and Safety Executive as a commercial diver. I am co-founder and director of Forge Consulting Ltd, a company whose principal business is the inspection, testing and site supervision of marine and underwater engineering structures.

In recent years my workload has included the supervision of construction of one of the world's largest sub-sea pipeline outfalls, the bomb-proofing of London Underground tunnels under the Thames, and the inspection and testing of many other marine and river structures constructed from the middle ages until the present day. As a practising engineer, my job is to inspect and test structures on which the public rely for safe travel, transport, water supply, etc., to determine the probability (if any) of failure, to assess the consequences of any such failure and to advise the owner of the structure accordingly.

I am registered by the Dumfries and Galloway Constabulary as a firearms manufacturer and dealer. This activity constitutes a small but growing branch of my company's business. Dumfries and Galloway is a very rural area of Scotland and most of our customers buy hunting rifles, but I have designed and built a number of long-range target rifles which have been used to win national and international competitions. In the last 12 months, these include the East of Scotland Open Championship, the West of Scotland Open Championship, the Irish Open Championship, and the Scottish Long Range Championship. I also designed and built the rifle which holds the current United Kingdom Bench-Rest Association record score at 1,000 yards. Last weekend another of my rifles won the UKBRA International 1000 yard Bench-Rest shoot.

I am a trade member of the Scottish Countryside Alliance and the British Association for Shooting and Conservation. I am a member of the Scottish Countryside Alliance Shooting Committee.

3 Scope of report

The charges relate to three Ruger 10/22 .22 LR rim-fire rifles whose muzzles have been modified to reduce the noise, recoil and muzzle jump caused by firing. These rifles were not available for me to test, but I have inspected and tested Ruger 10/22 rifle no. 244-76003 which has been modified to the same design.

The points which I have been asked to determine by engineering tests and to comment on as an engineer are as follows:

1. Have the barrels been unduly reduced in substance or strength?

2. Should the rifles have been re-proofed after the above modification?

3. Even if it was legally required, would it be common practice within the trade to re-proof firearms after carrying out such modifications?

4. To purchase a moderated rifle of this type, would a firearms certificate holder need an extension to their certificate to specifically enable them to acquire a sound moderator, bearing in mind these were integral to the weapon?

5. What proof marks should be displayed on the barrel after it has been submitted for proof?

6. Any general observations on the validity of the whole proofing process.

This report deals with each of the above points in turn.

A description of the engineering test procedures, numerical test data and calculation formulae are included. In the electronic version of this report, test data and calculations are included as embedded MS Excel spreadsheets to facilitate review and verification by others.

Figures are included at Appendix A.

Although as an engineer I usually work in the "SI" or metric system of measurement units, I have prepared this report and the associated calculations in

Imperial units. My reasons for this decision are: firstly, that most British citizens are more familiar with pounds and inches than with Newtons and millimetres and secondly, that the rifles in question are manufactured in the USA, a country which has yet to embrace the metric system, especially in the gun-making business.

4 Description of the modified Ruger 10/22 rifle

The following comments, measurements and test results refer specifically to rifle no. 244-76003 and, I believe, generally to all other Ruger 10/22 rifles modified to the same design.

The Ruger 10/22 rifle is one of the most successful sporting firearm designs of all time. Reasonably-priced, reliable and very strong, the 10/22 is also accurate, especially when fitted with a heavy "target" barrel. Many books and articles have been written about ways to customise or otherwise improve the standard product line, and a number of businesses have grown up to satisfy demand for 10/22 after-market accessories, modifications and replacement parts.

The modification marketed by Mr Beatham of The Gunshop, Barnet is as follows: the muzzle of the rifle is counter-bored to a depth of 5.85" and to an internal diameter of 0.705". The outside diameter of the barrel is 0.913" (this is the "minor" outside diameter, measured to the "troughs" of the hammered finish). These internal and external dimensions correspond very closely to the popular aluminium alloy screw-on sound moderator made by Helston Gunsmiths and marketed by Viking Arms Ltd of Harrogate, who are also official importers of Ruger rifles. The internal elements of the Helston moderator are inserted in the Ruger 10/22T muzzle counter-bore, which is threaded to accept the substantial Helston 0.7036" x 26 TPI aluminium alloy end cap.

The Helston moderator end cap and baffles have a generous 0.32" diameter hole for the bullet to pass through, so there is ample tolerance for any possible misalignment of the sound moderator and barrel bore. That said, in the case of the Beatham modification, any such misalignment is virtually impossible due to the method of manufacture, and if the end cap were off-centre by more than a few thousandths of an inch this unsightly but harmless error would be readily apparent.

It should be readily apparent to any competent gunsmith that the Helston aluminium sound moderator is more than adequately strong for use on a .22 rim-fire rifle. In fact, I had no hesitation in using one repeatedly with centre-fire 223

Remington ammunition on a full-bore rifle; this test was accomplished with no ill effect or over-stress on the barrel of the moderator as shown in my test results at Section 6 of this report. The Beatham integral sound moderator, being of similar dimensions but made of high-grade barrel steel instead of aluminium, will be nearly twice as strong where resistance to bursting is concerned. That must be obvious to anyone with the slightest technical training or knowledge of firearms.

All in all, the Beatham modification is a good, simple and immensely strong design well executed, and it turns the heavy-barrelled 10/22T target rifle into a handy, effective tool for farm pest control. It would also be suited to various forms of target shooting in areas where noise pollution must be kept to a minimum.

