DID WOGDON BEND HIS BARRELS CROOKED TO MAKE THEM SHOOT STRAIGHT?

by David S. Weaver

Figure 1. A cased pair of duelling pistols by Robert Wogdon ca. 1780. Photo courtesy of John O'Sullivan.

During the 1760s, the wearing of small swords fell out of fashion in England and by about 1770, pistols had become the weapon of choice for duelling, although various combinations of weapons were sometimes used.[1] There were no stipulations regarding the specific kind of pistol required, although it appears that holster pistols were originally a common choice. During the 1770s, a distinctive form of pistol was being made and sold in cased pairs with accessories for loading and cleaning. These pistols reflected the change in taste from the flamboyancy of the rococo in mid-18th century England to the simplicity and elegance of the neoclassical revival and ultimately became known as 'duelling pistols'.

Figure 1 shows a typical cased pair of duelling pistols made by Robert Wogdon ca. 1780.[2] Wogdon was born in Grantham in 1734 and carried out his seven year gunmaking apprenticeship under one of England's outstanding gunsmiths at the time, Edward Newton of Grantham.[3] Both he and John Fox Twigg, who was also to become one of England's leading gunsmiths, were made free of the City of Grantham on February 18, 1756, having completed their apprenticeships under Newton. Twigg moved to London and is known to have first occupied premises in Argyle court, Charing Cross, and by 1765 was renting a shop in the Strand. It is thought that Wogdon may have worked for Twigg at first, but by 1765 Wogdon was on his own in Cockspur St. and signing his guns Wogdon Charing Cross London. Throughout the 1770s, Wogdon was making pistols in the form shown in Figure 1 and by the 1780s was probably London's most prolific supplier of such pistols. Such was his reputation that he became immortalized in the poem "Hail Wogdon, patron of leaden death".[4]

There were, of course, numerous duelling pistol makers vying for market share and developing improvements in hopes of increasing their sales. Atkinson discusses these[5] and, in particular, examines a paper presented to the Royal Dublin Society in 1838 by John Rigby of the famous Irish gunmaking firm William and John Rigby of Dublin.[6] In his paper, Rigby states that Robert Wogdon, in order to overcome the *"universal error in the shooting of pistols made in the ordinary way"* of *"throwing high over the mark", "bent the barrels of his pistols crooked, to make them shoot straight"*. He goes on the say that it *"had the effect of making a reputation and a fortune for him"*. Atkinson expressed scepticism about this and, indeed, the idea does seem absurd.

This article presents the results of a study to determine whether or not Wogdon did 'bend his barrels crooked to make them shoot straight' and to consider whether the idea had any possible technical merit.[7] It is noted that, in a duel, there would likely be many factors at play, which could influence pistol accuracy, such as the agreed procedures for the particular duel being fought and the duellists' emotional response of the moment. Such effects are considered outside of the scope of this article.

What Rigby's Paper Said

Rigby's 1838 paper to the Royal Dublin Society outlines the "universal" problem of pistols shooting high over the mark, provides explanations for why he thought that happens, states how previous gunmakers had attempted to correct that and presents how his firm solved the problem.[6] In essence, the paper trashed his competitor's solutions to the problem, extols the superiority of his firm's products and takes credit for effectively ending

