CHAPTER 1

General Considerations on Scientific Discoveries, Technological Innovations and Modern Warfare

1.1 Introduction

War is a state of open, coordinated, and often a prolonged conflict between nations or states, carried on by force, whether for defense, for revenging insults and redressing wrongs, for the extension of commerce, for the acquisition of territory, for obtaining and establishing the superiority and dominion of one over the other, or for any other purpose. A war invariably causes societal disruption and high human mortality.\(^1\),\(^2\)

From the earliest conclusive archaeological evidence it transpires that the earliest human attack on a human settlement took place between 12,000 and 14,000 years ago near the present day town of Jebel Shaba in Sudan. By 2000 BC, war originated independently in different parts of the world.\(^3\)

While wars are guided by strategy, battles take place on a level of execution of such strategic planning. Throughout recorded history of mankind, since ancient to recent times, military engagements have always had significant impact on world history. Eminent English historian Edward Shepherd Creasy identified 15 decisive battles of the world fought between 490 BC and 1851 AD.\(^4\) Description of 100 decisive battles from the Egyptian battle

---


at Megiddo in the 15th century to the military action in Persian Gulf War in 1990-1991, portraying the impact of such battles on the shaping of world history, has been given by Paul K. Davis. Long-term impact of decisive battles, spanning over 2500 years, on the course of world history has also been studied by Geoffrey Reagan.

Historians in general agree that the Military Revolution in Europe took place due to radical change in military strategy and tactics during the period between late medieval era and the early modern period. Michael Roberts was first to propose a concept of military revolution. He believed that such a revolution happened around 1560-1660, due to advancement of fire weapons. Clifford Rogers developed a concept of five successive military revolutions in the 16th century, five weapons revolution between 1580 and 1630, and finally, increase of size of European armies between 1650 and 1715. According to Geoffrey Parker, military revolution spanned over a period from 1500 to 1800, when Europeans achieved supremacy over rest of the world. Jeremy Black gave an exhaustive account as to how war has been waged over the past five-and-a-half centuries in the European and non-European worlds. He pointed out that while European warfare revolutionized during the 19th century, the Ottomans during 13th to 16th century, the Mughals in the 16th century, and the Manchus in the 17th century were formidable in their own right. Kausik Roy has described how

---


12 great battles have changed the course of Indian history from 326 BC to 1999 AD. It can be argued that in most of these cases, scientific-technological aspects were crucial. Thus, the battle of Constantinople saw the Turks use cannon with tremendous effect, and this in turn sparked off widespread adoption of this military technology. Within the next half-century the Turks would use their artillery to extend their rule over a large part of Europe and also defeat their Persian opponents at the battle of Khaldiran. It was from this experience that Babar, the deposed prince of Ferghana who had set himself up in Kabul, learnt the value of the artillery and conquered North India within four years (1526-1530). However, it was in Europe that science, technology and military modernization came together most systematically in the age of emerging and rising capitalism.

Scientific discoveries and technological developments during the periods of European Scientific Revolution, and Industrial Revolutions in Europe and subsequently in America, had greatly influenced development of military weapons used in modern warfare from mid-nineteenth century to the end of the twentieth century. Ernest Volkman stated that military generals have always turned to science in their quest for ever-more-terrible weapons and cited examples of non-military scientific inventions that were useful for military purposes. The inter-relationship of science and warfare for centuries has been laid down by Antonie J. Bousquet. According to Max Boot four technological revolutions, namely the Gunpowder Revolution, the First Industrial Revolution, the Second Industrial Revolution, and the Information Revolution had great impact on warfare and in turn significantly

---


influenced the course of world history between 1500 and 2003.\textsuperscript{14}

In the present chapter, we are first looking in a summary fashion at major developments in science and technology in the West from the renaissance to the early twentieth century, which would inevitably be cursory and selective, but we will do so with a view to presenting the impact of science and technology on warfare in three modern wars, namely, the American Civil War, the First World War and the Second World War. This would enable us to situate the subject of our detailed investigation better.\textsuperscript{15}

### 1.2 Major Revolutions influencing Warfare

The world is believed to have passed through four major revolutions that directly or indirectly brought out such technologies which enabled mankind to develop more and more deadly weapons since 1300. We shall briefly discuss only on those revolutions that are relevant to our present study.

#### 1.2.1 The Gunpowder Revolution

Gunpowder, the first man-made explosive, was invented in the 9\textsuperscript{th} century in China. The correct prescription for making gunpowder with saltpeter, sulfur and carbon appeared in the early 11\textsuperscript{th} century Chinese literature. The Arabs and the Indians acquired the knowledge of gunpowder during the middle of the 13\textsuperscript{th} century. It was thereafter introduced in Europe, which brought in revolution in weapons manufacture as well as tactics on the battle fields. Italy was the first to develop gunpowder weapons in 1326.