If the Crown Prosecutor has been led to believe that there is the remotest chance of such a substantial integral steel sound moderator bursting in normal service on a .22 rim-fire rifle, then he has been misled.

5 Comments on points raised by the Defendant's solicitor

5.1 Have the barrels been unduly reduced in substance or strength?

The above question implies (perhaps wrongly, in my opinion) that the counter-bored section of the rifle barrel is still a "barrel" in the context of the Proof Acts. If so, the answer hinges on the interpretation of the word "unduly".

The Proof Master of the Worshipful Company of Gunmakers touched on this matter in his written statement of 23 May 2000. He wrote that "unduly" means "excessive" and that the removal of material in this case was, in his opinion, "very excessive indeed". Unfortunately, he gave no reason for his opinion, still less any engineering calculation or stress analysis to support it.

As an engineer, I would approach the meaning of the word "unduly" purely from the point of view of the safety of the firearm user. I would consider a barrel "unduly reduced in substance or strength" if, and only if, the work done had significantly increased the *hazard* to the user when the rifle is fired. Here, I'm afraid, we have the first of several items of engineering jargon, which I will do my best to explain.

Hazard, in engineering parlance, is the probability or chance of failure multiplied by the consequence of such failure if and when it happens. It may help to give a couple of everyday examples. The consequence of a bridge failing as we walk or drive across it would be pretty severe, but fortunately the engineers who design such structures aim to make them two or three times stronger than is absolutely necessary, so the chance of failure is very small. So the *hazard* is acceptably low, and most of us are quite happy to pay 60p to drive across the Forth road bridge without fear of falling into the river below. Another everyday example would be a game of football - the risk of a player being tripped or falling over is quite high, but the consequence, at worst, is a graze, a sprain or perhaps a broken bone or two. So the *hazard* of playing football is low to moderate.

Returning to the item in question, any suitably experienced engineer can see at a glance that the modified section of the barrel is still vastly stronger than it needs

to be to withstand any conceivable pressure of firing. In fact, my tests have shown that it is about 180 times stronger than it really needs to be. So, the chance of failure is not just vanishingly small, it is zero. Incidentally, it would be possible for civil engineers to design bridges which are 180 times stronger than they need to be, but no-one could afford to build them and once the so-called *factor of safety* is over about 5 or 10 (depending on the complexity and uncertainty of the stress calculations), any further increase is pointless and irrelevant - the part or structure isn't going to break, full stop.

The *factor of safety* is usually defined as the stress at which the material yields or deforms permanently divided by the average peak working stress.

In layman's terms, there is not the remotest chance of these or any similarly modified barrels being "potentially dangerous to any user" as the Crown Prosecutor has been led to believe, because in order to burst they would have to defy the laws of physics. As to the consequences of a burst (if it could somehow happen), the most likely injury would be to the composure of the firer. No one in his right mind stands in front of a rifle while it is being fired, and that is where any internal parts would fly if the end cap were somehow to fail. The sound moderator, located on the open end of the barrel, is the furthest part of the rifle from the user, and the potential consequence of any failure is reduced accordingly. So we have zero probability of failure multiplied by a negligible consequence of any such failure. Any number multiplied by zero is still zero, so the *hazard* posed by these rifles, before or after Mr Beatham's modification is zero. We can't get safer than that. I conclude that the barrels have not been "unduly reduced in substance or strength".

Further to the above, it is arguable that the modified or counter-bored section of the barrel is not in fact a "barrel" at all.

Certainly, this counter-bored section is not a rifle barrel in the conventional sense of the word, since it does not guide the bullet or contain the combustion gas in such a way as to accelerate the bullet, and it is subject to very little internal pressure.

The pressure in a rifle barrel reaches a peak when the bullet is just an inch or so from its starting position. As the bullet progresses down the barrel, allowing the gas behind it to expand, the pressure falls very rapidly (see Figures 1 and 2, Appendix C). In a rifle without a sound moderator, once the bullet leaves the muzzle, the gas expands freely and the already reduced pressure in the muzzle falls almost instantaneously to somewhat less than atmospheric pressure before returning to equilibrium. With a sound moderator, this secondary expansion takes place in a more controlled manner, but the peak pressure inside this and similar sound moderators is at most about 95 psi. This is considerably less than the pressure in a racing bicycle tyre.

In Section 4 of the Gun Barrel Proof Act, 1868 the term "barrel" is defined as including "every Part of every Small Arm in, from, or through which Part in the User of the Small Arm all or any Part of the Charge thereof would be exploded or discharged". However, the definitions in Section 4 all carry the proviso: "unless there be in the Subject or Context something repugnant to or inconsistent with such Construction". The language is archaic, but it seems to me that we are being asked to use a bit of engineering common sense and bear in mind the purpose of the Act when we read and interpret these definitions. We may also refer for enlightenment to the 1969 International Convention for the reciprocal recognition of proof marks, as the Proof Master has done on page three of his statement dated 23 May 2000.