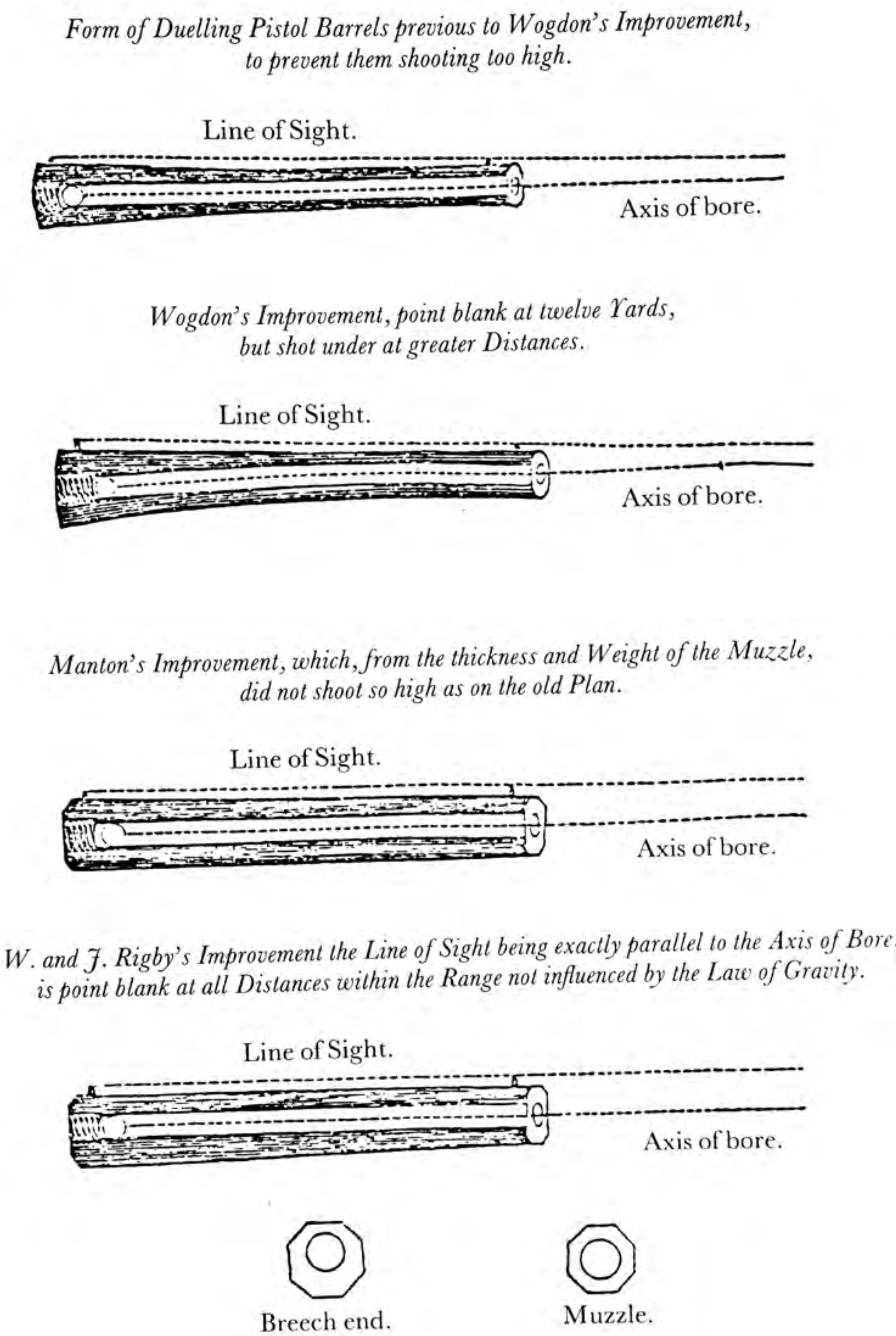

Figure 2. Sketches from John Rigby's 1838 Royal Dublin Society paper.

"the vicious practice of mortal quarrels over light causes" because their pistols were so accurate.[8]

The sketches accompanying Rigby's paper are shown in Figure 2.[9] He actually expressed regret that *"time does not permit to have them more accurately drawn"*. The top sketch indicates Rigby's notion that the reason for the universal problem of pistols shooting high was the angle between the top flat of the barrel and the bore, i.e., the axis of the bore is angled upwards compared to the top flat of the barrel because the breech was generally thicker than the muzzle. The second sketch shows, according to Rigby, Wogdon's solution by bending his barrels downwards. It is imagined that the trajectory of the ball would follow the curvature of the barrel after leaving the muzzle and, therefore, hit its mark.[10] Rigby's criticism was that, if the target was further away, then the ball would hit the target low, and by inference, if the target were closer then the ball would hit high. In his paper, he stated that *"the crooked tube could only shoot true at one particular distance"*. Figure 3 provides a scaled pictorial view of what Rigby was saying, with the curvature of the ball trajectory exaggerated somewhat to make the meaning clear.

The third of Rigby's sketches shows how Joseph Manton made the barrels heavy so they did not shoot so high. Rigby appears to believe that the effect was geometric, i.e., the thicker barrel at the muzzle made the angle between the top flat and axis of the bore smaller. His criticism was that the pistols still shot high and were *"so ponderous, as in weak hands to be unfit for rapid use"*.

Rigby's fourth sketch shows his firm's solution. The bore is made parallel to the top flat of the barrel so now the target is perfectly aligned with the bore of the pistol. Their simple and inge-