Such weapons were introduced in France in 1338, in Germany in 1340, and in England in 1344. Warfare in the early modern period was dominated by widespread development and use of gunpowder weapons.\textsuperscript{16} Sections 5.1 and 6.1 of this thesis give some details of gunpowder weapons used in modern warfare.

### 1.2.2 The Scientific Revolution

The Renaissance, a great cultural movement which began in Florence, Italy in the late 14\textsuperscript{th} century (or from the beginning of the 15\textsuperscript{th} century, according to some historians) and later spread to the rest of Europe brought about a period of scientific revolution and artistic transformation at the dawn of modern European History.\textsuperscript{17} According to John Desmond Bernal “the renaissance enabled a scientific revolution which let scholars look at the world in a different light. Religion, superstition and fear were replaced by reason and knowledge.”\textsuperscript{18}

The scientific revolution is the name given by historians of science to the period of European history between 1543 and 1700, when conceptual, methodological and institutional foundations of modern science were first established.\textsuperscript{19}

Nicholas Copernicus (1473-1543), a Polish astronomer and mathematician,

\begin{itemize}
\end{itemize}
in his book *De revolutionibus orbium coelestium* (On the revolutions of the celestial spheres) published in 1543 wrote “why then do we hesitate to grant [the Earth] the motion which accords naturally with its form, rather than attribute a movement to the entire universe whose limit we do not and cannot know? And why should we not admit, with regard to the daily rotation, that the appearance belongs to the heavens, but the reality is in the Earth?” Copernicus was the first person to formulate a comprehensive heliocentric cosmology, which displaced the then existing concept of geocentric cosmology propounded by Claudius Ptolemy (c 90-168), the Alexandrian geographer and astronomer. Historians of science are of the opinion that Scientific Revolution began in Europe with the publication of the book of Copernicus.\(^{20}\)

The crucial elements of the scientific revolution came after the renaissance, when revolutionary concepts in physics, astronomy, human anatomy and biology transformed the beliefs that had prevailed in ancient Greece and continued through Middle Ages in Europe. During this period, Tycho Brahe, Johannes Kepler, Galileo Galilei and Isaac Newton made significant contributions to scientifically unravel the mysteries of the universe. Tycho Brahe (1564-1601), a Danish astronomical and planetary observer, proposed a model of the universe that could be considered as both geocentric and heliocentric, where the Sun moved round the Earth, but all other heavenly bodies moved around the Sun. Johannes Kepler (1571-1630), a German mathematician and astronomer, based on astronomical data collected by his mentor Tycho Brahe, created three laws of planetary motion. He stated that planets move round the Sun in elliptical orbits and not in circular orbit, the speed of the planet in the orbit is not uniform, and there was a relationship that linked the distance of the planet from the Sun to the time a planet takes to make a full orbit. Italian physicist, mathematician, astronomer and philosopher Galileo Galilei (1564-1642) made further advancement to the theory of the universe. Through his

telescope, Galileo observed that the Moon had mountains, and the planet Jupiter had four satellites. He formulated the idea of gravity that could accelerate the motion of a falling body.

Isaac Newton (1642-1727), an English physicist, astronomer and mathematician, described universal gravitation and three laws of motion which governed the scientific view of the physical universe in his book *Philosophiae Naturalis Principia Mathematica* published in 1687. The law of universal gravitation stated that everybody in the universe attracts every other body with a force that is directly proportional to the product of their masses and inversely proportional to the square of the distance between them.\(^{21}\)

Andreas Vesalius (1514-1564), an anatomist and physician in the Habsburg, Netherlands, published one of the most influential books on human anatomy *De humani corporis fabrica* (On the fabric of the human body) in 1543. The book rectified some of the misconceptions about human anatomy laid down by Claudius Galenus (Galen of Pergamon) (129-199/217), a Roman physician, surgeon and philosopher during the second century AD. William Harvey (1578-1657), an English physician, was the first person to describe that the heart pumped blood from the atria into the ventricles and then into the rest of the circulatory system. His book *Anatomical Exercise on the Motion of the Heart and Blood in Animals* (1628) too overturned some of the concepts of Galen.\(^{22}\)

Establishment of a scientific society and an academy in Europe gave impetus to the Scientific Revolution. They provided ample opportunities to the philosophers of the period to discuss and publish their observations, hypotheses and findings with like minded intellectuals. The Royal Society, a private institution and the oldest learned society for science in existence,

---


was founded in London in 1660. The Academy of Sciences, a government institution, was established in Paris in 1666.  

