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Thomas Harriot's ballistics and english renaissance warfare

Steven A. Walton, *University of Toronto*

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History of Education Project, School of Education,
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THOMAS HARRIOT'S BALLISTICS

by

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THOMAS HARRIOT'S BALLISTICS AND THE PATRONAGE OF MILITARY SCIENCE

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STEVEN A. WALTON

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Steven A. Walton's work centres on the military technology of the English Renaissance, particularly the knowledge and practices surrounding gunnery. He has also worked on a wide variety of projects, from the early medieval sword trade to modern bridge engineering. He recently received his doctorate from the Institute for the History and Philosophy of Science and Technology at the University of Toronto (Canada) and holds degrees in engineering from Cornell University and the California Institute of Technology. He is currently developing a database of images in the history of science and technology. He also continues to investigate the military interests of the Northumberland circle and is transcribing for possible publication by the Thomas Harriot Seminar an index of the Harriot papers compiled by the late Prof. John W. Shirley.

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Introduction[1]

What was Leonardo da Vinci's occupation? Was he an artist, as Vasari claimed, or a scientist, as the majority of his papers show him to have been? The enigmatic smile of the *Mona Lisa* tells most people that he was an artist. But we know that his surviving papers and his letter to Ludovico Sforza asking for employment show he probably spent three quarters or more of his time as an engineer and that what we would today consider fine art only occupied a small part of his time, probably only as a way to maintain a steady income.

Similarly, what do we consider Harriot? A scientist, certainly. But what kind? An Americanist might say he was an anthropologist and naturalist, based on his *Briefe and True Report.* Historians of science would say he was a physicist, citing his work in optics and collisions. A count of his remaining papers shows that he was above all apparently a pure mathematician.[2] On the other hand, you could look at the years he spent as a secretary, agent, and estate manager for Walter Ralegh and Henry Percy and conclude he was a particularly gifted and over-qualified amanuensis. It is not the case that he was any one particular thing, but that he was many things and played different roles throughout his career.[3]

Of interest here is the role Harriot played in the 1590s when he worked on science relating to great ordnance, or more generally, ballistics. The scientists among us hear "ballistics" and salivate, since to hear that word and a date in the 1590s suggests that Harriot's work predates that of Galileo, with all the stunning implications of such a chronology. Historians of technology, however, see that Harriot's importance lies not only in applied mathematics and the derivation of a parabolic trajectory (which he did do, and before Galileo), but also in understanding how technologies are perceived by and integrated into society. This, then, is the guiding question of this paper: why did Harriot take an interest in artillery, the new and most powerful technology of the sixteenth century? The timing is crucial, for while ballistics and gunnery came of age technologically in the sixteenth century, they did not come of age scientifically until the end of the seventeenth century, as A.R. Hall has shown so many years ago.[4] Before proceeding to why Harriot investigated artillery, we should first review the work Harriot actually did on great ordnance.

Harriot on Ballistics

Harriot's ballistic writings are not polished, nor at all complete, and only a few examples of full paragraphs of thought remain. The idea that Harriot codified his thoughts on the matter into a systematic treatise for Sir Walter Ralegh – as John W. Shirley claimed[5] – is, as far as can be determined, completely unsupported: no such work survives, and what does survive does not suggest that such a formal treatise was ever composed. The remaining notes in his manuscripts comprise about 100 folios, some double-sided, with a large proportion covered with working diagrams and calculations. To frustrate matters further, there is no guarantee that Harriot's papers exist in anything like their original order; in fact, some clearly are out of order.

Harriot left scattered statements of principle, followed by tables of calculated numbers, and references to various sources: chiefly, William Bourne, Luis Collado, and Alessandro Capobianco.[6] We would expect his approach to be non-Aristotelian, for elsewhere Harriot described Aristotle as "the devell that was bound for a thousand years and after let loose to deceave the people in the four quarters of the earth."[7] Yet by and large, the tenor and scope of Harriot's work on ballistics has been somewhat distorted in the two primary analyses of his contributions to the field. In accordance with the belief that Harriot was a pre-Galileian Galileo, most historians of science have looked for theory behind Harriot's graphs and numbers. That theory, however, is not readily forthcoming. What historians have failed to acknowledge is how fully empirical his approach was.

Both Shirley and Lohne[8] have concentrated on Harriot's statements of doctrine scattered throughout the papers, yet only about a third of his papers contain prose statements or any clear geometrical equations. Harriot's writings more realistically present a picture of a man taking notes, sketching, calculating, and noting small conclusions, but not really "proving" anything such as a geometrical law or an axiom of free-fall. In fact, the most complete section of his work is a table of numbers for angles from 0° to 90° in painstaking increments of 10′, but these turn out to be simply the

calculated sines of the angles, although they are accurate to four decimal places.[9] We do not find an equation for the motion of a cannonball once it leaves the muzzle; we do however find graphs that *look* like trajectories. These are more correctly interpreted as geometrical constructions designed to calculate ranges which only secondarily present a parabolic trajectory. It is also a different sort of parabolic trajectory than Galileo would develop about a decade later. Stephen Clucas has most recently reappraised Harriot's ballistic work and has emphasized that it was indeed a form of mathematization of the world: applying abstract (ideal) mathematical concepts to mundane (corrupt) behaviours.[10]

Harriot left a number of diagrams showing retarded parabolic paths, the feature which more than any other has caused modern analysts to see strikingly modern ideas in his work. Harriot's trajectories, however, were not designed to provide graphical *representations* of cannonballs' flight. Rather, they were designed to provide graphical *solutions* to the overall range of the cannonballs' flight. The two are, of course, intimately related, but the distinction is worth noting. Tudor gunnery manuals emphasized ranges, not trajectories, so it would be logical that Harriot would be working with ranges as his *ens*, not trajectories. Nevertheless – and here his modernity does shine – he conceived of the motion of cannonballs in order to determine their distances.

Harriot essentially enumerated two fundamental principles of projectile motion: "gravitational attraction" and air resistance. "Gravitational attraction" here lies in inverted commas as an equivalent of the medieval *gravitas*, or weight, which can be understood in Aristotelian, Galilean, or even Newtonian frameworks. Harriot, however, simply uses the word "gravity." Although he does not fully set out his framework as Galileo would a decade later, it is clear that to Harriot, *gravitas* was a vertical action. His explication of both gravity and air resistance can be seen in figure 1, when he writes:

> I say because of the bulletes gravity the crooked line is made. If the gravity be abstracted the motion would be only in the right line **ad**; & if the resistance of the ayre

or medium be abstracted, his motion would be infinitely onward.[11]

Harriot correctly notes that it is the bullet's gravity which pulls its line of flight away from a simple straight line, *ad*. He also notes that if indeed, there was no air resistance, the bullet would move laterally forever. There are, however, two things to notice about this seemingly modern view. The first is that he believes that the bullet, when fired at an angle of 45°, struck the ground perpendicularly (that is, the curved line *abc* is tangent to line *dce* at point *c*). A Galilean explanation would say that in the absence of air resistance, the angle of impact (∠*bca*) is equal to the angle of elevation (∠*dac*); that is, if shot at 45°, the bullet would land at 45°. And even if air resistance were factored in, the angle of impact would still not be 90°.

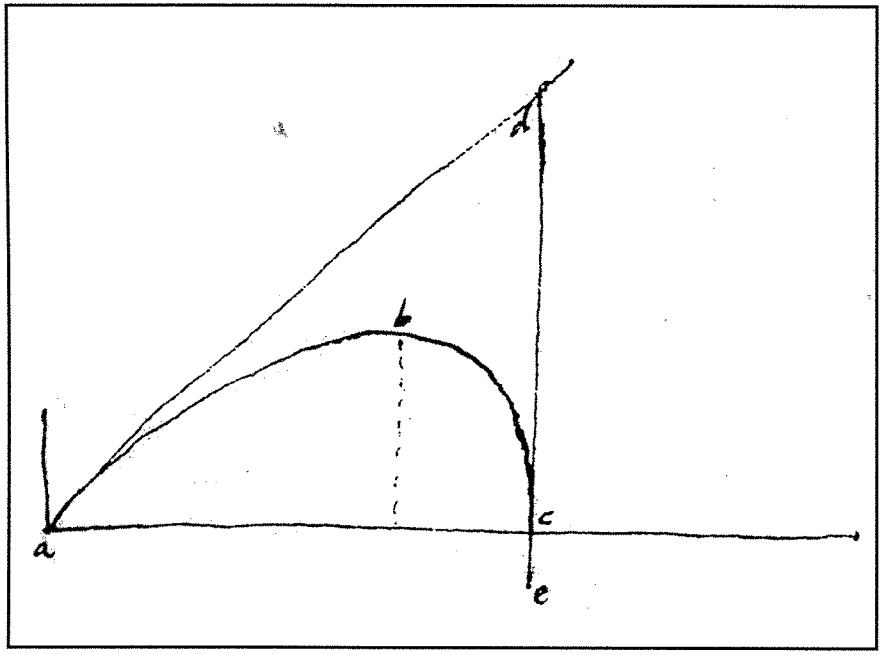

Figure 1: Thomas Harriot's Ballistic Trajectory
B.L. Add. MS 6789, fol. 30[r]

In making this claim, Harriot belies one of his primary assumptions: the forward momentum of the bullet is entirely exhausted in a finite distance. That is, the force imparted to the cannonball by the explosion of the gunpowder in the chamber is somehow "used up" in some finite amount of time. In this case, that distance is the same as the range *ac* and that somehow the bullet reaches the ground at the exact moment that its forward motion ceases. In other cases, however, we will see that this finite distance – which is here called the "momentum distance" – seems to be chosen quite arbitrarily.