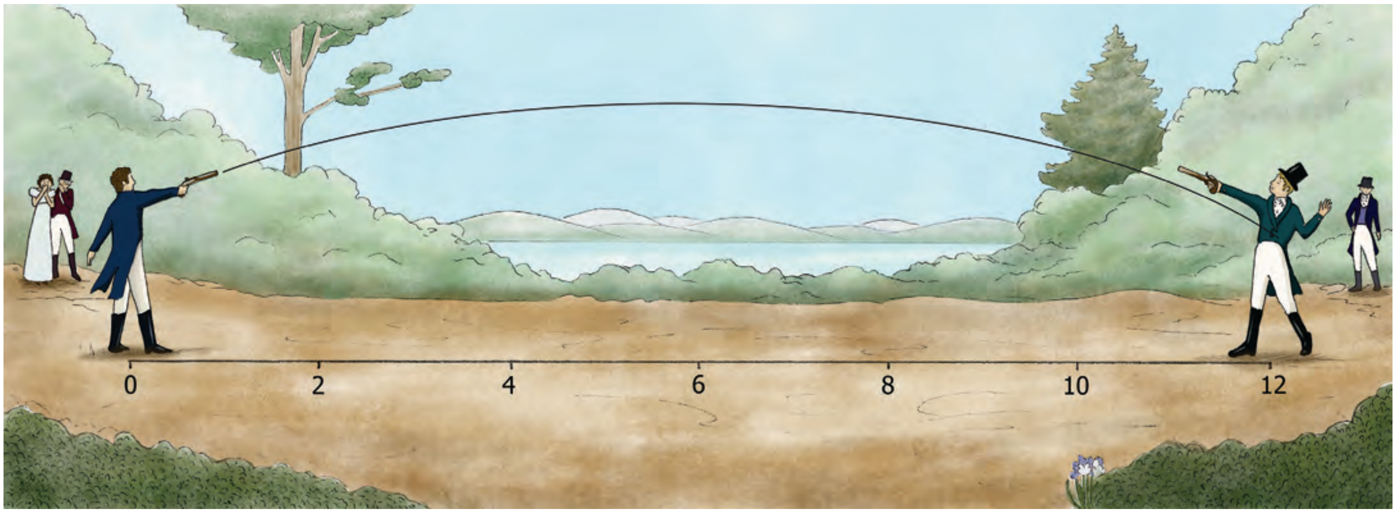

Figure 3. Curved trajectory of ball shot from curved barrel as assumed by Rigby. Illustration by Justine Greenfield.

nious development is so accurate, according to Rigby, that *"he is considered a mere tyro who cannot strike a figure three inches high and one wide"*. Indeed, since they introduced this development, the accuracy of their pistols was claimed to be so great that they helped put an end to duelling.

Apparently, the reaction of those assembled at the meeting was not recorded but it seems unlikely that anyone familiar with the laws of mechanics or the practice of duelling would have been impressed with the errors, hyperbole and false claims of this paper.

A Critical Analysis of Rigby's Ideas

Why a pistol shoots high.

The distinctive neoclassical form of English duelling pistols was characterized by its light and graceful lines and probably was inclined to shoot high over the mark as John Rigby stated. However, this would have had little to do with any angle between the top flat of the barrel and the axis of the bore. This angle was due to the thickness of the breech of the barrel being larger than that at the muzzle. At the small distance associated with duelling, typically 12 paces, this small angle would not appreciably affect the pistol accuracy on a man-sized target. Additionally, these pistols had sights on the barrel which could be used when taking careful aim. Thus, sighting would not be along the top barrel flat and the angle of that flat with the axis of the bore would be irrelevant.

The problem of a pistol shooting high can be explained by examining a pistol being fired off-hand as illustrated in Figure 4 and applying Newton's laws of motion. We know from Newton's second law that the explosive force caused by the burning powder accelerates the ball down the barrel, and that Newton's third law tells us that that force produces a reactive force, F, parallel to the barrel and against the shooter's hand. We also know that this force is above the shooter's hand grip on the pistol, so a rocking moment M is created which rotates the barrel upwards at it muzzle. Thus, the ball at the muzzle not only has the horizontal velocity imparted by the powder charge, but also a vertically upward velocity imparted by the upward motion of the muzzle. This reaction to firing is often referred to as 'kick up' and is illustrated in Figure 5, where the vertical kick-up velocity component has been exaggerated to make the phenomenon more clearly visible. The trajectory of the ball then is the combination of the horizontal and vertical velocities of the ball as it leaves the muzzle. The actual kick-up velocity will depend on the explosive pressure of the powder charge, the diameter of the bore, the mass of the ball, the mass of the gun and the

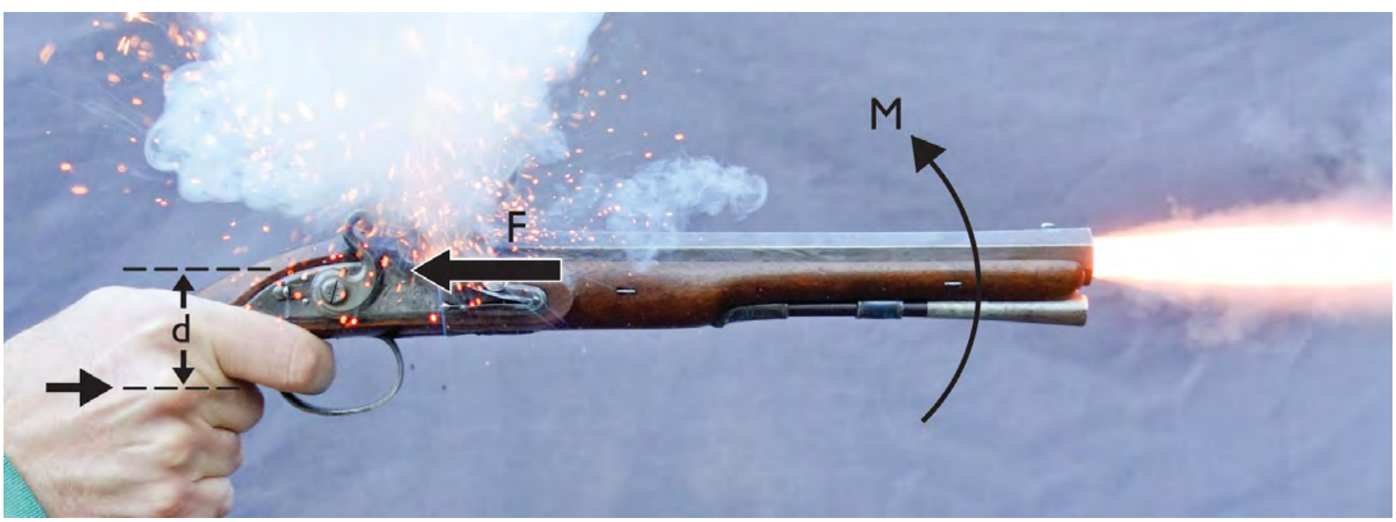

Figure 4. Photograph of duelling pistol being fired showing reaction forces causing barrel muzzle kick-up (where F is the reactive force rearward as the powder is discharged, d is the distance of the barrel from the shooters hand grip and M is the reactive moment causing the upward motion of the muzzle. Photo courtesy of John O'Sullivan.

