SHOULD THE U.S. ARMY ADOPT NEW 5.56MM AMMUNITION CARTRIDGE DESIGNS TO REDUCE OVERALL AMMUNITION WEIGHT?

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General Studies

by

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14. ABSTRACT

In today's conflicts, United States (U.S.) Soldiers are required to carry up to 80 pounds or more of combat gear into the fight, including an ammunition basic load of at least 210 rounds of 5.56mm ammunition. This ammunition weighs approximately 5.5 pounds, with roughly half of this weight from the brass cartridge case. As these cases are not normally recovered from the battlefield, it is weight carried that offers little return once the cartridge is fired. Given ongoing programs, patents, and technologies in development in both the Department of Defense (DoD) and commercial organizations to lighten the Soldier's overall load, there now exists an opportunity to reduce the weight of this 5.56mm ammunition. This thesis will present the history and reasons for the adoption of the current 5.56mm ammunition, potential new lightweight ammunition options, and the developmental considerations associated with approving a potential lightweight ammunition type. This thesis will then show the selection and evaluation criteria for these potential ammunition designs. Next, these different designs will be compared to the current standard M855 5.56mm ammunition, then to each other, to determine the best overall recommended design. Finally, this thesis will discuss the implications of the recommended design, and suggestions for future study.

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The opinions and conclusions expressed herein are those of the student author and do not necessarily represent the views of the U.S. Army Command and General Staff College or any other governmental agency. (References to this study should include the foregoing statement.)

ABSTRACT

SHOULD THE U.S. ARMY ADOPT NEW 5.56MM AMMUNITION CARTRIDGE DESIGNS TO REDUCE OVERALL AMMUNITION WEIGHT?, by Major Steven G. Miskinis, Jr., U.S. Army, 87 pages

In today's conflicts, United States (U.S.) Soldiers are required to carry up to 80 pounds or more of combat gear into the fight, including an ammunition basic load of at least 210 rounds of 5.56mm ammunition. This ammunition weighs approximately 5.5 pounds, with roughly half of this weight from the brass cartridge case. As these cases are not normally recovered from the battlefield, it is weight carried that offers little return once the cartridge is fired. Given ongoing programs, patents, and technologies in development in both the Department of Defense (DoD) and commercial organizations to lighten the Soldier's overall load, there now exists an opportunity to reduce the weight of this 5.56mm ammunition. This thesis will present the history and reasons for the adoption of the current 5.56mm ammunition, potential new lightweight ammunition options, and the developmental considerations associated with approving a potential lightweight ammunition type. This thesis will then show the selection and evaluation criteria for these potential ammunition designs. Next, these different designs will be compared to the current standard M855 5.56mm ammunition, then to each other, to determine the best overall recommended design. Finally, this thesis will discuss the implications of the recommended design, and suggestions for future study.

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TABLE OF CONTENTS

ACRONYMS

ARDEC	Armament Research, Development and Engineering Center
ATK	Alliant Techsystems Inc
DoD	Department of Defense
LSAT	Lightweight Small Arms Technologies
mm	Millimeter
U.S.	United States

ILLUSTRATIONS

TABLES

CHAPTER 1

INTRODUCTION

> Today, the average soldier load consists of a rucksack, weapon, ammunition, helmet and other gear; the total weight can range from 60-130+ pounds depending on the variables of mission type, duration, and environment. . . . infantry Soldiers carrying a load of 101 pounds for 12.5 miles had a decrease of 26 percent in marksmanship (number of targets hit), a 33 percent increase from the target center, and an increase in back pain compared to pre-load and march scores.
>
> — GEN Peter W. Chiarelli
> Testimony before the House Appropriations Committee
> Subcommittee on Defense

Purpose

This thesis contains information on options for adopting a new lightweight 5.56 millimeter (mm) ammunition design that maintains the same performance as the current M855 5.56mm ammunition. This thesis will present the history and reasons for the adoption of the current 5.56mm ammunition, potential new lightweight ammunition options, and the developmental considerations associated with approving a potential lightweight ammunition type. This thesis will then show the selection and evaluation criteria for these potential ammunition designs. Next, these different designs will be compared to the current standard M855 5.56mm ammunition, then to each other, to determine the best overall recommended design. Finally, this thesis will discuss the implications of the recommended design, and suggestions for future study.

Background

Since the beginning of both Operations Enduring Freedom and Iraqi Freedom, the amount of equipment the individual Soldier has to bear during operations is staggering, often well over 80 pounds for an infantry rifleman.[1] This is largely attributed to such essentials as weapons, body armor, helmet, water, food, radios, batteries and ammunition. A soldier's basic load of ammunition consists of 210 rounds of 5.56mm for the M4 rifle, and this weighs approximately 5.5 pounds, not including the magazines. Considering that half of this ammunition weight is made up of the cartridge case, and that this case is usually not recovered in combat after being expended, it may be worth considering a means to reduce the weight of ammunition.[2] The standard ammunition in this study is the United States (U.S.) M855 5.56mm cartridge, widely used by troops in theater, weighing a total 12.31 grams per cartridge, with 6.85 grams of it (56 percent) being the brass case.[3] Reducing the weight of soldiers' ammunition allows them to lighten their overall combat load, or at least carry more ammunition into combat.

The brass used in the conventional cartridge case is largely a non-recoverable item outside of training situations; soldiers in combat typically do not remain at or return to the scene of a fierce battle to recover their spent cartridges. This results in the loss of potentially hundreds of pounds of brass alloy that could be used for other purposes, resulting in significant materiel and cost savings. In fact, there were concerns over the depleting domestic copper reserves and their cost in the 1970s that sparked interest in developing alternative materials or configurations for ammunition cases.[4] By using suitable widely available lightweight materials in the case of these cartridges, such as aluminum, steel or polymer, one can potentially reduce their weight and cost. Add to this the development of viable caseless cartridges; even more such savings becomes possible.

Primary Research Question

Should the U.S. Army adopt new 5.56mm ammunition cartridge designs to reduce overall ammunition weight?

Secondary Research Questions

In order to answer the primary question, this thesis proposes to answer the following supporting questions:

1. What are the current performance criteria required by the U.S. Army for 5.56mm ammunition?

2. What are the reasons for the current design of 5.56mm ammunition, and what would be the immediate effects of any significant design changes?

3. What new ammunition designs, if any, is the U.S. Army or Department of Defense (DoD) currently exploring that reduce ammunition weight?

4. What new ammunition designs exist in the civilian sector that may be applicable to the defense sector?

5. What is the impact to the U.S. Army should it adopt a new, lightweight 5.56mm ammunition design?

Assumptions

For the purposes of this study, it is assumed that all performance, ballistic and technical data obtained from DoD and civilian weapons manufacturers' materials are accurate. The 5.56mm cartridge will still be the primary caliber of ammunition used in U.S. Army assault rifles and light machine guns. The M16/M4 series assault rifle will continue to be the standard 5.56mm small arms weapon for the next 10 years. There will be no significant changes in the bore diameter or chamber dimensions in U.S. Army assault rifles or light machine guns in order to accommodate other calibers of small arms ammunition. The current 5.56mm cartridge types in use may be the most viable option.

All 5.56mm designs options are capable of meeting the existing M855 ammunition performance requirements.

Definitions

Ballistics. This is the science of projectiles, from thrown rocks to rockets. The science of ballistics is further divided into four specific areas; these are interior ballistics, exterior ballistics, terminal ballistics, and forensic ballistics. Interior ballistics refers to all events concerning projectiles before they leave the launcher (firearms, in this case). External ballistics refers to all events concerning a projectile after it leaves the launcher, or barrel, and before achieves impact. Terminal ballistics refers to events concerning a projectile after impact. Forensic ballistics refers to the legal study of ballistics as it applies to law enforcement investigations and legal proceedings.[5]

Cartridge. Also referred to as a ―round"; the ballistic component of modern firearm shooting that consists of a self-contained package consisting of a case (the body), bullet (the projectile), propellant (that provides the energy to launch the bullet), and primer (the initiator of the propellant).[6]

Joint Service Small Arms Program. A DoD program that ―matures and demonstrates advanced technologies that integrate into individual and crew served weapons for all Services."[7] This program supports lightweight small arms and ammunition development via the Lightweight Small Arms Technologies (LSAT) program.[8] Development of these systems occurs at the Armament Research, Development and Engineering Center (ARDEC), Picatinny Arsenal, N.J.[9]

Lightweight Ammunition. For the purposes of the research in this thesis, lightweight ammunition is defined as any 5.56mm North Atlantic Treaty Organization standard ammunition that has a cartridge weight lower than that of the U.S. M855 ball 5.56mm ammunition with at least the same performance. Quantitatively, this weight is 190 grains, or approximately 12.30 grams, per cartridge.

Obturation. Any mechanism or process that prevents gasses caused by a fired cartridge to escape the gun breech, chamber, or bore. This is normally accomplished by the expansion of the cartridge case into the chamber walls of a firearm, effectively sealing it.[10]

Scope

There are a number of theoretical technologies that significantly reduce the weight of ammunition or eliminate the necessity of ballistic projectiles altogether. The comparative analysis of this study for the purposes of recommending a solution will confine themselves to those ammunition types either currently existing or reasonably capable of being fielded in the next 10 years. This study will only compare performance data for existing ammunition that has been tested and documented. It will also only discuss ammunition weight reduction technologies that are reasonably supportable in current and near future conflicts.

Limitations

The amount of materials relating to the creation of lightweight ammunition are limited, and of these, even fewer have been fielded on an appreciable scale by soldiers in any military. Further, there are only a handful of references open to the public or readily accessible due to the still nascent field. Finally, as a result of little testing or fielding data of the available lightweight ammunition types, many of the screening and evaluation criteria will need to be qualitative, rather than quantitative.

Significance

The subject of lightweight small arms ammunition alternatives to U.S. Army ammunition currently in use has not been pursued in any Masters of Military Arts and Sciences thesis or School of Advanced Military Studies monograph. As a practical matter, this work serves as an initial look into a subject that may garner further interest in the near future and assist in developing potential new lightweight ammunition designs for existing weapon systems, or even for new systems.

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[1]Ann Scott Tyson, ―Weight of Combat Gear Is Taking Toll," *Washington Post*, 1 February 2009, http://www.washingtonpost.com/wp-dyn/content/article/2009/01/31/AR2009013101717_3.html (accessed 24 October 2010).

[2]Gary W.Cooke, ―Gary's U.S. Infantry Weapons Reference Guide, 5.56 mm Ammunition," http://www.inetres.com/gp/military/infantry/rifle/556mm_ammo.html (accessed 26 September 2010).

[3]Advanced Caseless Ammunition Inc., ―Introduction," http://caselessammunition.homestead.com/indexcasesless.html (accessed 14 November 2010).

[4]U.S. Patent 3,797,396, ―Reinforced Lightweight Cartridge" (Invented by Frederick P. Reed, Approved 19 March 1974), 3; U.S. Patent 3,924,534, ―Lightweight Cartridge Case of Improved Aluminum Alloy Material That Eliminates Catastrophic Failures" (Invented by Frederick R. Gruner, Approved 9 December 1975), 2.

[5]Robert A. Rinker, *Understanding Firearm Ballistics* (Clarksville: Mulberry House Publishing, 2011), 396.

[6]Ibid., 398.

[7]Department of the Army, ―Exhibit R-2, RDT&E Budget Item Justification: PB 2012 Army," February 2011, http://www.js.pentagon.mil/descriptivesum/Y2012/Army/0603607A_3_PB_2012.pdf (accessed 1 June 2011), 1.

[8]Ibid.

[9]Ibid.

[10]Ibid., 409.

CHAPTER 2

LITERATURE REVIEW

Introduction

This chapter presents the literature used to determine the answer to the following thesis question: ―Should the U.S. Army adopt new 5.56mm ammunition cartridge designs to reduce overall ammunition weight?” This chapter surveys the references that discuss small arms operation and current small arms ammunition design. It also presents data regarding the history of and reasons for the current small arms weapons and 5.56mm ammunition design, as well as existing lightweight ammunition designs. Finally, this chapter contains references that assist the analysis of this data.