In asserting that the angle of impact was 90°, Harriot appears to have been following the lead of Niccolo Tartaglia, although without acknowledgment. Tartaglia's *Nova Scientia* of 1537 is considered the first modern work on ballistics, even though its conclusions were rapidly dismissed, even by Tartaglia himself. He presented the path of a bullet as an initial straight line, followed by the arc of a circle (*abc* in figure 2).[12] Tartaglia merely states – but nowhere justifies the assumption – that this circle is centered on the horizon with its size defined such that it is tangent to the line of elevation (*ad*). Therefore, it must be perpendicular to the horizon at the point of impact (*i.e.*, tangent to *dc* at *c*). By *geometrical definition*, then, Tartaglia's angle of impact must be 90°. Although Harriot nowhere defines his theoretical assumptions[13] nor mentions Tartaglia by name, and although his trajectory is clearly not as rigorous as Tartaglia's at the outset, he eventually developed a more elaborate one than Tartaglia ever proposed. Tartaglia abandoned his rigorous geometrical trajectory in his later work, *Quesiti et Inventioni* (1546), opting instead for a more qualitative description of a bullet's trajectory. The *Quesiti* had been translated into English by Cyprian Lucar in 1588 and we know for certain that Harriot read William Bourne's *Arte of Shooting in Great Ordnance* (1578 and 1588), which also depends on Tartaglia's later scheme. Bourne's definition of trajectories, however, (chapter 9, pp. 38-41) is qualitative only and lacks the line of elevation (*ad* in fig. 1) as an important element of the construction, so although Bourne's and Harriot's curves are qualitatively similar, Harriot could not have used Bourne as his

immediate source for framing the ballistics problem. Instead, he maintained a rigorous geometrical approach based on the line of elevation, although his later developments clearly abandoned the notion of a 90° impact angle in favor of the preservation of other geometric relations.

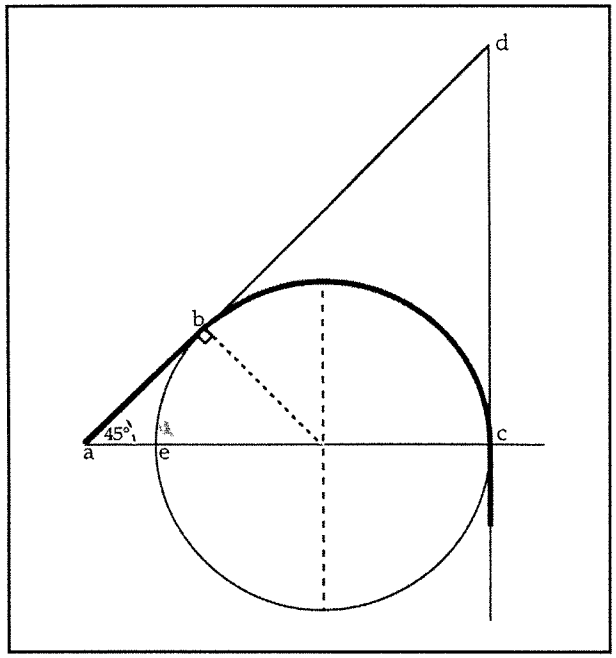

Figure 2: Niccolo Tartaglia's Trajectory

Ultimately, Harriot developed a retarded parabolic trajectory by adding to his axiom of *gravitas* one of air resistance. He divided the flight of the cannonball into an integral number of intervals and allowed it to fall vertically from the line of elevation by a certain amount in each interval. But rather than describing a horizontal motion of equal amounts in each time interval (as it would have been "if the resistance of the ayre or medium be abstracted"), he embodied his concept of air resistance by diminishing the horizontal motions in each succeeding interval up to the momentum distance (the bottom

right corner marked O in fig. 3); that is, the width of each interval shrinks from left to right on the graph. Ultimately, he clearly experimented with a number of numerical series, as he noted in the top left corner of the same diagram. Whether these series were for the diminishing intervals for his air resistance or for the amount of fall from the line of elevation, Harriot never specified. He did eventually settle upon a correct square law of fall, though.

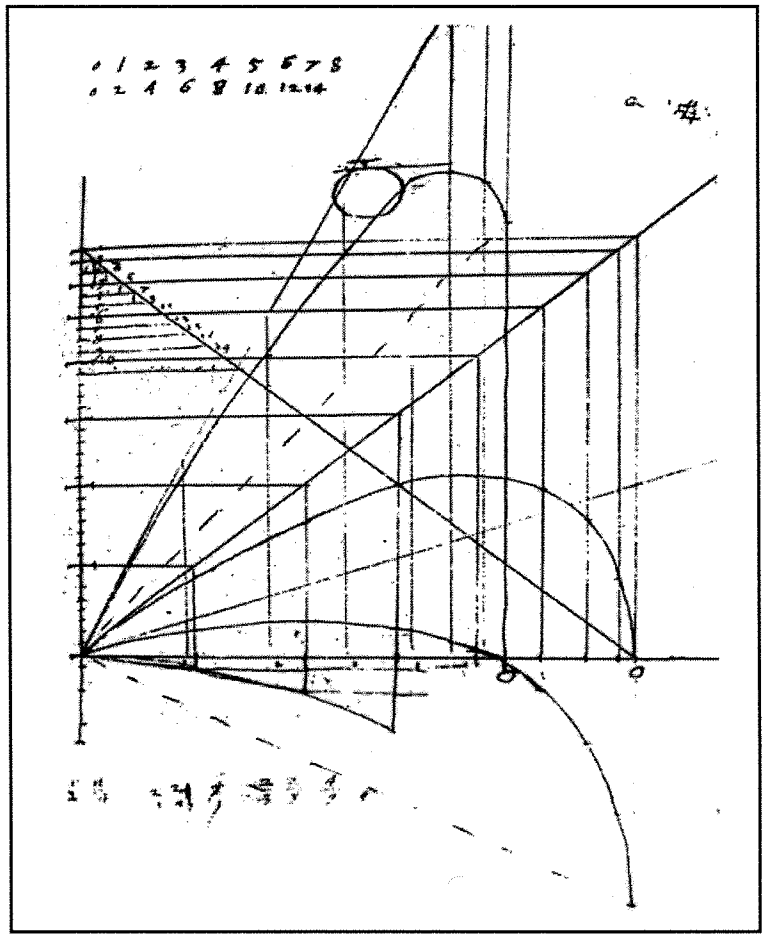

Figure 3: Harriot's Trajectories (Scratch)
B.L. Add. MS 6789, fol. 4r

While Harriot did not fully explain how he arrived at this construction, he did provide one page which formulates his reasoning.[14] The page is entitled "For oblique motions", a title which appears on numerous pages where he attempted to work out algebraic proof for his contention. Next to a schematic diagram (figure 4A), he writes:

> To finde where a motion at random will cut the horizon [*i.e.* the range], suppose it cut in the poynt ι & let ιδ be a perpendiculer. The time of δι is æquall to the time of δα; for γθ is æquall to γα & βη to βα, &c.

Having established that the motion along the line of elevation is independent of the vertical motion, he then defines his line of questioning: "Now the space of αε is geuen & the time: the time of δα or δι is required." In order to prove this, he set out another figure (fig. 4B) which defined relative velocities. The problem is to draw the line *bc* such that the ratio of areas of *bfnm* to *bac* is equal to the proportion αδ to δι. The solution apparently does not exist in his papers or is scattered across many pages, but he clearly tried to solve it by recourse to medieval geometric ratio theory from the Mertonian school.[15]