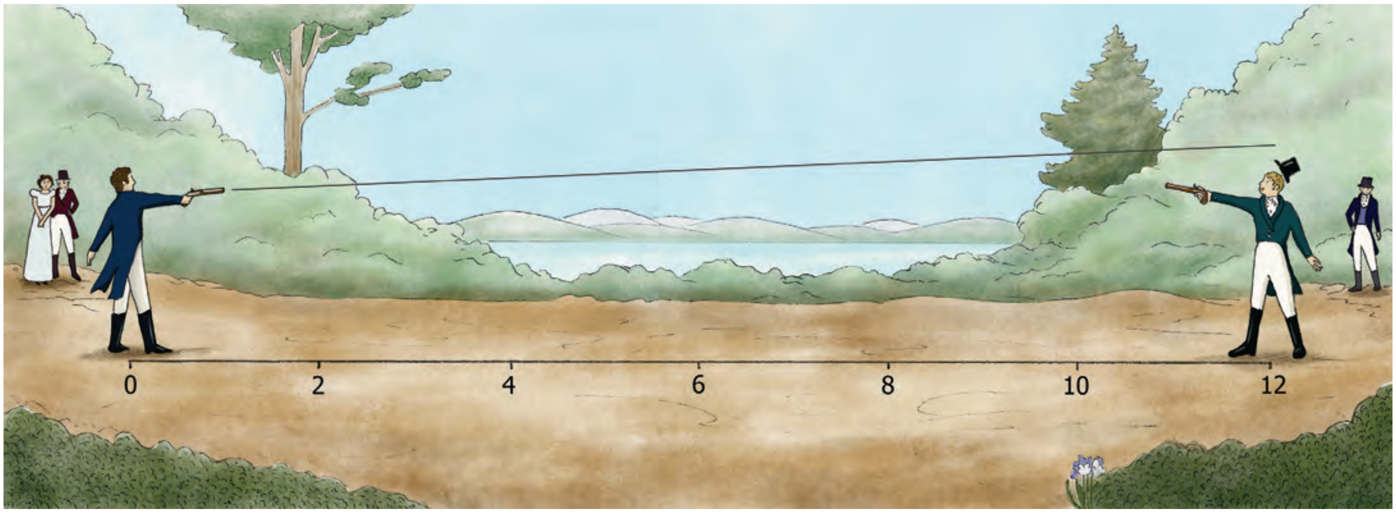

Figure 5. Sketch showing the ball trajectory upon leaving the barrel, including the upward velocity produced by muzzle 'kick-up'.

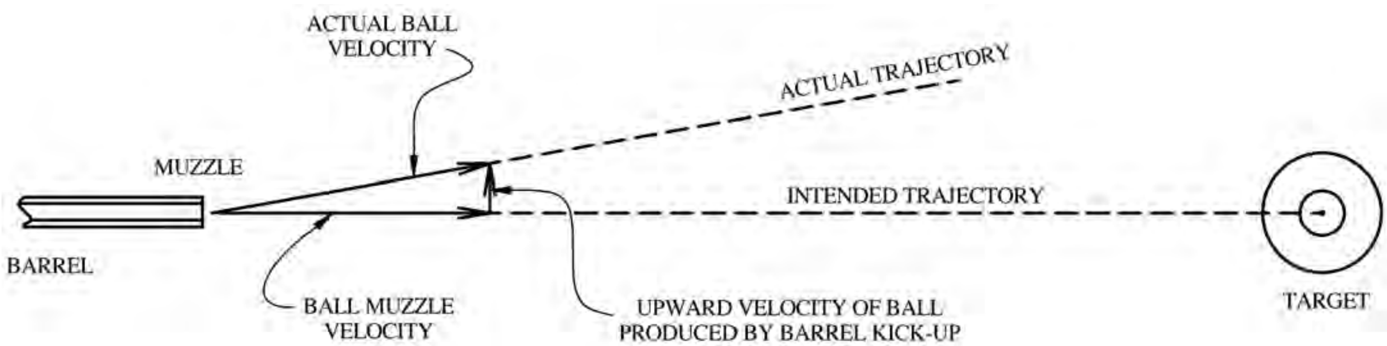

Figure 6. Sketch showing effect of 'kick-up' on ball trajectory.

strength of the shooter. It follows that shooting high is the result of the shooter-barrel dynamic response to the explosive force of firing the ball and has little if anything to do with the angle between the barrel top flat and the axis of the bore. This is shown practically in Figure 6 where the kick-up has produced a ball throwing high on the mark as described by Rigby as the 'universal' problem.

The Effect of Barrel Curvature on Ball External Ballistics.