The research methodology for this thesis is driven by the need to answer the secondary questions. Once these are answered, analysis of the answers will determine the recommended solution to the primary research question. Each secondary question is discussed below, with a summary of the research techniques and sources used to answer them. Throughout the research, books and periodicals are the preferred reference item. This work also contains relevant websites, patent data, subject matter expert interviews, primary research conducted during visits to the Lake City Army Ammunition Plant, the manufacturing site of a significant portion of the U.S. Army’s 5.56mm ammunition. Other references include slideshows from commercial manufacturers and the U.S. ARDEC discussing new weapon and ammunition designs offered to DoD for adoption. Finally, weblogs containing the testimonials of commercially available lightweight small arms ammunition provide some measure of their reliability, properties and issues.

What are the current performance criteria required by the U.S. Army for 5.56mm ammunition? To answer this, there are various military standards documents, as well as websites and the author's personal experience. However, the question must be limited to those criteria that are directly related to the topic of developing more lightweight ammunition. Also, since ammunition does not function without a suitable firearm, it is necessary to explore the capabilities of the U.S. Army weapons that use 5.56mm ammunition. In addition, it is important to research precisely what happens to internal ballistics when firing these weapons to better understand design difficulties.

What are the reasons for the current design of 5.56mm ammunition? Simply put, a short study of U.S. rifle development, associated ammunition, and the conflicts and events that shaped their development help to answer this. There are numerous books and websites that explore this subject.

What new ammunition designs, if any, is the U.S. Army or DoD currently exploring that reduce ammunition weight? Research and development for U.S. Army weapons systems typically comes from two sources: ARDEC or American commercial manufacturers. Information on current DoD research is not typically published in books, and only occasionally published in articles. Even then, the new items must reach a certain level of development before the information is released publicly. Therefore, in order to obtain current data, one must use password protected DoD websites, conduct interviews with subject matter experts, or visit arsenals and ammunition plants.

What new ammunition designs exist in the civilian sector that may be applicable to the defense sector? This question is the most difficult to answer in great detail. Developments in commercial enterprises are often guarded as trade secrets. Nonetheless, research for this query includes data requested from DoD affiliated ammunition corporations, available presentations from websites posted by other corporations, and news reports of breakthroughs in lightweight ammunition developments. Additional information is provided from the reports of the users of various commercially available ammunition types, in the form of web logs on various firearms enthusiast websites.

What is the impact to the U.S. Army should it adopt a new, lightweight 5.56mm ammunition design? Army equipment fielding is a methodical, lengthy process. This process, known more formally as the Defense Acquisition Management System, must nest with National Security Strategy objectives, meet the needs of the soldier, and fulfill the standards of all steps in between.[1] This research will consist largely of Army and DoD publications outlining this process, and focus on armaments fielding.

<u>Small Arms Operation References</u>

This work contains three primary references to discuss the details of firearms operation. Chief among these is *Understanding Firearm Ballistics, Basic to Advanced Ballistics*, by Robert A. Rinker. This book discusses topics concerning interior, trajectory and terminal ballistics, and offers great detail into the mathematical analysis behind firearms operation. It covers in detail the actions that occur in a modern firearm while firing, and delves into the scientific principles that govern pressure, gas expansion, rifling, velocity, drag, wind and ricochets.

The second reference is the Basic Ballistics Website, hosted by Anthony G. Williams. This reference provides a concise, but mathematical overview of the principles of internal, external and terminal ballistics, muzzle energy, recoil, and sub-caliber projectiles.

The third reference is also a website, entitled, Ballistics for Dummies from Peterson's Rifle Shooter. This work is limited in scope and provides a brief overview of ballistics, focusing on essential definitions and trajectory principles useful to the sportsman or hunter.

Current Small Arms Ammunition Design References

This thesis references several works that provide information on the various aspects of current ammunition design, from the very general to those focused on the specifications of the 5.56mm ammunition in use by the U.S. Army.

The book, *Military Small Arms Ammunition of the World, 1945-1980*, by P. Labbett, covers a brief history of ammunition development, individual cartridge profiles, and a registry of ammunition producers, color identification codes, and packaging. Its purpose is to serve as a reference for identifying small arms cartridges of various nations. It is a fairly comprehensive handbook, if lacking the latest in ammunition development data.

James Bevan's and Stephanie Pezard's *Basic Characteristics of Ammunition: From Handguns to MANPADS*, offers the reader unfamiliar with the subject an overview of the widest range of munitions' types, their design and operation. This work is part of a series published under the Small Arms Survey, from the Graduate Institute of International Studies, Geneva, Switzerland.

Regarding the specifications of current U.S. Army 5.56mm series of cartridges, there are a number of websites that possess a great deal of information. The Alliant Techsystems Inc (ATK) Website provides the most definitive reference on the subject, being the website of the manufacturer of these cartridges. It presents data on the dimension, weight, muzzle velocity, chamber pressure, accuracy, action time and national stock number of each of the models in use. Other websites, such as Gary W. Cooke's Gary's U.S. Infantry Weapons Reference Guide and the Olive Drab websites offer similar information, with additional parenthetical knowledge relevant to these cartridges' development, use and limitations.

History of U.S. Small Arms and 5.56mm Ammunition Design References

Works on the history of arms and ammunition development are abundant enough to conduct in depth research at least into the causes that shaped the creation of our modern small arms. This thesis uses two primary sources to discuss the history of ammunition and weapons development, in addition to the information contained in the references discussed above.

The book, *American Rifle, A Biography*, by Alexander Rose, offers a detailed history of the development of U.S. rifles from the birth of the nation to modern times, with a glance into future weapons development. This work recounts the historical and political events that shaped U.S. firearms history, and the various people that championed their progressive designs. It also explores the former days of the Ordnance Department's oversight of arms and ammunition development, the ebb and flow of the theories of marksmanship versus volume of fire, and the integration of commercial arms development.

The technical services work, *The Ordnance Department: Planning Munitions for War* discusses the varied developments and challenges faced by the U.S. Ordnance Department from 1919 through 1945. Covering topics as diverse as aircraft bomb to body armor, this work also provides insight into the efforts made to conserve materials during World War II. This includes a history of the use of steel cases in place of brass in order to preserve copper.

The Masters of Military Arts and Science thesis entitled, ―The Influence of Organizational Culture on the Acquisition of the M16 Rifle," by Major Danford Allen Kern, 2006, provides a short history of American rifle development, focusing on how U.S. Army culture changed throughout history and how this affected the development of combat rifles. It especially focuses on the tradition of marksmanship, cost effectiveness, and the political and performance biases in testing the M16 rifle during the Vietnam War.

The Website WorldLingo.com provides a brief yet informative history of the development of 5.56 x 45mm North Atlantic Treaty Organization cartridge specifically. It also discusses 5.56mm ammunition properties and compares them to those of the 7.62 mm North Atlantic Treaty Organization cartridge.

Existing Lightweight Ammunition Designs References

Weapon Systems

There are relatively few historical references pertaining solely to the development of lightweight ammunition; this subject has been little explored until recently, except the topic of weapons developed to fire lighter cartridges. For the ammunition specifically, there are a handful of references that are devoted to both lightweight cartridge case and to caseless cartridges.

There are references describing two weapon systems developed and manufactured in the last 30 years that use caseless cartridge ammunition exclusively that are discussed in this thesis. The first reference is the Remtek website, which discusses the German

Heckler and Koch HK11 assault rifle. The website also presents the specialized design characteristics of the HK11, and its beneficial attributes derived from using caseless cartridges. The second caseless cartridge reference is the Voere website. The topic of this reference is the Austrian Voere VEC Model 91, a bolt action hunting rifle that features an electrically fired, caseless cartridge.

Patents

While there are few examples of lightweight ammunition in wide use, and none by any modern military, there are a number of patents that show promise in offering a savings in weight. At least four patents developed in the 1970s used designs that were intended to make aluminum cases viable and on par with their more conventional brass counterparts. U.S. Patent 3,659,528, ―Composite Metal Cartridge Case," submitted by Tuevo Santala of Texas Instruments in May 1972, presents the idea of using layers of composite aluminum to form a lightweight, but durable cartridge case. This invention also features a cuplike reinforcement of the laminate at the base of the case, for added resistance to damage from firing. U.S. Patent 3,765,297, ―Non-Eroding, Lightweight Cartridge Cases," developed by Leonard W. Skochko and Reed E. Donnard in October 1973, offered another aluminum design that used a conical shaped buffering of aluminum inside the base of the case designed to prevent the escaped of flammable gasses in the instance of rupturing. Next, U.S. Patent 3,797,396, ―Reinforced Lightweight Cartridge," invented by Frederick P. Reed in March 1974, presented yet another technique to reinforce aluminum cartridges. Instead of using a laminate or conical buffering, this design used an epoxy resin cup lining the base of the case, which was more deformable than the surrounding aluminum and provided a moderate shock absorbing effect. This patent used the same paradigm for brass and steel bullets as well. The last aluminum based development referenced in this series is U.S. Patent 3,924,534, —Lightweight Cartridge Case of Improved Aluminum Alloy Material that Eliminates Catastrophic Failures.” Developed by Frederick R. Gruner in December 1975, this design featured the use of high strength aluminum oxide (Al_2O_3) alloy into the existing aluminum case material to prevent the propellant and gasses from burning through the case.

Two more patents were submitted in late 1988 by none other than Eugene M. Stoner, a lead designer for the M16 assault rifle. Stoner submitted his patents as an employee of Ares, Inc., and introduced a revolutionary design in small arms ammunition. U.S. Patent 4,770,098, —Telescoped Ammunition Round” presented a new cartridge configuration that made the entire item cylindrical in shape. Stoner achieved this by seating the bullet completely into the cartridge case, nesting it almost completely within the propellant, and securing it with a polymer based cap, creating a cylindrical cartridge. Originally intended for the .50 caliber cartridge, the advantages of this design are a smaller overall cartridge and the possibility of designing a more compact weapon system to fire it. Complementing this patent was U.S. Patent 4,790,231, —Lightweight Belt Link for Telescoped Ammunition and Belt Formed Therefrom.” This polymer belt link was specifically designed to feed cylindrical telescoped cartridges into their automatic weapon systems.

The final lightweight case patent available in this work’s reference list is U.S. Patent 7,610,858, —Lightweight Polymer Cased Ammunition,” invented by Sengshin Chung in November 2009. This design used three cylindrical shaped polymer components to make a reinforced cartridge case, without changing the conventional shape of the cartridge. The goal of this configuration is to make the polymer cartridge more durable and resistant to malfunctions.

Also worth mentioning is an application for a patent for a lightweight cartridge that combined both fiber reinforced polymer and steel components, submitted and recorded in December 2009 by Joseph T. South. The shape of the cartridge remained conventional, but the design is reported to allow for a significant reduction in weight while maintaining the required strength.

In addition to lightweight cartridge designs explained above, there are also records of caseless ammunition developments from decades ago. The study conducted and submitted in a report by Scanlon, Quinlan and Vanartsdalen entitled, ―Combustible Ammunition for Small Arms" detailed the testing of an obturation device designed to allow an M1903 Springfield to fire sixty 7.62mm rounds of caseless ammunition. This is a remarkably forward thinking study, having been published in 1965 and containing references dating back to 1957. The team had to make significant modifications to the weapon in order for it to fire such ammunition, such as redesigning the bolt and chamber; nonetheless, it clearly demonstrated the feasibility of future caseless weapon systems.

Recent Developments

For recent developments in lightweight ammunition technology, there are many references used in this thesis. First, and perhaps most compelling, is the ongoing LSAT program being conducted by ARDEC. Led by Kori Phillips of ARDEC and Phillip Shipley of AAI Corporation, this program is designed to offer linked lightweight polymer cased ammunition and a light machine gun designed to fire it. This combination of ammo and machine gun has been extensively tested, with over 10,000 rounds fired successfully.

If the program’s products are approved by the U.S. Army for production, they may replace the current M249 squad automatic weapon. This LSAT program also pursued caseless ammunition, but, as of May 2009, only officially supports the polymer cased cartridge.

