Early 18th Century Hand Grenades on the North American Atlantic Coast
An Experimental Archaeology Study
by

Stephen Lacey

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Director of Thesis: Donald H. Parkerson, Ph.D.

Major Department: History, Program of Maritime Studies

ABSTRACT

In the first half of the eighteenth century, standardization of weapons appears in cannon, shot, and small arms. No comparative study has been conducted to determine if grenades follow this pattern. In this study, three collections of cast iron grenades dating from 1700–1750 were compared to determine if any statistical significance exists. If so, this will form the basis to create a taxonomy to assist in dating sites. Furthermore, grenade blasts from this era are reported in the historical record but recorders barely understood ballistics. An experimental phase has been designed into the project to fully record a blast via controlled detonation. The concussive force and decibel levels were recorded to help assess potential damage. Upon completion, medical evaluations can be made to determine the full lethality of cast iron grenades. This allows an evaluation of historical records for unexplained deaths, altered behaviors post battle, and critical evaluation of historical documents on grenade lethality.

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APPROVED BY:

DIRECTOR OF THESIS: ______________________________
Donald H. Parkerson, Ph.D.

COMMITTEE MEMBER: ______________________________
Bradley A. Rodgers, Ph.D.

COMMITTEE MEMBER: ______________________________
Lawrence E. Babits, Ph.D.

CHAIR OF THE DEPARTMENT
OF HISTORY: ______________________________
Christopher Oakley, Ph.D.

DEAN OF THE
GRADUATE SCHOOL: ______________________________
Paul Gemperline, Ph.D.

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Chapter 1: Introduction

Gunpowder is one of the most revolutionary inventions in human history with unequalled affects, both positive and negative, in many cultures. What first began in China as a propellant for aesthetic entertainment through fireworks, rapidly morphed into several weapon types. Grenades are one of those early weapon types. Expedient to build, rudimentary to use, and extremely effective, grenades found a permanent place on battlefields. Even today grenades are still used for their original intended function, to inflict damage and disrupt resistance. These functions are well represented in the historical and archaeological records, but historical documents only provide a glimpse into the information grenades can yield. This thesis analyzes the historical and archaeological record for grenade use, production, and standardization to expand current industry knowledge and assess the viability of creating a taxonomy to assist in dating grenades, using my archaeometry approach.

Limited references in historical documents form biases that must be recognized to fully comprehend the text. Obfuscations of accuracy develop for several issues, reasons, or intentions but nonetheless exist. Documented content should be evaluated, but similarly those parameters that remain unrecorded. Assessment of historical documents for: intentional or unintentional falsification; authors' limits in experience, observations, knowledge, and racism, must all be factored for reliability. Since these methods have not always been common practice, generalizations and assumptions have rooted themselves into our accepted public memory (Young 2000) despite known falsehoods.

Our limited knowledge of grenade use at sea in the 18th century has been based upon assumptions. While historical documents make claims to the use and effectiveness of grenades, the authors clearly barely understand ballistics (Hall 1952:1–6). With a questionable cognizance of ballistics and the full effect of a blast, one cannot rely upon historical accounts alone for explanations. Therefore, a comprehensive study was necessary to evaluate the use and effectiveness of grenades. This study consisted of comparative and experimental components to answer several fundamental questions. Only then can conclusions be drawn, an accurate understanding of grenade lethality known, correct interpretations of historical documents made, and the plight of those unfortunate who felt the wrath of grenades first hand be precisely understood.

Justification and Research Problems

Naval warfare and battles have been one consistent research area in maritime studies. Historians and archaeologist try to interpret battles accurately through historical documentation, paintings, battlefield analysis, and archaeological evaluations. Extensive experimental comparative studies of material culture show the use and employment of different battlefield technologies. This study examines the use of grenades on the maritime battlefield for the 1st time.

This study begins with an extensive comparison of early 18th century cast iron grenades found on shipwrecks on the North American Atlantic coast. To date, only one other comprehensive comparative study of grenades has been performed to evaluate variances in size, shape, material, weight, and construction methods, and that was produced by treasure salvors (Hamilton 1987). Similar comparative studies of clay pipes, ceramic wares, nails, glassware, ship design, buttons, lithics, and cannon, all resulted in diagnostic markers that help establish origin and manufacture dates (Schlereth 1985; Deetz 1996; Hume 2001). These are excellent tools to establish a relative timeframe for both the artifacts and by association, the sites. Furthermore, grenades have been dismissed in ordnance studies if they are even mentioned at all (Ffoulkes 1937; Cipolla 1965; Kennard 1986). The prevailing attitude has been to marginalize grenades into a lesser, secondary role rather than a weapon equally as important as cannon, small arms, or edged weapons. But grenades are directly related to the casting of solid shot and a more forgiving arena in which to test different casting techniques. Defects or failures can simply be recast with less loss of total manufacturing hours since the materials are easily recycled. At a time when standardization of cannon, shot, and shoulder arms became a focal point for military arsenals, grenades too were subject to contemporary efforts of military weapon standardization.

The magnitude of grenade production and use in the early 18th century can be easily exhaustive and exceed the scope of a Master's thesis. For this reason, it is necessary to establish a refined scope for this study of sufficient length and detail. Therefore, the focus was solely on the North American Atlantic coast. Several European nations are known to have been active in this area during the early 18th century; each must be represented in this study, and there are numerous archaeologically recorded shipwrecks. Additional parameters are necessary to reduce the number of eligible shipwrecks to be evaluated. These parameters are: a wreck dates between AD 1700 and 1750 and contains grenades that must be physically accessible, either in a museum or collection. The legal status for the ship at the time of sinking must also be documented, and the ships' combat status at the time of sinking must be known to help with tracing nationality of armaments.

Analysis of each associated collection of grenades included: dimensions, weight, fuse hole orientation, fuse materials, cast iron compositional materials, and other physical features. These variables were necessary to distinguish diagnostic features to assist with identification, construction methods, and national origin. Once the data had been compiled, each collection underwent statistical analysis to examine variance within individual assemblages. Little variance suggests nuanced construction techniques, designs, and a standardization within a nation.

Significant variance suggests pronounced differences as may exist between nationalities. Either degree of variance does not alter the next phase of this study, experimental replication.

The experimental phase will answer research questions about the production and utilization of early 18th century cast iron grenades at sea. By fully recording and evaluating lethality, a more complete understanding of the power and magnitude of grenades in battle is developed. Another intended goal of this study is to understand the impact and damage a grenade inflicts upon the human body. It has been assumed 18th century cast iron grenades are fragmentary devices, but other factors are equally plausible. High decibel levels from an explosion can disrupt or stun combatants, and may prove indispensable in combat decisiveness. Concussive blast waves can be lethal by themselves or lead to permanent neurological damage, such as Traumatic Brain Injuries (TBI), or physical damage including soft tissue damage by blunt force trauma. Psychological effects grenades had on sailors or Marines before, during, and after a battle have yet to be evaluated. These studies are instrumental to fully connect with 18th century sailors and Marines, which in turn better enables us to readily identify biases within the historical record and our own public memory. These questions are answerable only through full replication and experimentation by controlled detonation.

Summary

This study will have two phases, a comparative and an experimental. The comparative output reviews grenade collections from the 1715 and 1733 Spanish plate fleet wrecks, the Beaufort Inlet shipwreck (31CR314), and *Whydah*. These wrecks are located along the North American Atlantic coast and are dated between AD 1700 and 1750. The grenades were measured, then replicated, using the archaeologically recorded measurements. The data was queried in SPSS to determine the significance of variance within and between each assemblage.

The experimental phase consisted of sand casting and controlled detonations of a grenade. Detonations recorded blast force, overpressure, shrapnel, and audible levels to access lethality.

Ultimately this study corrects inherent fallacies in recorded history and answers research questions concerning early 18th century: grenade casting technology, the degree of variance from one grenade to another and from one nation to another, the practical distance grenades can be thrown, the lethality of grenades, and suggest insight into historical Traumatic Brain Injuries (TBI) and Post Traumatic Stress (PTS).

Chapter 2: History of Explosives

Explosives underwent many transformations between the 17th and 19th centuries. Both land and sea forces utilized explosives in different ways, leading to certain adaptations more favorable to one arena. Despite splintering explosive development, overall aims and employment were mirrored. Once European nations began to standardize production of weapons and munitions in the 18th century, types of explosives merge into general use or disappear completely.

To be considered ready for combat, garrisons required a stock of diverse weaponry (Figure 1). General de Malortie lists the necessary equipment, “the requisite quantity of artillery, grenades, blunderbusses, rampart-fusils, common musquets, pikes, and other weapons” (Malortie 1824:179). Ships equally required artillery, grenades, firearms, edged weapons, and powder to leave port on military or commercial ventures. Additional forms of explosives were necessary and found their way into munition stores. Bombs, carcasses, mines, mortar shells, and rockets are but a few. Each were uniquely suited for one purpose, to detonate.

Employment of an explosive had several different intentions and was largely dependent upon the theatre it was used in, and defensive or offensive applications. Offensively, bombardments of fortified positions could shorten a siege through damaging defensive positions or equipment, injuring personnel, ruining provisions, and draining the resistors’ morale. Carcasses, mortars, rockets, fire arrows, and powder pots could ignite fires, causing a diversion of resources to extinguish the flames. Grenades could provide fire superiority for attacking troops, preventing defenders from mounting resistance or creating the inability to sustain positions. Potent odorous devices could coax defenders from below decks without igniting large quantities of powder.

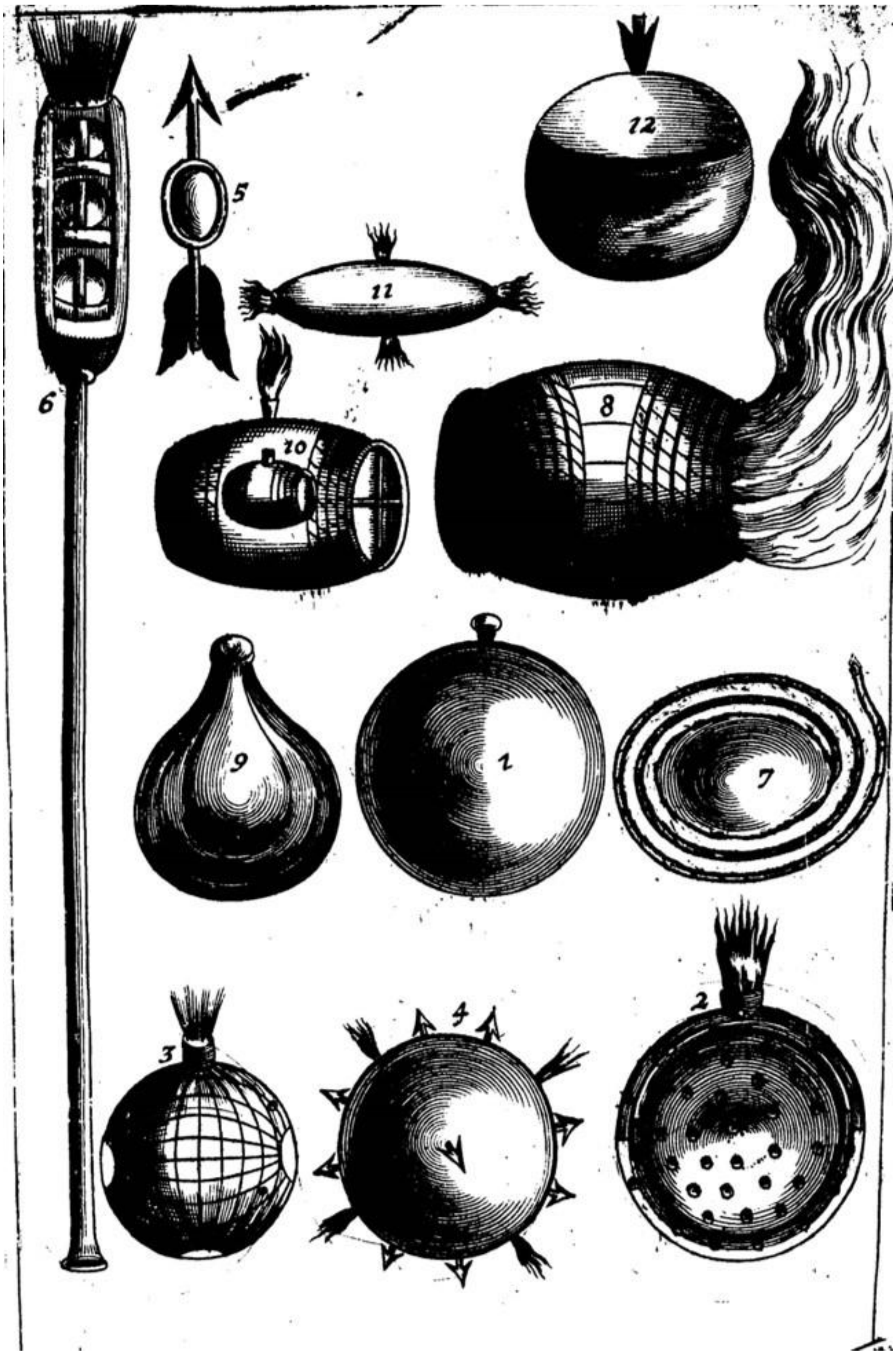

FIGURE 1. Different explosive types. (Adapted from Binning 1676:Plate C).