1.2.3 The Industrial Revolutions

Industrial revolutions had a major impact on all aspects of human society and culture. It refers to a period from the mid-18\textsuperscript{th} century to the early 20\textsuperscript{th} century when unprecedented advancements in agriculture, mining, manufacturing, transportation and technology had occurred. Modern historians call the period between the 1760s and the 1840s as the 'First Industrial Revolution' which is characterized by development of textile manufacture, iron making, and steam power, led by Britain. They call the period from the 1850s to the 1910s as the 'Second Industrial Revolution' when steel, electrical technologies, automobiles, and aircrafts were introduced.\textsuperscript{24,25,26} These are presented in section 1.4 of this chapter. There are numerous applications of the industrial developments in warfare which happened between 1792 and 1918, a few of them are detailed in sections 1.5 and 1.6.

1.3 Science in the 18th and 19th Centuries

1.3.1 Physics


\textsuperscript{26} Landes, David S. The Unbound Prometheus: Technological Change and Industrial Development in Western Europe from 1750 to the Present. Cambridge: Cambridge University Press, 2003.
Between the 18th and 19th centuries, physics advanced to a great extent, both in terms of development of theories and experimentation. In 1704, Isaac Newton's book *Opticks: A Treatise of the Reflections, Refractions, Inflexion and Colours of Light* was published. Daniel Bernoulli (1700-1782), a Dutch-Swiss mathematician, did pioneering work in fluid mechanics, probability, and statistics. His book *Hydrodynamique* was published in 1738. Benjamin Thomson (1753-1814), an Anglo-American physicist published his paper “An inquiry concerning the source of heat which is excited by friction” in the *Philosophical Transactions of the Royal Society* in 1798 and initiated the revolution in thermodynamics that would take place in the 19th century.27

Nature of light was studied extensively during the 19th century. William Herschel detected infrared light (1800); Johann Wilhelm Ritter (1776-1810), a German physicist and chemist discovered ultraviolet light (1801); and German optician Joseph von Fraunhofer (1787-1826) discovered dark absorption lines (1814) in Sun's spectrum. English physicist Thomas Young (1773-1829) in 1802 developed the wave theory of light. French physicist Augustin-Jean Fresnel (1788-1827) studied the behavior of light both theoretically and experimentally. He demonstrated the wave nature of light in 1816. Young and Fresnel demonstrated in 1817 that light waves vibrate transversely. Albert Abraham Michelson (1852-1931), an American physicist, measured the speed of light in 1879. James Clerk Maxwell (1831-1879), a Scottish physicist and mathematician formulated classical electromagnetic theory of light in 1861. German physicist Heinrich Rudolf Hertz (1857-1894) clarified and expanded the theory and in 1888 generated and detected radio waves. German physicist Wilhelm Conrad Röntgen (1845-1923) produced and detected a type of electromagnetic radiation, known as X-rays.28

---


Great advancement in the field of electricity and electromagnetism happened in the 19th Century. Alessandro Volta (1745-1827), an Italian physicist in 1800 invented electric battery, a continuous source of current electricity. Danish physicist Hans Christian Oersted (1777-1851) discovered in 1820 that electric currents create magnetic fields, which established the theory of electromagnetism. Michael Faraday (1791-1867), an English physicist and chemist built an electric motor in 1821 and demonstrated that electrical forces can produce motion. Michael Faraday in England and Joseph Henry (1797-1879) a physicist in America independently discovered the phenomenon of electromagnetic induction in 1831. Faraday in 1832 announced his Laws of Electrolysis.

1.3.2 Astronomy

Astronomers of the 18th century made precise measurements of position and classification of heavenly bodies. During the 19th century they applied the existing knowledge in mathematics, physics, chemistry and geology to understand the make-up of these bodies. English astronomer, mathematician and physicist Edmond Halley (1656-1742), published his book *Synopsis Astronomiae Cometicae* in 1705, wherein he stated that the comet seen in 1456, 1531, 1607 and 1682 related to the same comet and predicted that it would be seen again in 1758. Thomas Wright (1711-1786), an English astronomer and mathematician described the shape of the Milky Way in 1750. Another English astronomer James Bradley (1693-1762) made two fundamental discoveries in astronomy, the aberration of light and nutation of Earth's axis. He also compiled a catalog of 60,000 stars. A catalog of more than 100 nebulae was compiled in 1781 by French astronomer Charles Messier (1730-1817). German-born British astronomer