Rigby's explanation of Wogdon's use of bent barrels depends on the idea that a ball following a path down a curved barrel will continue following that curved path after it leaves the barrel. This was shown in Figure 3 in which the curvature was exaggerated slightly to illustrate the idea. This curved path was alleged to have been designed by Wogdon to precisely compensate for the angle between the top flat and the axis of the barrel bore. Rigby took pains to point out that the problem with this idea is that the pistol is then only accurate at the given distance for which the curvature was designed and would shoot too high at shorter distances and too low at longer distances. With a target the size of a man's torso at 12 paces, one can imagine the curvature required of the ball trajectory to be "point blank" at 12 paces but miss the target at other distances likely in a duel. If Rigby had made better scaled drawings, he might have had second thoughts about this criticism.

Beyond the problem raised by Rigby of shooting true at only a single distance, is the idea that the ball will follow the curvature of the barrel after leaving it. Newton's first law states that a body remains in a state of rest or uniform motion unless acted upon by an unbalanced force. Since there are no such forces acting on the ball during it's free fight after leaving the muzzle of the pistol, the ball will follow a straight-line trajectory, ignoring aerodynamic and gravity effects (which is a reasonable assumption over the short distances used for duelling). This is shown in Figure 6 where the ball's trajectory relative to the barrel follows the straight-line tangent to the muzzle and not the curved path following the barrel curvature. The idea that bending the barrel to correct for shooting high is contrary to the laws of Newtonian mechanics.

Effect of Barrel Mass on Accuracy.

According to Rigby, Joseph Manton's improvement involved increasing the barrel weight which Rigby apparently thought was caused by the geometric effect of making the top flat more nearly parallel to the axis of the bore. This criticism is a real stretch, especially the suggestion that the barrels became too heavy for practical use. Making the barrel heavier actually did reduce kick-up, by virtue of increasing the barrel mass (larger mass reduces barrel acceleration produced by the same reactive force of firing a shot) and was almost universally adopted by duelling pistol makers by about 1800.

Was Rigby's 'Improvement' an Improvement?

Rigby's improvement was to make the axis of the bore parallel to the line of sight which appears to be along the top flat of the octagonal barrel. Since the barrel was tapered from breech to muzzle and the bore was centred in the barrel at the muzzle, this meant that the bore was not centred at the breech as shown in Rigby's sketch. The reader is not told how this was accomplished in making their barrels but, since the line of sight was not the cause of the problem of shooting high, it is difficult to imagine that Rigby's improvement did anything but make the barrel more difficult to manufacture while also weakening the breech by reducing its minimum thickness.

Did Wogdon Actually Bend his Barrels?

Having examined Rigby's assertions in his paper to the Dublin Royal Society and found them to be wanting, the question remains did Wogdon do as Rigby claimed, bend his barrels crooked to make them shoot straight? There is no reference to this practice in anything Wogdon wrote or advertised, nor has there been found any contemporary reference to it beyond what Rigby stated in his paper. It appears that the question can only be answered by a careful examination of extant Wogdon duelling pistol barrels. This may have been what Rigby did in an early bit of industrial espionage.

In fact, it is not easy to determine with any precision whether a duelling pistol barrel has been bent slightly and by how much. An external examination of a Wogdon barrel provides no clue as to whether or not the barrel bore has been bent. More than any other gunmaker, Wogdon swamped all sides of his octagonal barrels, the top flat usually being nearly straight on many of his pistols, the sides being clearly swamped, and the bottom flat being heavily concave with the minimum barrel thickness being about two-thirds of the way from the breech to the muzzle. All these features are clearly shown in Figure 7. Interestingly, the amount of 'swamping' of the flats varies significantly from one pistol pair to another and, because the top flat and bottom flat are so differently swamped, the barrel thickness may be noticeably different at the point of minimum barrel dimension as well. These barrels were a *tour-de-force* in barrel filing and must have been difficult to stock with a close fit. The benefits of such swamping are not clear, especially along the bottom flat, which is not visible unless the barrel is removed from the stock. The barrels would have had to be submitted for proofing in nearly completed form. It may be that Wogdon purposely filed up his barrels in this way to disguise the fact that the bores were bent.

To the author's knowledge, the first person in recent years to seriously address the question of Wogdon bending his barrels was Dr. John O'Sullivan of Melbourne, Australia. In 2004, he obtained industrial X-rays of the barrels of seven pairs of Wogdon duelling pistols.[11] The results were unequivocal. The barrels had all been bent a small amount, concave downward in the vertical plane. The X-rays also showed that they were all straight in the horizontal plane. There could be no doubt that the barrels were bent and that the bending was purposeful. The problem with these X-rays was that the bore definition was unclear near the breech and muzzle so that precise measurements of the angle of bend could not be determined. It was at this point that the present author became directly involved and, in 2008, a study was undertaken to see if thermal neutron radiography might provide improved measurement possibilities.

The research nuclear reactor at McMaster University in Canada was used to obtain the neutron radiographs shown in Figure 8.[12] The results confirmed the conclusion drawn from the X-rays that

Figure 7. Photograph of Wogdon barrel showing 'swamping' of octagonal flats. Photographs courtesy of John O'Sullivan.