132 years ago, before the modern era of production engineering, computer-controlled machinery, x-rays and non-destructive testing, the purpose seems to have been to give any weak guns a chance of blowing up before they got into the hands of the user. Common sense dictates that there was then and is now no point in testing every barrel band, foresight clamp, interchangeable shotgun choke, muzzle brake, flash-hider or sound moderator which might be attached to the open end of a barrel. The "charge" or combustion products pass through all these parts, but they are not subject to significant pressure, so it seems in the context of the Act, "repugnant" to treat them as parts through which the "charge" is "exploded or discharged". Referring to the present-day requirements of the

International Proof Commission (CIP), these are by no stretch of imagination "highly stressed" components. Furthermore, these parts are located at the furthest end of the barrel as it is fired, so if and when they do come unscrewed or fail (as they may if neglected or blocked by snow, etc.) the user, at worst, gets a bit of a surprise, a bill and a ticking-off from his gunsmith.

In view of the above, it is my opinion as an engineer that the counter-bored section of the barrel in question is no longer a "barrel" either in the context of the Gun Barrel Proof Act or in any conventional sense of the word. In essence, the modification which was carried out by a skilled machinist on Mr Beatham's behalf has shortened the barrel by 5.85 inches.

5.2 Should the rifles have been re-proofed after modification?

The rifles were duly proofed after importation. They have been shortened, and the original muzzle section has been converted into a well-made, effective and excessively strong sound moderator. Even if this modified section of the original barrel were perversely deemed to be a "barrel" under Section 4 of the Gun Barrel Proof Act, 1868, the modification can not by any engineering calculation or test be shown to have the remotest effect on the safety of the user. In these circumstances there is no legal or engineering requirement to re-proof the rifles.

5.3 Even if it was legally required, would it be common practice within the trade to re-proof firearms after carrying out such modifications?

Modifications to .22 rim-fire rifle barrels such as fitting new sights or barrel bands, or cutting an external thread for a flash-hider, recoil-reducer (muzzle brake) or sound moderator are routine "bread and butter" gunsmiths' work. The same goes for modification of shotgun chokes. If it was legally required to re-proof barrels after such work it would certainly be common practice to do so, but I have never seen a proof mark on any rim-fire sound moderator, muzzle brake, flash-hider or on any interchangeable shotgun choke, nor any re-proof mark on a rim-fire barrel which has been screw-cut for any such attachment.

If all such items did have to be proofed, this would add significantly to the turnover and profits of the Proof Houses. It would also become uneconomical for

provincial gunsmiths to carry out such modifications on a "one-off" basis, because the minimum Proof House charge of £17.60, plus packing, insurance and carriage to and from London or Birmingham, would amount to more than twice the cost of, say, screw-cutting a rim-fire rifle muzzle.

I note that on page three of his statement dated 23 May 2000, the Proof Master of the Worshipful Company of Gunmakers wrote that the MoD requires all sound moderators, flash-hiders and other muzzle attachments to be proof tested and proof marked, but he omits to say how many of these attachments involve the kind of low-powered rim-fire rifles which are the subject of this case. It seems to me important that the Court should not be misled in this regard.

Furthermore, to the extent that Mr Pitcher's statement implies that all MoD flash-hiders, etc. are proof-marked, I believe that the Court is in danger of being misled.

5.4 To purchase a moderated rifle of this type, would a firearms certificate holder need an extension to their certificate to specifically enable them to acquire a sound moderator, bearing in mind these were integral to the weapon?

If a sound moderator is a detachable "accessory" it is treated as a separate "firearm" under Section 57.-(1) (c) of the Firearms Act 1968.

In this case the sound moderator is not detachable although its internal components can be removed for cleaning. It is an integral part of the rifle which is neither an "accessory" nor, as explained above, is it a part of the "barrel" in the context of the Gun Barrel Proof Act, 1868.

When a firearm certificate holder is authorised to purchase one or more firearms, the certificate specifies the number calibre and type of firearm(s) to be acquired. The wording varies somewhat between police areas, but it is usually of the form "one .22 rim-fire rifle" or "one .22 rifle". Either authorisation would cover a moderated rifle of this type.

I believe that the attempt to license sound moderators separately was introduced as some kind of anti-poaching measure. If so, it is hardly the most successful or

best thought-out section of the Firearms Act. An air rifle owner may purchase and possess a .22 sound moderator without any paperwork. Failing that, an empty 500 ml plastic Coca-Cola bottle taped onto the muzzle of a .22 rifle makes a satisfactory *ersatz* sound moderator.

5.5 What proof marks should be displayed on the barrel after it has been submitted for proof?

Many different proof marks are employed in the various countries which are party to the CIP, and some of these can be seen in the booklet "Notes on the proof of shotguns and other small arms" which is issued by the two English proof houses.

Depending on the date and place of Proof, the barrel may also bear an insignia and numbers or letters denoting the date of proof. The proof houses may also mark the cartridge for which the rifle barrel is chambered, if this has not already been done by the maker. According to the above booklet, when a barrel has been re-proofed, it should be marked with a crown over the letter "R". These marks may be stamped or, in the case of high quality firearms, engraved.

5.6 General observations on the validity of the whole proofing process

The present method of proof has its origins in the 16th century and materials science has moved on somewhat since those days. The aero industry now uses non-destructive testing procedures on the actual components, confining the overstress "semi-destructive" tests to sample components. Their reason was that such tests on the actual components to be used were found to actually contribute to the failure rate of those components.

Various proposals have been advanced for a more modern and effective quality assurance (QA) system for firearm manufacture, but they have been opposed by the Proof Houses. At the CIP plenary session in Moscow in 1998, the British delegation voted down a proposal to move from individual proof to "Prototype Type Approval". Discussions with some of the top people in CIP revealed that there was a lot of resistance to Prototype Type Approval, as the principle of

individual proof was seen as central to the ethos (and profitability) of the CIP Proof Houses. There matters rest - for now.