A presentation titled ―Research and Development Effort: Fabricate a 5.56mm Aluminum Cartridge Case,” by Chris Still and Mark Leng of ATK, summarizes a 2010 study revisiting the development of aluminum cased ammunition.

Another reference, ―Component Technology Investigations for Light Machine Gun Applications,” a slide presentation developed in May 2005 by Mr. Lucian Sadowski of ARDEC, contains information on the initial developments of lightweight ammunition for U.S. Army use. In the slideshow, the author discusses the attributes and development potential of initial ammunition designs, such as aluminum and polymer. The work also contains information on a lightweight barrel design for a light machine gun and ammunition using enhanced propellant, which allows for a reduction in overall cartridge volume and weight.

The next reference is the Colt Defense LLC website, which contains information on two designs to making ammunition lighter. The first of these is referred to as a modular case, designed for .50 caliber through 40mm sized cartridges. This case resembles a conventional brass cartridge case, but with most of the length of the case being cut out from two sides, leaving two strips of metal on opposite sides holding the metallic base and neck together. A formed combustible propellant cylinder is then inserted and sealed into the case skeleton, resulting in a hybrid cased-caseless cartridge with significant weight savings. The second development is a complete polymer case, with the innovation of spiral ribbing, providing additional strength and durability. This design is intended for use with 5.56mm through .50 caliber cartridges.

Another key lightweight technology reference is the documented work of Nick Malkovich and Robert Gagne of Mississippi Polymer Technologies, Inc. In a presentation from May 2005 to the National Defense Industrial Association entitled ―Lightweight Ammunition: A Material Science Challenge," the pair unveiled a new cartridge case with the trade name Parmax, described as a self-reinforced polymer, that was highly resistant to extreme temperatures. This case was comprised of two components: a caselet, which formed the basic shape of the case, and a base, in that the primer was to be seated. The complete case was formed by fitting the base into the rear portion of the caselet, then adding the bullet to the neck, as with most other conventional cases.

There are a few references that provide product information on lightweight cartridges. For steel cartridges, the Russian ―Wolf" performance ammunition website contains data on .223 caliber steel cased rifle cartridges designed with a very thin layer of copper jacketing on the case, termed ―bimetal" by the manufacturer. This steel is softer than the steel used in the chambers of firearms, which is a design necessity to reduce wear. Another commercial reference is the website for the CCI line of Blazer ammunition CCI is a subsidiary of ATK, that specializes in small arms aluminum cased ammunition of many calibers. According to their website, their ammunition is cheaper than conventional brass cartridges. Finally, the PCP ammunition company website contains information on lightweight polymer cased cartridges of calibers from 5.56mm to .50 caliber, and advertises an overall cartridge weight reduction of 25 percent. Their ammunition is reported to be commercially available in 2011, with the same reliability as brass cartridges.

Primary Research

The author was able to conduct some limited primary research into the manufacture and testing of small arms ammunition by visiting the Lake City Army Ammunition Plant on two occasions. In the first visit on 2 December 2010, the commander of the facility, LTC Elizabeth Keough, along with ammunition engineer Mr. Tom Hermann, provided a tour of the facility to the author. The tour included an overview of the production capacity of the plant, a walkthrough of the areas producing and testing 5.56mm, 7.62mm, .50 caliber ammunition and links for these ammunition types. The tour also included a firsthand look at the manufacturing of the M855A1 enhanced performance round, to be fielded in 2011. The M855A1 is a newly designed, environmentally friendly cartridge with a steel tipped projectile designed to have armor penetrating power equivalent to 7.62mm ammunition.

The author conducted a second visit to the Lake City Army Ammunition Plant on 15 March 2011, hosted by Mr. Leonardo Ojeda, an ATK employee and an ammunition testing supervisor. During this visit, Mr. Ojeda conducted a comprehensive overview of the military specifications for various ammunition calibers, visual inspection criteria and small caliber ammunition test procedures of the various ammunition types, as well as some information on Army level ammunition production methodology. He also furnished and discussed the digital technical manuals and military standard manuals for the M855, M193 and other ammunition models.

Additional References

No discussion of the development of a weapon system or ammunition development for use in the U.S. Army would be complete without materials discussing marksmanship, acquisition and fielding. There are also relevant works that deal with ammunition and weapons development, but not strictly with the focus of creating lightweight technologies.

The U.S. Army Field Manual 3-22.9, *Rifle Marksmanship M16A1, M16A2/3, M16A4, and M4 Carbine* is a comprehensive guide to these rifles' operation, marksmanship fundamentals, instruction, training and evaluation of proficiency with the soldier's rifles in use in today's conflicts. It also provides information on the many modular attachments for these rifles, such as night vision, thermal and optical sights, and scopes, along with how they affect accuracy.

For a study of the challenges in overcoming the barrier of distance in long range target engagement in combat, this work refers to, ―Increasing Small Arms Lethality in Afghanistan: Taking Back the Infantry Half-Kilometer," a School of Advanced Military Studies monograph written in 2009 by Major Thomas P. Ehrhart. Ehrhart discusses the history of marksmanship training from the days of the American Revolution to the present day, reflecting especially on how the modern configuration of the U.S. infantry squad and current individual marksmanship training is unsuitable for the frequent engagements that occur beyond 300 meters in Afghanistan. He presents arguments supporting the use of a rifle that uses a larger caliber cartridge than the standard 5.56mm for the squad designated marksman. He also investigates some modern innovations that may help improve accuracy, and suggest several changes to doctrine and current marksmanship training to better reflect the battlefield ranges infantrymen face in theater.

For a broad overview of how a new technology or system transitions to proposal to fielding into the U.S. Army, this thesis references the Command and General Staff College publication —F100: Managing Army Change, Selected Readings and References," May 2010 edition. Within, it discusses in detail the DoD planning, programming, budgeting, and execution process, as well as the materiel development and operational needs statements that drive Army transformation and development.

The Masters of Military Arts and Sciences thesis, entitled, —Small Arms Ammunition Production and Acquisition Strategy for the U.S. Army," written by Major Mark W. Siekman in 2009, offers a detailed look at the process of transforming a new small arms idea becomes a part of soldiers' equipment. He attempts to answer the question of whether the current U.S. ammunition acquisition strategy can meet small arms ammunition demands should there be a major conflict. To answer this, his work discusses the overarching Army acquisition strategy, the sources of cartridge components, the manufacturing of cartridges, the history of U.S. ammunition acquisition strategies, and the production and business practices of Lake City Army Ammunition Plant, the sole operating government-owned contractor-operated small arms ammunition production facility.

There several other websites referenced in this thesis that provide additional information. The official ATK website contains basic information on the physical characteristics of 5.56mm ammunition, as do the websites Olive Drab and Gary's Infantry Weapons Guide. The website SI Metric provides various data on the specific densities of common metals and alloys, such as brass, steel and aluminum. The slide presentation entitled ―Galvanic Corrosion Study on Stainless Steel Cartridge Design" available on the Corrosion Defense website, provides data on an experiment testing the corrosion of cartridge stainless when either coupled or alloyed with aluminum or copper. The goal of the experiment was to determine if a new lightweight cartridge design using the physical contact of stainless steel and other metals would have an effect of corrosion rates or resistance. The website Metalprices.com offers current prices of raw, scrap and finished metals, for a rough comparison of the cost of possible case materials.

For informal testimonials regarding commercial ammunition types, there are various ammunition forums and weblogs available. There are certainly limitations to this; any claims of expertise by any who submit their views on these websites may not be verifiable, along with any information presented. However, relevant ammunition website forums do at least provide some data on performance, issues, upcoming developments and comparisons of ammunition types and manufacturers. Web forums referenced in this thesis are: The High Road, The Firing Line, and The Firearm Blog.

Brief Overview of U.S. Firearms Operation

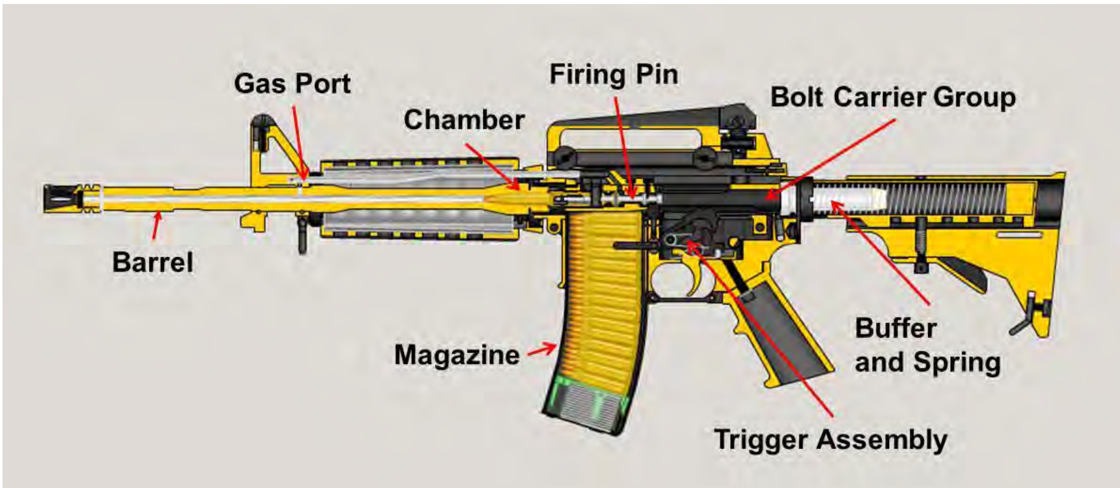

Figure 1. M4A3 Carbine Transection
Source: Bushmaster Firearms International, LLC, http://www.bushmaster.com/anatomy_bushmaster.asp (accessed 15 May 2011). Annotated by author.

For the reader to better understand the design difficulties associated with ammunition development, it is useful to describe the mechanical steps rifles undergo when firing a cartridge. While most readers certainly understand basic firearm principles such as loading, aiming, firing, recoil, and unloading, this section deals with the mechanical sequence of events known as the cycle of functioning.[2] The cycle of functioning occurs after a loaded magazine is fed into the weapon's magazine well. In order, the functions are feeding, chambering, locking, firing, unlocking, extracting, ejecting, and cocking.[3] These functions are described in detail in U.S. Army Field Manual 3-22.9, and are summarized below.

The mechanical energy used in feeding, chambering, and locking occurs from one of two sources: automatically, from the released compression of a buffer assembly of an assault rifle, or the operator, in the case of bolt action rifles. ―Feeding” occurs once the cartridge is pulled from the magazine or belt by the action of the weapon or firer. ―Chambering” occurs when the bolt carrier group pushes the forward, seating it into the chamber. Finally, the bolt carrier group is driven forward and seated firmly into the chamber, completing the ―locking” function.

Once the weapon is locked, it can then be ―fired” using the trigger assembly; the trigger pin will release the hammer. This hammer then drives the firing pin forward into the primer cap of the cartridge, initiating the combustion process and releasing a great deal of hot gas. As this gas propels the bullet down the barrel, some of it is driven into the weapon’s gas port at the top of the barrel. This gas travels from this port down the gas tube and expands rapidly into the chamber, locking the bolt in place.

Gas operation and recoil energy in semi-automatic and automatic rifles, or manual operation in bolt action rifles, provides the energy to complete the unlocking, extracting, ejecting and cocking functions. As the bolt carrier group moves rearward, it is untwisted from the chamber, thereby ―unlocking” it. Then, the extractor on the bolt carrier group grasps the rim of the now empty cartridge case, and ―extracts” it from the chamber rearward. Immediately after this, the ejector on the bolt carrier group launches the case out of the rifle, ―ejecting” it. Finally, completing its momentum rearward, the bolt carrier collides with the hammer, forcing it back down into the weapon’s lower receiver, compressing the hammer spring, ―cocking” the weapon for future firing.