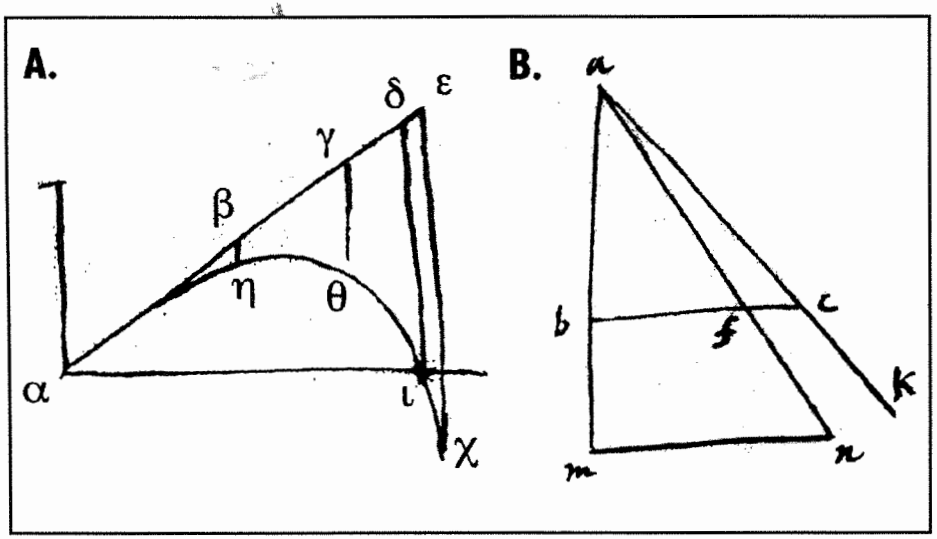

Figure 4: Thomas Harriot's Trajectory Diagrams
B.L. Add. MS 6789, fol. 26

An example of Harriot's polished ballistics construction is shown in figure 5: a momentum distance (*ah*) is defined; a line of elevation is extended up to it (*ag*); the line of elevation is divided into a diminishing series (*ab>bc>...>fg*), and then the trajectory line is found by "dropping" the bullet from those points. This method of construction also has the byproduct of abandoning the 90° impact angle. Harriot also realized that his construction was equivalent to a tilted parabola, as shown by the auxiliary construction (*aijk*) perpendicular to the line of elevation and defined by the points where the trajectory crosses the vertical divisions. With this construction, the trajectory may be conceptualized as a parabola tilted by half the complement to the elevation angle (*i.e.* [90-α] /2), as the dotted lines indicate. Whether Harriot came to realize that his method generated a parabola or had believed that the trajectory should be a parabola is not immediately clear.[16] Harriot spent a great deal of time in explicating the geometry of conic sections, including parabolas, independent of his work on ballistics, and this may either precede or antecede his ballistic work. It seems clear that Harriot's (non-Galilean) parabolic trajectories were a logical outgrowth of his geometrical reasoning, but not necessarily a product of theoretical reasoning about motion. Ultimately, though, this rigorous geometrical method based upon the tilted parabola led him astray. In another formal diagram of these parabolas labeled "*maximu*[*m*]" he calculated 27°55′ as the elevation providing the maximum range, and this is confirmed by his tabulated values elsewhere in his manuscripts.[17] Thus, he ended up with the "wrong" answer for the elevation giving the maximum range of a projectile, rather than the correct value of about 42° when air resistance is taken into consideration. Thus it seems clear that Harriot did not conceive of his ballistic trajectories and range calculations in terms of a "retarding force depending on the initial velocity," as Lohne claimed,[18] but rather as a geometrical construct which facilitated his analysis. His ballistic considerations did not exist in a purely theoretical space. Rather, that his impetus and data were entirely practical in their origin becomes clear when one looks at his numerical, as compared to graphical, investigations.

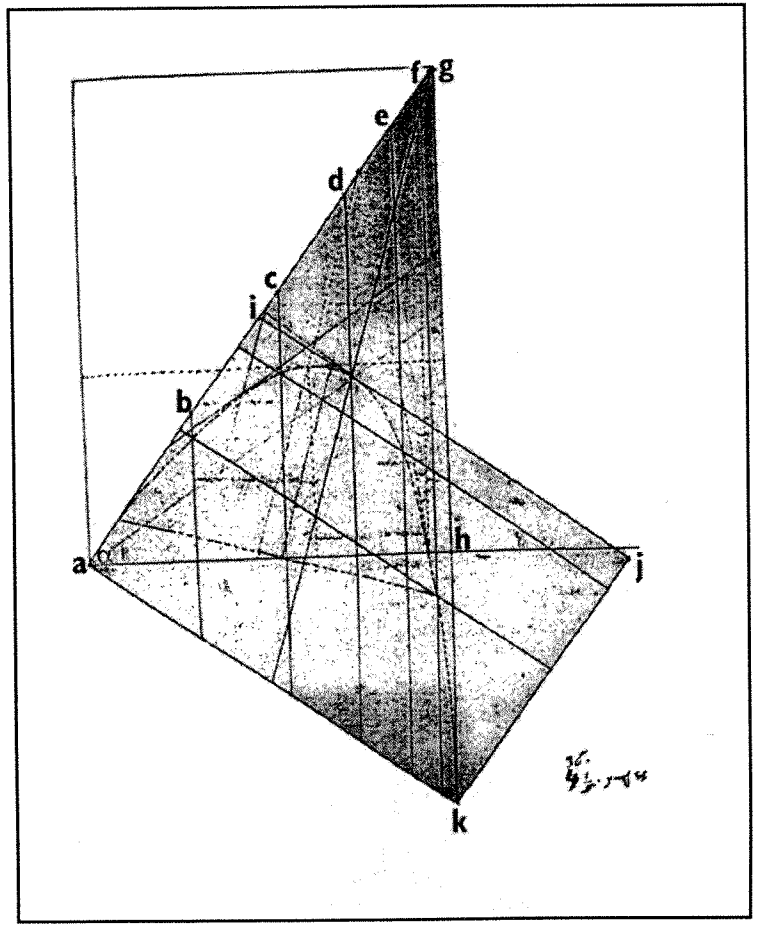

Figure 5: Harriot's Trajectories (Polished)
B.L. Add. MS 6789 fol.64[r]

Harriot left various but numerous tables of numbers scattered throughout his ballistics papers. In one place he compared values for ranges vs. angle of elevation from Alessandro Capobianco's *Corona e Palma Militare di Artiglieria*.[19] Harriot tried to reduce his ranges to an arithmetical series: for every increase in elevation of

7.5°, the range increases by certain ratio relative to the point-blank range at 0° elevation. Although Capobianco had enumerated these same ratios in his text, Harriot manipulated them into an integer series which he thought he could use to develop a convenient rule for ranges. Realizing that the series was diminishing, and in conjunction with his assumption that there was a finite momentum distance, he therefore assumed the series was an asymptotic series. Thus, on a number of folios he tried various fractional series that approach a unit value in a unit time (*i.e.* the proceed from 0 to 1 in the time of 1 unit, such as 1/2, 3/4, 7/8, 15/16,...), although he never clearly chose one.[20]

In another place Harriot looked to Luis Collado's *Pratica Manuale di Arteglieria* (or perhaps his later *Platica Manuale de Artilleria*) and tried another method: first differences. He noted the angles of elevations, in degrees and "points" and then the ranges Collado recorded for 1-3 shots at that elevation. Harriot then noted the difference between the ranges between two elevations (again at 7.5° increments). Clearly, when the asymptotic integer series for absolute ranges yielded no clear results, he then tried to see if the *range differences* between each successive value might suggest some pattern to him. Evidently it didn't, for he came to no clear conclusion in this case either.

In trying to discover how these series behaved, Harriot looked to two neo-Scholastic authorities: the early sixteenth century Portuguese mathematician Alvarus Thomaz, whose *Liber de triplici motu* discussed the work of Richard Swineshead,[21] and Bernardo Torni, a Florentine professor of medicine at Pisa, and his work, *Caputulum de motu locali Heytisberi*, commenting on the work of William Heytsbury.[22] Harriot, far from Lohne's suggestion of doing purely "modern" (that is, Galilean) science, clearly used the medieval *Calculatores* tradition of numerical ratio theory in local motion.

Thus it appears that Harriot's ballistic work is not primarily concerned with constructing the geometrical trajectories of cannonballs. Instead, I argue that he used geometry as a means to an end to predict ranges, an entirely different programme. He was not

interested in trajectories or laws of motion, as Galileo, Torricelli, and Newton would later be. His aims were practical, even if he usually abstracted this practice to a theoretical level for solutions that appear "wrong" to modern analysis (as some are patently incorrect). But at the end of the sixteenth century his methodology would have been approved by most mathematicians. More importantly, the goal would have been of great utility to military men, had it yielded any usable results.

The Inspiration for Harriot's Ballistics

More interesting (and tractable) than *what* Harriot was doing with ballistics, is *why* he was doing it in the first place. John Shirley concluded that Harriot was asked by Sir Walter Ralegh to do these investigations and present him with a formal "report" in the same way we know that Harriot wrote the navigation manual, *Articon*, for Ralegh in the 1580s. Shirley therefore dates Harriot's ballistics to the early 1590s, making them part of the preparation for Ralegh's first Guyana voyage of 1594. I propose a different explanation which I believe makes more sense, given the place of artillery in English warfare and military culture in the last decade of the sixteenth century.

First, consider where Harriot might have initially encountered the study of gunpowder artillery. As far as we know, Harriot's first encounter with military matters occurred on his voyage to Virginia in 1585-86. Ralegh's expedition was a voyage of colonization, but in the sixteenth century, and indeed well into the eighteenth, colonial voyages were by definition also military voyages. Sir Richard Grenville and his lieutenant Sir Ralph Lane commanded the Second Virginia Voyage – Grenville as a career diplomat who had probably never been to sea before, but Lane as an experienced seaman, soldier,

pirate/privateer, and administrator. Their personalities immediately clashed, probably because Lane was too headstrong to be merely the Lieutenant, and Grenville was not nearly experienced enough to be the commander of a colonization venture. Grenville left the colony after only 2 months, leaving Lane in charge. Lane then moved the site from Wococon Island to Roanoke Island, specifically because he considered Wococon poorly defensible.