Each scenario presented above can be reversed in favor of defensive forces. Troop movement can be retarded or altered by explosives. Advancement of attackers can be altogether thwarted by overwhelming firepower achieved through explosive devices. Malortie describes this philosophy, "As soon as it is perceived that the enemy is commencing any descent, shot made of combustibles should be thrown upon the spot where he is at work, as well as shells from mortars and howitzers" (Malortie 1824:232). Boarders can be forced onto specific paths on decks by powder chests or prevented from boarding at all by fire arrows and fire pikes. (Figure 2) Weakened defensive points can be made more formidable by large explosives such as buried bombs and mines, thrown hand grenades, or rolling mortar shells to impede movements (Malortie 1824:234).

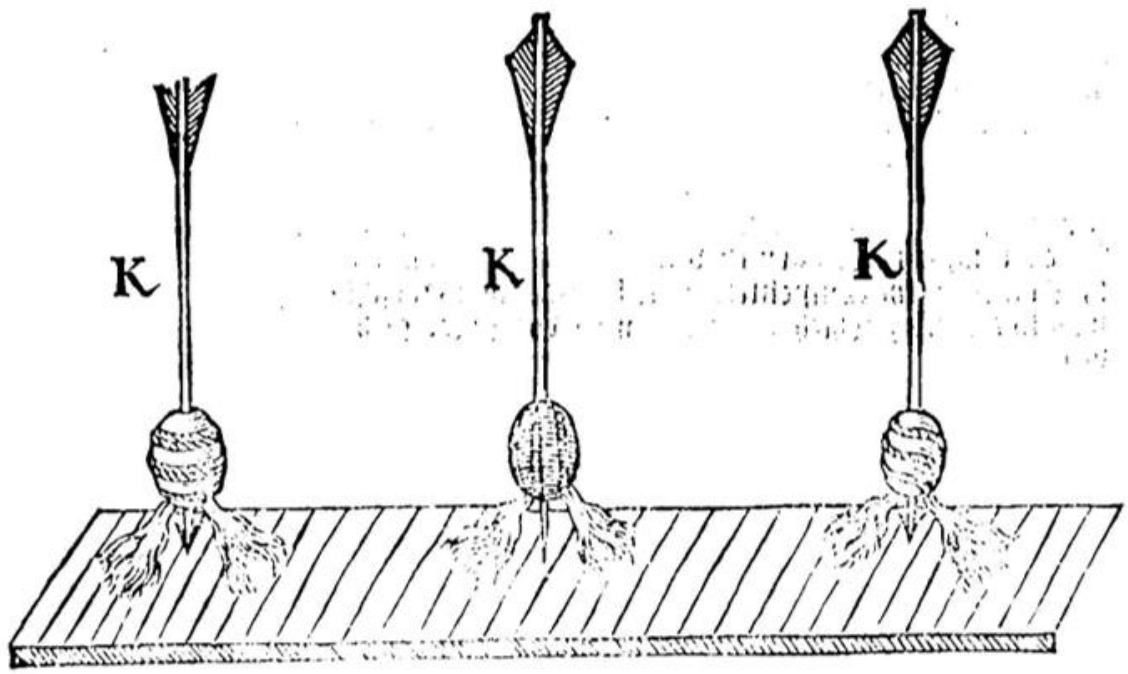

FIGURE 2. Early fire arrows with detachable heads. (Adapted from Smith 1643:96).

Explosives influence, if not determine, battle tactics more than is generally believed. Battle results rested largely on the number and types of explosives available and the damage they could inflict. The pursuit of increased lethality led to experimentation in design of explosives, mainly their material composition. Concomitantly, advancements in gunpowder production and power further complimented explosive lethality.

In this chapter, explosives are discussed in sections pertaining to each device or related devices. Histories, intended use, basic descriptions, gunpowder compositions, alterations, and material compositions are covered as the primary sources indicate. Relevant tables, plates, and images have been included, some with minor format adaptations for ease of reference and uniformity. Quotations differ only from the originals in the replacement of the 'long s' in accordance with the Society of Historical Archaeology's writing guidelines.

Gunpowder

<u>Production</u>

The basic mixture of gunpowder changes minutely between the 17th and 19th centuries. Two types of gunpowder existed for military use, serpentine and corned. At the beginning of the 17th century, serpentine powder had been phased out by corned powder for use in cannon, mortars, and explosives. Fireworks were the last refuse for serpentine powder until the latter quarter of the 17th century when production of serpentine powder for military operations ceased. Differences in production methods and the power of the finished product caused the delineation of both types. Serpentine powder is the earliest form, made from mixing ground saltpeter, charcoal, and sulfur. Corned powder uses the same ingredients but with an additional step. Once the gunpowder is mixed, it is moistened, dried, and ground again (Smith 1653:67). This produces more powerful gunpowder, more resistant to moisture (Smith 1653:67.)

Another byproduct of reground corned gunpowder is that the grains produced resemble crushed peppercorn flakes. Distinct visual reference was the key to distinguishing serpentine or corned gunpowder. Visual reference in granular size will later be key to determining the quantity of ingredients in each production run of gunpowder. Ingredient ratios for corned gunpowder vary depending on the powder's intended use (Smith 1653:67; Sturmy 1669:65; Binning 1676:153; Seller 1691:193–194; Dawks and Boddington 1701:162–163). Primarily, the ratio of saltpeter in the mixture determined how the gunpowder would be used,

> "the Musquet or Pistol *Powder* is now commonly made of Salt-peter five parts, one part of Brimstone, and one of Cole; *Canon-Powder* of Salt-peter four times as much as of Brimstone, and as of Cole. The reason why Pistol *Powder* being the strongest of 6-1-1 is not so good for the *Canon* as 4-1-1 the weakest, although you take but so much of the Pistol *Powder* as you find by an Engine to be of like strength with another quantity of *Canon-Powder*" (Sturmy 1669:65).

Many other authors followed these ratios throughout the rest of the century, until it was no longer specified (Binning 1676:153–154; Seller 1691:188–189,193–194). Presumably no specification indicates the ratio became common knowledge or was no longer worth distinguishing. A classification system, still in use today, developed to indicate which type of weapon the gunpowder is intended based upon granular size. Course gunpowder is best for cannon but as the barrel diameter is reduced, so is granular size. This progresses until gunpowder becomes equivocal to dust, best for pistol priming. The system in place today denotes cannon powder as Fg, musket powder as FFg, rifle powder as FFFg, and pistol powder as FFFFg.

<u>Storage</u>

The earliest primary source in this study devotes a chapter to storing, preserving, and renewing gunpowder (Roberts 1639:49–52) which is copied by later authors almost verbatim (Sturmy 1669:66; Seller 1691:195; Love 1703:187). According to these sources, the biggest fear of storing large quantities of gunpowder in barrels, was that it could spoil. The prevailing thought was saltpeter leeched from the top to the bottom of a barrel when stored. An adopted preventative measure to stave leeching was to simply turn the barrel endwise every two or three weeks (Roberts 1639:51; Sturmy 1669:66; Moretti 1673:107; Seller 1691:190; Love 1703:188).

For smaller quantities of gunpowder, the powder was wetted, then formed into small balls. These balls were dried and stored in a glazed earthen pot (Roberts 1639:51; Sturmy 1669:66). When the powder in these balls was needed, they could be crushed, sifted, and used.

Testing and Rejuvenation

With the potential for gunpowder to spoil, quality tests were necessary. John Seller described the characteristics of quality corned powder, "take this for a general Rule, for a sign of good Powder; that which gives fire soonest, smoaks least, and leaves least sign behind it, is the best sort of Gun-Powder" (1691:190). Less than favorable outcomes could also be a result of tests, therefore, methods to restore gunpowder were sought after. Constantly an issue for large military operations was the possibility gunpowder could decay. Primarily decay was the result of humidity changes, much more common at sea than on land. Partially decayed gunpowder could be restored by mixing in new parts of refined saltpeter. The ratios are, "for every hundred pound of powder, adde foure pound, or sixe pound of refined salt-peeter …" (Roberts 1639:50). Even fully decayed gunpowder can be restored by extracting the saltpeter and making a new batch (Roberts 1639:50; Sturmy 1669:66). John Roberts describes this process in detail,

> "If it be wholly decayed, lay a Rayson Frayle, or mat in the bottome of a bucking-tub, upon a fagot made of purpose, or lathe, set on edge, to keepe the mat from the bottome, and put in straw layd cross-wayes: uon which power the decayed poder, and warme water, being put thereon, and let it stand and soake ten or twelve houres, that all the Salt-peter ma bee assuredly dissolved: then let out the liquor tap which congeale to Peter, and thereunto adde a due proportion of Coles and Sulphure, and make it into powder, …" (Roberts 1639:50).

Ignition Sources

Fuse Plugs

To detonate an explosive, ignition was necessary. It was delivered by a fuse, commonly held in place by a plug. Wooden fuse plugs were used for mortars, grenade shells, bombs, mines, carcasses, and several other types of explosives. Often, fuse plugs follow a similar pattern of construction between the types of explosives. The main purpose after all, is to hold the fuse in place. Two types of fuse plugs exist, those with holes and those without. Plugs without fuse holes could be used on stationary explosives like powder barrels and powder tubs. Plugs for moving explosives like mortars and grenades, have a hole the fuse passes through. Generally, plugs with holes are tapered towards the bottom and ¾ the length of the shell thickness, but wide enough to be seated firmly with a mallet (Sturmy 1669:84–85). These holes were ¼ of the fuse plug's overall diameter usually (Sturmy 1669:84) but this would depend on the fuse diameter itself.

<u>Fuses</u>

Fuses for explosives are made in the same manner as match cord for use in a cannon linstock. Constructing cannon match cord involved placing twisted cotton yarn in a saltpeter and water solution. Once taken out of the solution, the cord was wrung of water, then rolled on top of finely ground saltpeter and sulfur, and left to dry (Roberts 1639:52; Faulkner 1747:25; Mountaine 1747:119–120). Fuse for explosives uses a slightly different mixture of gunpowder, to increase the burn rate. A higher ratio of saltpeter and sulfur was used, with a final treatment of linseed oil and alcohol to ensure ignition in inclement weather (Roberts 1639:52; Binning 1676:156). Rockets use an even greater amount of saltpeter for a more aggressive burn (Roberts 1639:52).

Non-Lethal Options

<u>Stink Balls</u>

A non-lethal alternative to subdue a well-entrenched enemy is stink or smoke balls. Both are concoctions of potent odorous materials set ablaze and thrown between decks, into rooms, or behind other forms of cover. One recipe consists of certain ratios of diced manure, wax, gunpowder, lard, and oils (Binning 1676:163). These ingredients were placed in an oil dipped bag, a fuse added, lighted, and thrown by hand. Accounts claim the bag emits a potent smoke, unbearable to any foe (Binning 1676:163). An alternative recipe calls for mixing gunpowder, pitch, tar, saltpeter, sulfur, and horse hoofs into a liquid state (Seller 1691:198–199). Afterwards, any type of cloth available would be added to soak up the solution, rolled into balls, and employed in the same manner. Stink and smoke balls are a great option when an explosion is likely to cause a tactical setback, such as igniting a powder magazine on a ship.

Explosives

<u>Bombs</u>

Today bomb is a generic term for an explosive device but in historical sources included in this study, bomb appears to have been a broader term. Detailed descriptions differ slightly from those of mortar shells, grenade shells, or carcasses. Primarily, bombs were iron or brass shells filled with fine powder (Moretti 1673:73; Faulkner 1747:6) but could also be made of earthenware or glass (Hamilton 1744a:141). Like mortar shells, they range in identical weight from 50l to 100l mainly, and up to 300l (Moretti 1673:73).