Basic Ammunition Cartridge Design

Most modern ammunition cartridges are fitted together in the manufacturing process of four key components: case, bullet, propellant and primer. The case, as its name indicates, forms the general structure of the cartridge and houses the other components. Modern U.S. Army small arms munitions have brass cases, due to the unique metallurgical properties of the alloy, that will be discussed in later chapters. The projectile is often a formed, conical-shaped bullet of lead encased with a copper jacket, though there are numerous varieties. The propellant is a low-explosive, low smoke producing chemical component that provides the energy to propel the projectile (bullet) forward down the barrel of the weapon to perform its kinetic function on a target. Finally, the primer is the pressure senstive high explosive element often wrapped in thin brass or other alloy and embedded in the bottom portion of the cartridge, opposite the projectile, that is struck by the firing pin of the firearm. The activation of the primer, often composed of lead styphnate, then initiates the propellent, creating the violent release of gasses from the highly exothermic chemical reaction designed to take place within the cartridge case.

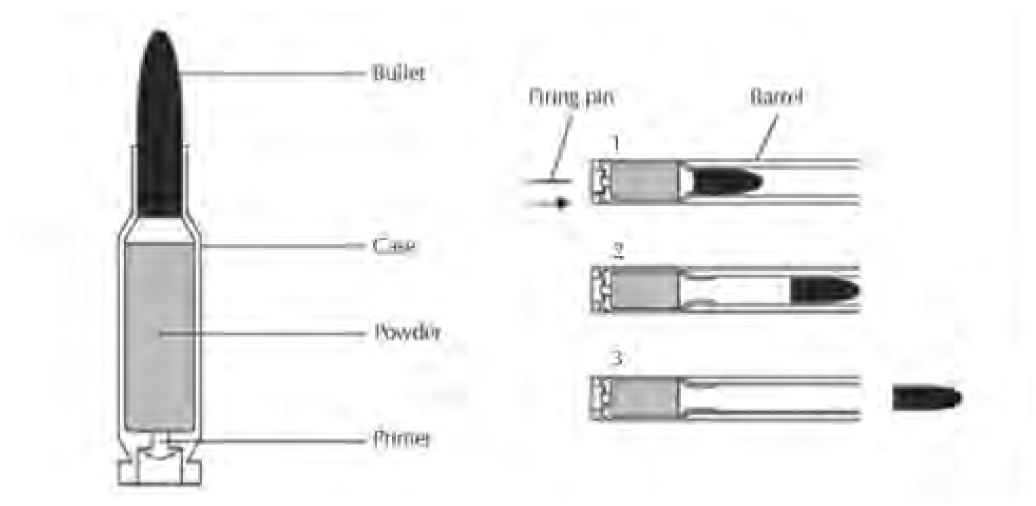

Figure 2. Cartridge Case Design

Source: James Bevan and Stephanie Pezard, ―Basic Characteristics of Ammunition: From Handguns to MANPADS," 2006, http://www.jamesbevan.org/images/Bevan_TAmmo_2006.pdf (accessed 24 October 2010).

One key property of a brass cartridge case is that it expands when fired to seal the chamber from excess gas; this process is called obturation. Without sufficient obturation, the undesired escape of gases from the chemical reactions in the cartridge can cause irregularities in the firing, or possibly even cause jamming or damage to the chamber. This problem largely makes designing lightweight alternatives to the brass case quite difficult. The challenge is to identify materials or compounds that can replicate the ability of brass to create reliable obturation, and are also sufficiently durable and plentiful for use in the manufacture and use of millions of rounds of ammunition.

History of the U.S. Military 5.56mm Cartridge

To understand the current configuration of the modern 5.56 mm cartridge, one must understand its development. U.S. Army rifle designs from the decades after the Civil War to World War II focused on maximizing accuracy out to 500 meters or beyond; this had been a long standing design philosophy often termed ―the cult of accuracy.”[4] The goal was to have well trained American soldiers able to engage and destroy the enemy with accurate fire that the enemy could not match in terms of range. A counter argument to this was the principle of volume of fire. In this philosophy, American soldiers firing sufficient aimed shots at a rate that outmatched the enemy’s would allow U.S. soldiers to prevail in combat. The marksmanship philosophy had more support from designers and senior military leaders of the time; thus the M1 Garand was the staple of American servicemen throughout World War II.[5] The M1 Garand was a .30 caliber semiautomatic rifle that had a magazine of only eight rounds; contrast this with the modern M-4, which has a magazine of thirty rounds. U.S. Soldiers supplemented their volume of fire by using machine guns at the squad level.

By the latter days of World War II, the German Army had developed a rifle design for the infantry that was intended to combine the aspects of both marksmanship and volume of fire. Based on existing carbine designs, and by designing ammunition intended to be effective between 100 to 330 yards, the eventual result was the Sturmgewehr 44, the first assault rifle.[6] As a result of the Russians seizing thousands of these weapons on the battlefields of eastern Germany, the Russians were able to design their own assault rifle designed to be exceptionally durable and easy to use. The Russians would call it the Kalashnikov model AK-47.[7]

It was not until after the Korean War that the U.S. seriously considered transitioning infantry rifles to ammunition smaller than .30 caliber.[8] Studies from the combat experiences of soldiers in World War II and the Korean War indicated that the majority of combat engagements were rarely beyond 500 yards and usually far less than this.[9] At about the same time, emerging studies in Europe had revealed that relatively small caliber bullets travelling at high velocities were actually more physically damaging to enemy personnel than those commonly used in the rifles of the time.[10] This began the transition from larger, heavier rifles and larger caliber ammunition to smaller, lighter weapons firing fast moving projectiles.

Finally, in 1957, the U.S. had developed a rifle that fired a smaller caliber round: a 7.62x51mm cartridge. This rifle was the M14, with selective automatic or semiautomatic fire, and equipped with a 20 round magazine intended to allow for greater volume of fire.[11] By the late 1950s, reports from soldiers in the field indicated that the 7.62x51mm ammunition used in the M14 was difficult to fire accurately, especially in automatic fire mode, because of its significant recoil.[12] The weight of the ammunition and weapon systems of the time was also burdensome for soldiers to carry. This, in part, led to the consideration of using even smaller calibers of ammunition that were thought to be viable as substitutes.[13]

As a result of these factors, and interest from the U.S Air Force in designing a lightweight rifle for downed pilots, development began on just such a weapon to achieve these goals.[14] U.S. weapon manufacturers sought a new ammunition type that roughly matched the performance of the 7.62x51mm at a significant reduction in weight and recoil, using a small caliber, high velocity paradigm.[15] Manufacturers, including Remington and Arma-Lite along with Army ordnance specialists, started in the late 1950s with the Remington .222 as the baseline. The reason was quite pragmatic; Remington .222 was lighter than the current 7.62mm military cartridge, was in regular civilian use, and was widely available.[16] After modifications to the overall cartridge case to accommodate higher chamber pressures due to more explosive propellant, the final design had a slightly longer case. To distinguish this modification from other .222 caliber designs, it was renamed the Remington .223.[17] After further testing and modifications, the final 5.56x45mm design was finally perfected by Robert Hutton and Eugene Stoner. Stoner was then employed by Arma-Lite, the firearms manufacturing company that designed the AR-15 (M16) rifle.[18] The end result of this modified Remington .223 design was redesignated the M193 cartridge once it was adopted by the Army. It had a shorter effective range than the 7.62x51mm cartridge, but possessed comparable lethality.[19] The U.S. conducted further refinement in the 1970s and, in coordination with Belgian weapons manufacturer Fabrique National, developed the North Atlantic Treaty

Organization standard SS109 cartridge; this cartridge was designated the M855 by the U.S. Army in 1980.[20]

Current Lightweight Ammunition Designs

Works in this thesis specifically discussing the problem of reducing the weight of ammunition generally fall into one of three categories. These categories are lightweight cartridge cases, caseless cartridges, and ammunition in series. For lightweight cases and caseless cartridges, there is also the option of using a telescoped cartridge configuration to further decrease volume and weight.

Lightweight Cartridges

The first documented approach to reducing ammunition weight is to use alternative materials in the case. Rather than using brass as the case alloy, these proposed cases use lightweight metals, such as steel and aluminum, or polymers. The Joint Service Small Arms Program is currently exploring polymer-based cartridges in its LSAT program, with a proposed 40 percent weight reduction in its 5.56mm ammunition as compared to the standard M855 5.56mm ammunition.[21] There also exists at least one patent on an aluminum case granted in 1973.[22]

A major design difficulty in the development of these alternative cases is overcoming the issue of heat transfer. One of the key features of a brass case is its ability to remove much of the heat from within the chamber of a firearm upon ejection, reducing overall chamber temperature and expansion. One design consideration is ensuring a cartridge case has sufficient resistance to the internal pressure created upon firing so as not to rupture or become severely distorted. Another consideration is ensuring the cartridge possesses enough durability to withstand the rigorous conditions and environments in that soldiers use these rounds.

Finally, as with most alternative technologies, cost becomes a consideration in its adoption. Should the cost be prohibitively high compared to existing ammunition, it is unlikely these lightweight cartridges would be widely used.

Caseless Ammunition

The second approach to ammunition design is the caseless cartridge. A caseless cartridge uses water-resistant, hardened propellant as the base structure that holds the primer and projectile together. Existing literature indicates those manufacturers who are currently pursuing this option propose significant reductions of up to 50 percent of cartridge weight.[23] Once a caseless cartridge is fired, the entire portions of both internal and external propellant are consumed.

The idea of a caseless cartridge is actually quite old. Many rifles in the Civil War had black powder cartridges made of specially treated flammable paper that would combust with the firing of the round. However, the paper would usually not burn completely, leaving a residue in the chamber and barrel of the rifles, fouling them far more than the rifles of today. This fouling often caused the rifles to malfunction, and they would thus require frequent cleaning.

The first major modern innovation in assault rifle design that tackled the problem of firing caseless cartridges was the Heckler and Koch G11 rifle, developed in 1988 for the German Army.[24] However, the rifle was never fielded; the overwhelming costs of the reunification of the German nation after 1990 drove all weapons research funding to a minimum. Nonetheless, the design details of the G11 were used in the development of the

Joint Service Small Arms Program proposed weapon system, specifically the revolving chamber to dissipate some of the chamber heat.[25]

The only commercially available modern caseless cartridge rifle available in the thesis research is the Austrian Voere VEC-91. It is a bolt-action, electrically fired hunting rifle with a price of approximately $2000, with an ammunition cost of about $2 per round.[26] This is quite expensive compared to many common hunting rifles and ammunition domestically. Nonetheless, it boasts performance at least equal to that of conventional rifles of similar caliber and type.[27]

While the reduction in cartridge weight of a caseless cartridge is obvious, with some estimates as high as 50 percent, there is one article that discusses the advantages, drawbacks and design difficulties of caseless combustible cartridges.[28] One key issue is chamber pressure. Due to the explosive cartridge, and no case to contain the firing pressure once initiated, the chamber of a caseless cartridge weapon sustains extremely high pressure. This causes considerable chamber wear compared to cased cartridges.

Another design difficulty is the obturation problem. Obturation is any mechanical process that seals the chamber from cartridge gas, allowing for a more efficient use of propellant gases to launch the bullet. Obturation can be induced by sufficient case expansion within the chamber, or via the bullet along the barrel once fired. Without case-induced obturation, there is less performance consistency, and accuracy suffers. Caseless designs may also result in larger amounts of chamber residue than conventional ammunition, as there is no case to shield the chamber. This additional residue could cause more frequent malfunction, and would require more maintenance.

An interesting design benefit of caseless ammunition is simpler weapons design. As there is no case, there is no requirement for cartridge extraction during the weapon's cycle of functioning. This can make the entire firing mechanism more reliable, as it contains fewer moving parts. Fewer parts could also make for a lighter weapon. This design also allows for much higher rates of fire than conventional firearms. While this may not necessarily be of use in assault rifles, it may be of use in machine guns and air defense guns, where the momentary creation of a wall of bullets is often the desired defensive technique against incoming missiles or aircraft.

Telescoped Cartridges

An auxiliary development to both lightweight cases and caseless cartridges in recent years to reduce weight is the innovation of the telescoped cartridge. Whereas the projectile protrudes from the case in conventional cartridges, the projectile in a telescoped cartridge is encapsulated entirely within the case. The result is a cylindrical cartridge. This makes packaging of the rounds easier, with less space required and less likelihood of the bullet accidentally being dislodged from the cartridge during use or shipment.