Just before sailing for Virginia, Lane had been sent to Ireland to build fortifications (1582-3) and was later in charge of coastal defences during the Armada scare. There is no documented influence of Lane on Harriot in the area of the military sciences, but Lane's career and interests could not have helped but influence the young, eager, inquisitive Harriot – whose job it was, after all, to be inquisitive. Lane was clearly impressed by Harriot and wrote a warm preface in Harriot's *Briefe and True Report* upon their return, referring to him as "an Actor in the colony, or a man no lesse for his honesty then learning commendable."[23] But although Lane was very clearly interested in fortification, the other side of the coin – gunnery – seems to have been secondary for him, and indeed for the entire Voyage. An anonymous 4-page planning note, entitled "For Master Rauleys Viage"[24] – possibly written by Sir John Smythe, Sir Roger Williams, or Thomas Digges – prescribed a force of 800 soldiers, 400 harquebusiers, 100 sword and buckler men, 150 longbows, 100 pikes and 50 half-pikes. Notably, there is no provision for large ordnance. The author does, however, detail the construction of fortifications, and specified that "Euery bulwarke shall have bye It a cavalir to bet the feald, or tow wer better."[25] The list of specialized personnel includes officers, a physician, geographer, painter, apothecary, surgeon, metallurgist ("alcamist"), mineralogist ("lapidary"), and an "Ingenyr", but makes no mention of specially trained gunners. They could, of course, have been provided from the standard complement of crew from the ships, from which the guns for the fort would have come, but their absence in the document suggests that they were not considered all that important.

Artistic representations of this and other contemporary voyages also suggest that cannon were not a high priority for the

settlers. John White's watercolours have a curious lack of heavy ordnance, despite their immaculate detail of everything else. When one compares, for example, White's drawings of Lane's forts in Puerto Rico (figure 6) with contemporary Spanish diagrams of St. Augustine or Saint Elena (figure 7),[26] the paucity of English ordnance is quite clear. In White's image, Lane's revetments are quite clearly drawn to scale and major features within the encampment are clear. But White does not record any large artillery in the enclosure, despite the inclusion of the *Tiger* firing its cannon fore and aft while at anchor off shore. In Spanish images of St. Augustine in Florida and Saint Elena, on what is now Paris Island, South Carolina, respectively 11 and 7 pieces of large ordnance are shown (along with 11 large wall-mounted matchlock weapons), despite the St. Augustine fort being apparently slightly smaller than Lane's first encampment and the fort at Saint Elena being roughly the same size as Lane's "salt-fort". The Spanish clearly privileged artillery more than the English in their voyages, for when Drake took St. John's fort at St. Augustine in 1586, he found "thirteene or fourteene great peeces of brasse ordinance" upon what were apparently substantially-built artillery platforms.[27] Admittedly, a distinctly different rhetoric is at work in the Spanish illustrations, one of aggressive demonstration of defensive capability (although this level of armament is actually what one would expect from a colonizing effort).[28] White, on the other hand, drew the native flora, fauna, and inhabitants, as well as the fortification outlines, with impeccable accuracy (especially for an Elizabethan artist) and yet failed to show any cannon. We should not conclude, therefore, that White consciously omitted artillery for some hidden agenda,[29] but rather was likely recording the salient features he saw while he was there. The Second Virginia Voyage, then, must have had little ordnance to spare for shore defence.

The colonists would certainly have had some small cannon, but generally it would appear that the voyage – and note that it was *Ralegh's* voyage – was anything but bursting with artillery. Nevertheless, Harriot would have been exposed to ordnance upon the ship, and Lane was an experienced veteran of various military

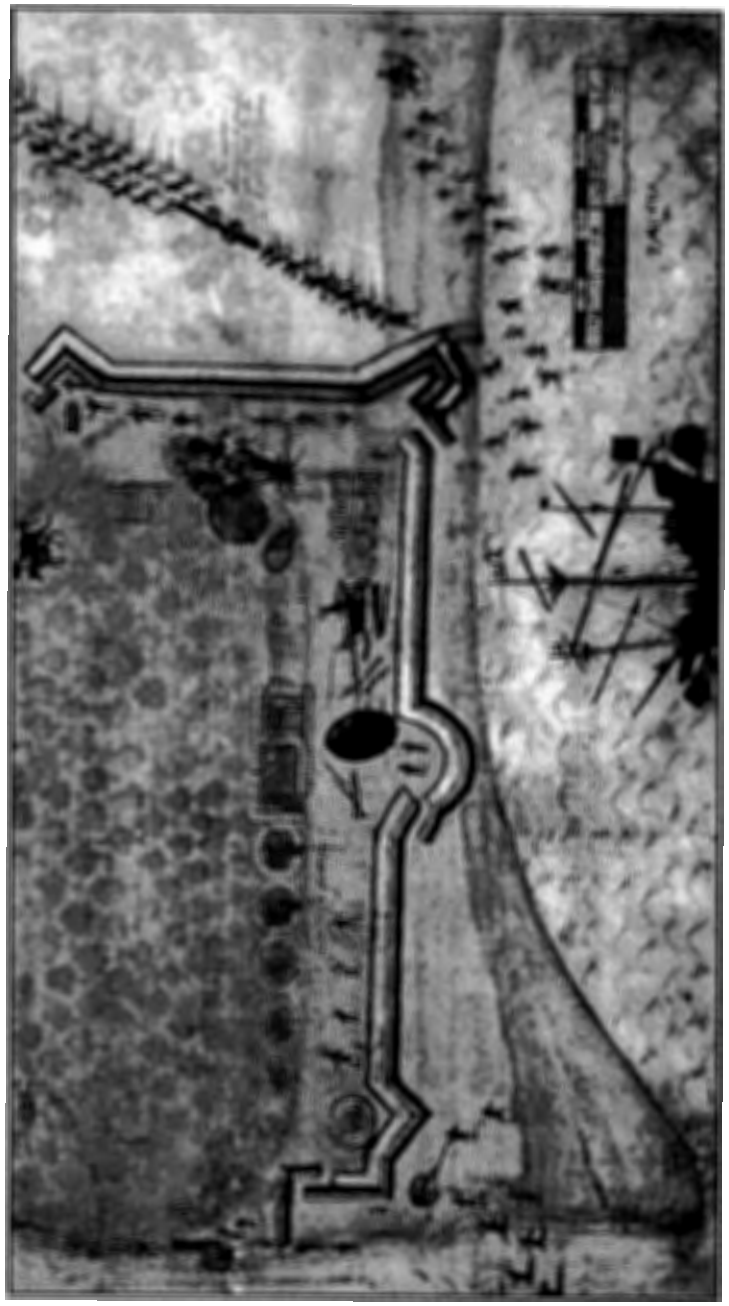

Figure 6: Ralph Lane's Fort in Puerto Rico from P.Hulton, *America 1585: the complete drawings of John White* (Raleigh-Durham, NC, 1984), plate 3 and 4