It should be noted that Switzerland and the USA both have well-developed firearms manufacturing industries and relatively high *per capita* rates of civilian gun ownership. In neither country are there queues of people clamouring for proof laws or membership of the CIP because their guns have blown up in their faces. In fact, rifle-makers and users these countries regard our archaic proof laws and procedures with bafflement or derision.

It is false to suggest (as the Prosecutor has done in his opening note), that in this day and age it is only the strict application of the CIP proof system which ensures the safety of operation of all small arms produced in this country. If anything, my experience as a gun dealer suggests that the opposite is true. By what appears to be lax quality control of their own procedures, the English Proof Houses do sometimes blow up some perfectly good rifles (like Mr Callum Ferguson's 6 mm PPC Stolle rifle which was destroyed with a charge of the wrong powder by the Birmingham Proof House). More worrying, however, is the fact that the English Proof Houses sometimes fail to identify potentially life threatening faults such as the excessively long bedding screw which I found on Remington M700 rifle no. E6896813 which could have prevented the bolt from being properly closed. Unsuspecting dealers and users are led to believe that if a gun has been proof-marked it must be safe (or at least that a court will judge it so), and they may be lulled into skimping essential pre-delivery and regular safety maintenance checks.

Apart from guns, there are few other items which are required to be proof tested before or during their service lives. Two examples are construction site or factory lifting apparatus and high pressure gas cylinders. However, the testing of these items differs from gun barrel proof testing in the UK in several important respects. These include:

- when gas cylinders or lifting equipment are tested, the test procedure involves the application of a precisely-measured force or pressure, whereas the actual overload from a Proof cartridge is unknown;

- gas cylinder and lifting equipment test stations measure strain or deformation of the test piece during the test;

- there are many gas cylinder and lifting equipment test facilities distributed throughout the UK, and they compete effectively on quality of service and price, while adhering to common professional standards;

- many of these independent testing facilities are run by qualified engineers and are certified to ISO 9002 or a similar QA standard.

6 Test procedures and results

6.1 General principles

It is alleged by the prosecution that there might have been some danger of the Beatham sound moderators bursting in service and causing injury to the user. As discussed above, even someone who is only remotely familiar with engineering design or firearms manufacture would quickly see that this allegation is false.

However, the allegation has been made in a sworn statement by a Proof Master, a person who might be expected to be a professionally qualified engineer and to have some personal experience of firearms manufacture. Therefore, in order to show the magnitude of his error, I have carried out engineering tests and stress analysis to show just how high is the residual factor of safety of the modified part of the rifle.

The following discussion uses the engineering terms *stress* and *strain*.

Stress is force divided by area, in the limit as the area approaches zero. Stress is expressed in *pounds per square inch*, which is usually abbreviated as *psi*. *Stress* is a vector.

Strain is deformation divided by the length in which the deformation occurs. Since *strain* is a length divided by a length, it is dimensionless. *Strain* is a vector.

I analyse in detail only one mode of failure of the Beatham sound moderator: the bursting of the tube due to excessive hoop stress. Mr Pitcher has suggested that there might also be some risk of the moderator end cap being damaged or coming loose. This is very unlikely, but if it were to happen, the end-cap and baffles would be propelled approximately in the direction in which the muzzle is pointing. That is never a good place to stand when a gun is being fired.

To determine the factors of safety against yield (permanent deformation) and failure (bursting), I need to determine the hoop stress in the tube and compare this result with the ultimate (failure) stress and yield stress of the barrel steel. These

material properties I obtained from Sturm, Ruger & Co, the firearm manufacturer through the kind assistance of their official importer, Viking Arms Ltd.

6.2 Test procedure and formulae

One of the simplest methods of determining the stress in a metal is to measure the strain ε and calculate the stress σ using Hooke's Law:

$$\varepsilon_x = 1/E\ (\sigma_x - \nu\sigma_{y)}$$

(where E is Young's Modulus and ν is Poisson's Ratio)

Unfortunately, this direct approach failed, because even with the high velocity "Winchester Laser"22 LR ammunition the transient hoop strain on the outside of the Beatham moderator was too small to be measured using a strain gauge and peak strain meter designed for checking strain in the breech area of rifles and shot guns.

This absence of any reading indicated that the working stress in the Beatham moderator is negligible, but I was determined to get a measurement of some sort. I measured the strain in an aluminium alloy Helston moderator which has the same internal dimensions and components as the Beatham moderator. The aluminium moderator was fitted to a BSA bolt-action rifle with a short 16" barrel. With subsonic ammunition there was no measurable strain, but with Winchester Laser ammunition 20 shots produced an average of just under 19.6 microstrain with a standard deviation of 4.1 microstrain. (Note, 19.6 microstrain corresponds to an extension of less than 1 1/4 inches in a mile - so we are talking about a rather small deformation of this aluminium tube). Using this figure and the formula for a closed ended tube: P = ('E'*'ea'*(('a'/'b')^2-1))/(2-'n'), I determined that the average peak service pressure inside the Helston moderator is 95 psi. Using the formula for an open-ended tube (no axial stress) it would be 80 psi. In fact, the sound moderator is neither closed-ended nor open-ended, but something in between the two. But 95 psi is the worst case.