<u>Bullets</u>

Bullets have a very similar function to balls of wildfire. Instead of cotton or hemp, bullets were a mixture of melted sulfur, wax, tar, and pitch, rolled in gunpowder (Roberts 1639:55). As the mixture cooled and solidified, it became extremely hard, rivaling the strength of stone (Roberts 1639:55). Like balls of wildfire, a common adaptation was to drill holes and pack them with fine gunpowder for greater intensity (Roberts 1639:55). A larger design for bullets must have come out later because another source advises packing four or five pounds of gunpowder inside (Moretti 1673:115). Based upon the previous description, it would be quite the challenge to place such a large quantity of powder inside a few drilled holes.

Carcasses

One of the more underappreciated types of explosives is the carcass. The body of carcasses was assembled first in an egg like shape (Figure 3). Commonly, leather was stretched over three iron bars, one horizontally and two vertically, (Dawks and Boddington 1701:167–168) or two iron caps for ends were joined by two iron hoops in the middle (Mountaine 1747:120**)**. Later these developed into cast iron spheres 8–25” imperial diameter (Mountaine 1747:121). In succession**,** five, three, then one hole, to be filled with gunpowder and fuse, with a staple to hoist larger carcasses into mortars (Mountaine 1747:121). The amount of gunpowder packed into a carcass varied but certainly would create a powerful explosion. One large explosive event was reported by prisoners about whom it was stated, “I find [learn from] by the Prisoners, we had like to have had a lucky Incident from one of our Carcasses falling into the great Church where the principal magazine for their Powder was, and set Fire to the Timber and Plank that covered it …” (Raymond 1744:52). This evolution describes a mortar shell as we generally associate them today, but interestingly contemporary authors do not consider them equivocal.

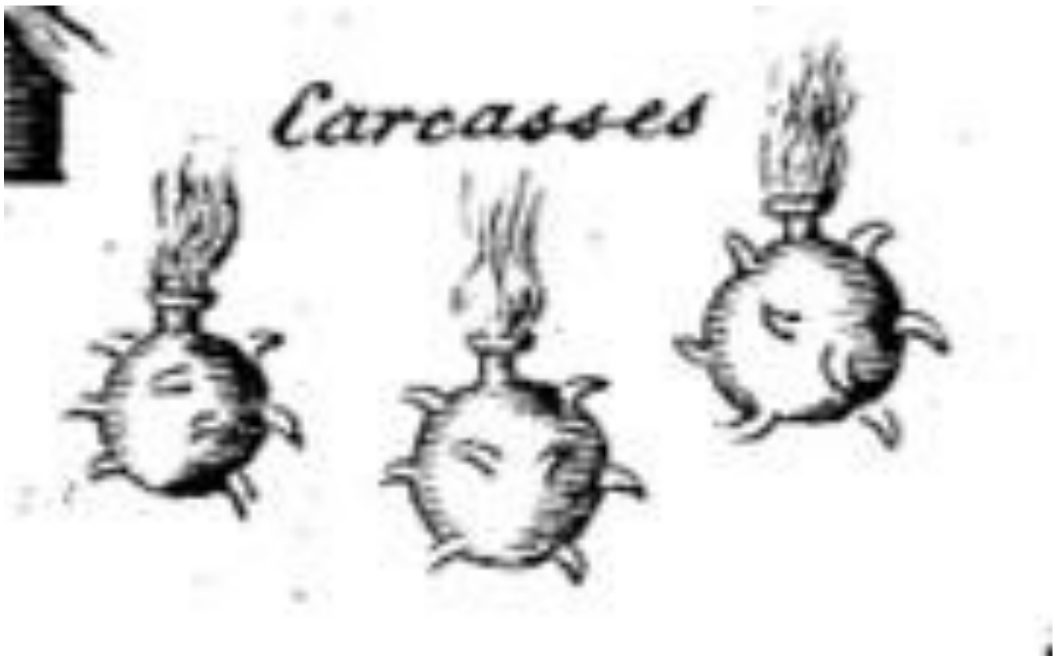

FIGURE 3. Examples of carcasses. (Adapted from Faulkner 1747:Plate A).

Fireworks and Rockets

Many contemporary texts addressed the manufacture and use of various types of fireworks during this period. The first weaponized fireworks consisted of a pole or pike fitted with a device which emitted a flame or profuse sparks. A later adaptation gave rise to fire arrows, increasing their range since they were launched from a bow or musket and not limited to arms reach (Figure 4; Roberts 1639:54; Norton 1643:90–92; Smith 1643:89–109; Smith 1653:67; Moretti 1673:117–124). It is unclear how quickly the transition from pike to arrow, to firearm took place. Since this transition was noted in the earliest documents and sustained for the next half century, it may have been an ongoing transition or at least happened within living memory.

FIGURE 4. Archer firing an early fire arrow with detachable head. (Adapted from Smith 1643:109).

Early descriptions of fireworks depict the image of a canvas bag filled with diluted gunpowder. This dilution would ensure longevity of flames and prevent the bag from simply exploding (Roberts 1639:53). Removable heads on pikes and arrows made canvas bags obsolete, in favor of the shaft of the head containing the ignition fuel. This made fire suppression more difficult as the source had to be physically removed from objects (Sturmy 1669:85; Moretti 1673:117–124; Binning 1676:161). At sea, removing an imbedded ignition source had to be done immediately, or else the entire ship would become ablaze. Early and later fireworks could be defensive weapons as well. They could ignite an attackers' sails, ropes, masts, and the ship (Roberts 1639:53–54; Smith 1653:67; Sturmy 1669:85; Binning 1676:154).

Fireworks were also adapted to fulfill non-combat roles. Foremost is as signals or illumination of areas. These types were shot by bow, shoulder arms, cannon, mortars, and signal mortars, until eventually they were self-propelled (Norton 1643:90–92; Sturmy 1669:86; Binning 1676:154). The self-propelled types are referenced as rockets, a technology still employed today as entertainment. Strategic value was seen in rockets, so a weaponized version was developed shortly afterwards.

Grenades

The historical record consists of a plethora of uses for hand grenades. A grenades' most notable feature is that it explodes to cause casualties from fragmentation. Concomitantly, grenades can cause confusion and chaos, resulting in exploitable tactical situations. Recommendations to repel attacks on fortified terrestrial positions call for, "a profuse quantity of grenades should also be thrown upon them, and, as soon as any confusion among them is perceived, the troops… are to charge those of the besieger …" (Malortie 1824:229). On ships, grenades could be thrown at boarding forces. If the ship was prepared properly for close combat, defenders would have protection from the blast and only the boarders would incur casualties.

Similarly, assaulting forces can use grenades for confusion and chaos to their advantage. A blast from a grenade can clear a deck of exposed defenders or limit the effectiveness of more built up defenses. An amphibious assault can take a surprising turn for defenders not expecting massive firepower,

> "I rowed directly towards it, and they within expecting to have a Message to carry to the King, stood gazing till we came close to the Wall, and then we saluted them with a Shower of twenty or thirty Granadoes, which so frightened them, that happy was he who got first away" (Hamilton 1744b:104).

Movements can be redirected or retarded completely by grenades (Muller 1747:57, 70, 75, 171–175). In 1571 during the siege of Famagosta, defending Venetian forces exacted a heavy toll on besieging forces,

> “The Turks, having advanced their trenches almost to the counterscarp, now effected their entrance into the fosse, where, however, they suffered severe losses by the various pyrotechnic devices of the defenders. Hand grenades were especially effectual in keeping them at a distance” (Stirling-Maxwell 1883:367).

By directing movements, larger explosives like mines, bombs, thunder barrels, and powder pots can be used to devastating effects. At sea, the full repulse of an attack can provide just enough opportunity to escape the threat altogether or until assistance arrives. Terrestrial defenses would not necessarily have the option of escaping in siege situations, but it can cease further hostilities until a relief force can help lift the siege.

Protection from grenade blasts was a continual issue and a few techniques were implemented. In fortified positions on land, sheds could be built over trenches and ramparts with their roofs sloped so grenades would simply roll off (Malortie 1824:193). Logically this necessitated having adjacent areas the grenades would continue to roll towards, where their damage would be negated. At sea, it would be much easier to deflect a grenade to a safe area, since the sea would absorb most of the blast damage. This could be done by deflecting the grenade off the deck by any successful manner such as kicking it off the deck.

Tales of explosion survivors call into question the acclaimed lethality of hand grenades, especially when grenades detonated while still in possession of their ignitor. One instance was recorded at the Battle of Lepanto in 1571,

> “Federico Venusta, a captain of Spanish artillery on board Doria’s *Doncella*, had his left hand mutilated by a grenade which exploded as he was about to fling it amongst the Turks. He went up to one of the galley-slaves, and begged him to cut off the bleeding hand with a long knife which he wore. The man refusing to undertake this operation, Venusta performed it himself” (Stirling-Maxwell 1883:422).

While many more instances document the devastating effect of grenades, there are survival stories. No reasons are theorized for why some grenades caused excessive damage while others merely caused the loss of a limb. Skepticism would contribute a wide spectrum to over exaggeration of grenade lethality. A similar claim can be lodged against survival stories, making all accounts questionable.

A specialization of handling grenades was incorporated into the military at the time. These troops are known as grenadiers and several descriptions exist portraying them as gallant, resolute soldiers (Dawks and Boddington 1701:30–36; Woodward 1709:102-103). Grenadiers even have a section devoted entirely to their movements in manuals of arms (Bland 1734:34–40; Mountaine 1744:139–143). The prowess of grenadiers in battle was well known to opposing troops. Captain Shelvocke used this to his advantage in a ruse to avoid battle, “I ordered my people to put on their Grenadier caps, and to spread themselves fore and aft, to appear as formidable to them as we could” (Shelvocke 1757:87). For such a ruse to have been successful, it was necessary for an opposing force to be timid of grenades and the troops renown to masterfully wield them.

The material composition of grenade shells was limited to any available material: cast iron, bell metal or bronze, earthen, glass, tin, brass, canvas, and wood (Norton 1643:87–88; Sturmy 1669:8; Seller 1691:196–197; Love 1703:188–189; Park 1704:63–64; Mountaine 1744:181–182; Faulkner 1747:19). Not only are grenades diverse in material composition, they similarly have various sizes and weights. Overall exterior diameters are listed as 3, 4, 5, and 6” imperial (Mountaine 1747:84). Weight of shells is recorded as 15l caliber if iron and roughly 2/3 the weight (Moretti 1673:74). The preferred gunpowder grade used in grenades was fine powder.

Exact amounts of gunpowder range from four ounces to one pound, presumably corresponding to overall dimension (Norton 1643:87–88; Mountaine 1747:116; Muller 1747:152).

Depending on the material used, alterations were used to create additional secondary shrapnel. Glass grenades were double shelled by gunners and fire-makers. This entails coiling rope around the shell, then placing a layer of musket balls cut in half all over and fastened by pitch, and finally covered with paper or canvas (Smith 1653:67; Sturmy 1669:85; Seller 1691:197–198; Love 1703:188–189). Including flint in earthen shells was suggested as another form of secondary shrapnel (Mountaine 1747:84). Around 1670, glass and clay grenades began to fall out of favor because they create a lesser blast than cast iron shells, but they were still utilized if available (Moretti 1673:74). To prevent grenades being tossed back in case a fuse was too long, the shell could be wrapped in paper and set ablaze (Mountaine 1747:83). Although the grenade could be picked up and thrown back, the second thrower would suffer a burnt hand and thereafter be partially combat ineffective. The favorability of these alterations further questions grenade lethality by suggesting they needed to be altered from the state in which they were shipped.

Transportation of quantities of grenades sufficient for ship stores or military expeditions made standard shipping containers necessary. By mid-eighteenth century, two types of boxes were in use (Table 1). The exact number of grenades allotted for ship stores depended on the number of cannons the vessel carried (Table 2).

Hedgehogs

Almost identical to balls of wildfire, hedgehogs are constructed in a similar manner. Cotton or hemp forms the body and it is treated with the same mixture of gunpowder (Roberts 1639:55). Instead of drilling a hole, spikes are driven through and the container then filled with gunpowder. The main functional difference for hedgehogs is they were thrown by hand into sails, where the spikes puncture the cloth and prevent the device from descending to the deck (Roberts 1639:55; Smith 1643:105–106). A fuse is also necessary to prevent burns to the hand of the launcher.