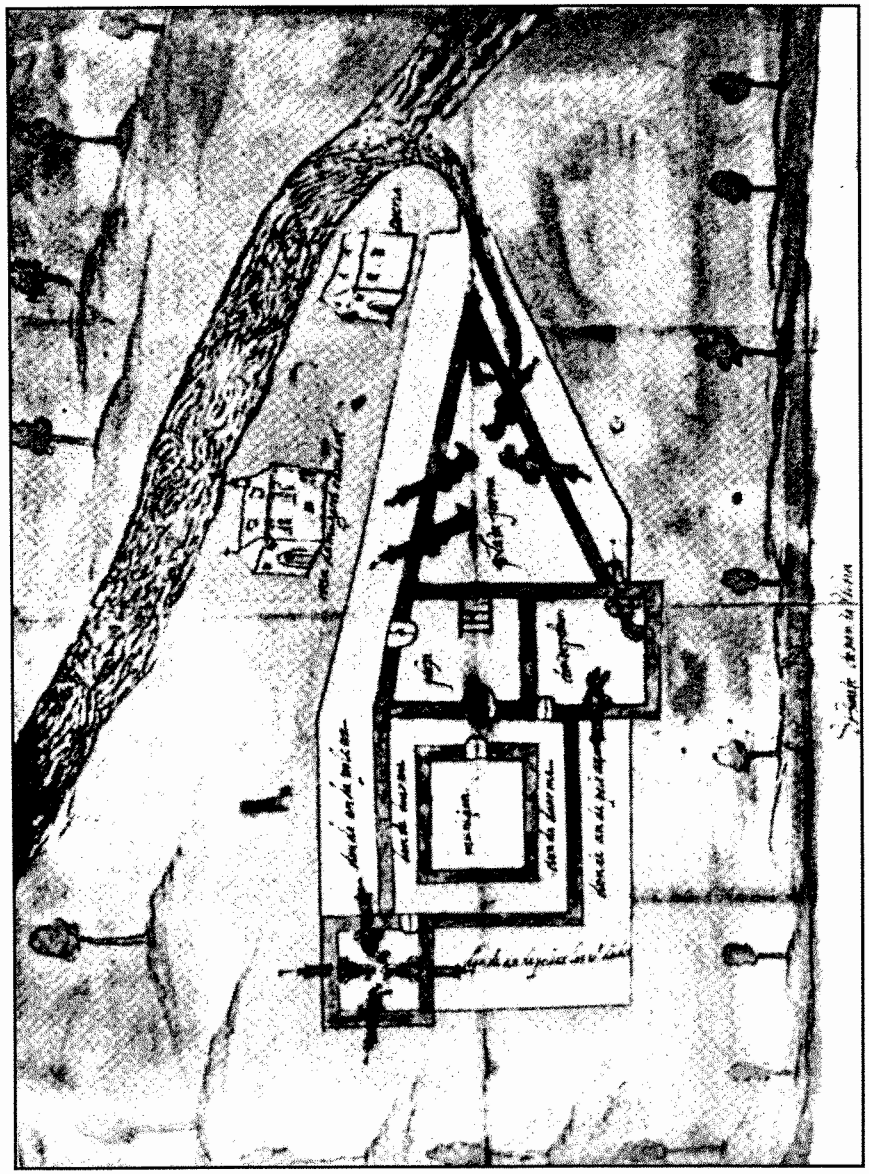

Figure 7: Spanish Fort at St. Elena (now South Carolina) from P.E. Hoffman, *Spain and the Roanoke Voyages* (Raleigh-Durham, NC, 1987), p.14.

engagements who would undoubtedly have extolled the virtues of great ordnance (that is, the *rhetoric* of ordnance). After returning from America, Harriot's three or four years in Ireland as a colonist and as Ralegh's estate manager at Molanna Abbey are shrouded in mystery, but there is little reason to think that he might have worked on ballistics while there. Numerous of the books he refers to in his ballistic notes were yet to be published and although Ralegh was a soldier of the crown, coping with endemic insurrections throughout Elizabeth's reign, at this time there was little activity in the south of Ireland. Additionally, artillery was not terribly useful in Irish warfare anyway.[30]

In 1591 Harriot moved into Ralegh's London home, Durham House, where he continued as his personal secretary, as well as refining his own scientific experiments. The 1590s, the decade in which Harriot apparently did most of his work on ballistics, were a time of transition. Ralegh's colonization efforts in the Americas had largely failed and his first Guyana voyage of 1596 would be a failure as well (his second Guyana voyage in 1618 would also bankrupt him, rob him of his only son, and lead to his death warrant under James I). The Queen was unhappy with the lack of profit from his voyages, and Ralegh increasingly fell out of favour. Saddled with accusations of atheism, favouritism, and treason, Ralegh removed himself to Sherborne Castle, Dorset in 1592 to try to create a new life as country gentry for himself, his wife, and young son. Harriot remained his agent in London, but he also took this opportunity to come under the patronage of Henry Percy, ninth Earl of Northumberland, whose fondness for mathematicians was common knowledge.

Before moving to Percy, however, consider another of Harriot's manuscripts for a moment. In one place, Harriot wrote himself a "laundry list" of items in the corner of a page which reads:

Memorandum
The properties of the four elements
Master Allens Book
Varro
My notes of ordinance
Proclus de moto.

Harriot clearly jotted down a number of things that he needed to remember to do, or look into, in the near future. John Shirley italicized the fourth item and concluded that "what this undoubtedly means is that Sir Walter Ralegh ... has asked Harriot for the conclusions of his study on the improvement of gunnery, possibly about the time he was preparing for his voyage to Guyana where he expected to meet the Spanish," that is, in 1594 or 1595.[31] This final report with its accompanying tables and diagrams would then have been lost with the rest of Ralegh's papers after his imprisonment in 1603.

The first item on the list, "the properties of the four elements" suggests that at the time Harriot was interested in Aristotelian matter theory, which Shirley noted peaked in May and June, 1599.[32]

The second item, "Master Allens Book," is clearly a reference to a book belonging to his Oxford teacher, Thomas Allen, which Harriot had either borrowed or wanted to borrow, but given the discussion above, it might well have been Thomaz's or Torni's books. In his career at Oxford, about which we know too little, Harriot seems to have primarily attached himself to Allen, a scholar in residence at Gloucester Hall who was primarily known to his contemporaries as a mathematician. Allen would of course not have been firing cannon, and probably would not have even thought much about them, but it is he who Harriot would probably have turned to for questions concerning the physics (or more correctly, the mathematics) of motion when he did consider cannonballs.

"Varro" would seem to be a reference to the Roman historian and agronomist (and, incidentally, military commander) Marcus Trentino Varro (116-27BC). However, neither his *De re rustica* on farming and husbandry or his *De lingua latina* on Latin etymology and syntax would seem to relate directly to scientific matters as Harriot practised them, so perhaps the note could have been triggered by needing to borrow or return a different book to Allen or someone else. More likely, however, is that "Varro" is a misspelling of "Verro", referring to *Phisicorum Libri X* by Sebastian Verro, a Jesuit from Freiburg, Switzerland, which had been simultaneously published in Basel and London in 1590. Additionally, Henry Percy

owned a copy of Verro's *Physicorum*, placing the likely composition of this list within a period when Harriot was within the Northumberland circle.It is a summary of modified Aristotelian classification schemes and although there is little that would be of use to Harriot in his ballistic investigations, that the book is a primer of Aristotelianism is relevant given the last item on the list.

Skipping the note on ordnance for now, "Proclus de moto" unambiguously refers to a work by the fifth-century Byzantine philosopher and theologian named Proclus, entitled the *Elements of Physics*. In the Middle Ages and Renaissance, however, this work was frequently known as *de motu* – "On Motion," and it summarizes and mathematizes Aristotle's *Physics*, Books VI and VII and *De Cælo*, Book I. It boiled down the thought of Aristotle into something, as the introduction to a 1545 edition put it, "whereby one may in a few days know what otherwise would take many months to learn from Aristotle."[33] *De motu* would have provided little new or stunning information to Harriot, merely confirming Aristotelian ideas of motion with no "modern" concepts of impetus or air resistance, but its treatment of motion as relative lengths of different line segments would have been exactly what Harriot was looking for in his section "on oblique motions." It would also have been entirely complementary to the analyses of Thomaz and Torni, although he did not note Proclus as a source.

By the mid-1590s, Shirley has shown that Harriot had begun to act more like a free-agent than an employee of any one patron. Placing a contemporary work on motion immediately after one on ordnance (and possibly in the same list as a work on motion from his teacher, and a third Aristotelian work) suggests that there is indeed a link between the items on the list. And it also suggests that the "book of ordnance" was more thoroughly Aristotelian than has been previously admitted.

In the 1590s, then, we have a choice between Sir Walter Ralegh and Henry Percy, Ninth Earl of Northumberland as patrons who might have encouraged Harriot's research on the ballistics of great ordnance. And recall that throughout the 1590s, Harriot worked for both of them, in roughly equal capacity; there was no

"pink-slip" day with Ralegh and "hiring" with Percy. By now, it should be obvious I will argue that Harriot's interest in ballistics came from Percy rather than Ralegh, but first consider why it was unlikely to have come from Ralegh.

Sir Walter Ralegh was a soldier, explorer, poet, author, courtier, and eventually prisoner, and he flitted about the Elizabethan court as a favoured minion, procuring for himself a living quite above his station (being the second son of a country gentleman's third marriage). Ralegh hired Harriot fresh from Oxford to tutor him in mathematics and to undertake practical investigations that might profit Ralegh's various endeavours, such as tables of longitude and quick-reference works on navigation for the training of his crews, possibly ideas on shipbuilding,[34] and of course, a useful handbook on ballistics, or so they say.

There are a number of telling remarks in Ralegh's work, however, that suggest he would not have bothered to turn to Harriot or anyone else for help on ballistics. Before his imprisonment in 1603, Ralegh's scientific leanings tended to be more practical than theoretical. When he went to Harriot he asked for specific advice on specific questions to help him further his goals. Ballistics was not practical and did not serve any of his needs in the 1590s. In his 1598 *Notes on the Royal Navy*, Ralegh is at great pains to complain of the over-gunning of ships. During the "Islands Voyage" of 1597, he noted that there was a "huge & excessive proportion of Artillery, wherof if many had not bene stroken down into holt [*i.e.*, stored in the hold] ... , diverse of the Shipps with the host & charge therof, would have foundered in the Sea," a complaint he would repeat in other works.[35] Ralegh was complaining of his flagship, the *War Spite*, which although new was not built to take the large number of guns assigned her. If Ralegh had been a strong supporter of artillery, he might have complained about the ship rather than the ordnance.