Wogdon Vertical Plane

Wogdon Horizontal Plane Neutron x-rays of Wogdon barrel

Figure 8. Thermal neutron radiograph images of horizontal and vertical views of a Wogdon barrel. Images courtesy of Nray Services Inc., Dundas, Ontario, Canada.

the barrels were bent and, happily, that the images could be used to determine the nature of the bend as well as its included angle. It was found that the curvature was not uniform along the entire length of the barrel, which is not a surprise because that would have been very difficult to accomplish. Furthermore, the bore was essentially straight for a short distance at the breech and at the muzzle. In order to obtain an accurate measurement of the angle between the straight-line tangent to the bore at the breech and that at the muzzle, a vernier protractor was used as shown in Figure 9.[13] That angle was 1.2°, with the bore essentially parallel to the top flat of the barrel at the muzzle and inclined slightly upwards at the breech in the direction of the muzzle. Such radiographs were obtained for a pair of Wogdon barrels as well as the single Wogdon barrel illustrated in Figure 8. The measurements were amazingly consistent, within 10 minutes of arc, amongst the 3 barrels examined. The protractor was then set at the 1.2° angle and laid over the X-rays of the 14 barrels previously taken in Australia. As far as could be determined, this angle was essentially identical to those of the X-rayed barrels. This strongly suggested a manufacturing process in which Wogdon made his barrels straight, bored them through, and then bent them hot in a specially designed jig which precisely controlled the geometry of the completed barrel. The barrels were then filed up. More details on the barrel measurements and how Wogdon might have been bent the barrels are provided in O'Sullivan and Bailey (see endnote 7).

At this point, it had been established that Wogdon did bend at least some of his barrels but the obvious question was, did he bend all of his pistol barrels and what kind of evidence would be required to establish that. It was not practical to obtain neutron radiographs or industrial X-rays of large numbers of barrels so John O'Sullivan developed an ingenious device which could serve the purpose. It used a straight steel rod with a spring-loaded stud at one end which was fixed at right angles to the rod. The rod was stiff enough that it did not flex during use and the height of the stud was such that it would fit snugly into a suitable range of pistol bores. The spring under the stud was compressed, the rod inserted into the barrel, stud end first, and pushed down to the breech. The stud pressed the rod to one side of the bore and if the bore were straight, the rod would lie along the barrel over its entire length and emerge at the muzzle touching the bore. If the bore were bent, there would be a gap between the rod and the bore. Used with care, this device provided a reliable indicator of whether a barrel was bent and was used by O'Sullivan on 15 more pairs of Wogdon pistols, two of which were X-rayed showing the rod device inserted. He also had high resolution digital X-rays taken of the original seven pairs to confirm previous measurements.[14]

Overall, proof of Wogdon's barrel bending had been obtained from the original 7 pairs of barrels, the 3 barrels neutron radiographed and 15 pairs using the rod device, 47 barrels in all. They were all bent in the vertical plane, straight in the horizontal plane and no exceptions were found. Control tests were done on duelling pistol barrels by other makers, and they were all found to be straight within the precision of the measurements. It can be concluded with confidence that Wogdon did bend the pistol barrels examined. The sampling was not truly random from all extant Wogdon barrels but the selection was all the barrels of Wogdon duelling pistols available to be measured by John O'Sullivan and the present author. Since that number was not small and none were found which were not bent, it is cautiously concluded that Wogdon bent the barrels of all his dueling pistols.

Does Bending a Barrel Crooked actually make it Shoot Straight?

The research for this paper was initiated out of curiosity regarding an assertion made by John Rigby before the Royal Dublin Society that Robert Wogdon, a gunmaker famous for his duelling pistols, bent his pistol barrels crooked to make them shoot straight. Rigby went beyond that, stating that Wogdon had not invented the idea but that it *"had the effect of making both a reputation and a fortune for him"*.[15] The research summarized in this paper demonstrated unequivocally that he did bend his barrels. However, it remains to determine whether there was any validity in the assertion that it improved pistol accuracy. Some people might argue that the only way to determine that would be to carry out comprehensive firing tests. Unfortunately, such testing is fraught with difficulties. Firstly, there are no known duelling pistols by Wogdon which had straight barrels so the straight barrel control data against which the bent barrel data would be compared would have to be pistols deemed to be equivalent to a straight barreled Wogdon. Secondly, these pistols are smooth bored, black powder muzzle loaders. The effects of random variations due to loading, powder, shooter skill and smooth bore ballistics are significant, so many shots would be required to properly establish performance statistics. Then a number of different shooters would have to replicate the shooting tests to eliminate the effects of shooter skill. Since the effects of slightly bending the bore are expected to be small at 12 paces, they may not be distinguishable from 'noise' in the data. Thus, an exhaustive

Figure 9. Vernier protractor measuring angle between bore tangents at breech and muzzle of a bent Wogdon barrel from a full-scale neutron radiograph.

series of firing tests may not supply statistically significant differences and therefore not answer the question.[16] On the other hand, there are sound technical reasons based on Newtonian mechanics that predict that bending barrels to make them shoot straight is a poor idea.[17]

To begin with, Newton's laws as illustrated in Figure 4 show that the reactive forces produced in firing a pistol off-hand cause the pistol barrel to 'kick-up' at the muzzle, thereby imparting a vertical velocity to the projectile. This is what causes the 'universal problem' of the pistol shooting high over the mark as described by Rigby, not the 'line of sight' along the top flat having a small angle relative to the axis of the barrel bore. No amount of line-of-sight correction will eliminate the kick-up.