TABLE 1
IMPERIAL DIMENSION OF SEA SERVICE HAND GRENADE BOXES

Quantity in Box	Length Overall	Width Overall	Height Overall
50	2’ 7”	1’ 2”	1’ 1”
30	1’ 9”	1’ 2”	1’ 0”

(Adapted by author from Mountaine 1747:76).

TABLE 2
HAND GRENADES ALLOTMENTS TO SHIPS

Cannon	Hand Grenades
100	200
90	200
80	200
64	180
58	120
50	100
44	100
20	100

(Adapted by author from Mountaine 1747:126).

Mortars

Confusion can arise in early references to mortar shells because they are noted as Granadoes or Granados, an interchangeable reference for hand grenades (Norton 1643:87–88; Smith 1653:67). To further obfuscate definitions, Moretti describes bombs as differing from grenades, “onely in bigness, because the Granadoes are less, and are cast by hand …” (Moretti 1673:73–74). Fortunately, each passage gives a reference to the propellant for each device as shot or thrown. This means the key to correctly distinguishing mortars from hand grenades, is the propulsion method.

Mortar shells were comprised of diverse materials, each for a specific purpose. Projectiles made of smoothed and shaped stone battered fortified positions well (Moretti 1673:38; Binning 1676:158). Canvas projectiles formed into a sphere, hardened by pitch, and filled with gunpowder, set fire to houses exceptionally well (Sturmy 1669:84; Binning 1676:158; Dawks and Boddington 1701:163). Shells of cast iron, bronze, or brass, filled with gunpowder served as anti-personnel, anti-equipment, and could start fires to structures (Binning 1676:158; Dawks and Boddington 1701:166–167). With several types of projectiles, a bombardment could be customized to inflict the maximum amount of damage.

Early mortar shells were wrapped in cording, to act as an extra buffer between the propellant powder of the mortar and the explosive powder in the shell (Sturmy 1669:84). This method would cover any cracks in the shell, plus reduce windage in the bore. Weights of shells varied with the overall diameter and material type. Tomaso Moretti lists the weights of mortar shells between 50*l* to 100*l* generally, with some larger shells topping 300*l* (Moretti 1673:39). Shells of such large sizes would take up vast amounts of space as assessable stores.

To spatially manage large quantities of stores and large mortar pieces, some sort of uniformity had to be set. In General de Malortie's treatise, the recommended spacing between mortars is 15 feet (Malortie 1824:54). General de Malortie places the effective range of mortars at 140 yards for stone projectiles, but explosive? grenades could reach greater distances (Malortie 1824:86). To great distress, General de Malortie does not mention if these grenades are mortar shells or hand grenades adapted to be shot from mortars, but mortar shells had completely developed into a separate type of shot by the time of his recordings.

Assessable stores were necessary to sustain bombardments. Not only would a constant barrage of exploding shells do physical damage, it will take a psychological effect as well. After a full night of shelling one account relays, "for we could hear some of them in the front of their Army cry, *Dida mouboggel ada orang Hollando*; which is as much as to say, I will fight no Longer against the Hollanders'" (Frick 1700:73). Fear on a battlefield was not new, but the ability to destroy traditionally secure positions was. For this reason, the mental effects of mortar shells must be accounted for.

Petard

Thieves are credited with designing the petard to enter houses or cities. Naturally, the combat effectiveness of this device was noticed by formal militaries and quickly adopted. Petards are an early shaped charge, designed to direct a small blast to a specific area (Figure 5). These devices were mobile and reusable, which made them a very effective weapon when compared to other explosives.

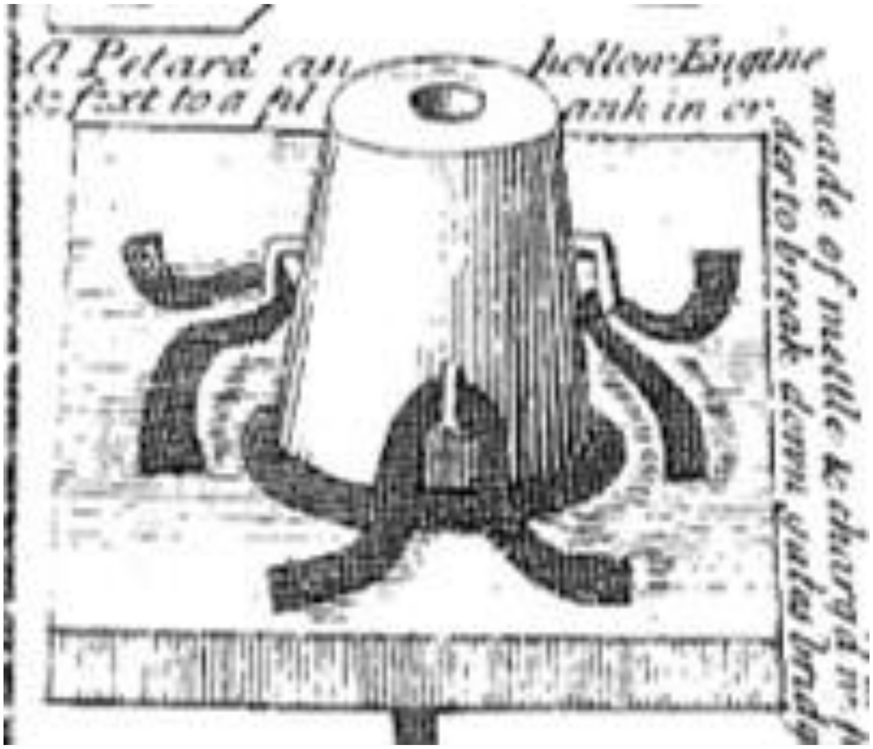

FIGURE 5. Petard set on a mandrill. (Adapted from Faulkner 1747:Plate A).

The basic design of a petard followed that of a mortar or bell, but was much more compact and thinner walled (Moretti 1673:97; Binnington 1676:157). Petards came in several different sizes, specifically dimensioned to penetrate exact obstacles. The mouth is recorded as having a diameter measuring 16” imperial and the breech diameter as 10” imperial, with a thickness of 2” imperial and 1” imperial respectively (Moretti 1673:98). Another source states petards have a length of 12” imperial, a mouth of 10” imperial, a breach of 7 ½” imperial, a thickness of 1 ¼” imperial, with a total weight of 76 ½ lbs (Binnington 1676:157).

Three main materials were used in the evolution of the petard (Moretti 1673:97; Binnington 1676:157). Wood with iron hoops as reinforcement was the earliest. Next iron was tried but proved too brittle, but brass circumvented this problem. Metal composition and resistance to brittleness is crucial to a device used multiple times. Since the petard would inviably become weaker with each use, the amount of powder was reduced accordingly. Moretti lists the weight of powder used for each blast (Table 3) but does not mention if the weight is in pounds or ounces (1673:99). To hold the powder compacted in place, a piece of paste board was inserted on top. The ratio for petard powder is given as: 3 parts fine gunpowder, 6 parts sulfur, and 9 parts saltpeter (Morettie 1673:100). Wax coatings could protect the petard from inclement weather that might otherwise render the device inert. Theoretically, petards could be used for sea service engagements but no sources in this study mention petard use in ship to ship engagements.

TABLE 3
PETARD BLAST NUMBER AND POWDER WEIGHT

Blast Number	Powder Ounces Used
1st	9-10
2nd	6-7
3rd	5-7
4th	3-4

(Adapted by author from Moretti 1673:98).

For the best result, petards had to remain stationary for the blast but a few obvious complications are evident. Foremost is being in combat with projectiles and other defensive mechanisms attempting to repel an assault that included the petard carrying team. A well-placed petard blast could create an entrance for assailing forces, so firepower would likely be concentrated on troops brazenly wielding a petard. Second, the amount of powder used and the deteriorating state of a petard made it just as lethal to handlers as it was to the obstacle being blasted. Lastly, the sheer weight of a brass petard exceeds reasonable expectations for two men to hold for prolonged periods. Therefore, a squared 2’ imperial oak plank, from 3-4” imperial thick, was used to seat the petard and keep it pointed towards or against the intended target (Binning 1676:157). This wooden plank was called madrillo, madrill (Moretti 1673:101), and madrier, with metal plates added to protect the front of the plank (Moretti 1673:101; Faulkner 1747:26, 31).

Powder Chests and Powder Pots

Devices to thwart boarding parties are numerous but not many were concealable. Powder chests were fashioned to be inconspicuous on ship decks and able to be scattered over the entire length of the ship for a strategic defense. The basic design of powder chests was three boards nailed into a triangle, then filled with combustible materials and secondary shrapnel, with the end of the chest capped (Roberts 1639:57; Sturmy 1669:86; Seller 1691:198; Love 1703:189–190; Park 1704:64–66; Mountaine 1744:182–183, 1747:83–83).

Ignition was through a drilled hole, in which a blank pistol could be fired. Following this design, defenders could ignite powder chests from below decks while only boarders were exposed to the blast. Not only would boarders bear the physical brunt of this style of warfare, but mentally as well. Since powder chests were concealable and potentially anywhere, boarders' morale could be diminished completely by a few timely powder chest explosions.

To counter powder chests, powder pots or fire pots were developed to explode and prematurely detonate antiboarding devices. These pots were made of clay or thick glass bottles, filled with gunpowder and ignited by a fuse (Roberts 1639:56; Sturmy 1669:86; Seller 1691:197–198; Love 1703:190; Mountaine 1744:183; 1747:84–85). Earthen powder pots are distinguished by diagnostic ears for attaching match rope (Norton 1643:89–90; Sturmy 1669:86; Seller 1691:197–198; Love 1703:190).

An adaptation to this style of fire pots was to stick a grenade inside an earthen pot for added effect (Moretti 1673:115). Roberts describes the use of powder pots, "[to be] thrown upon the decks, or other where, which will much prejudice the enemy, and many times fire their owne powder-chests" (Roberts 1639:56). The ratio of gunpowder for powder pots and fire pots, is different than other explosive devices. One pound each of gunpowder, saltpeter, sulfur, and

Solomonic was the ratio given by Captain Samuel Sturmy (1669:86). Seller follows this formula with an addition of four ounces of camphor (1691:197–198). If an explosion could prove dangerous, powder pots and fire pots could substitute gunpowder for vile odorous materials as a nonlethal option (Love 1703:190).

Thunder Barrels and Powder Tubs

Eventually the ability to have one explosion and several subsequent delayed explosions was designed. A basic and inventive design was thunder barrels or powder tubs. These were everyday wooden barrels filled with grenades, fire pots, and other explosive devices but each device was protected from the blast of another (Moretti 1673:116; Park 1704:66–68; Mountaine 1744:184, 1747:85). No description exists on exactly how each device was protected from other blasts but they are present in the historical record. The only description to have some insight is through placing other explosives nearby with fuses of varying lengths intertwined with the barrels' fuse (Mountaine 1747:85). This option would set off many smaller explosions nearby but not expose the barrel directly to each blast.

Trunks

The function of a trunk was to explode, releasing balls of wildfire or bullets into the surrounding vicinity. Sources do not indicate what material was used to construct a trunk but describe it as a concave tube, sometimes with spikes on the mouth for fixing the trunk on a wood, stone, or soil target (Roberts 1639:54; Norton 1643:88–89; Binning 1676:161–162). When employed tactically, trunks could ignite houses, ships, or cause disruption to combatant movements.

Wildfire

Balls of wildfire are described as balled lengths of untwisted match cord or hemp rope, treated with varying mixtures of gunpowder (Roberts 1639:55; Smith 1643:104–107). Cannons, mortars, and trunks were the primary devices used to launch balls of wildfire (Roberts 1639:55; Smith 1643:104–107). Wildfire would just be added to any type of explosive charge for added effectiveness in igniting fires. An additional device was the fireball, a thick canvas bag shaped into a hollow ball and filled with gunpowder (Norton 1643: 89; Moretti 1673:112–113; Faulkner 1747:13). The only requirement of these balls was they had to burn when ignited, but alterations could be made to intensify the flame. Treatments with more volatile ratios of gunpowder intensified flames, with drilled holes packed with fine gunpowder as another option (Roberts 1639:55).