Figure 3. Cased (Top) and Caseless (Bottom) Telescoped Cartridges, Linked
Source: Official ARDEC photo, http://www.army.mil/-images/2010/07/29/81585/ (accessed 10 October 2010).

The primary design difficulty of this type of round is ensuring that the propellant's explosive force can efficiently push the projectile down the barrel, without a loss of performance. Research indicates that Joint Service Small Arms Program has had some success in this design, as they feature it prominently in both cased and caseless variants of their LSAT program.[29]

Ammunition in Series

A recent development in the field of firearms is that of arranging ammunition in the barrel, in an alternating sequence, or stacks, of propellant and projectile. Instead of feeding ammunition into the chamber via a belt or magazine, the ammunition is loaded into the barrel in stacks of alternating projectiles and propellant-primer packs. This approach is inherently caseless, and more lightweight for each individual projectile fired. This mechanism is then electrically fired, with arrayed sensors in the barrel tuned to ensure that there are no timing failures. The forward projectile is fired first, its expanded propellant effectively sealing off the rearward portions of the barrel from the rest of the projectiles. It is this principle that was developed by, and is used in, the ―Metal Storm” firearms technologies. The end result of this engineering is staggering rates of fire, up to one million rounds per minute.[30]

Figure 4. ―Metal Storm” Grenade Launcher Concept Drawing, Showing a Three Round ―Stack” or Ammunition in Series

Source: Metal Storm Limited, website, http://www.metalstorm.com/content/view/66/110/ (accessed 24 October 2010).

Despite these claims of firing rates, it is important to note that they cannot be sustained for more than a second at a time. There are also no known assault rifle applications suitable to the U.S. Army with this system; the current Metal Storm ammunition in series weapons are primarily designed as stationary defense platforms or area denial weaponry. These factors do not necessarily limit it for future development into a suitable soldier's weapon, given time and research initiatives. However, there are no indications of Metal Storm pursuing such a development.

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[1]U.S. Army Command and General Staff College, *F100, Managing Army Change*, *Selected References and Readings* (Fort Leavenworth, KS: Government Printing Office, May 2010), F104AA-6.

[2]Headquarters, Department of the Army, Field Manual (FM) 3-22.9, *Rifle Marksmanship M16A1, M16A2/3, M16A4, and M4 Carbine* (Washington, DC: Government Printing Office, April 2003), Section 4-2, 4-3.

[3]Ibid., 4-3.

[4]Alexander Rose, *The American Rifle, A Biography* (New York: Delta Trade Paperbacks, 2009), 201.

[5]Ibid., 319.

[6]Ibid., 331.

[7]Ibid.

[8]Ibid., 336.

[9]Ibid., 337.

[10]Ibid., 336-337.

[11]Ibid., 349.

[12]Worldlingo, http://www.worldlingo.com/ma/enwiki/en/5.56x45mm_NATO (accessed 7 December 2010).

[13]Ibid.

[14]Ibid., 361.

[15]Ibid.

[16]Ibid.

[17]Ibid.

[18]Olive Drab, http://www.olive-drab.com/od_firearms_ammo_556mm.php (accessed 7 December 2010).

[19]Ibid.

[20]Worldlingo.com.

[21]Kory Spiegel and Paul.Shipley, ―Lightweight Small Arms Technologies," presentation for the NDIA International Infantry & Joint Service Small Arms Systems Annual Symposium, May 2008, http://www.dtic.mil/ndia/2008Intl/Spiegel.pdf (accessed 10 October 2010).

[22]U.S. Patent 3,765,297, —Non-Eroding Lightweight Cartridge Cases," Submitted by Leonard W. Skochko, and Reed E. Donnard, granted 16 October 1973, http://www.google.com/patents (accessed 23 October 2010).

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[25]Kory Spiegel and Paul Shipley, —Lightweight Small Arms Technologies," presentation for U.S. Army Research and Development Command, May 2009, http://www.dtic.mil/ndia/2009infantrysmallarms/wednesdaysessioniv8536.pdf (accessed 21 January 2011).

[26]Voere Corporation, —The Electronic Rifle VEC," http://www.voere.com/model_vec91.htm (accessed 26 September 2010).

[27]Ibid.

[28]Spiegel and Shipley, 2008.

[29]Ibid.

[30]Metal Storm, —Features and Benefits," http://www.metalstorm.com/content/view/66/110/ (accessed 24 October 2010).

CHAPTER 3

RESEARCH METHODOLOGY

Introduction

This chapter discusses the methodology used to research and analyze the data concerning the primary thesis research question: Should the U.S. Army adopt new 5.56mm ammunition cartridge designs to reduce overall ammunition weight? The steps of the methodology used in this work are: identification of facts and assumptions, option development, option screening, option evaluation, option comparison, and option recommendation. The analysis of the ammunition options, using this methodology, is presented in chapter 4 of this thesis.

Methodology Overview

As the key question of this thesis is well within the scope of a military oriented problem, it is fitting to use a methodology to solve this problem using a modified version of the U.S. Army's Military Decision Making Process. The details of Military Decision Making Process are discussed in detail in U.S. Army Field Manual 5-0, *The Operations Process,* Appendix B.

The analysis in this thesis will use a modified Military Decision Making Process approach to find a recommended solution to the problem as conveyed in the thesis question. There are several reasons for this. First, the problem is defined by a clear question, with several subordinate questions, per chapter 1. Second, there are clear, quantifiable criteria that already possess standard definitions that are in use in the well-established disciplines of firearms and ordnance manufacturing, and their combat applications. Finally, there are a number of potential solutions available, and these can be compared against measurable criteria, and against one another.

The modified Military Decision Making Process steps used in this thesis are: identification of a problem, problem analysis, development of possible solutions (options), option analysis, option comparison, and option recommendation.

Included in problem analysis is the identification of facts and assumptions. Solution development researches existing lightweight ammunition options. Solution analysis requires the use of screening criteria to eliminate options unsuitable for further consideration. The process concludes with a recommendation for a lightweight ammunition option.

Identification of Facts and Assumptions

In order to better scope the specific nature of the problem of recommending a lightweight small arms ammunition, it is necessary to establish facts and assumptions. This work accomplishes this early in the process to prevent lost time researching facets of the problem not immediately pertinent to the thesis question, and to refine the logic of comparisons in later analysis.

A fact is defined as, ―a statement of truth or a statement thought to be true at the time.”[1] Examples of relevant facts for this problem include the weights of various optional munitions, and any documented effects the firing of lightweight cartridges may have on various weapon systems.

An assumption is defined as ―a supposition on the current situation or a presupposition on the future course of events, either or both assumed to be true in the absence of positive proof, necessary to enable the commander in the process of planning to complete an estimate of the situation and make a decision on a course of action."[2] Facts and assumptions relevant to the research question and its answer are specifically identified in chapter 4.

Option Development

It is well beyond the scope of this thesis, and the author's abilities and resources, to independently develop viable options for lightweight ammunition intended for Army-wide use. Therefore, all options developed and considered in this thesis emerged from the literature review, rather than from direct experimental research and development.

Option Screening and Screening Criteria

Once developed, each of the options will undergo initial screening to determine if it is suitable for further consideration. In this thesis, the options will be screened using two criteria: compatibility and maturity. These criteria are qualitative, and are binary in nature; options will either pass or fail.

Compatibility is defined as whether or not a given ammunition type operates with existing U.S. Army weapon systems, specifically rifles in the M16 series, the M4 series, and the M249 light machine gun. Any option that requires a basic weapon design change is unacceptable. Basic weapon design changes include replacement or modification of a major component, such as a bolt, bolt carrier group, or barrel. The weapon systems listed above must be able to function properly in their current configurations using the ammunition option in question. This criterion drives an assumption: any option that has the same chamber dimensions as the M855 5.56mm cartridge, and does not require replacement or major modification of the M-4/M-16 or M249 weapons systems is acceptable.

Maturity is defined as the level of development of the lightweight 5.56mm ammunition design option as it relates to meeting the requirements of the U.S. Army. Ammunition options that will require more than 10 years of development to be adopted are unacceptable. Complete development includes successful design, production, testing and fielding to U.S. soldiers. However, lightweight ammunition is still a very experimental field, with few examples of mature products. In order to account for this in presenting any lightweight ammunition options using this criterion, this work make the following assumption; any ammunition option currently in successful initial production, testing, or fielding either commercially or to U.S. soldiers is acceptable.

The screening of the options will be displayed using table 1, below.

Table 1. Example Option Screening Table

Criteria	*Opt. 1*	*Opt. 2*	*Opt. 3*	*Opt. 4*	*Opt. 5*	*Opt. 6*
Compatibility	GO	NO GO	NO GO	GO	GO	GO
Maturity	NO GO	GO	NO GO	GO	GO	GO
Screening Result	FAIL	FAIL	FAIL	PASS	PASS	PASS

Source: Created by author.

Option Evaluation and Comparison Criteria

After all lightweight ammunition options are screened, those options that pass will then be compared to the current standard of the M855 5.56mm cartridge under a series of evaluation criteria. These criteria include cartridge weight, cost, corrosion resistance and flammability. In order to avoid confusion, the criteria that considers weight will be labeled as “mass,” in order to avoid confusing the criteria label with the function of relative weighting the criteria. Although the terms are not quite synonymous, the distinction in this context is moot. Each option will be valued numerically using these evaluation criteria. Higher numbers are better scores. The M855 standard is counted among the other options, and will be valued relative to the other options for each criterion. For example, if the M855 standard is the best of four options, it will be given a score of four. The purpose behind this is to avoid a value of zero or negative numbers that would render any total scores with weighted criteria to be meaningless. Each option will then be discussed in terms of the evaluation criteria, and then compared to the M855 standard. Finally, all of the options, with the M855 standard, will be compared with each other. Each comparison will use only whole number values. Options scoring equivalent to the M855 brass standard in a given criterion will be given the same value as the standard. The results of all the scores for each option will be added together to determine both the total and weighted total score for that option. The option with the highest prioritized total score will be interpreted as the best option for recommendation. The results of the comparisons will be summarized in a table (see table 2) to clarify them. This table is modeled after one used in Field Manual 5-0, page B-35.

Table 2. Example Option Comparison Table (Standard + 3 Options)

Criteria	*Weight*	*M855*	*Option 1*	*Option 2*	*Option 3*
Mass	2	1(2)	2(4)	3(6)	4(8)
Cost	1	1	3	2	1
Corrosion Resistance	1	2	1	1	3
Flammability	1	2	2	3	1
Total		6	8	9	9
Weighted Total		8	10	12	13

Source: Created by author.

The criterion of mass will be given increased priority over the other three criteria. For the purposes of this comparison, any scores under the criterion of mass will be doubled. This reflects the importance of mass in recommending a more lightweight small arms cartridge under the terms of this thesis.

For comparison purposes, the standard ammunition type is defined as the M855 5.56 Ball, North Atlantic Treaty Organization approved ammunition. This is the ammunition most widely produced and in use at the beginning of this study (October 2010) in U.S. Army M16 and M4 series rifles, as well as the M249 light machine gun. This ammunition has a cartridge mass of 190 grains (12.30 grams), with a projectile mass of 62 grains (4.02 grams).[3] The cartridge case alone has a mass of approximately 106 grains (6.85 grams).[4] Its performance criteria include a muzzle velocity of 3000 feet per second (plus or minus 40 feet per second), a muzzle energy of approximately 1,345 foot pounds, and an accuracy of 7.8 inch spread at 600 yards.[5] It is also completely compatible with the existing U.S. combat rifles and light machine guns, and is a mature technology in terms of development.

The comparison of each option being evaluated also makes one important assumption: ammunition options that pass the screening criteria, and therefore have the same chamber dimensions of the M855 5.56mm ammunition, have the capability to meet the M855 performance criteria of muzzle velocity, muzzle energy, and accuracy.

Mass is the weight of the cartridge, measured in grains, an English unit specific to ammunition, bullets and propellant powder.[6] One grain is equivalent to approximately .065 grams. Of the evaluation criteria, this is the only one that can be measured quantitatively. Each option will be given a value commensurate with its comparison to its mass, relative to the mass of the M855 cartridge and other options. This comparison of mass will be displayed in the analysis as per table 3.