I then assumed that the same transient peak pressure might exist in the Beatham sound moderator. This is a very conservative assumption, because the Ruger rifle is a self-loading type, and the breech will have opened before full pressure is developed in the moderator, whereas the breech of a bolt-action rifle remains closed and gas-tight. My best estimate is that the pressure in a sound moderator on a self-loading rimfire rifle is not more than 1/4 of the corresponding pressure on a bolt action rifle with a similar barrel length, but I have not had time to confirm this by tests. So I have used the above "bolt-action" pressure figures of 96 and 80 psi in my calculations.

For a closed-ended tube the hoop stress on the inside wall is: ('P'*'b'^2/('a'^2-'b'^2))*('a'^2/'b'^2+1), where 'P' is the internal pressure, and 'a' and 'b' are the outside radius and inside radius of the tube, respectively.

This gives a peak external hoop stress of about 277 psi, which is 180 times less than the yield stress of the barrel steel.

As noted above, there are some broad-brush assumptions in the above analysis, the details of which are shown in the tables which follow. However, the assumptions err on the side of safety, and are insignificant in relation to such a very high factor of safety.

To sum up, the calculated *factor of safety* of the Beatham moderator is not less than 180. The best engineering requirement would be not more than 5, so the moderator is at least 36 times safer than any engineer requiring maximum safety would demand. In fact, because of the "safety valve" effect of the semi-automatic breech described above, I believe the *factor of safety* is much higher than that which I have calculated. Further tests are to be undertaken to quantify this effect, but my current estimate is that the moderator is at least 100 times stronger or safer than best engineering practice would demand.

6.3 Test results

[Please note: in the electronic version of this document which is available by email request to the author <pj@forgeconsulting.co.uk> the following tables are included as embedded MS Excel spreadsheets to facilitate checking and review by the reader].

Helston Aluminuim Alloy Sound Moderator

Microstrain measurements

	Ammunition	
	Winchester	Federal 223
Record no.	Laser 22 LR	Remington
1	22	507
2	29	956
3	23	704
4	20	655
5	22	657
6	23	514
7	19	516
8	16	564
9	23	657
10	16	515
11	20	
12	14	
13	25	
14	18	
15	15	
16	16	
17	17	
18	23	
19	14	
20	16	
Average	19.6	624.5
Standard deviation	4.1	138.5

6.4 Calculations

Property	*Unit*	*Symbol*	*Helston aluminium alloy sound moderator*	*Helston aluminium alloy sound moderator*	*Modified Ruger 10/22 barrel*
Ammunition			Winchester Laser 22 LR	Federal 223 Remington	Winchester Laser 22 LR
Input data:					
Outside hoop strain		ea	0.000020	0.000625	0.0000082
Inside diameter	inch	ID	0.700	0.700	0.705
Inside radius	inch	b	0.350	0.350	0.353
Outside diameter	inch	OD	0.938	0.938	0.913
Outside radius	inch	a	0.469	0.469	0.457
Poisson's ratio		n	0.330	0.330	0.300
Young's modulus	psi	E	10,000,000	10,000,000	29,000,000
Ultimate stress	psi	sf	42,785	42,785	85,000
Yield stress	psi	sy	33,358	33,358	50,000
Calculated results (closed ended tube):					
Internal pressure	psi	P	95	2,978	95
Outside hoop stress	psi	sa	240	6,290	277
Internal hoop stress	psi	sb	335	10,463	374
Factor of Safety (ultimate)			179	7	307
Factor of Safety (yield)			139	5	180
Calculated results (open ended tube):					
Internal pressure	psi	P1	80	2,486	81
Outside hoop stress	psi	sa1	200	6,250	238
Internal hoop stress	psi	sb1	280	8,736	318
Factor of Safety (ultimate)			214	7	357
Factor of Safety (yield)			167	5	210
Conversion factors:					
		psi	*N/mm2*		
		1	0.006895		