Summary

Between the 16th and 19th centuries, explosives evolved into a diverse array of devices. Switching from serpentine to corned gunpowder increase the potential power of explosives. When coupled with inclusions of secondary shrapnel and shell composition, lethality supposedly increased correspondingly. An increase in the size and weight of launched projectiles is visible, while thrown or stationary devices are employed in new tactical scenarios. This helps explosives become an indispensable and decisive technology in military operations.

Explosives developed for very specified applications. Carcasses, mortars, and bombs became the key to bombarding fortified positions from a distance. Incendiary devices like fire arrows, canvas balls, and wildfire had a prolonged burn time and were harder to extinguish. Propulsion of fireworks evolved from bow and arrow, to self-propelled entities. Anti-boarding and anti-explosive technology were also revolutionized, ushering new tactics.

Specialization of explosives, coupled with the standardization of devices, rendered many obsolete or impractical in later centuries. Logistically and empirically, standardized explosives are easier to produce, transport, arm, and have consistent results when compared with improvised devices. The more professional military forces of the 18th and 19th centuries utilized these advantages and clearly identified in the historical record. Furthermore, without newly developed explosive technology, many complex campaigns could not feasibly have been undertaken. For these reasons, the neglected evolution of explosives needs an illumination rivaling a sail lit by a hedgehog.

Chapter 3: Literary Sources and Site Overviews

For the purpose of this study it is necessary to provide brief coverages of literary sources and site histories. The issue with the historical record lies in the researcher's ability to determine fraudulent or embellished accounts. A matter of further complication occurs when these questionable sources are believed correct, creating a false paradigm. Once a paradigm is created and finds widespread support, it is difficult to contradict or critically assess it. Ultimately, this leads to the preservation not of history but of what history is believed to be. These paradigms can go so far as to influence the histories of archaeological findings, going against the very basic nature of that discipline. For that reason, this study negated any possible inclusion of false paradigms by evaluating the artifacts themselves, using only the assumed dates and individual shipwrecks as a means of differentiation.

Primary Literary Sources

Searching the National Archives Database in Washington, D.C., produced no relevant primary documents on hand grenades until the American Revolution in 1776. A search of the British National Archives contained sixteen documents related to grenades, and spelling variations thereof, discounting documents referencing the Grenades Islands. Of the sixteen matches, none mention any account of exactly how grenades were produced. Even the filling of grenades remains cryptic, "I gave the order to Mr. Jones to make the Grenades and Shot, and, I afterwards filled the Grenades myself, which is a secret art…. I learned the art of filing Grenades after I had served my Apprentiship…." (NA 1820).

Quantities of munitions upon ships and in garrisons are not uniform but does follow some general traits. When *Descent Frayne* left port in 1702, she carried 4000 hand grenades for the voyage (NA 1702). No mention about the nature of the voyage was given but this number seems extremely high for just ship use. A few years later, another large quantity of 5000 grenades were ordered but it is unclear if they were issued to the three bomb ketches or some five hundred men to be raised (NA 1711). Compared to the garrison at Carlisle, which only had 114 total grenades in their armory (NA 1746), these numbers seem extremely high. Clearly the quantity taken aboard *Descent Frayne* was outside normalcy for use solely upon one ship.

Regulations from this era direct 300 grenades for 1st rate ships of the line after the English navy ordered the number doubled in 1706 (NA 1706). The number declined regularly with the ship's rating. As the century passed, ships increased the quantity of grenades, shown by the sloop *Wolf* 's arsenal of 100 grenades in 1742 (NA 1742). What can be surmised is that large shipments of grenades as on *Descent Frayne,* were for transport and later dissemination. In this practice of transference, grenades captured from other nationalities are likely to be used in conflicts the parent nation was not directly involved in. One source mentions the capture of French and Spanish ships whose grenades were sent for use on the Swedish and Russian fronts (NA 1719). A practice such as this should be considered in future research aimed at identifying where the grenade was made, versus where it was recovered and the suspected user.

Contemporary military manuals and fighting instructions indicate the use of grenades during engagements on land and sea. A clear division is evident in many manuals, denoting a transition from clay or glass grenades in favor of cast iron (Norton 1643:87–88; Sturmy 1669:8; Seller 1691:196–197; Love 1703:188–189; Park 1704:63–64; Mountaine 1744:181–182; Faulkner 1747:19). Another contemporary movement was standardizing cannon, cannonballs, and shoulder arms. From the literary record, it is unclear if grenades follow a similar effort of standardization but a thorough study of the material record may elucidate this missing information.

Secondary Literary Sources

A plethora of secondary literary sources exist about the use of grenades and their history. So far, the most comprehensive is *Boarders Away II* by William Gilkerson (1993). Gilkerson details storage, size ranges, distances thrown, and transportation during combat. Overall, *Boarders Away II* provides a great overview on grenades. The main drawback lies in what is cited and what is not. Differences over what is common knowledge and what should be cited plague many books with excerpts on grenades. One of the most commonly cited authors is Charles Ffoulkes. When Ffoulkes authored *The Gun-Founders of England* in 1932, he described the history of cast iron grenades on one page and cited no sources, commonplace in his era (Ffoulkes 1937). A. N. Kennard builds upon Ffoulkes' history, but the origin of the differences in grenade histories are not cited (Kennard 1986). Such scholarship has established an incomplete record of undocumented history, but without proper citations those sources cannot be evaluated for trustworthiness. In turn, this has led to creating false paradigms in which an uncited historical account is believed as true and becomes the "common knowledge" authors no longer provide citations for.

1715 Spanish Plate Fleet Wrecks

During the War of Spanish Succession, monetary resources in Spain were low due to disruptions in treasure convoys, from weather, and privateers. On 24 July 1715 the *Flota de Indias* (NPS 2019a), the combined *Tierre Firme* and New Spain fleets, twelves ships, departed Havana port for to Seville (NPS 2019b). A hurricane caught the *Flota de Indias* six days later, wrecking all but one ship off the Florida coast. Contemporary salvage efforts were made by the Spaniards, who recovered over half the specie listed on the manifest (NPS 2019b).

Four shipwrecks from this fleet are in the present study. They are listed as Cabin Wreck, Corrigan's Wreck, Douglass Beach Wreck, and General. Protection of each wreck is mandated by state legislation to prevent unpermitted disturbances, preserving these wrecks for future generations and researchers. The Bureau of Archaeological Research in Tallahassee, Florida, curates artifacts recovered from these wrecks. It was at this facility that measurements of the *Flota*'s grenades were taken.

Beaufort Inlet shipwreck (31CR314) Perhaps the best known ship, related to one of the most infamous pirates, is Beaufort Inlet shipwreck (31CR314) supposedly *Queen Anne's Revenge*. Originally a French slave ship named *La Concorde*, this ship was taken at sea by Blackbeard in 1717 (NCDNCR 2019c). *La Concorde* was renamed *Queen Anne's Revenge*, serving as Blackbeard's flagship until it ran aground at Beaufort Inlet in 1718 (NCDNCR 2019a). Afterwards the ship was stripped of most armament, specie, and the crew abandoned it.

Rediscovered in 1996, the wreck was confirmed by "18th century artifacts, nine cannon tubes, and two large anchors" (NCDNCR 2019b). This unsubstantiated evidence caused the wreck to be listed on the National Register of Historic Places (NRHP) in 2004. Since then continual systematic excavation, conservation, and curation has been performed by the North Carolina Department of Natural and Cultural Resources (NCDNCR). A research lab was established in Greenville, North Carolina, on the West Research Campus of East Carolina University, where the grenades from this ship's collection were measured.

1733 Spanish Plate Fleet Wrecks

The story of the 1733 wrecks is very similar to the 1715 *Flota*'s, except for the obvious passage in time. On 13 July 1733, the *Flota de Indias* compose of four armed galleons, eighteen merchant naos, and an unknown number of smaller ships, departed the Havana for Seville (BAR 2006:7). When the weather abruptly changed the next day, the fleet was ordered to return to Havana to escape an impending hurricane. Unfortunately, *Nuestra Senora de Rosario* was the only ship to return to port, while the remainder perished in the hurricane (BAR 2006:7). Relief efforts were made to rescue survivors and salvage the wrecks as best they could. Cartographers charted the wreck locations and years of exhaustive salvage operations, produced more cargo recovered than was listed on the ship manifests (BAR 2006:7).

Three of these shipwrecks are in the current study and listed on the NRHP, *San José de las Animas* in 1975, *San Felipe* in 1994, and *Nuestra Señora de las Angustias* in 2007. Each wreck is protected by federal and state statues from unlicensed disturbance but can be visited as an underwater heritage trail (BAR 2005). Artifacts recovered from each wreck are curated in the Bureau of Archaeological Research in Tallahassee, Florida, where the measurements of grenades were taken.

Chapter 4: Experimental Methods

Three grenade collections of meet all the established criteria. Those collections are: the 1715 and 1733 plate fleet wrecks in Florida, the *Whydah* in Massachusetts, and the *Queen Anne's Revenge* in North Carolina. Fortunately, the geographic coverage represents several areas along the North American Atlantic coast as well different nationalities and pirates. Controversy surrounds two wrecks, *Whydah* for archaeological integrity, and the identity of the supposed *Queen Anne's Revenge* (Miller et al. 2005:339—341; Moore 2005:335—339; Rodgers et al. 2005:24—37; Wilde 2006:160—195). The controversies surrounding these wrecks are outside the focus of this study because they do not pertain directly to grenades and will not be included.

Data from each collection was gathered by several methods. Each grenade was recorded using an individual form (Appendix A). These forms outline each measurement in a step by step fashion, with a reference diagram to consult for specific terminology. Using calipers, basic measurements were taken to compare each shipwreck and fleet individually, in addition to as a whole. The interior cavity of the grenade was recorded by water if still in wet conservation or if in dry conservation, by measuring the level of beads it can hold. These measurements are crucial to determine ideal averages for each grenade aspect, allowing relationships between grenades to be explored. Furthermore, each replication and projected blast effect depended upon these averaged measurements. Available fuse plugs were subjected to the same recording methods both in and separated from their correlating grenade.

Once the measurements and readings were recorded, they were analyzed in SPSS. Variance within each collection was factored to determine if the grenades hail from one population or multiple. A high level of variance or a bimodal distribution is indicative of multiple populations whereas a low level of variance or normal distribution is indicative of one population. Comparisons between assemblages show how greatly each differs. This had a result of significant variation to show different origins of production for each collection or that each assemblage had different base models for grenades.[1] A Levene's test for homogeneity shows if groupings exist, with a Tukey-Kramer test showing the significance between groupings. These results will also answer the research question of the extent grenades vary between nations.

Once completed, the experimental phase began. The most average grenade was replicated in cast iron and glass, to compare the lethality of the material types. Glass grenade shells were replicated at ECU's Glass Station in Farmville, North Carolina. Cast iron grenades were replicated in Greenville, North Carolina.

The use of gunpowder created another complication. Ideally gunpowder based upon contemporary historical formulas would be created, imitating experiments by the Medieval Center in Nykøbing Falster, Denmark. Production of gunpowder is extremely dangerous and illegal without proper licenses, therefore in concern for safety and legality commercial manufactured powder was used. Specifically, GOEX black powder was used since they follow a similar formula for gunpowder produced in AD 1801 and this powder is commercially available. Gunpowder is graded by granular size to denote the explosive force generated. Historical documents indicate the use of "fine gunpowder" (Norton 1643:87–88; Mountaine 1747:116; Muller 1747:152) in grenades. Without a clear definition of "fine gunpowder" FFg musket grade powder was used in this study, because gunpowder for muskets was available on ships in larger quantities than more refined rifle or pistol gunpowder.

For detonation the grenades were taken to an approved federal explosive range on Marine Corps Base Camp Lejeune. Federal military explosive ranges have highly trained Explosive

[1] Mortars and grenades are thought to have been wet sand casted using a wax or clay mold to form the cavity.

Ordnance Disposal Technicians to oversee the handling, arming, detonation, and disposal of unexploded ordnance, along with an established safety protocol. This was the safest option for all participants and complied with federal regulations (Zipf and Cashdollar [2010]:1).

A wide spectrum of measuring devices was necessary to fully document and evaluate a grenade blast. Using ballistic gelatin torsos as "witnesses" provides ideal targets to evaluate shrapnel effects and visualize concussive force. Models with representative skeletal structures and organs would provide the best trauma evaluation because it would be visually evident but were not available. Clear ballistic gelatin torsos without any inclusions were used and still recorded the same data but with less visual representation. Ballistic gelatin torsos are very expensive, so only one was used for each test with additional wooden witnesses as alternatives at various distances. Concussive force generated by the blast determines the extent of trauma to the body, often with minimal visual indicators. To record these levels, pressure film was placed on each witness. High-speed visual recording devices were used to document every stage of the blast for later detailed evaluation.