Although he did note that the "Perfection of our ordeinance & Gunners" was a goal to be sought (along with all the other dreams of a naval captain such as "aboundance & reddines of our victuallinge" and "goodness of our havens & harboroughes"), he nevertheless complained that there was an over-reliance on shipboard artillery.[36]

While he knew it would be foolishness to abandon great ordnance, he argued strenuously that less is more. Citing the famous 1545 sinking of the *Mary Rose*, Ralegh argued that ordnance should never be mounted lower than four feet above the waterline and that small, nimble and lightly-armed ships were more useful than heavily-gunned ones.[37] Ultimately, he says that "It were also very behoveful that his majesty's ships were not so over-pestered and clogged with great ordnance as they are." The forty pieces that common wisdom places on board are even more than the "twenty or thirty good brass pieces [that are] a royal battery for a prince to bring before any town or strong fortress."[38] Not only did he claim that a reduction in number would save powder, shot, and stress on the ships, it would also make them more agile for the broadsides encounters which were the only sort of encounter fought to any effect anyway.

Ralegh, then, discounted offensive artillery at sea in his writings, but he also seems to have discounted its effectiveness against him in his personal experience. During a rash move (against Essex's orders) on the "Islands Voyage" of 1597, Ralegh landed on the island of Fayal, intending to take the town. Quite to the amazement of his men, he advanced in the face of "thick" defensive fire, urging them on repeatedly. As reported by Sir Arthur Gorges, Ralegh's brother-in-law and captain of the *War Spite*, "whilst with their great ordnance and musketry [we] were very shrewdly pelted," Ralegh continued the assault on Fayal town.[39] Despite various wounds from small arms fire and even as "two of [their] train had their heads stricken clean from their shoulders" by "the great artillery which did beat upon the old walls amongst the which [they] were to pass," Ralegh succeeded in taking the fort. While allowing for a certain amount of bravado in the actions as well as the reporting, it is clear that Ralegh was not overly concerned about the effectiveness of the Spaniards' ordnance. He echoed as much in his relation of the Cadiz expedition the year before: he noted that as he sailed into Cadiz harbor, the forts of St. Philip and Puntal "terrified us not, ... though it played upon us with four demi-cannons within point blank, from 6 in the morning till 12 at noon."[40] And indeed, other Elizabethan naval commanders echoed Ralegh's attitude: Monson

opined, "he that shooteth far off at a ship has as good not shot at all."[41] In short, then, there would have been no compelling need for Ralegh to have sought Harriot's advice on degree-by-degree shooting. And Ralegh always came to Harriot out of need, not out of interest.

Turning to Harriot's other patron, Henry Percy, we find Shirley aptly describing him as follows:

> Percy had followed the pattern expected of the heir in a wealthy and noble family. He had been broadly educated at home under private tutors ..., and had mastered not only the sports and skills demanded of Elizabethan gentlemen, but also the extremely sophisticated education in languages and humanistic studies that had come into vogue with the Renaissance.[42]

For much of his life, Percy was an avid inquirer into new and potentially dangerous ideas, including questions of metaphysics. It was into this household of a patron of the arts and friend of Spenser, Shakespeare, and Jonson as well as scientific dilettante with deep pockets to which Harriot would gravitate in the 1590s.

Percy's studies ranged from architecture, gardening, and political science to geography and military science, and much of his time was spent in alchemical, astrological, and astronomical pursuits. By the end of his life, Henry Percy's library contained nearly two thousand volumes including a sizable collection of works on military matters.[43] He annotated a number of books, including general military works as well as specific works on cavalry, leadership, and fortification.[44] Nor did he confine himself to printed editions, for in 1600 he commissioned a manuscript translation of Simon Stevin's work on fortification, *De Sterctenbouwing*, originally printed in Leiden in 1594.[45] It is instructive to note, however, that of the annotated military works in his library which Batho noted, all were printed in 1602 or earlier. This date's significance will become clear when we consider Percy's "public" career.

Percy never served the crown in any official military capacity,

but in 1587 Percy was sent as a volunteer with Leicester to the Low Countries. He must not have remained there long, however, for he was back in England during the Armada scare. Generally, he preferred to donate large sums of money for others to go and fight in his stead,[46] although in 1593 he became a Knight of the Garter. Percy punctuated the day by commissioning a commemorative poem from George Peele (interestingly, apparently also one of Harriot's friends). The poem, "The Honour of the Garter," records the deeds of Percy and the other inductees and those deeds recorded for Percy are peculiarly non-military in nature:

> Thrice-noble earl...
> That artisans and scholars dost embrace,
> That admirable mathematical skill,
> Familiar with the star and zodiac,
> To whom the heaven lies open as her book;
> By whose directions undeceivable,
> Leaving our schoolmen's vulgar trodden paths,
> And following the ancient reverend steps
> Of Trismegistus and Pythagoras,
> Through uncouth ways and unaccessible,
> Dost pass into the spacious pleasant fields
> Of divine science and philosophy. (ll. 2, 6, 8-17)[47]

By comparison, Lord Borough, who later held the decidedly military post of Lord Deputy of Ireland, was noted for his military and political abilities in the same poem:

> Borough, brought up in learning and in arms,
> Patron of music and chivalry,
> Brandish thy sword in right, and spend thy wit
> In commonwealth affairs (ll. 385-88)

Percy, on the other hand, would later receive an honorary M.A. from Oxford as "a great encourager of learning and learned men, especially mathematicians."[48]

Percy nevertheless made a second attempt at a military career in 1600/01. At that time he and six other nobles outfitted themselves

lavishly and embarked for the Low Countries to lend their support for Elizabeth's efforts against the Duke of Parma, the Earl himself serving as an official envoy for Elizabeth to the States General. He joined together with the Earl of Rutland, Lord Monteagle, Lord Grey, Lord Cobham, and Sir Walter Ralegh and set out to join in the fighting at Ostend in June. They outfitted themselves magnificently, dressing more for a court pageant than the reality of a siege in the Low Countries. Upon their arrival at Ostend, which was shortly to see the worst and most prolonged siege of the wars in which the English participated, the commander of Ostend, Sir Francis Vere, made it quite clear how little he appreciated the assistance of these "popinjays."[49] Since they were not royal envoys, but rather "spoilt children of fortune" volunteering for active service (the reality of which they were completely ignorant), Vere suggested that "the gold so lavishly expended upon their backs might have been used to greater advantage in furnishing sorely needed recruits for the service"[50] and that "their room was preferred to their company."[51] The two Earls, three Lords and Sir Walter did not enjoy being reprimanded by their social inferior, even if he did hail from a noble family with direct lineage to William the Conqueror's expedition.

Vere was known for being a hard but not unreasonable commander, and the year before had refused a number of captains he felt unfit for service that the Earl of Essex had sent over to his command. He had also rather quickly dismissed one of Percy's "inefficient... creatures," a Captain Lower.[52] But even James I took off his hat in deference to Vere's military skill.[53] For his part, Vere apparently overcompensated in the situation and treated these volunteers perhaps more sternly than he needed to, but the volunteers were also less than interested in the gritty details of Renaissance warfare. With the exception of Ralegh (and perhaps Lord Grey), they were only students of military science, interested in learning all the new and important theories of war developing on the Continent. They were not, however, hardened soldiers.

Shortly after the group's less than cordial welcome, Northumberland posed a "certain question of strategy" to Vere. Vere, uninterested in the higher – and from his point of view irrelevant –

points of military theory, returned a "surly and even contemptuous answer." Percy did not appreciate the brusque treatment, and made his displeasure known. In September, 1601, the "popinjay" party finally got the message that their presence was not appreciated, and departed from Ostend. Rumours of the incident made it back to London, for in July John Chamberlain wrote to Dudley Carleton that he did not "easilie beleve... a flieng report... that at a banquet in the Low Countries the erle of Northumberland had stroken [Vere]."[54] While none of the members ever publicly slandered Vere for his actions – after all, he was within his rights as the commander of the English forces and he never publicly disgraced any of them – neither did they forget his slight.

Upon Vere's return to London in 1602 after his until-then successful defence of Ostend, Percy challenged Vere to "give satisfaction" for his rude behaviour to a superior. As Chamberlain reported the event:

> The erle of Northumberland sent Cap: [Edmund] Whitelock with a letter to Sir Fra: Vere, [saying] he had wrongde him in such and such points, and therefore desired to be satisfied: wishing him to take his horse and bring one with him, as he of his honor wold do the like, and meet him where he shold apoint, willing him to send his determination yea or no by word of mouth and not by writing. Sir Fra: Vere wrote an aunswer and sent yt by Captain Ogle, which the erle refued to receve. The contents was that though he assured himself he could satisfie him, yet he would not go about to satisfie any man that has his sword in his hand, but yf they might meet in peacable manner before any persons of the state whom his Lordship wold choose, he wold geve him reasonable satisfaction, otherwise let him take what course he thought best.[55]

The Dutch ambassador took it upon himself to notify the Queen of these developments, and she prohibited Northumberland from taking any action against Vere. Public pamphlets from both parties

followed: Northumberland published a declaration against Vere calling him "a knave, a coward, and a buffoon" in English, French, and Italian; Vere responded in form, citing the Queen's protection and calling Percy "a liar and a base minded man", although he one-upped the Earl by adding Spanish to the languages of his reply. There the affair rested when Vere went back to defend Ostend, but the whole matter festered for over two years. After James ascended the throne, Percy struck Vere in front of the King and was confined to Lambeth Palace for a time. But after 1602 or 1603, Percy never again showed any interest or aptitude in military matters.