Secondly, the proposed effect of bending the barrels depends on the projectile following the curvature of the barrel after it has left the barrel. This is contrary to Newton's first law of motion. The ball's initial trajectory relative to the barrel is actually the straight line following the tangent to the bore at the muzzle as shown in Figure 6.

Thirdly, while the ball is travelling down the curved barrel, it must have a force acting on it from the barrel to make it follow such a curved path as shown in Figure 10. Newton's third law states that for every action there is an equal and opposite reaction, i.e., the ball will create a reactive force on the barrel. Since the barrel is bent downward, this reactive force (F) is upward and will therefore tend to drive the barrel upward. Thus, the effect of bending the barrel downward is to increase the 'kick-up' and make the problem of shooting high worse.

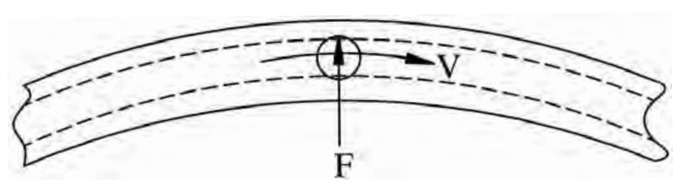

Figure 10. Reactive force (F) of ball travelling at velocity V in curved barrel

Finally, if the ball is not tight in the barrel and the barrel is bent downwards, the ball will tend to roll along the top of the barrel as shown in Figure 11, putting a spin on the ball as it leaves the muzzle. The effect of such a spin is to put a lift force on the ball, called the 'Robins effect'[18], thereby further increasing its tendency to shoot high over the mark, i.e., it would also make the problem worse (Figure 11). This effect is used to advantage in many sports such as baseball and golf. It should be noted that Wogdon recommended always to patch the ball so it should never be loose in the barrel.[19]

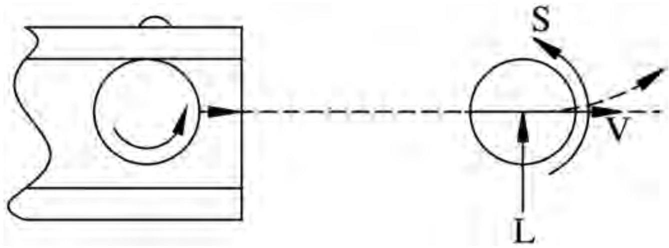

Figure 11. Robin's effect producing lift force (L) on spinning ball (where S indicates the direction of spin and V is velocity).

Conclusions

In a paper presented to the Royal Dublin Society in 1838, John Rigby of the well-known firm of Dublin gunmakers William & John Rigby, extolled the superiority of his company's firearms and, in the process, criticized his competitors' attempts to improve pistol accuracy. He argued that a 'universal' problem with pistols was that they shoot high over the mark and claimed that Robert Wogdon, a famous London gunmaker, had bent the barrels of his pistols cooked to make them shoot straight. He went on to say that this had the effect of making a reputation and a fortune for Wogdon. Curiously, no contemporary evidence has been found that Wogdon ever made such a claim, although it is true that he enjoyed fame for his duelling pistols and had a prosperous business. This paper summarizes the results of research to determine if, in fact, Wogdon did bend the barrels of his duelling pistols, and to assess whether this would improve the accuracy.

Digital X-rays, thermal neutron radiography and several measurement methods were used to carefully examine a total of 47 Wogdon duelling pistol barrels. The results were analyzed and are summarized here.

1. Every Wogdon duelling pistol barrel examined was found to be bent in the vertical plane with a downward concave curvature, but perfectly straight in the horizontal plane. The results were surprisingly consistent with an included angle between tangents to the breech and muzzle of about 1.2°. There can be no doubt that the bending was intentional. While the sample was not huge, it was considered representative of the span of Wogdon's production life, and no exceptions were found. It is therefore cautiously concluded that Wogdon purposely and very carefully bent the barrels of all his duelling pistols.
2. Newton's laws of motion demonstrate that the problem of a pistol 'throwing high over the mark' discussed by Rigby is caused by the upward acceleration of the barrel muzzle when fired, called 'kick-up'. The problem is not, as claimed by Rigby, due to the angle between the line of sight and the axis of the barrel bore. Newton's laws also show that bending the barrels was a bad idea since the projectile does not follow the curve of the barrel after it exits and the forces generated in the barrel due to its curvature actually tend to increase kick-up, i.e., make the problem worse.
3. While there is no known evidence that Wogdon bent his duelling pistol barrels to improve their accuracy as Rigby stated, there seems no other reason he would take the trouble to do such a thing. It is an interesting observation that two leading gunmakers of the period exhibited such poor understanding of Newton's laws and of external ballistics.

Figure 12. 1808 Duel with blunderbusses in hot air balloons over the Tuileries in Paris. Illustrations by Justine Greenfield.

Addendum: A Duel with Blunderbusses in Hot Air Balloons.