Each recording device on the range was set in a systematic fashion. A designated position on the deck indicated where to place the grenade and served as the reference point for other recording equipment. First, the targets were placed around the grenade. Witnesses was placed at varying interval of 1 m, 3 m, and 5 m, elevated to make the notional height 5' 10". Pressure film was placed under each witness with nothing obstructing the path to the point of explosion. The high-speed camera and a backup camera was placed far enough out of range from the blast, but in focus to appropriately record the entire blast. A test of all equipment was performed and upon successful completion, a grenade was made live by the Explosive Technicians. Afterwards, an electric detonation device was installed, the grenade placed in position, and the detonation device made ready. At this point the federal personnel oversee the range and all safety protocols was adhered to. After detonation, the targets and all equipment was checked, the data collected backed up, and necessary adjustments or replacements made. Another check was performed to ensure the entire pre-detonation criterions mentioned above are met, the steps are taken exactly as previously done, and repeated for every blast.

Explosion data was analyzed to determine the lethality of 18th century grenades. Visual observation of the targets will indicate of the amount of shrapnel present for each blast. A medical examination was performed on gelatin torsos to ascertain if the internal damage is lethal or not. The pressure film will indicate the force generated by the blast at each distance. This can then be applied to modern theoretical models of tissue and organ damage caused by explosions. Modern blast studies have shown behavioral alterations attributed to PTS and TBI but no concomitant historical study has been performed to see if these behavioral alterations are presented by those individuals exposed to blasts or their culture’s acceptance of these behavioral alterations.

Chapter 5: Data Collection and Analysis

Creation of a comprehensive taxonomy required several steps, but in this study, three were used. First was data collection, where several artifacts were measured systematically. Of course, this system of measurement encompassed every aspect and measurement the artifact possessed. Second, this data was catalogued and categorized for statistical analysis. A thorough organization of data helped with the more complex algorithms when the data was processed to demonstrate or disprove relationships. Third, a predictive model was made by inputting corresponding mean values for missing data. Inputting values in this manner allowed for a narrower range and better defined relationships between assemblages.

Collection Methods

As mentioned in previous chapters, three collections were measured for this study. They were: the Beaufort Inlet shipwreck (31CR314) at the Queen Anne's Revenge Laboratory (QARL) in Greenville, North Carolina and the 1715 and 1733 Spanish Plate Fleet wrecks at the Bureau of Archaeological Research in Tallahassee, Florida. In total 60 grenades were measured, each under an identical systematic approach. Missing data was due to the variance in conditions of preservation for each artifact.

Ideally each grenade would be completely intact, yet that was not reality. Broken and missing pieces occurred in several grenades, presumably due to damage while in-situ, stabilization, or from decades of storage and moving. When possible, accurate measurements were extracted from damaged grenades. This included measuring a fuse hole on a broken piece, weighting all broken pieces for total weight, or refitting pieces together to determine interior cavity size. If there was no possible manner to accurately collect the data, it was left blank and given no value in the organization table.

For ease of collection in this and future endeavors, a form with diagram was created listing all the measurements to collect (Appendix A). A quick explanation of each measurement provides clarification and ease of reference, with everything dependent upon fuse hole orientation. Mold seam refers to the line left from the casting process relative to the fuse hole. It indicates how the sand cast mold halves were situated in construction. It is possible these seams were removed intentionally, as in cannonball construction, possible options are: not visible, vertical, horizontal, or unknown.

Both vertical and horizontal overall dimensions (OAL V and OAL H) are necessary to determine their spherical accuracy and denote irregularities. Similarly, fuse hole minimum and maximum diameters (Min Fuse Dia and Max Fuse Dia) elucidate circular accuracy and irregularities. Weights for each grenade, complete with broken pieces, were taken as a means for comparison against the other factors. Likewise, a grenade's cavity volume (Internal Cavity) were recorded with the same intent as the weight. Grenades conserved in water were filled with water and the volume measured, but if the state of conservation was dry, then small spheres were inserted and measured to calculate volume.

General Statistics

Overall this study has 60 cases from 8 shipwrecks, enough for a good sample size towards the aim of this study. Not every measurement was extracted from each case, primarily due to extensive damage. Therefore, no value was input for that measurement when it could not be recorded. To create the predictive model means were inserted in in place of missing values; this is indicated in the text.

TABLE 4
GENERAL DESCRIPTIVES FOR ALL SHIPWRECKS

Measurement	Mean	Minimum	Maximum	Standard Deviation
OAL V	78.09	48.20	120.6	13.91
OAL H	80.86	48.00	119.80	10.11
Min Fuse Dia	17.29	10.00	34.4	3.78
Max Fuse Dia	17.92	10.70	39.90	4.03
Internal Cavity	97.21	10.00	240.00	41.89
Weight	655.54	93.5	4300.00	601.22

*All measurements are in millimeters, milliliters, or grams respectively. (Source: author)

Although the statistics for all cases (Table 4) give good parameters, they do not show any comparisons between assemblages. Dividing the cases into their respective shipwrecks showed variance between assemblages (Table 5). Within each assemblage, means for each were input for missing values to create a prediction of what those values would be if measurable. Since mean range for each assemblage was very small and the datasets defined in totality of known artifacts for each assemblage, the likelihood of skewed data from this was extremely low. This antecedent improves accuracy of the tests, but it was necessary to eliminate wrecks with less than three grenades from the remaining tests, resulting in *n*=56, for higher accuracy.

TABLE 5
MEANS BY SHIPWRECK

	OAL V	OAL H	Min Fuse	Max Fuse	Int. Cavity	Weight
Cabin	91.53	92.26	19.56	20.13	140.00	1216.67
Corrigan’s	74.10	74.66	12.80	14.38	55.00	581.25
Douglass Beach	80.10	80.40	10.90	11.80	40.00	400.00
General	76.80	78.13	16.05	16.50	72.50	277.16
Beaufort Inlet shipwreck (31CR314)	69.72	77.53	17.84	17.94	94.71	707.57
San Felipe	79.52	81.08	17.87	18.39	116.57	528.91
San Jose	101.55	105.30	26.00	28.8	120.00	2525.00
San Rafael	85.00	87.20	16.50	16.90	40.00	1200.00

*All measurements are in millimeters, milliliters, or grams respectively. (Source: author)

Variance between each wreck was demonstrated and the question became whether this variance was significant. To determine significance, an analysis of variance (ANOVA) was performed by wreck (Table 6) and fleet (Table 7) as those are the assemblages where association was sought. The results showed differences between each variable according to measurement factor was significant to the .05 level.

TABLE 6
ANOVA BY SHIPWRECK

ANOVA – Wreck		
Variable	**F Value**	**Pr > F**
OAL Vertical	3.87	0.008*
OAL Horizontal	3.58	0.012*
Max Fuse Diameter	8.56	<.0001*
Min Fuse Diameter	14.84	<.0001*
Cavity Volume	11.38	<.0001*
Weight	5.12	0.0015*

** Significant at .05 level* (Created by Danielle Martin)

TABLE 7
ANOVA BY FLEET

ANOVA – Fleet		
Variable	**F Value**	**Pr > F**
OAL Vertical	0.65	0.5248
OAL Horizontal	0.87	0.4244
Max Fuse Diameter	6.31	0.0035*
Min Fuse Diameter	8.05	0.0009*
Cavity Volume	8.97	0.0004*
Weight	0.98	0.3808

** Significant at .05 level* (Created by Danielle Martin)

A Levene's test for homogeneity organized by wreck (Table 8) and fleet (Table 9) was then used to determine if the variables can be grouped. Results are significant at the .01 level for both wreck and fleet assemblages. A Tukey-Kramer test best illuminates non-significant differences between populations through groups, organized by wreck (Table 10) and fleet (Table 11).

TABLE 8
LEVEN’S TEST FOR HOMOGENEITY BY SHIPWRECK

Levene's Test for Homogeneity of Variances - Wreck				
Variable	**Levene Statistic**	**df1**	**df2**	**Sig.**
OAL_Verticle	0.729	4	51	0.577
OAL_Horizontal	0.952	4	51	0.442
Fuse_Dia_Max	2.266	4	51	0.075
Fuse_Dia_Min	3.537	4	51	0.013
Cavity_Volume	1.149	4	51	0.344
Weight	1.573	4	51	0.196

*Significant at .01 level (Created by Danielle Martin)

TABLE 9
LEVEN’S TEST FOR HOMOGENEITY BY FLEET

Levene's Test for Homogeneity of Variances - Fleet				
Variable	**Levene Statistic**	**df1**	**df2**	**Sig.**
OAL_Verticle	0.699	2	53	0.502
OAL_Horizontal	0.242	2	53	0.786
Fuse_Dia_Max	1.212	2	53	0.306
Fuse_Dia_Min	3.101	2	53	0.053
Cavity_Volume	0.986	2	53	0.38
Weight	3.053	2	53	0.056

*Significant at .01 level (Created by Danielle Martin)

TABLE 10
TUKEY-KRAMER GROUPING BY SHIPWRECK

OAL Vertical Means with the same letter are not significantly different.				
Tukey Grouping		Mean	N	Wreck
	A	91.533	3	Cabin Wreck
B		79.521	27	San Felipe
B		76.8	6	General
B		76.455	11	Beaufort Inlet shipwreck
B		74.1	9	Corrigan Wreck

Max Fuse Diameter Means with the same letter are not significantly different.					
Tukey Grouping			Mean	N	Wreck
	A		20.133	3	Cabin Wreck
B	A		18.396	27	San Felipe
B	A		17.845	11	Beaufort Inlet shipwreck
B		C	16.05	6	General
		C	14.388	9	Corrigan Wreck

OAL Horizontal Means with the same letter are not significantly different.				
Tukey Grouping		Mean	N	Wreck
	A	92.267	3	Cabin Wreck
B	A	81.084	27	San Felipe
B		78.133	6	General
B		77.536	11	Beaufort Inlet shipwreck
B		74.663	9	Corrigan Wreck

Min Fuse Diameter Means with the same letter are not significantly different.					
Tukey Grouping			Mean	N	Wreck
	A		19.567	3	Cabin Wreck
B	A		17.945	11	Beaufort Inlet shipwreck
B	A		17.873	27	San Felipe
B			16.5	6	General
		C	12.8	9	Corrigan Wreck

Weight Means with the same letter are not significantly different.				
Tukey Grouping		Mean	N	Wreck
	A	1216.7	3	Cabin Wreck
B		707.6	11	Beaufort Inlet shipwreck
B		600.5	9	Corrigan Wreck
B		528.9	27	San Felipe
B		277.2	6	General

Cavity Volume Means with the same letter are not significantly different.					
Tukey Grouping			Mean	N	Wreck
	A		140	3	Cabin Wreck
B	A		116.58	27	San Felipe
B		C	94.71	11	Beaufort Inlet shipwreck
		C	72.5	6	General
		C	57.58	9	Corrigan Wreck

(Created by Danielle Martin)

TABLE 11
SIGNIFICANT TUKEY-KRAMER GROUPING BY FLEET

Max Fuse Diameter Means with the same letter are not significantly different.				
Tukey Grouping		Mean	N	Fleet
	A	18.396	27	1733
B	A	17.8455	11	1718
B		15.9864	18	1715

Min Fuse Diameter Means with the same letter are not significantly different.				
Tukey Grouping		Mean	N	Fleet
	A	17.9455	11	1718
	A	17.8727	27	1733
B		15.2636	18	1715

Cavity Volume Means with the same letter are not significantly different.				
Tukey Grouping		Mean	N	Fleet
	A	116.58	27	1733
B	A	97.71	11	1718
B		76.29	18	1715

(Created by Danielle Martin)

Results

As the tables show, the results of each test were significant to various degrees. Once the cases were divided into wrecks as subsets within a fleet, the means show even greater diversity between assemblages. With the elimination of clear outliers, populations of less than three, the input of means in place of missing values, the remaining tests showed a higher degree of significance. Results from the Tukey-Kramer groupings best show the significant relationships between populations. In the Tukey-Kramer groupings by fleet, the Beaufort Inlet shipwreck (31CR314) aligns with the 1715 and 1733 fleet wrecks on all variables except minimum fuse diameter. Even when sorted by wreck, the Beaufort Inlet shipwreck groups with both fleets. This was interesting because the fleet wrecks were Spanish whereas the Beaufort Inlet shipwreck was a pirate primarily manned by English, but the ship may have been French prior to piracy. Therefore, a mixture of grenades sourced from multiple nationalities was expected. A significant overlap like this suggests several possibilities about the grenades recovered from the Beaufort Inlet shipwreck: they are Spanish in origin, differences between grenades of different national origins are not significant on their own, and/or the Beaufort Inlet shipwreck is not *Queen Anne's Revenge*. Answers for this overlap can determined by expanding this study with more cases, from multiple wrecks, and containing time periods outside the scope of this study.