Conclusions

From the foregoing analysis, a number of conclusions can be drawn. First, the impetus for Harriot's work on ballistics likely came not from Sir Walter Ralegh, but from the Ninth Earl of Northumberland. From about 1587 to 1602, Percy tried occasionally to find a place for himself in Elizabeth's military establishment. He had no real experience or training, but the proper function of a wealthy nobleman was to defend his country, and as Percy interpreted it, this meant outfitting ships, hiring recruits, and leading musters.[56] The unmonied elite found their place in the thick of battle – witness Sir Francis Vere or Lord Mountjoy – while the likes of Northumberland contented themselves with a passing knowledge of the newest and best military theories. Percy also seems to have seen his role as more chivalrous than the warfare of the day would allow. Ralegh, on the other hand was a sea captain and explorer. He was quite familiar with how to run a military engagement and did so successfully on a number of occasions. But in none of these occasions did he show any interest in developing the role of artillery for offence or defence. Ralegh hired Harriot to teach him what he could use and did not know – navigation in this case – not what would be of little use to him. Percy would use Harriot to instruct him on unknowns, and here

those unknowns would have been artillery and ballistics. This seems much more in accordance with his scientific and mathematical leanings.

G.R. Batho notes that outside his well known literary attempts such as *Advices to his Son* and a few other minor period-pieces, Percy's only attempt at composition was an unfinished work on the art of war.[57] As it turns out, that work has very little to do with gunnery, but therein lies its importance. The work exhaustively covers virtually every other branch of land warfare, and demonstrates the intense energy Percy devoted to understanding the military science of the day. Percy's presumed request to Harriot for information on gunnery can be made no more clear than by a note he made in this manuscript in a section on "The Marshall's instruments in the field", that is, his officers. It reads:

> Note that the Gen: of the Artillery is here left out as one of the Marshalls intruments (*sic*) in the field, bycause by him he is not commanded, butt by the Gen: onely; in many place being esteemed as an officer of equall rank with the Marshall, yett for diuers rea=[sons] I cannot allow him other then a subordinate officer in the army.[58]

Although he admits gunnery has a place in the army, he here notes that it is an independent area of knowledge; although it is subordinate to the general, even the marshal of the army had little understanding of this "separate sphere." Thus the one area Percy did not try to analyze was just the one area that Harriot did. It is most likely, therefore, that he was specifically asked to do so by Percy, not Ralegh.

Second, these analyses allow us to reconceptualize and redate Thomas Harriot's work on ballistics. Rather than the positivist story of a pre-Galilean Galileo, it is more correct to see Harriot here as a late medieval, neo-Scholastic investigator still fully entrenched in the ideas of geometry and ratio theory. His conclusions, while interesting and geometrically elegant, were simply wrong. Sadly, here we do not have the equal of Kepler or the forerunner of Snell; we have a dead-end investigation of retarded projectile motion.

However, it does suggest how a late sixteenth-century scientist was attempting to adopt and adapt the medieval concepts of motion to explain what was then the hot research topic. That he failed in this instance is less important and interesting than that he tried at all.

With respect to the dating of the work, though, the previously accepted chronology must be revised. Shirley's dating of 1590-95 for Harriot's ballistic work inferred from the supposed request from Ralegh should be revised forward at least five years. Instead, the period from 1595-1600 would appear to be a more probable period for their composition. Given that Percy's military pretensions peaked in 1600-1601, the most likely time for Harriot's work would be in the last one or two years of the sixteenth century as Percy prepared to go abroad to fight for Queen and country.

Finally, the story of Ralegh, Percy, Harriot, and cannon also speaks volumes about the position of artillery at the end of the sixteenth century. Everyone recognized it was there to stay, but seasoned veterans – especially naval veterans – paid it less attention than dilettante outsiders. It was these latter people who would indirectly push the study of gunnery ahead in the next century. Technological change is frequently driven by the "outsiders" who have no stake in the *status quo*. Scientific change, of course, can really only be advanced by the scientists, but often in response to technologies which have evolved around them, quite independently of any necessary scientific understanding of their function. In the case of Thomas Harriot and artillery at the very end of the sixteenth century, a scientist attempted to understand a maturing technology for a nobleman who wanted to gain a measure of control over military matters – matters which were by rights his.

NOTES

[1] This paper was originally delivered to the Durham Thomas Harriot Seminar, 15 December 1998. I would like to thank G.R. Batho for his encouragement and Stephen Clucas for his challenging comments upon the paper.

[2] John W. Shirley tallied the contents of all the pages of the B.L., Add. MS and Petworth House HMC MS. Of the 5,162 non-blank and non-scratch pages (out of a total of 8,882 pages), some 54% (2,778) are devoted to pure mathematics.

[3] This is in distinction to the "epistemological field[s], the categories, and divisions which elaborate and articulate the world of the known in any historical period" (p. 1) that S. Clucas investigates with regard to Harriot in *Thomas Harriot and the Field of Knowledge in the English Renaissance*, 1994 Thomas Harriot Lecture, Oriel College, Oxford (Oxford, 1995).

[4] A.R. Hall, *Ballistics in the Seventeenth Century* (Oxford, 1965). See also in general, F.L. Taylor, *The Art of War in Italy, 1494-1529* (Cambridge, 1921), ch. 5.

[5] J.W. Shirley, *Thomas Harriot: a Biography* (Oxford, 1983), p. 242-3: "The next assignment that Ralegh gave his young friend was much more challenging – to bring his science and mathematics to bear on improving the accuracy of fire of his heavy ordnance, particularly of the cannon on his ships at sea." Shirley's biography will be hereafter referred to as "Shirley, *THB*".

[6] William Bourne, *The Arte of Shooting in Great Ordnaunce* (London, 1578); Luis Collado, *Pratica Manuale di Arteglieria* (Venice, 1586) or *Platica Manuale de Artilleria* (Milan, 1592), the latter being a revised edition of the 1586 edition "sufficiently different to be considered a distinct work" (M.J.D. Cockle, *A Bibliography of Military Books up to 1642* [London, 1957] , pp. 171-2); and Alessandro Capobianco, *Corona e Palma Militare di Artiglieria* (Venice, 1598 or 1602). Shirley, *THB*, p. 259, n. 33 and 34, following Cockle, noted these same authors and books, yet despite the dating of Capobianco to 1598 or later, still dated Harriot's ballistic work as "characteristic of... the period 1590-95" (p. 250).

[7] B.L. Add. MS 6782, fol. 374^{v}, as quoted in H. Gatti, *The Renaissance Drama of Knowledge: Giordano Bruno in England* (London, 1989), p. 58.

[8] These two works are Shirley, *THB*, pp. 241-68 and J. Lohne, "Essays on Thomas Harriot. II. Ballistic Parabolas," *Archive for the History of Exact Sciences* 20 (1979): 230-64.

[9] B.L., Add. MS 6789, fol. 8-16^{r}.

[10] S. Clucas, "'No Small Force': Natural Philosophy and Mathematics in Thomas Gresham's London," in F. Ames-Lewis (ed.), *Sir Thomas Gresham and Gresham College: Studies in the intellectual history of London in the sixteenth and seventeenth centuries* (London, 1999), pp. 146-74, esp. 164-71. Harriot stands in contradistinction to John Dee, who felt the world of pure mathematics was only analogically (although profitably) applicable to the description of natural processes.

[11] B.L., Add. MS 6789, fol. 30^{r} (Shirley, *THB*, p. 255).

[12] N. Tartaglia, *Nova Scientia*, bk. II, prop. ix (trans. in S. Drake and I.E. Drabkin, *Mechanics in Sixteenth Century Italy: Selections from Tartaglia, Benedetti, Guido Ubaldo, & Galileo* [Madison, 1969] , pp. 94-7).

[13] In fact, Clucas ("Natural Philosophy and Mathematics," p. 165) notes that one of Harriot's great advances over medieval applications of mathematics to nature was that he did not worry about exactly what the forces involved were ("the vis[,] be it materiall or imateriall"), only that it did exist and could be used as a starting point for mathematical investigation.

[14] B.L., Add. MS 6789, fol. 26.

[15] On this, see Clucas, "Natural Philosophy and Mathematics," pp. 165-70, and, less satisfactorily, Lohne, "Ballistic Parabolas," p. 250.

[16] He did note that these trajectories are parabolas on B.L., Add. MS 6789, fol. 67r, and Clucas ("Natural Philosophy and Mathematics," p. 170) considers it a conclusion from the Mertonian mean-speed analysis (as Galileo also appears to have done).

[17] B.L., Add. MS 6789, fol. 63.

[18] J. Lohne, "Ballistic Parabolas," p. 233.

[19] B.L., Add. MS 6789, fol. 36.

[20] His work on these series fill B.L., Add. MS 6789, fol. 41-2 and 44.