Table 3. Example Option Mass Comparison (Standard + 3 Options)

Criteria	*M855*	*Option 1*	*Option 2*	*Option 3*
Mass (in grains)	190	160	120	145
Score	1	2	4	3
Weighted Total (x2)	2	4	8	6

Source: Created by author.

Cost represents the overall price of the cartridge case, and is derived from the relative price of raw materials and production complexity. This is a relative value derived from the information in the literature review. It represents a comparison of general material cost for each option as compared to the cost of brass cased 5.56mm small arms cartridges; raw material cost will be used where available, estimates from relevant sources will be used if raw material data is unavailable. This comparison of cost will be displayed in the analysis as per table 4.

Table 4. Example Option Cost Comparison (Standard + 3 Options)

Criteria	*M855*	*Option 1*	*Option 2*	*Option 3*
Cost	Standard	Less costly	More costly	Least costly
Score	2	3	1	4
Weighted Total (x1)	2	3	1	4

Source: Created by author.

Corrosion Resistance represents the long term storage durability and oxidation rate of the ammunition option. This is a qualitative criterion evaluated from the research material, and each option is evaluated as it compares to the corrosion resistance of brass cased 5.56mm small arms cartridges. This comparison of corrosion resistance will be displayed in the analysis as per table 5.

Table 5. Example Option Corrosion Resistance Comparison (Standard + 3 Options)

Criteria	*M855*	*Option 1*	*Option 2*	*Option 3*
Corrosion Resistance	Standard	More resistant	Less resistant	Most resistant
Score	2	3	1	4
Weighted Total (x1)	2	3	1	4

Source: Created by author.

Flammability refers to the overall ability of the cartridge type to resist burning or melting in the presence of flames or extreme heat, especially as it pertains to storage or shipping. It also represents a general measure of safety during use. This is a qualitative criterion evaluated from the research material, and each option is evaluated as it compares to the flammability of brass-cased 5.56mm small arms cartridges. For this criterion, less flammability results in a higher score; greater flammability will result in a lower score. This comparison of flammability will be displayed in the analysis as per table 6.

Table 6. Example Option Flammability Comparison (Standard + 3 Options)

Criteria	*M855*	*Option 1*	*Option 2*	*Option 3*
Flammability	Standard	Less flammable	More flammable	Least flammable
Score	2	3	1	4
Weighted Total (x1)	2	3	1	4

Source: Created by author

Option Recommendation

After all options are evaluated, the option with the highest numerical value will be identified as the recommended option. Chapter 5 will cover the implications and caveats of selecting this option. Chapter 5 will also discuss recommendations in light of this ammunition recommendation, to include expanding the design to additional calibers, future consideration of specific lightweight weapon systems, and a brief discussion of other recent relevant advancements in ammunition.

[1]Headquarters, Department of the Army, Field Manual (FM) 5-0, *The Operations Process* (Washington, DC: Government Printing Office, March 2010), B-8.

[2]Ibid., B-8.

[3]ATK, Official Website for 5.56mm ammunition, http://www.atk.com/capabilities_defense/cs_as_ma_sc_5.56mm.asp (accessed 18 January 2011); Olive Drab, website, http://www.olive-drab.com/od_firearms_ammo_556mm.php (accessed 7 December 2010).

[4]Advanced Caseless Ammunition Inc., ―Introduction,” http://caselessammunition.homestead.com/indexcaseless.html (accessed 14 November 2010).

[5]ATK, Official Website.

[6]Robert A. Rinker, *Understanding Firearm Ballistics* (Clarksville: Mulberry House Publishing, 2011), 403.

CHAPTER 4

ANALYSIS

This chapter will cover the analysis of the lightweight ammunition options that emerged from data presented in chapter 2 of this thesis, using the methodology described in chapter 3 of this work. All facts and assumptions not already discussed in this thesis will be presented in this chapter. Each lightweight ammunition option will be briefly reviewed, then screened. The remaining options will then be evaluated by comparison to the M855 5.56mm ammunition cartridge presented as a baseline. Finally, these options will be compared with each other to determine the recommended option and answer the primary research question of this work.

Facts and Assumptions

Facts. The U.S. Army currently uses the M855 5.56mm ammunition as its standard in its M4 and M16 series rifles, as well as the M249 light machine gun.

Assumptions. There are two critical assumptions from chapter 3 regarding the screening criteria of compatibility and maturity that are restated here to clarify the analysis. Regarding compatibility, any option that has the same chamber dimensions as the M855 5.56mm cartridge, and does not require replacement or major modification of the M-4/M-16 or M249 weapons systems is acceptable. Regarding maturity, any ammunition option currently in successful initial production, testing, or fielding either commercially or to U.S. soldiers is acceptable.

Options

It is beyond the scope of this thesis for the author to review all possible lightweight small arms ammunition options. However, to provide a useful analysis of some of them in an effort to provide a recommendation, six available options emerged from the literature review. These options are: (1) caseless cartridges, (2) ammunition arrayed in series, (3) telescoped configured cartridges, (4) steel cased cartridges, (5) aluminum cased cartridges, and (6) polymer cased cartridges. These options were selected based on available data. Each of these options will be further discussed throughout the screening, evaluation and comparison phases of the analysis.

Option Screening

This section discusses the lightweight ammunition options and determines whether they pass the initial screening criteria of compatibility and maturity.

Option 1: Caseless Cartridges

These cartridges offer the greatest promise of weight reduction. These cartridges are not currently in use by U.S. Army soldiers' rifles, and the research indicates no other military uses them in their small arms weapons either. Caseless cartridges have profoundly different effects within the chamber of a rifle, compared to conventional cased cartridges. They create significantly increased chamber pressure, have no case-induced obturation, and lack any mechanism to operate with extractors. Increased chamber pressure in a weapon system causes increased chamber wear, or, worse, catastrophic damage to the weapon and injury to the firer. Caseless cartridges also create more heat within the weapon, due to the lack of a cartridge case to carry the heat of firing away from the chamber. Lack of case-induced obturation creates inconsistencies in accuracy and operation in gas operated rifles. Finally, all caseless cartridges found in the research have a different shape and different dimensions than the cartridges currently used in U.S. 5.56mm weapon systems, rendering them incompatible with current chamber dimensions. These attributes render caseless cartridges incompatible with current U.S. Army rifles and light machine guns. This option fails the compatibility criteria.

Caseless cartridges, because of the difficulties mentioned above, have been difficult to develop successfully. There are only a handful of manufacturers who have developed reliable caseless cartridges; however, in all of these instances, they were designed for exclusive use in specific weapon systems, like the HK G11, or the Voere bolt action hunting rifle. The ARDEC LSAT program has developed a lightweight machine gun that can fire caseless ammunition, but has faced design challenges, and the most recent literature available for this thesis states that it will not be considered for continued development.[1] There is no literature regarding the development of caseless ammunition for any existing U.S. Army weapon system in their current configuration, even experimentally. Considering that a weapon must be specifically designed to fire caseless cartridges, in addition to the design difficulties to overcome, the development time for any caseless rifles for the U.S. Army would likely take longer than 10 years. For this reason, this lightweight ammunition option does not pass the maturity criterion.

This option fails both the compatibility and maturity criteria, and must be screened out.

Option 2: Ammunition in Series

This ammunition is a recently developed design that arrays ammunition in the barrel of a weapon system, with alternating projectiles and combination propellant-primer pellets. In this case, the barrel is strengthened to function somewhat as a chamber, as well. When fired, the primers are electrically initiated from the front to the rear of the weapon's barrel-chamber very rapidly. The result is a very high rate of fire, with a lightweight projectile. In terms of compatibility, there is no feasible way to fire this type of ammunition configuration from existing U.S. Army rifles and light machine guns. The differences in the designs and operation of these weapons and the Metal Storm variety that uses this ammunition in series are too extreme to allow for compatible use. Metal Storm ammunition is designed for specialized weapons that have an entirely different cycle of function.[2] For these reasons, this ammunition type does not pass the compatibility criterion.

In terms of maturity, only the Metal Storm manufacturer currently has weapon systems designed to fire this type of ammunition. The manufacturer does have operational weapon systems, and even advertises possible DoD uses on their website. However, there is no literature that indicates that any military uses this ammunition in rifles or light machine guns, or that Metal Storm is even developing a weapon or ammunition for such an application Also, there are no indications in the literature that suggest any consideration for adoption by the U.S. Army. Were this weapon system and ammunition type proposed for use as a new rifle design, it would very likely take longer than 10 years to get it designed, produced, tested, and fielded to U.S. soldiers. Therefore, this ammunition option does not pass the maturity criterion.

This option fails both the compatibility and maturity criteria, and must be screened out.

Option 3: Telescoped Configured Cartridges

Telescoped cartridges are a recent development that changes the overall shape of the conventional cartridge into that of a right cylinder. This design allows it to take up less volume and a bit less weight in storage, and greatly reduces the risk of the bullet from becoming unseated from the rest of the cartridge. This configuration can be used with both cased and caseless cartridge designs. However, due to their shape, these cartridges do not conform to the chamber dimensions of the M16, M4 or M249, making telescoped cartridges incompatible.

From a maturity standpoint, the news is a bit more favorable. The LSAT program has already designed their lightweight light machine gun to fire telescoped, cased ammunition. The latest literature on the topic indicates that, if approved, LSAT would go on to develop rifles using this type of cartridge. Considering the advancements already made, it would likely take less than ten years to develop this type of rifle, or even a modified M4, though there are no plans for DoD at this time to commission such a weapon or modification.

This option fails the compatibility criterion, but passes the maturity criterion. However, as this option does not meet both criteria, so it must be screened out.

Option 4: Steel Cased Cartridges

Steel cartridges differ from conventional cases only in the material of the case, and the engineering steps to render it more resistant to corrosion. Steel cases match the chamber dimensions of U.S. Army rifles and light machine guns currently in the inventory and are compatible from this standpoint. Steel cases also have the strength to withstand the chamber pressures of these weapons, provide sufficient case obturation, and operate sufficiently in the cycle of functioning without modifying the weapon. This makes steel cased cartridges compatible with U.S. Army 5.56mm weapons.

Steel cases have been in use in small arms ammunition for decades. Soviet bloc countries used a type of steel case ammunition extensively to save on the material cost of copper, which is used in the brass alloy of approximately 70 percent copper and 30 percent zinc. Commercially, steel cased 5.56mm ammunition is manufactured by the Russian Wolf ammunition company, and their .223 caliber cartridge can be used with AR-15 rifles, the civilian equivalent of the M16 rifle.[3] This indicates that steel cased cartridges are sufficiently developed to consider adoption.

This option passes both the compatibility and maturity criteria, and will be analyzed further for evaluation and comparison.

Option 5: Aluminum Cased Cartridges

Aluminum and steel cartridges share many design similarities. Much like the steel option, aluminum cased cartridges only substitutes aluminum for brass in the case. They also meet chamber dimensions and can be used without modification to the M4, M16, or M249 weapon systems, making them acceptable in terms of compatibility.

Aluminum case designs were pioneered, at least in patents, in the U.S. at least as far back as the 1970s. They have been developed commercially; there is at least one manufacturer, CCI in its Blazer line of ammunition, which makes sufficient quantities of these cartridges to make them commonly available for large scale civilian use.[4]

This option passes both the compatibility and maturity criteria, and will be analyzed further for evaluation and comparison.

Option 6: Polymer Cased Cartridges

A polymer cased cartridge shares the same design paradigm with steel and aluminum cartridges in that it uses a suitable surrogate material for the case: specially formulated and molded plastic. As plastic is, by its very nature, formable, it can be used to make cartridges that meet M4, M16, and M249 chamber dimensions. Due to advancements in materials over the past 20 years, polymer cased cartridges have sufficient strength and durability to meet the rigorous requirements of firing without weapon modification. These attributes make this option compatible.