Chapter 6: Replication and Detonation

With a dearth of historical sources on grenade production coupled with a plethora of unreliable historical accounts on grenade lethality, not much accurate information exists. However, accurate information was gleaned from experimental archaeological techniques of replication and detonation of grenade shells. Replication of shells provided insights into the production challenges of a grenade shell. Only one shell was produced at a time and the challenges encountered may be offset in the production of multiple shells simultaneously, however, with no known historical sources on the subject these challenges remain elusive without attempted replication. Detonation provided empirical data on grenade lethality, to negate inaccuracies in historical accounts. Successful recordation of lethality provided a framework to identify inaccuracies and falsehoods. The experimental phase of this study answered many research questions and provided potential future research.

Glass

On 8 November 2017 at ECU's GlassStation in Farmville, North Carolina, Michael Tracy oversaw the replication of the glass grenade shells. Modern equipment for glassblowing was used but was not much different than that used in the 18th century. Tools consisted of a blowpipe, calipers, and a wooden block mold. A furnace and cooling rack, powered by natural gas, were used but still follow the same principles their 18th century counterparts but took advantage of the modern convenience of natural gas regulation.

In general, the process of glassblowing has remained relatively similar over the centuries. A furnace heats the materials to make molten glass, collected by the blowpipe. Once on the blowpipe, the glass glob began to solidify and periodically required additional heat. When not being worked, glass was reheated by a separate furnace and flame, then transferred directly back to being worked. After collection and heating, air was blown through the pipe to create an interior air bubble (Figure 6). Creating a large enough air bubble was critical shape the glass.

To shape the exterior glass into a sphere, a wooden block was used. This block had a cavity for the glass to sit within as it was shaped to the specified measurements (Figure 7). During this process, heat had to be retained, the glass had to be kept spinning, and air added to the interior as necessary. Once all the proper dimensions we met, the shell was broken off the blowpipe and cooled on the rack for 24 hours. Clearly, proper oversight and instruction from an experienced glassblower was essential for the entire process and the reason for its' success. Yet under direction, a complete novice can successfully create a grenade shell.

FIGURE 6. Creating the air bubble in the glass shell. (Photograph courtesy of Michael Tracy).

FIGURE 7. Shaping the glass shell into form. (Photograph courtesy of Michael Tracy).

Overall, 6 glass shells were made to the dimensions averaging an external diameter of 3" and a ¼" thickness, then cooled for 24 hours. Each took roughly 15 minutes to produce from collection until placed in the cooling rack. Using this as a model for production potential, in a

48-hour window a total of 96 grenades can be made and ready for use. This total was accomplished by novice glassblowers, at a factory with 24 operations, and a 24 hour cooling down period, but the numbers are quantifiable. An experienced glassblower making these shells would decrease production time and increase the output appreciably.

Cast Iron

Casting iron shells was an entirely different process. A 3d model was made to use as a pattern for greensand casting (Figure 8). Other required materials were: greensand, a locking sand box, blast furnace, crucible, tongs, and cast iron. Suitable locations to cast were readily available because the propane blast furnace was self-contained and built to be mobile. Mobility does sacrifice heat retention after multiple use but to a small degree, although upkeep on the heat retention material corrected this issue.

For the process of sandcasting iron shells, many steps were taken simultaneously. The cast iron was heated in the blast furnace until liquefied, generally an hour with this furnace. This entailed placing the cast iron in the crucible, lighting the furnace, placing the crucible in the furnace, and enclosing the furnace with the lid. As the metal was heated, all the other processes were undertaken.

To make the mold for the liquid iron, greensand was packed into a box half. When the box was almost full, the three dimensional pattern was placed in the half and then sand packed in the remaining space. Once flush, the second half of the pattern was placed to make the full shell form. The other box half was placed on top, packed with greensand, and leveled off. Once level, the halves were separated, and the pattern removed, leaving a negative of the future grenade's shape. A sprue and pour hole were cut into the top half, creating a place to add the liquid metal and an escape for air displaced by the rising metal.

FIGURE 8. Three dimensional printed grenade shell pattern set in greensand. (Photograph by author).

To make a hollow sphere, a core had to be inserted. A mixture of greensand and non-iodized salt was packed into the core, and around a wooden rod. Salt absorbed the moisture in the sand, increasing the rigidity of the core (Figure 9). Once dried, the core was inserted into the top half with a wooden rod through the sprue hole. Small pieces of cast iron encompassed each side of the core, ensuring the correct position. The halves were then rejoined and locked so as not to move when the metal was added.

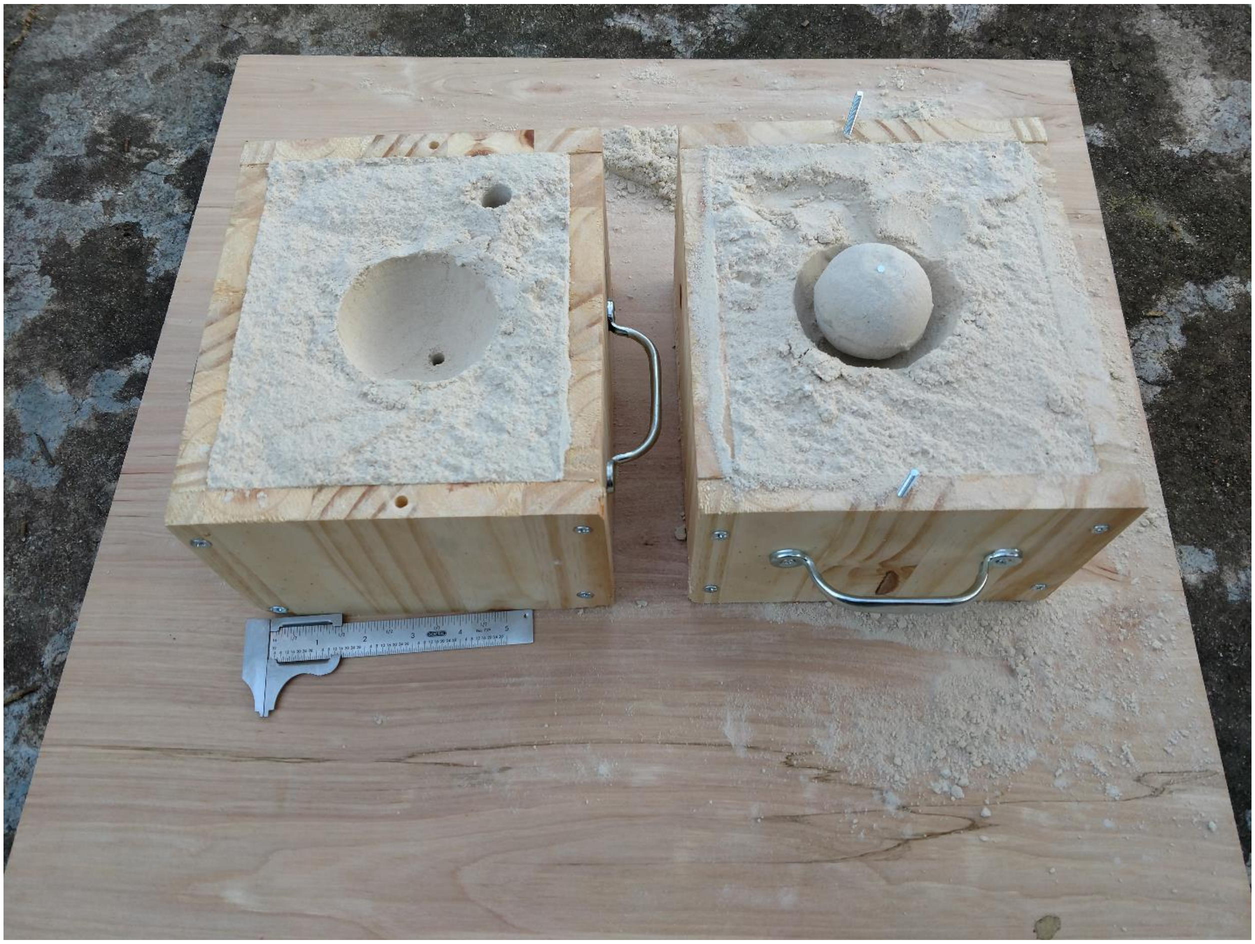

FIGURE 9. Salted sand core in the casting void. (Photograph by author).

When the metal was added through the pour hole, it rapidly solidified but remained extremely hot for another hour. The box halves were separated and the hardened greensand broken to reveal the cast. Removal of the wooden rod and core were the next step. The last step was to remove flashing protrusions from the pour hole and mold seams to finish the shell. Many complications plagued the pours, mainly with the iron solidifying before fully enclosing the core. The rapid cooling left large holes in the shell rendering it useless for blast test purposes. Unfortunately, a successful cast was never made for this experiment, but the failures revealed complications in the production process and a general production time.

Regarding production time, the entire cast iron process takes much less time than the glass. What takes 24 hours and 15 minutes in the glass process, was achieved in two hours with cast iron. For production of individual shells, glass was much more expedient. Therefore, in the same 48-hour period, only 24 cast iron shells can be made using this single shell process. Substantially less than the overall glass production, four times less. But the possibility of incomplete castings was a major detraction and has no counterpart in the glass production. In the 18th century, grenades were mass produced on a much larger scale, and with much hotter metal. For the blast test, a cast iron reproduction was procured from a reenactor vendor with an external diameter of 2.75" and a thickness of ¼".

Detonation

To safely perform the detonation, a federal explosive range was booked. Thankfully, the Explosive Ordnance Disposal (EOD) unit at Marine Corps Base (MCB) Camp Lejeune volunteered the use of their range and EOD team. On 21 March 2018, equipment for the test was packed and taken to MCB Camp Lejeune in Jacksonville, North Carolina.

On the range, everything was set up following the plan outlined in the methods chapter. A central focal point was chosen, with the witnesses placed in their appropriate positions. Pressure film accompanied each witness. A video record was achieved using the Photron mini UX100 Highspeed camera recording at 4k/fps, and a Cannon Powershot ELPH 180 recording at normal speed. All equipment was double checked before the shells were made live.

Arming the shells consists of several small steps to ensure safety. First, 3–4 oz. of FFg black powder was poured into the grenade as indicated in the historical record (Norton 1643:87–88; Mountaine 1747:116; Muller 1747:152). An electric match was then inserted to serve as the igniter, along with shock cord as a second ignition system. These cords were then unspooled until everyone was behind the safety zone, where they were made ready. A last check of the cameras was made for proper operation. Finally, the electric match was initiated, to detonate the shell.

The glass shell was detonated first, then the cast iron. Historically, glass shells underwent alterations to improve their lethality and these alterations were undertaken as part of the experiment (Smith 1653:67; Sturmy 1669:85; Seller 1691:197–198; Love 1703:188–189). Essentially, a cord was wrapped around the shell after covering it with tar, half cut musket balls were tarred to the cord, and the entire device sewn into a canvas wrapping. The cast iron shell does not need secondary alterations, so none were used in this experiment.

Post Blast Investigation

Results of the detonation were interesting between the two shell types. Musket balls, part of the glass shell alterations, were scattered around the point of blast in a 30 cm radius (Figure 10). One small glass shrapnel penetrated an inch into the ballistic gelatin torso, on the right lower abdomen (Figure 11). The placement and depth of the shrapnel was not lethal by itself but complications in removal or healing have the potential to make it lethal. None of the pressure film indicated reaching 7 psi (the lowest end of the film's scale) or above. Yet the video recordings indicate a 5 psi rating because of the audible pop created by the blast. Regrettably, the high speed camera lost power in the data transfer to cause the system to reset, which automatically deleted the footage.