While on the subject of absurdities related to duelling, one of my favourites took place in Paris in 1808.[20] It seems that a Mademoiselle Tirevit, a celebrated opera dancer, was being kept by a Monsieur Grandpré but having 'an intrigue' with a Monsieur Le Pique. Grandpré apparently took exception to this and challenged Le Pique to a duel. It was decided to carry this out in hot air balloons over the Tuileries. According to the newspaper account, *"Each, attended by his second, ascended his car, loaded with blunderbusses, as pistols could not be expected to be efficient in their probable situations"*. No further explanation was provided. A crowd gathered to observe the spectacle as the balloons rose about 80 yards apart and to a height of about 900 yards. Le Pique then fired his blunderbuss ineffectually, immediately followed by Grandpré, who punctured Le Pique's balloon. Le Pique and his second left the scene by rapid descent and were *"both dashed to pieces on a house top"*. It seems that this duel, caricatured in Figure 12, was short on honour and long on foolishness.

Acknowledgements

The author gratefully acknowledges the inspiration and collaboration of Dr. John O'Sullivan in the research for this project, and for kindly providing the photographs of Figures 1, 4 and 7. The assistance of Rankin MacGillivray of Nray Services Inc. of Dundas, Ontario and Barry Diacon of McMaster University played an essential role in producing the neutron radiographs required for bore measurements in this research. Special thanks are due to Wajih Hamouda for his help with the technical drawings and to Justine Greenfield for her artistic flare in creating the duelling illustrations of Figures 3, 6 and 12.

Endnotes

1 J. G. Millingen, *History of Duelling, 2 vol.*, Richard Bentley, London, 1841.

2 Photograph courtesy of Dr. John O'Sullivan.

3 John O'Sullivan & De Witt Bailey, *Robert Wogdon, Wogdon and Barton, London Gunmakers 1764 – 1819, 2019*, Bonhams London. This extensively researched and finely produced book is the definitive work on Wogdon, his life and his work.

4 Ibid. Appendix 10, 'Stanzas on Duelling, a Poem, inscribed to Wogdon, the celebrated Pistol Maker', with footnotes by the late DHL Back. pp 331-334.

5 J.R. Atkinson, *The British Duelling Pistol*, Museum Restoration Service, Canada, 1978.

6 The firm of William and John Rigby of Dublin were amongst the leading gunmakers of their day, a company with its origins going back to 1760 and which survives to the present day in London. DHL Back published an excellent book on the company in the series Great British Gunmakers, *Messrs Rigby 1760 - 1869*, Historical Firearms, Norwich, UK, 1992.

7 The study was carried out by the present author, David S Weaver, in response to questions raised by Dr. John O'Sullivan about Wogdon bending his barrels, and was presented in the book by John O'Sullivan and De Witt Bailey (see endnote 3) as Chapter 7, Did Wogdon Bend his Barrels? pp 62-73.

8 John O'Sullivan & De Witt Bailey, 2019, *op cit.* Appendix 2. 'John Rigby's Second Paper to the Royal Dublin Society. pp 308-309.

9 J. R. Atkinson, 1978. op cit., p 55.

10 The text of the paper (see endnote 7) stated *"Wogdon actually bent his barrels downward, so that at twelve yards the incurvation of the ball from the crooked tube was so great, it struck the point the sights covered."*

11 The assistance of Ian Butler of Engineering Testing and Research Services, Victoria, Australia is gratefully acknowledged.

12 Nray Services Inc., of Dundas Ontario Canada using the research nuclear reactor at McMaster University, Hamilton is gratefully acknowledged for taking these neutron radiographs. The exposure time was 4.5 minutes.

13 The protractor used was made ca. 1820 by W & T Gilbert

14 The assistance of Gert Venter of Lectromax Australia Ltd in 2012 is gratefully acknowledged for providing high resolution digital X-rays of the barrels of the original seven pairs of Wogdon barrels. While the bore definition was still a little fuzzy to obtain precise measurements, these images served to illustrate well the curvature of the bores and swamping of the barrels.

15 John O'Sullivan & De Witt Bailey, 2019, op cit., p 308.

16 John O'Sullivan and De Witt Bailey independently conducted target shooting trials using Wogdon duelling pistols. Each fired at least 10 shots at a target at 12 paces and found that they consistently fired high on their target. Of course, these results cannot be considered conclusive, but they make sense based on the physics and do not encourage more exhaustive trials.

17 Sir Isaac Newton published his famous laws of motion in his 1687 manuscript *Principia Mathematica.* Originally published in Latin, an English translation was published in 1729 by Andrew Motte, so they were well known over 100 years before John Rigby presented his paper to the Royal Dublin Society.

[18] Benjamin Robins, *New Principles of Gunnery*, London, 1742. Robins was the first to explain that a lift force normal to the direction of a musket ball's flight was created by the spinning of the ball. This Robin's effect was explained in mathematical terms by the German scientist Heinrich Magnus in 1853 and is often referred to as the *Magnus effect* despite having been explained over a 100 years earlier by Robins. An excellent account of this can be found in David F Harding's *Small Arms of the East India Company 1660-1856, Vol. III, Ammunition and Performance*, Foresight Books, London 1999.

[19] Proc. of the Old Bailey t1782 065-1. Robert Wogdon was called as a witness in a murder trial and when asked did he have any particular way of loading, he answered "I put a piece of leather about the ball always".

[20] Based on a column published in the Northampton Mercury 23 July 1808.