Appendix A: Figures

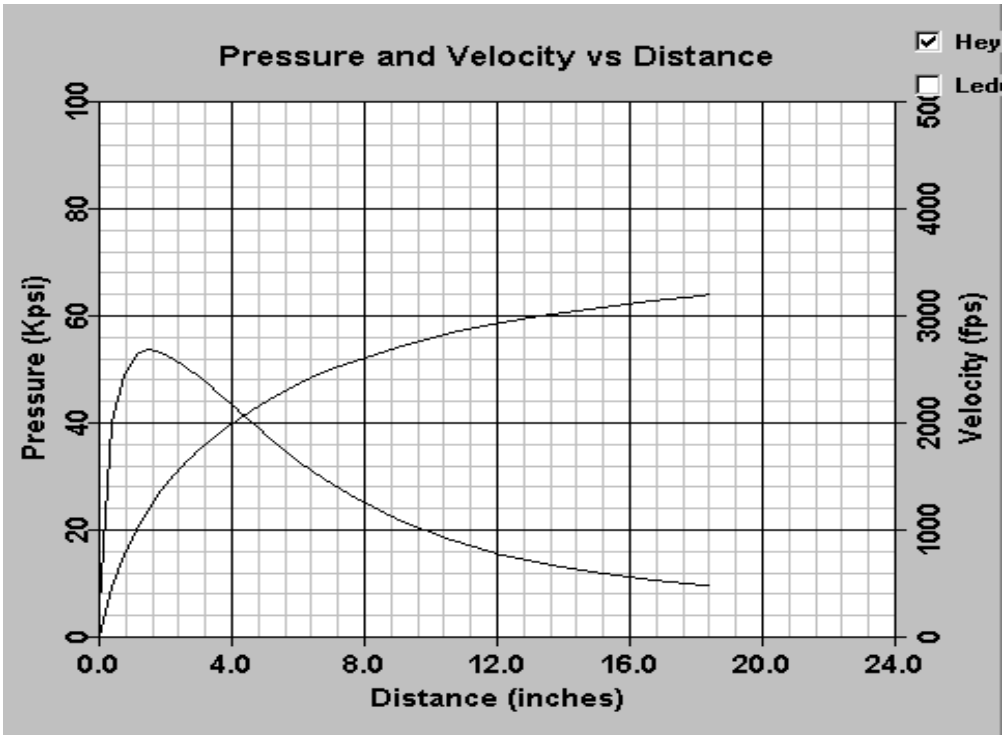

Figure 1: Typical pressure and velocity curves for 223 Rem centre-fire cartridge

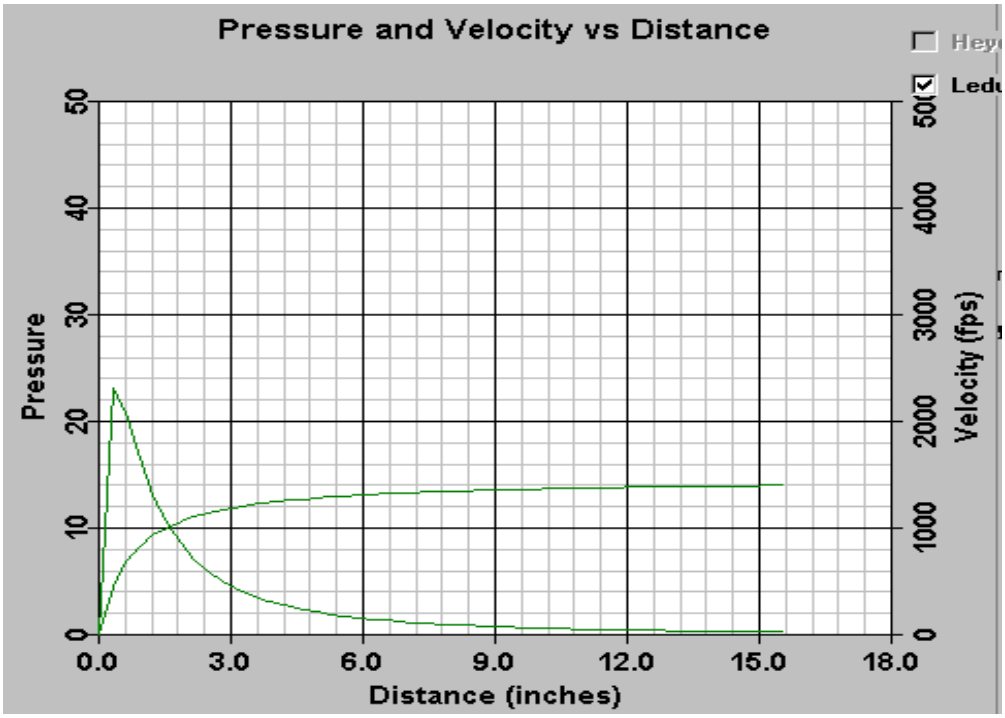

Figure 2: Typical pressure and velocity curves for .22 rim-fire cartridge

Appendix B: Notes on strain measurement

Peak strain meter specifications

The Fabrique Scientific Peak Strain Meter is an analogue peak detecting, auto zeroing instrument with a LCD digital voltmeter (DVM) readout. Recent developments in operational amplifiers and instrumentation amplifiers and inexpensive DVM ICs have made this possible. The fast response time lends itself well to firearm applications, although the meter can be used in other applications.

Gauge resistance: 350 ohms

Input section: DC coupled bridge circuit to high quality instrumentation amplifier

Peak Hold section: picoamp FET diode feeding polystyrene hold capacitor with a femto amp input bias electrometer grade operational amplifier buffer.

Droop rate: peak hold droop less than 1 division / 10 seconds typical

DVM section: 7106 type analogue to digital converter with low battery detection circuitry

Power: single 9V battery in separate compartment, current drain is 35-40 milliamps for estimated battery life of 12 hrs.

Bandwidth: to 3 kHz half sinewave pulses

Theory of operation

The strain gage resistance is connected to a Wheatstone bridge circuit at the input of the meter. The bridge is powered from the regulated 5 volt (nominal) supply. The reference end of the bridge is connected to the positive input of the precision high bandwidth low power supply voltage instrumentation amplifier. The gauge end is designed for use with 350 ohm gages and is in series with a 348 ohm bridge resistor. The reference side resistors are 1K ohm to reduce battery drain. The bridge is arranged so the input of the amp. will have a fixed low resistance to ground when the input lead jack is removed. A