[21] Alvarus Thomaz, *Liber de Triplici Motu Proportionibus Annexis... Philosophicas Suiseth Calculationes ex Parte Declarans* (Paris, 1509). See W.A. Wallace, *Prelude to Galileo: Essays on medieval and sixteenth-century sources of Galileo's thought* (Dordrecht, 1981), pp. 80-90, 100-1, the entry on Thomaz in the *Dictionary of Scientific Biography* (DSB), and E.D. Sylla, "Alvarus Thomas and the Role of Logic and Calculations in Sixteenth Century Natural Philosophy," in S. Caroti (ed.), *Studies in Medieval Natural Philosophy* (Firenze, 1989), pp. 257-98.

[22] Bernardo Torni, *Bernard Tornij Florentini Medici ac Philosophi in Capitulum de Motu Locali Hentisberi quedam annotata incipiunt* (Pisa, 1494); W.A. Wallace, *Prelude to Galileo*, p. 99. Torni has no DSB entry.

[23] Thomas Harriot, *A Briefe and True Report* (London, 1588; STC

12875), sig. A2^{r-v}. This dedication is often forgotten since it was not included in the better-known 1590 deBry edition of *A Briefe and True Report*.

[24] Transcribed in D.B. Quinn, *The Roanoke Voyages 1584-1590*, 2 vols. [Haklyut Society, vol. 104-5] (London, 1955), I.130-39. Quinn's work will be hereafter referred to as "Quinn, *RV*".

[25] "Cavalir" may either refer to *calivers*, a form of large musket, or to *culverins*, medium to large-sized cannon.

[26] See P. Hulton, *America 1585: the complete drawings of John White* (Raleigh-Durham, NC, 1984) , plate 3 and 4 for Puerto Rico and P.E. Hoffman, *Spain and the Roanoke Voyages* (Raleigh-Durham, NC, 1987), p. 14 for Saint Elena.

[27] Quinn, *RV*, I.288-9.

[28] National differences clearly come into play in the type of discourse chosen for various topics. Consider, for example, the French account of Drake's voyage which begins, "They took six or seven score bronze pieces..." and notes that upon his return to England, Drake's "lading was of hides, wine and piece of cannon only." Drake himself was not nearly as concerned with cannon as were the French (Quinn, *RV*, I.309-10).

[29] This sort of conspiratorial reading of available evidence is a trap into which some new historians (want to) fall; see, for example, S. Greenblatt, *Shakespearean Negotiations* (Oxford, 1988) on Harriot or C.C. Breight, *Surveillance, Militarism and Elizabethan Drama* (London, 1996) on the regime of Lord Burghley.

[30] See, in general C. Falls, *Elizabeth's Irish Wars* (London, 1950), and for artillery in particular G.A. Hayes-McCoy, "Strategy and Tactics in Irish Warfare, 1593-1601," *Irish Historical Studies* 2.7 (1941): 255-79, S. de hÓir, "Guns in Medieval and Tudor Ireland," *The Irish Sword* 15.59 (1982): 76-88, and S. O'Domhniall, "Warfare in Sixteenth-Century Ireland," *Irish Historical Studies* 5.17 (1946): 29-54.

[31] Shirley, *THB*, p. 250. The list is on B.L. Add. MS 6786, fol. 364^{v}.

[32] Shirley, *THB*, p. 238 and on the experiments, pp. 268-73.

[33] Justus Velsis's introduction to the 1545 Latin edition quoted by L.J. Rosán, *The Philosophy of Proclus: the final phase of ancient thought* (New York, 1949) , p. 50.

[34] Muriel Seltman has suggested that Harriot worked on 4th order polynomial equations as solutions to optimal ship hull profiles (IHPST Colloquium, University of Toronto, 26 April 1996). I have not fully investigated this possibility, and although he did clearly take an interest in hull design and naval architecture in general, I am tempted to argue that

this, too, may turn out to be an example of a personal interest (in polynomial arithmetic and graphing) becoming intertwined with employment duties (provisioning and outfitting ships for Ralegh's voyages, both Virginia in the 1580s and Guyana in the 1590s).

[35] S. Gossett, "A New History for Ralegh's *Notes on the Navy*," *Modern Philology* 85 (1987): 18. Here she convincingly argues that *Note on the Navy* was composed about 5 years *before* Elizabeth's death. Further quotations, however, are from a Jacobean version; hence the use of 'his' majesty.

[36] *Ibid.*, p. 20. He did, however, recognize the general importance of artillery, for, as he said, "what are all the ships in the world to be valued at, other than a company of floating tubs, were they not furnished with ordnance, either to offend others, or defend themselves?" Ralegh, "A Discourse of the Invention of Ships, &c." [Sir W. Ralegh, *The Works of Sir Walter Ralegh, Kt. Now First Collected*, 8 vols., ed. Oldys and Birch (Oxford, 1829), VIII.331 — hereafter "*Works*"].

[37] See "A Discourse of the Invention of Ships, &c." [*Works* VIII.337-9] and "Observations concerning the Royal Navy and Sea-Service" [*Works* VIII.347-8], where he argues that the "superflous great pieces in every ship" might more profitably be withheld to provide instead "swords, targets of proof, morions, and curats [cuirasses]" to embolden the sailors when they close with the enemy.

[38] "Observations concerning the Royal Navy", § "Of great ordnance", *Works* VIII.342-3, where he also notes the chronic under-supply of gunners in the Navy.

[39] S. Coote, *A Play of Passion* (London, 1993), pp. 266-69.

[40] Raleigh, *History of the World*, V.i, quoted in C.R. Markham, *The Fighting Veres: Lives of Sir Francis... and Sir Horace Vere* (London, 1888), p. 228, n. 1. Contemporaries set point-blank range for demi-cannon at something like 400 paces (2000 ft. or 610m).

[41] M. Oppenheim (ed.), *The Naval Tracts of Sir William Monson* (London, 1913), IV.43.

[42] Shirley, *THB*, p. 168.

[43] See N. Taunton, *Watching the Watch: surveillance of the camp in sixteenth-century discourse of war*, Durham Thomas Harriot Seminar Occasional Paper no. 26 (Durham, [n.d.]) for her reading of a particular subset of these books.

[44] Shirley, *THB*, pp. 254-55.

[45] Leconfield MS 138, now held at Petworth House, Sussex – dated 1600. It is unclear whether Percy had retained Paul Ive to translate the work for him, or whether Ive dedicated it to Percy after its completion in hopes of

remuneration. Either way, Percy had clearly obtained a reputation as an appropriate patron for such a work.

[46] Nichols, *The Progress of Queen Elizabeth*, vol. ii, quoted in G. Brenan, *A History of the House of Percy* (London, 1902), p. 46.

[47] A. Dyce, *The Dramatic and Poetical Works of Robert Greene & George Peele* (London, 1874) , pp. 582-3.

[48] G. Brenan, *A History of the House of Percy* , p. 98.

[49] See *Ibid.*, pp. 68-77, and the DNB article on Sir Francis Vere.

[50] G. Brenan, *A History of the House of Percy* , p. 68-69.

[51] C.R. Markham, *The Fighting Veres*, p. 317.

[52] On Essex: Chamberlain to Carleton, London, 15 Feb. 1599 (N.E. McClure, *Letters of John Chamberlain*, 2 vols. [Philadelphia, 1939], I.68). On Capt. Lower: C.R. Markham, *The Fighting Veres*, p. 307.

[53] J.P. Collier, "Sir Walter Raleigh and Sir Francis Vere," *Archaeologia* 35 (1853): 372.

[54] Chamberlain to Carleton, London, 8 July 1601 (N.E. McClure, *Letters of John Chamberlain*, I.127).

[55] Chamberlain to Carleton, London 8 May 1602 (*ibid.*). Chamberlain had first heard the rumor on the 25th of April.

[56] S. Clucas, in his *Honour, Public Office, and Renaissance Careers – the Case of Henry Percy, 9th Earl of Northumberland* (Middlebrook History Lecture, Newcastle Royal Grammar School, 19 Nov. 1996), argues that Percy's behaviour in the commissions he accepted and his public services was designed to increase his "honour and virtue," regardless of cost. So, as the envoy to confer the Order of the Garter on Henry IV (of Navarre) in 1596, he accepted a high profile job that did not take too long (*i.e.*, did not cost too much), and that Percy's service in the Low Countries was about the appearance of being and doing what a noble should, rather than simply the 'dilettantish image' of the nobleman that others have suggested.

[57] See G.R. Batho, "The Library of the 'Wizard' Earl: Henry Percy Ninth Earl of Northumberland (1564-1632)," *The Library* 5th ser., 15 (1960): 249-50 and 250, n.1. The MS in question is Alnwick Castle MS 512, a Ramist-style explication of every officer, munition, duty, and procedure in the army.

[58] Alnwick Castle, MS 512, p. 10. In the case of "rea=[sons]", Percy forgot to finish his hyphenated word on the next line. I should like to thank G.R. Batho and Colin Shrimpton for their assistance in securing access to the Percy papers at Alnwick Castle.

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