Development of this cartridge type has been cutting edge and fraught with complications over the past few decades, even with a number of patents proposing designs. Being a new technology, there are few manufacturers of this cartridge; PCP Ammunition is the only major commercial manufacturer of 5.56mm ammunition, and other calibers, available in the literature.[5] On a more optimistic note, the LSAT program has experimented extensively with polymer cased cartridges as part of its lightweight light machine gun replacement proposal.[6] While not currently produced by Lake City Army Ammunition Plant, the success of LSAT and commercial producers will likely make development for large scale military production viable within a decade, if this option is selected for further development.

This option passes both the compatibility and maturity criteria, and will be analyzed further for evaluation and comparison.

Screening Summary

The table 7 shows the summary of the screening results of the six lightweight ammunition options presented above.

Table 7. Option Screening Table

Criteria	*Opt. 1* *Caseless*	*Opt. 2* *Ammo in Series*	*Opt. 3* *Telescoped Config.*	*Opt. 4* *Steel Case*	*Opt. 5* *Aluminum Case*	*Opt. 6* *Polymer Case*
Compatibility	NO GO	NO GO	NO GO	GO	GO	GO
Maturity	NO GO	NO GO	GO	GO	GO	GO
Screening Result	FAIL	FAIL	FAIL	PASS	PASS	PASS

Source: Created by author

Option Evaluation

Having refined the options to three different types of materials for conventional cases, with the standard brass cartridges for comparison, this section will evaluate each of the different material types in terms of weight, cost, corrosion resistance and flammability. Each option will be compared to the baseline of brass, then to each other. The results will be consolidated using tables, as described in chapter 3.

Brass Cased Cartridges

Brass cartridges in their current basic configuration have been used as the standard material for American cartridge cases since 1849.[7] More properly defined, the brass used in ammunition is a composition of approximately 70 percent copper and 30 percent zinc, also known as cartridge brass. In general, brass has a specific weight of 8,430-8,730 kilograms per cubic meter.[8] M855 5.56mm ammunition has a cartridge weight of 190 grains, or 12.30 grams.[9] As a material, brass costs roughly $3.14 per pound, based on the recent proportionate prices of copper and zinc.[10] This alloy has good thermal properties in that it absorbs and dissipates heat rapidly, a clear benefit in withstanding highly exothermic chemical reactions such as found in the rapid firing of large quantities of ammunition.[11] Brass is also highly resistant to corrosion. It has a melting point of 900 to 940 degrees, Celsius (1652-1724 degrees Fahrenheit) and is resistant to sparking, reducing flammability.[12] Compared to other common alloys, brass is relatively easy to form into desired shapes with metal machining tools. It also has enough ductility to be reused in cartridge cases numerous times.[13] Finally, its composite metals are sufficiently available in the U.S. to make it viable for long term production.

Steel Cased Cartridges

Steel cased cartridges are not a new design concept; designs for using steel to substitute for brass were explored by the U.S. Ordnance Department during the latter years of World War II.[14] Steel is strong for its weight, with a specific weight of 7,850 kilograms per cubic meter for rolled steel, and 7,480 to 8,000 kilograms per cubic meter for stainless steel.[15] When applied for use as a 5.56mm cartridge case, this results in an approximate cartridge weight of 179 grains. The price of flat stainless steel is approximately $1.93 per pound at the time of this writing.[16] Steel corrodes relatively easily unless treated with a protective coating. Coating is usually done by coupling it with some other metal, like copper, or by applying a lacquer.[17] Steel can also be alloyed with corrosion resistant materials to enhance its corrosion resistance. Steel sparks easily, but has a melting point of 1353 to 1363 degrees Celsius (2500 to 2550 degrees Fahrenheit).

Steel is approximately 11 percent lighter than brass for the same volume. Steel is also cheaper, with an overall cost savings of roughly 39 percent. Unfortunately, steel corrodes far more easily. While this can be mitigated somewhat, some of the treatments can cause problems. For example, lacquered steel ammunition tends to foul firearms, as the lacquer often burns off and leaves residue during firing. While steel sparks more easily than brass, it also has a much higher melting point; its overall resistance to fire roughly approximates that of brass. Using steel for cartridge cases has certain drawbacks. Cartridge steel is a hard alloy compared to brass, which creates increased wear on a firearm's internal components over the long term.[18] It also has a low capacity for heat absorption or dissipation; it does not expand as rapidly as brass in response to the high chamber pressures created by firing, resulting in reduced case obturation that causes more gas to foul the weapon.[19] This results in increased weapons maintenance.

Aluminum Cased Cartridges

Aluminum is widely known for its favorable strength to weight ratio. Foil aluminum has, on average, a specific weight of 2,700 to 2,750 kilograms per cubic meter.[20] The 2005 Sadowski study indicates that use of aluminum cases resulted in a 60 percent savings in case weight compared to brass cartridges; this would make the cartridge weight approximately 126 grains.[21] The material cost for aluminum is approximately $1.13 per pound.[22] Aluminum has a fair amount of corrosion resistance; exposed aluminum will develop an exterior coating of aluminum oxide, which incidentally helps prevent further corrosion. The caveat to this is that aluminum oxide is actually harder than steel, which greatly increases weapon wear.[23] However, aluminum suffers from some weakness in dealing with exposure to rapid chemical reactions; this is indicative of increased flammability. Early aluminum case designs were occasionally subject to being burned through during firing, especially if the chamber was already very hot from the firing of a large number of cartridges.[24] Aluminum also has less elasticity than brass, which creates more residue in the weapon when firing aluminum cased ammunition due to reduced case obturation.

Compared to brass, aluminum is significantly lighter, as mentioned above. It is also much cheaper, with an overall cost reduction of about 64 percent. Aluminum's overall corrosion resistance is slightly less than that of brass; considering the hardness of aluminum oxide, this is especially problematic. The chief drawback with aluminum, however, is its flammability; it is significantly greater than that of brass and consequently has reduced resistance to fire.

Polymer Cased Cartridges

Polymer materials vary greatly and the precise composition of many commercial polymers are not widely published. However, the primary component of any polymer is a complex hydrocarbon, usually chemically treated with other chemicals to fulfill specific requirements. The PCP Ammunition Company website indicates that their polymer cased cartridge has a weight reduction of 25 to 30 percent.[25] This is roughly equal to a cartridge weight of 133 grains. Existing polymer cased ammunition costs approximately the same as brass cartridges.[26] Polymer cases, being non-metallic, are not subject to corrosion. However, these cases compare poorly to brass in terms of flammability and fire resistance. While they are non-metallic and thus not subject to sparking, previous NATEC designs have had issues with cases splitting at the neck during firing when the weapon chamber was hot.[27] Reports also indicate that polymer cased cartridges create a buildup of disintegrated polymer dust in the gas ports and other weapon components, causing weapon failures.[28]

It is clear from the information above that polymer cartridges are lighter than their brass counterparts. This savings in weight is not accompanied by an equal reduction in cost; polymer cartridges are equivalent in price to brass. Polymer cartridges are much more resistant to corrosion than brass. Finally, polymer cartridges fare poorly against brass with regard to flammability, as discussed in the examples above.

Option Comparison

This section displays tables that summarize the comparison of each lightweight ammunition option against the brass M855 brass standard, and each other, using the data above. There is one table for each criterion, with an overall evaluation table consolidating the overall results. Each option is compared using the tables described in chapter 3.

Table 8. Option Mass Comparison

Criteria	*M855*	*Steel*	*Aluminum*	*Polymer*
Mass (in grains)	190	179	126	133
Score	1	2	4	3
Weighted Total (x2)	2	4	8	6

Source: Created by author.

Table 9. Option Cost Comparison

Criteria	*M855*	*Steel*	*Aluminum*	*Polymer*
Relative Cost	Standard	Less costly	Least costly	Same cost
Score	1	2	3	1
Weighted Total (x1)	1	2	3	1

Source: Created by author.

Table 10. Option Corrosion Resistance Comparison

Criteria	*M855*	*Steel*	*Aluminum*	*Polymer*
Corrosion Resistance	Standard	Least resistant	Less resistance	Most resistant
Score	3	1	2	4
Weighted Total (x1)	3	1	2	4

Source: Created by author.

Table 11. Option Flammability Comparison

Criteria	*M855*	*Steel*	*Aluminum*	*Polymer*
Flammability	Standard	Same flammability	More flammable	Most flammable
Score	3	3	2	1
Weighted Total (x1)	3	3	2	1

Source: Created by author.

Table 12. Option Evaluation Table

Criteria	*Weight*	*M855*	*Steel*	*Aluminum*	*Polymer*
Weight	2	1(2)	2 (4)	4 (8)	3 (6)
Cost	1	1	2	3	1
Corrosion Resistance	1	3	1	2	4
Flammability	1	3	3	2	1
Total		8	8	9	9
Weighted Total		9	10	13	12

Source: Created by author.

As defined by the evaluation criteria, aluminum cased cartridges score the highest overall. This indicates that the aluminum cased cartridge is the best option, though this conclusion and recommendation must be made with caveats. The next chapter presents the implications and limitations of this result and counterpoint analysis using different criteria weights. It also contains recommendations for additional research to develop a more thorough and holistic investigation into the development of lightweight small arms ammunition.

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[1]Kori Phillips and Paul Shipley, ―Lightweight Small Arms Technologies" (Presentation to the U.S. Army Research and Development Command 2009 Lightweight Small Arms Technologies Conference, May 2009), 5.

[2]Metal Storm, website, http://www.metalstorm.com/content/view/66/110/ (accessed 24 October 2010).

[3]Wolf Performance Ammunition, web catalog, http://www.wolfammo.com/pdf/WPA_2011_catalog.pdf (accessed 16 May 2011).

[4]Blazer Ammunition, website, http://www.blazer-ammo.com/default.aspx (accessed 15 May 2011).

[5]PCP Ammunition, website, http://www.pcpammo.com/index.html (accessed 15 May 2011).

[6]Phillips and Shipley, 5.

[7]Alexander Rose, *The American Rifle, A Biography* (New York: Delta Trade Paperbacks, 2009), 125.

[8]SI Metric, http://www.simetric.co.uk/si_metals.htm (accessed 18 May 2011).

[9]ATK, Official Website for 5.56mm ammunition, http://www.atk.com/capabilities_defense/cs_as_ma_sc_5.56mm.asp (accessed 18 January 2011).

[10]Metal Prices.com, http://www.metalprices.com/ (accessed 22 May 2011).

[11]Constance McLaughlin Green, Harry C.Thomson, and Peter C. Root, *The Ordnance Department: Planning Munitions for War* (Washington, DC: U.S. Army Center for Military History, 1990), 488.

[12]Muggy Weld LLC website, http://www.muggyweld.com/melting.html (accessed 24 May 2011).

[13]Ibid., 488.

[14]Ibid.

[15]SI Metric.

[16]Metal Prices.com.

[17]Wolf Performance Ammunition.

[18]U.S. Patent 3,924,534, ―Lightweight Aluminum Cartridge Case of Improved Alloy Material That Eliminates Catastrophic Failures," Submitted by Frederick R, Gruner, granted 9 December 1975, http://www.google.com/patents (accessed 14 November 2010), 1; The Firing Line forums, http://thefiringline.com/forums/ showthread.php?t=283313 (accessed 4 May 2011).

[19]The Firing Line forums.

[20]SI Metric.

[21]Lucian M. Sadowski, ―Component Technology Investigations for Light Machine Gun Applications," (slideshow, May 2005), http://www.dtic.mil/ndia/ 2005smallarms/wednesday/sadowski.pdf (accessed 15 May 2011).

[22]Metal Prices.com

[23]The High Road forums, http://www.thehighroad.org/archive/index.php/t-401623.html (accessed 4 May 2011).

[24]U.S. Patent 3,797,396, ―Reinforced Lightweight Cartridge," Submitted by Frederick P. Reed, granted 19 March 1974, http://www.google.com/patents (accessed 23 October 2010).

[25]PCP Ammunition, website, http://www.pcpammo.com/index.html (accessed 15 May 2011).

[26]The High Road forums, http://www.thehighroad.org/archive/index.php/t-401623.html (accessed 4 May 2011).

[27]David Crane, ―Problems with NATEC PCA-Spectrum Polymer-Cased Ammunition?" 17 December 2005, http://www.defensereview.com/problems-with-natec-pca-spectrum-polymer-cased-ammo/ (accessed 23 May 2011).