increased strain on the gauge will cause a decrease in the negative input voltage on the amp. resulting in an increased output voltage at a gain of around 735. The output voltage is fed back through one half of the dual LM358 op amp acting as a inverting low pass filter with a time constant of around 0.2 seconds to the reference lead of the in. amp. The DC level output of the in. amp. is thus kept at zero volts. Pulses much shorter than the time constant will appear at the output which is connected to the other half of the LM358 op amp which is configured as a unity gain buffer driving the hold capacitor through the ultra low leakage FET diode. The femto amp level input bias current op amp is configured as a voltage follower from the hold capacitor and the output provides the feedback to the LM358 via a compensation RC network for stability. This feedback arrangement removes any voltage drop effect from the diode. The input lead to the op amp is intentionally bent out and physically floated from the PC board in order to avoid any leakage effects from the board. The track vs peak mode switch connects the DVM input to the in. amp. feedback level or the output of the peak hold buffer amp. The DVM reference lead is connected to the 15 turn calibration trimmer which divides down voltage from the 5 volt reference and sets the scale for the display. The reset button is a momentary contact switch that shorts the hold capacitor to ground. The calibrate/test button is another momentary contact switch that shorts a 215K metal film resistor across the 348 ohm bridge resistor to simulate a momentary strain increase in the strain gauge.