For the cast iron, no shrapnel was recovered or observed. The pressure film showed results similar to the glass shell as less than 7 psi was recorded. Again, the footage indicates reaching a 5 psi level because of the audible pop. Unfortunately, the highspeed camera failed again due to power loss in data transfer.

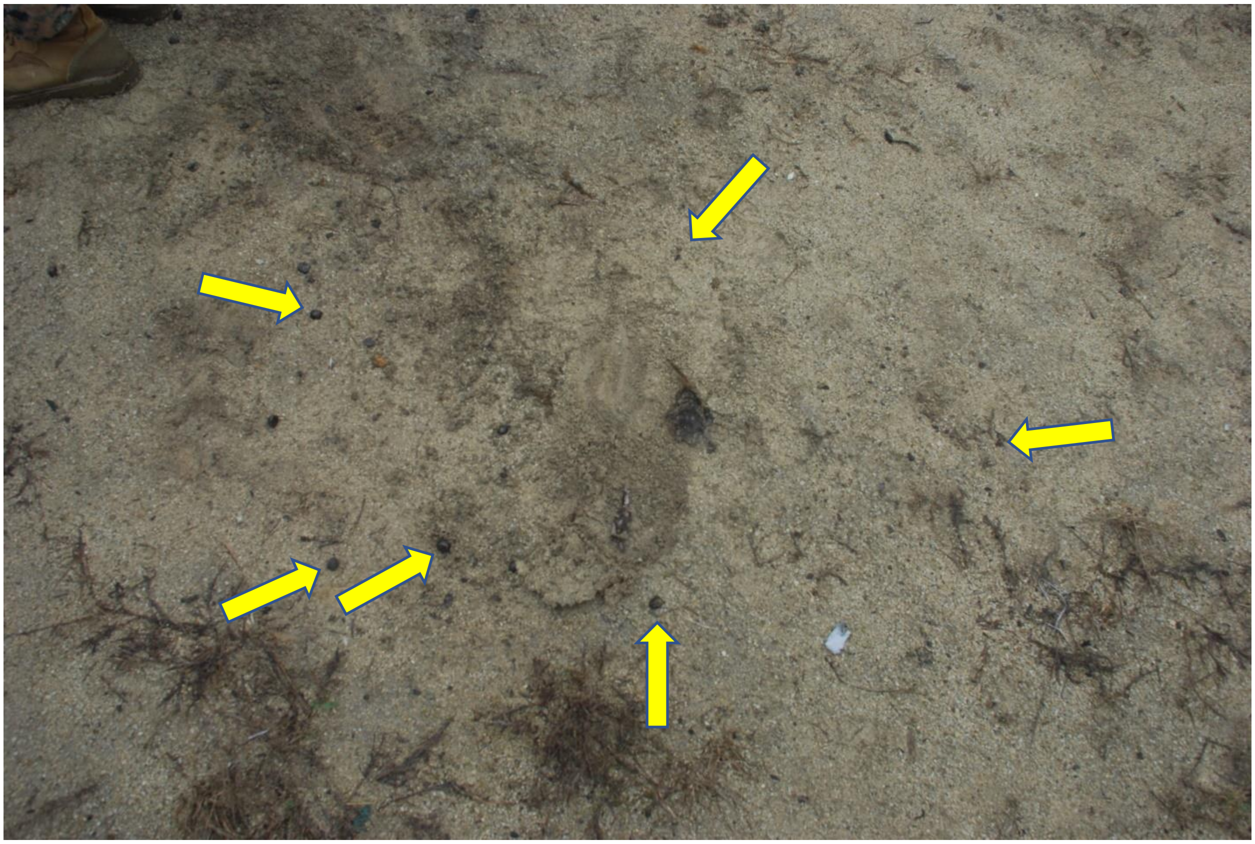
FIGURE 10. Post blast half cut musket balls in 30cm radius. (Photograph courtesy of L. Babits).

Despite malfunctions, the experiment was a success. Each shell type had both similar and different results, to show consistency in overall design but individual features depending on material type. Cast iron did not prove as lethal as glass shells, but not appreciably lower. A fragmentation test is necessary in the future to better define the casualty radius than this experiment could perform. Better pressure sensors can be used to record the blast overpressure with greater precision. With these two adjustments, a future test will provide more complete data than was possible with this test.

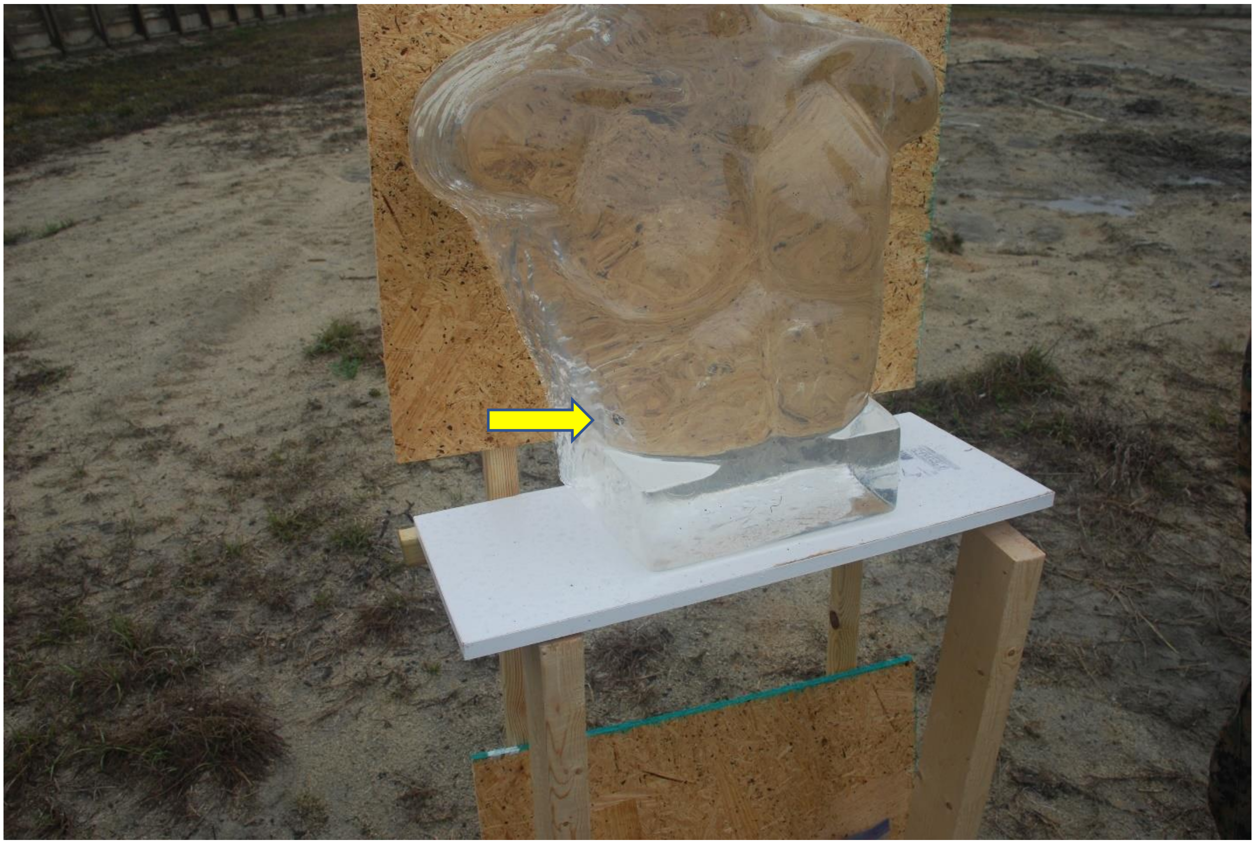

FIGURE 11. Glass shrapnel in ballistic gelatin torso lower right abdomen. (Photograph courtesy of L. Babits).

Chapter 7: Conclusion

Throughout this study, each step contained a compartmentalized conclusion. Now each factor is decompartmentalized and a wider holistic view of their collective meanings taken. Only then are research questions answered to the extent possible by this study. For simplicity discussions will follow chronologically in the order the chapters appear throughout the study.

Within the introduction, the research questions were outlined as to the purpose of the project. Simply restated, the purpose of this study was to determine the feasibility of a taxonomy of grenades and to determine their lethality through experimentation. Both aims are discussed in detail below, but they were answered. Although more questions have arisen in this study, examination of those questions requires additional study, with refined research questions.

In the broad historical overview of explosives, patterns emerged. Different types of explosives morphed into special functions but later reunited as multipurpose. Evidence of this in hand grenades was found in their different forms: explosive, fireballs, and stinkballs. Each type strived for the same outcome of disruption or incapacitation, with only the actual method of execution differing. Differences between a mortar and a grenade seems to have relied solely upon size and weight of the shell. Exactly when, where, and what parameters for this determination would benefit from a more focused study.

Exaggerations in primary sources obscure accurate battlefield conditions. In turn, later authors build false paradigms based on inaccurate information, compounded by subsequent studies based upon these falsehoods. Warped interpretations eventually become accepted reality to make any critical assessment instantly asinine. Nonetheless, critical assessments need to be performed and as this study shows, irrefutable results can change the narrative.

Detailed reasoning for methods, data collection, and analyses allows others to review or replicate the work. Ideas can be shared and improved upon with transparency. With this study, the datasets were grouped with high levels of significance. This means a taxonomy was feasible but requires a larger sample, broader geographic area, and longer timespan for optimal results. Hopefully, a multinational collaboration effort can be made in examining collections at a local level and the information sent for assessment. By far the biggest issue was the dates associated with each collection, identifying a much wider problem within the discipline of sometimes dating sites haphazardly. Discrepancies can be identified when groupings matched multiple date ranges on several categories.

Replication and experimentation produced several new questions and highlighted the issues present in false paradigms. Production methods for grenades are unknown, as are the reasons for the transition between shell materials. As this study showed, the transition to cast iron was not cost effective in terms of manpower, time expenditure, or lethality, but the shift happened. There must be an unknown factor not accounted for, which explains the transition. Detonations showed how limited lethality was, to expose the inaccuracies in primary accounts through empirical evidence. Recommendations for improvement on future tests and different types that can be subjected to similar tests were given. Additional tests may show more aspects which should be considered or different research questions to explore. Either are welcomed so long as safety protocols and local laws are followed.

One discussion outside this study's scope, is psychology of warfare and how it affects rational thought. Modern studies on Post Traumatic Stress (PTS) and Traumatic Brain Injuries (TBI) outline specific contributing factors. Many contributing factors exist within this study when accurate historical sources and empirical data of the detonation are combined. Justifiably, the dates for conditions now known as PTS can easily be moved from their accepted emergence in AD 1900, to AD 1700, possibility to the initial combat use of gunpowder. An interdisciplinary effort by historians, psychologists, and archaeologists on this endeavor ought to reveal many different expressions of PTS throughout history and help destigmatize it, to assist in the healing process and to help cope with these issues.

Overall this study answered the specified research questions. Although a whole new set of questions has been discovered that takes additional research and testing to answer. In the end, a taxonomy was feasible but requires more samples to make identification of date ranges, nationality, and foundries possible. Lethality was minimal, but the grenade's main purpose was seemingly fulfilled through disruption of movements and incapacitation. Future applicability of this study can have immediate benefits to the discipline. Creation of a more widespread taxonomy will aid in shipwreck identification of year range and nationality, concomitantly reducing expensive and lengthy conservation efforts towards that end, like currently exists with cannon, Improvements to the detonation tests can be made, then applied to other historical explosive devices to accurately comprehend lethality upon these battlefields and to what extent this influenced veteran behavior. Consideration of all the aspects presented in this study generate a more accurate version of early eighteenth-century battlefields and the challenges faced by those unfortunates, whom found themselves in combat.

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APPENDIX A: GRENADE FORM

Grenade Form

Artifact Number ________________________ State of Conservation________________________

Artifact Description

Grenade	Whole	Whydah Typology: __________________________
Plug	Broken	Description of Damage: ______________________
Both	Damaged	____

Measurements

A. Mold seam orientation relative to fuse hole
   a. Not Visible
   b. Vertical
   c. Horizontal
   d. Unknown
B. Overall dimensions of grenade
   a. Vertical ___________________
   b. Horizontal ___________________
C. Diameter of fuse hole
   a. Max ___________________
   b. Min ___________________
D. Interior Volume ___________________
E. Weight ___________________
F. Diagnostic surface features: (mold scars, spurs, secondary holes, divots) ______________

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Notes

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Diagram of Grenade Components