[28]Ibid.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

This chapter will present the implications of the results, analysis limitations and some counterpoints of the evaluation of the viable lightweight small arms ammunition types analyzed in the previous chapter. This chapter will also present recommendations for further research and analysis into the subject of lightweight small arms ammunition.

Conclusions

The evaluation of the lightweight ammunition options in the previous chapter concluded that the aluminum cased cartridge had the highest score of all the options, and therefore was the best overall choice to recommend for future U.S. Army lightweight 5.56mm ammunition adoption. However, this analysis is only a summarized and very simplified glimpse into a very complex problem. While it is beyond the scope of this work to explore all the ballistic, scientific and environmental factors that contribute to lightweight ammunition development and selection, this section presents a few additional topics for consideration.

Alternate Criteria Priorities

The analysis in the previous chapter used four criteria to determine that of the three options that remained after screening was the best choice for recommendation. The criteria used were mass, cost, corrosion resistance and flammability, with mass given a weight of two. Nonetheless, it is important to vet the result to consider other possible outcomes using alternate prioritizing of criteria to provide a more complete study. For instance, if all criteria were weighted equally, as in table 13, the results would present two equally suited options: aluminum and polymer. Brass and steel also tie, but aluminum and polymer would be preferred. This indicates sensitivity to weighting, and the importance of relative weighting would carry in a decision to proceed with development or even production.

Table 13. Option Evaluation Table (Equally Weighted Criteria)

Criteria	*Weight*	*M855*	*Steel*	*Aluminum*	*Polymer*
Mass	1	1	2	4	3
Cost	1	1	2	3	1
Corrosion Resistance	1	3	1	2	4
Flammability	1	3	3	2	1
Total		8	8	9	9

Source: Created by author.

If the criterion of corrosion resistance was given a weight of two, to reflect the importance of stability in long term storage or resistance to environmental conditions, the evaluation, per table 14, would indicate that polymer cased cartridges were the best choice.

Table 14. Option Evaluation Table (Corrosion Resistance x 2)

Criteria	*Weight*	*M855*	*Steel*	*Aluminum*	*Polymer*
Mass	1	1	2	4	3
Cost	1	1	2	3	1
Corrosion Resistance	2	3(6)	1(2)	2(4)	4(8)
Flammability	1	3	3	2	1
Total		8	8	9	9
Weighted Total		11	9	11	13

Source: Created by author.

As these examples indicate, varying the weight of criteria leads to different results. The decision authority, be it a commander or program manager, could decide that any criteria should be weighted to account for mission requirements. The decision authority may also have entirely different criteria; any analysis intended to recommend the adoption of a system should reflect this.

Implications of the Recommended Option

While aluminum cased ammunition is the recommended option by the research and analysis conducted, there are still many design challenges to overcome if this option were to be adopted. First, there is still the issue of how to design aluminum cased cartridges to reliably withstand the chamber pressures and temperatures sustained in U.S. assault rifles and light machine guns. Unfortunately, there is no viable commercial or military aluminum rifle cartridge design in the literature. While the research indicates that the –€CI Blazer” line of ammunition does offer aluminum cased ammunition, they are all for pistols, not rifles.[1] Pistol cartridge cases are primarily shaped as hollow cylinders, and are simpler in design than rifle cartridges. Pistol ammunition also sustains lower chamber pressures and temperatures than rifle cartridges.

There are two difficult obstacles to overcome when designing aluminum-cased rifle cartridges to fit the chamber dimensions of current U.S small arms weapons. First, aluminum has less heat absorption and dissipation capacity than brass, which means less heat is removed from the chamber of the weapon. This heated chamber, in turn, applies thermal stress to the case, especially to the bent portions, such as the neck, where the bullet is seated. Second, aluminum has less resilience than brass when subjected to the extreme pressures inside rifle chambers during firing. When combined with the heat dissipation issue, this can cause the propellant of aluminum cased cartridges to burn through the relatively weak and stressed neck portion of the case. It was precisely these difficulties that the designers of early aluminum cartridges attempted to overcome in the 1970s.[2] The most recent experimental designs from ATK in 2005 were not able to completely resolve these issues, though there were some preliminary studies into the use of applying a heat resistant coating to the interior of the case to prevent burn through.[3] ATK also studied the application of additional case heat treatments to prevent gas escape from the case, and selecting a stronger, more resilient aluminum alloy than those used in previous designs.[4] This appears to be a solvable problem, if the outcome is worth the investment required for further development and testing.

Weight Savings

With the identification of aluminum cased cartridges as the recommended lightweight ammunition option, there still remains the matter of whether the savings in weight is worth adopting this option over existing ammunition.

It is important to identify how much weight in ammunition soldiers carry. The average basic load for a soldier is 210 cartridges of M855 5.56mm ammunition. This is seven fully loaded magazines: one loaded in the weapon and six stored in ammunition pouches on the soldier's field gear. As the weight of the M855 cartridge is 190 grains, the basic load adds up to 2.6 kilograms. This does not include the weight of the magazines themselves. If hypothetically viable aluminum cased ammunition were to be developed with the 60 percent case weight savings assessed in this work, this would reduce the weight of the cartridge to approximately 126 grains. Applied to the soldiers' basic load, this would reduce the ammunition weight down to approximately 1.7 kilograms. This reduces the soldiers overall carried weight by 0.86 kilograms, or 1.9 pounds, provided the soldier's primary weapon is the M16 series rifle or the M4 carbine. This is a slight benefit to the soldier, but may not be worth the cost in development without additional weight reduction from the weapon and other gear.

The weight saving is more significant for M249 squad automatic weapon gunners and assistant gunners. Gunners carry 400 cartridges of linked M855 ammunition, and assistant gunners carry more, usually 600 rounds. The weight of the gunner's ammunition, not including the links, is roughly 4.9 kilograms. In this example, a cartridge weighing 126 grains lightens the load by about 1.7 kilograms, or 3.7 pounds for the gunner and 2.5 kilograms, or 5.6 pounds, for the assistant gunner. This is more beneficial to a soldier conducting foot patrols in the rugged hills of Afghanistan, or similar patrols in the hot, urban environments of Iraq. However, it may still be a debatable issue of whether this weight savings is significant enough in relation to development costs, or compromises in terms of corrosion and fire resistance.

The Importance of Testing

There is no way to truly assess the effects of a new design or innovation without extensive testing. The field of ballistics is no exception. With the myriad factors that affect the properties of cartridges and firearms, it is easy to overlook one property that may affect the overall performance of the system.

An example of this is the Hornady Manufacturing study on the effects of gas port location in relation to the barrel of a weapon.[5] Hornady Manufacturing makes the Superformance line of ammunition, advertised to achieve muzzle velocities 100 to 150 feet per second higher than other ammunition brands, derived from an improved propellant. At first blush, this sounds like all good news.

Most gas operated firearms have a fixed gas port, designed to capture some of the gas that propels the bullet. In an M-4 or M16, this gas is redirected to the chamber to the bolt carrier to operate the bolt during the cycle of functioning. During function testing, Hornady discovered that, since their Superformance ammunition had a significantly different time-pressure curve; the timing of gas operation was acceptable in an M-16, but not in an M-4. This means that their Superformance ammunition would not reliably cycle in an M-4 carbine. The solution they provided was relatively simple, but dramatic: adjust the location of the gas port.[6] The solution would be entirely unsuitable for our purposes, and would have violated the screening criteria of compatibility. This is an excellent example of why extensive lab and field testing of options is essential. There may be unexpected results that appear during testing; it is essential to discover such surprises in development, not after fielding.

Another purpose of testing is to ensure that the product in question functions to all required standards. A critical assumption in this thesis was that all successfully screened options would meet or exceed the performance criteria of the M855 round. Should factory or field testing indicate that a lightweight ammunition option not meet M855 performance criteria, any potential weight savings may become irrelevant and the ammunition option would likely be rejected.

Recommendations

The result of the analysis presented in this thesis has revealed some topics for further research for study or development. These include the continued research and development of lightweight cased ammunition, the application of successful lightweight ammunition technologies to the spectrum of calibers used in the U.S. Army, and development of lightweight, modular weapons designed to take advantage of telescoped cased or caseless ammunition.

Further research and development for lightweight ammunition should be focused on aluminum or polymer cased cartridges, as these present the best potential for overall weight savings. Steel cases simply do not have the weight savings potential with current designs to consider further development, and are inferior to brass in corrosion resistance. Testing for aluminum or polymer designs should be focused on ensuring that options using these cases not only meet the M855 performance criteria of muzzle velocity, muzzle energy and accuracy, but also the option's long term storage potential, stability in extreme temperatures, waterproofing, fire resistance, physical resistance to damage and reliability while firing.

Both aluminum and polymer cased cartridges still have design obstacles that need to be overcome to make them truly viable. Future aluminum case designs should not suffer from burn through and oxide wear in weapon chambers. Polymer cases need to be developed that do not melt, break or foul weapon components with burned particulates.

Any success in the development of lightweight 5.56mm rifle ammunition should also be extended to other common U.S. Army ammunition calibers, such as 7.62mm or .50 caliber. Two commercial manufacturers are already either exploring or producing lightweight ammunition products in a variety of calibers. The first of these is PCP Ammunition. While their website indicates their polymer cased ammunition will not be ready for retail sale until late 2011, it does advertise ammunition in 5.56mm, 6.8mm, 7.62mm, .338 caliber and .50 caliber. Another company, Colt Defense LLC, is exploring a reinforced, spiral ribbed polymer cased ammunition design for use with calibers from 5.56 through .50 caliber. In addition, they are designing a modular case consisting of a brass case frame to be used with a cylindrical molded propellant insert; this is for larger calibers, ranging from .50 caliber through 40mm.

The greatest small arms ammunition weights saving options available in the literature are the telescoped cased cartridges and caseless cartridge designs. While the screening criteria deemed them unsuitable for recommendation in this thesis, this should not limit cooperative development of these ammunition types and lightweight weapons designed to fire them. The goal of the ARDEC LSAT lightweight machine gun program is to accomplish both. The weapon itself is designed to fire cased telescoped ammunition, and is 45 percent lighter than the M249. The ammunition is not only 35 to 40 percent lighter than the M855, it also has a 10 to 15 percent volume reduction due to its shape. The LSAT program has also extensively explored caseless telescoped ammunition, which is assessed to provide an even greater weight reduction. However, LSAT program engineers still face significant design challenges with this.

In summary, while there may be some weight savings for ammunition in current U.S. weapon systems, the most significant weight reduction designs involve entirely new weapon designs and their associated ammunition configurations. If the focus of systems development is weight reduction, existing weapons using the M855 5.56mm ammunition simply cannot take advantage of the most lucrative options. As has happened so many times in the history of American rifle development, revolutionary technological advances in materials and mechanics create new possibilities that benefit soldiers that can only be exploited by revolutionary weapon and ammunition designs.

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[1]Blazer Ammunition, website, http://www.blazer-ammo.com/default.aspx (accessed 15 May 2011).

[2]U.S. Patent 3,659,528, ―Composite Metal Cartridge Case," Submitted by Tuevo Santalo, Granted 2 May 1972, http://www.google.com/patents (accessed 14 November 2010); U.S. Patent 3,765,297, ―Non-Eroding Lightweight Cartridge Cases," Submitted by Leonard W. Skochko and Reed E. Donnard, Granted 16 October 1973, http://www.google.com/patents (accessed 23 October 2010); U.S. Patent 3,797,396, ―Reinforced Lightweight Cartridge," Submitted by Frederick P. Reed, Granted 19 March 1974, http://www.google.com/patents (accessed 23 October 2010).

[3]Chris Still, and Mark Leng, ―Research and Development Effort: Fabricate a 5.56mm Aluminum Cartridge Case," ATK presentation, http://www.dtic.mil/ndia/2010armament/WednesdayCumberlandChrisStill.pdf (accessed 22 May 2011).

[4]Ibid.

[5]Hornady Manufacturing, ―Superformance in Gas Operated Firearms," http://www.hornady.com/ammunition/superformance-in-gas-operated-firearms (accessed 25 May 2011).

[6]Ibid.

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