Appendix C: Photographs

Figure 3: Modified Ruger 10/22T with peak strain meter

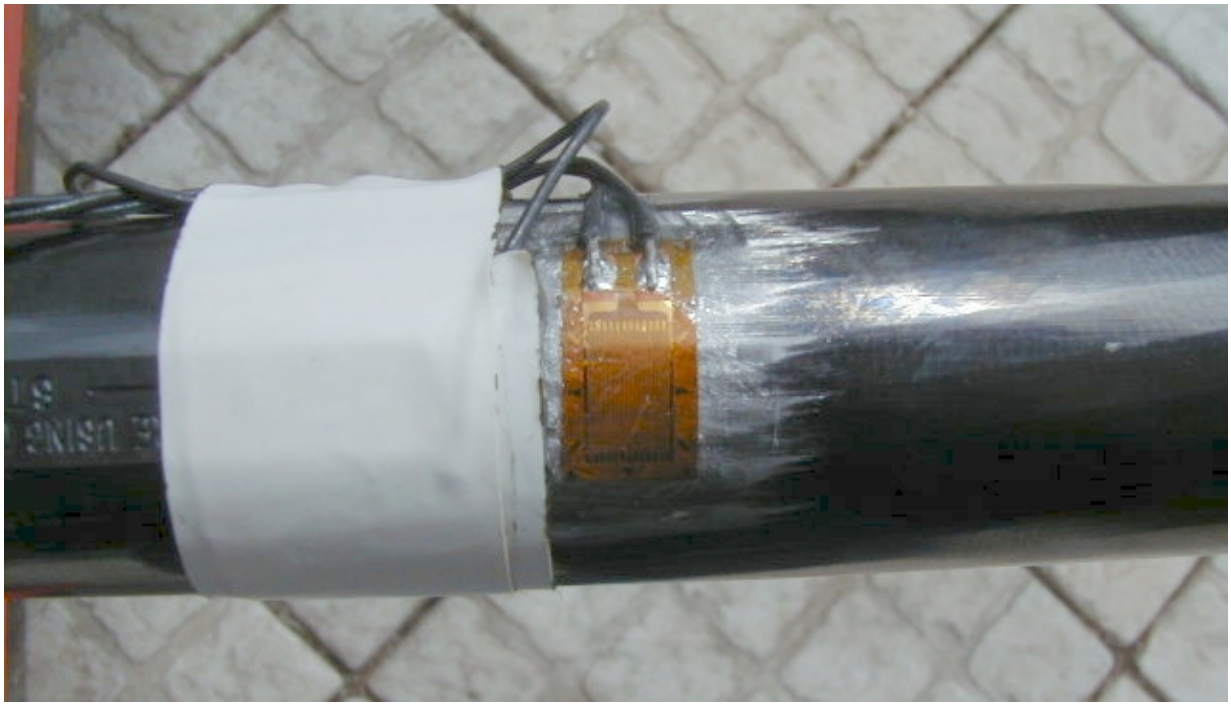

Figure 4: Strain gauge on modified Ruger 10/22T

Figure 5: Strain applied by hand to check strain gauge and meter operation

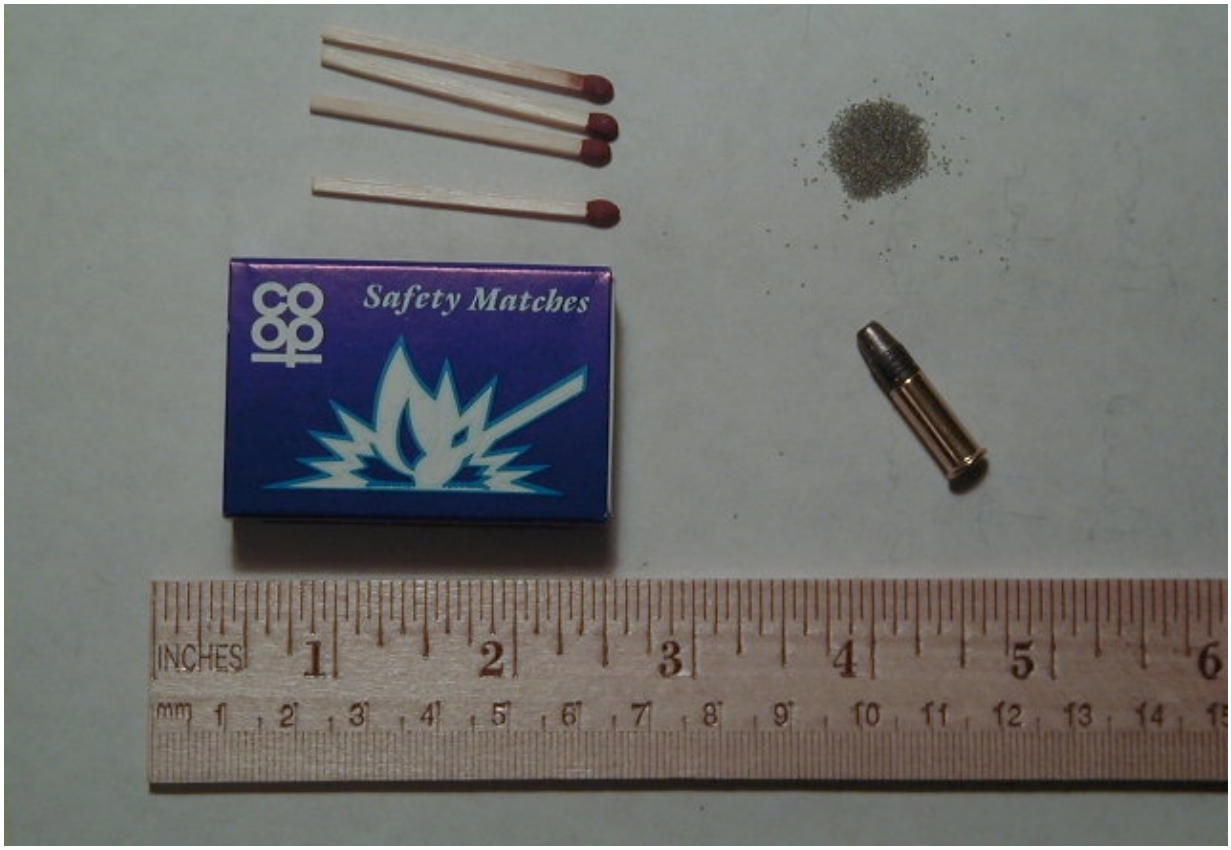

Figure 6: A .22 LR cartridge contains very little powder

Figure 7: Comparison of .22 LR rim-fire and 223 Rem. centre-fire cartridge cases

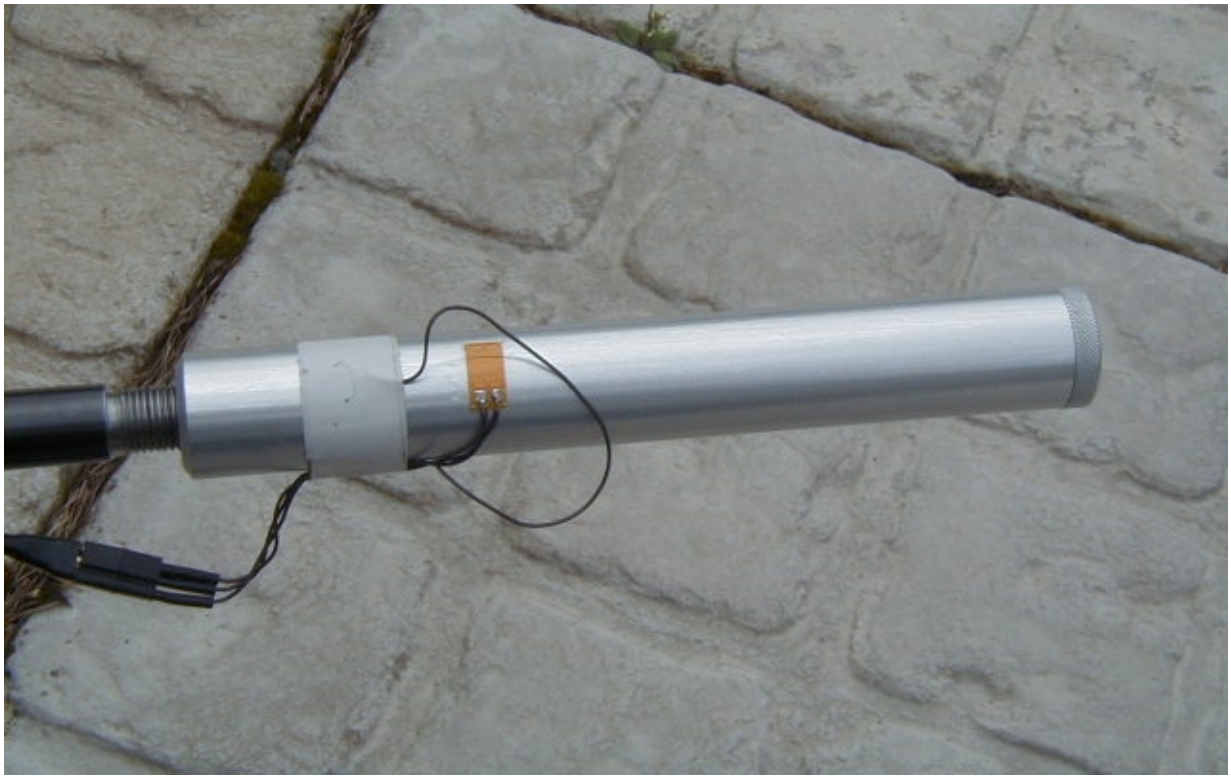

Figure 8: Strain gauge on detachable aluminium sound moderator