---

Frederick William Herschel (1738-1822) built a 40-ft. long reflecting telescope in 1800. He discovered the planet Uranus and its two moons in 1781. It was the first planet to be discovered since antiquity which sparked a new interest to search for new planets in the solar system. A series of minor planets, or asteroids: Ceres, Pallas, Juno, Vesta, Astraea and Hebe were discovered between 1801 and 1847, while looking for a planet between Mars and Jupiter. Further, based on mathematical prediction, Johann Gottfried Galle (1812-1910), of the Berlin Observatory and Heinrich Louis d'Arrest (1822–1875), a student at the University of Berlin, discovered the planet Neptune in 1846.

In 1859, Robert Wilhelm Bunsen (1811–1899) and Gustav Robert Kirchhoff (1824–1887) discovered that the spectrum of sunlight produced by a prism could be compared with spectra produced by chemicals burned in the laboratory, and by applying this method the elements present in the Sun could be found out. Venus passed across the face of the Sun in 1761 and 1769, again in 1874 and 1882.

### 1.3.3 Chemistry

Significant advancement in the field of fundamentals of chemistry was made possible due to extensive experimentation by the learned European chemists of the 18th and 19th century.\(^{30}\) The nature of air was discovered during the second half of the 18th century. Daniel Rutherford (1749-1819), a Scottish physician, chemist and botanist isolated nitrogen in 1772. Two years later Joseph Priestly (1733-1804) an English natural philosopher isolated oxygen. Joseph Black (1728-1799), a Scottish physician discovered carbon dioxide in 1776. British physicist and chemist Henry Cavendish (1731-1810) discovered hydrogen in 1766 and also

demonstrated in 1783 that water was made of oxygen and hydrogen. Antoine Lavoisier (1743-1794), a French nobleman, discovered that although matter may change its form and shape, its mass always remains the same. In 1789, he listed 23 of the elements we find today in the periodic table. Joseph Louis Proust (1754-1826), a French chemist propounded the law of definite proportions, which states that a chemical compound always contains exactly the same proportions of elements by mass.

John Dalton (1766-1844), an English chemist, physicist and meteorologist did pioneering work in the development of modern atomic theory in the early 19th century. Thereafter, Amedeo Avogadro (1776-1856), an Italian savant, propounded the molecular theory. In 1815, William Prout (1785-1850), an English chemist, suggested that hydrogen was the fundamental atom and all other atoms were built up from different numbers of hydrogen atoms. Swedish chemist Jons Jacob Berzelius (1779-1848) worked out the chemical formula notation and in 1818 published his table of atomic weights. Russian chemist Dmitri Ivanovich Mendeleev (1834-1907), created the first version of 'periodic table of elements'.

William Ramsey (1852-1916) a Scottish chemist in 1895 discovered the element helium on Earth. He also discovered other noble gases, namely, neon, argon, krypton and xenon. British physicist Joseph John Thomson (1856-1940) discovered the electron in 1897. French physicist Pierre Curie (1859-1906) was a pioneer in crystallography, magnetism, piezoelectricity and radioactivity. Marie Sklodowska-Curie (1867-1934), a Polish-French physicist-chemist, along with her husband Pierre Curie isolated radium and plutonium in 1898.

1.3.4 Life sciences

Biological sciences, such as botany and zoology became increasingly professional scientific disciplines over the 18th and 19th
centuries. Carolus Linnaeus (1707-1778), a Swedish botanist, zoologist and physician, laid the foundation of modern scheme of naming species of living things. His most important publications were *Systema Naturae* (1735), *Philosophia Botanica* (1751), and *Species Plantrum* (1753). English biologist Edward Anthony Jenner (1749-1823) in 1796 used vaccination against smallpox and in turn saved lives of smallpox victims all over the World.

During 1838-1839, three Germans, Matthias Jakob Schleiden (1804-1881), Theodor Schwann (1810-1882), and Rudolf Virchow (1821-1902) founded the cell theory which states that cells are the basic units of structure in every living things, both plants and animals. Louis Pasteur (1822-1895), a French chemist and microbiologist, proposed the germ theory of disease. He developed “pasteurization” a process of heating a liquid (especially milk) sufficiently to kill bacteria without changing its flavor, composition and nutrition. English naturalist Charles Robert Darwin (1809-1882) published his book *On the origin of Species* in 1859, wherein he described his theory with evidence in support of evolution of life by natural selection.

### 1.3.5 Science Academies

New scientific societies and academies were founded in Europe and America during the 18\textsuperscript{th} and 19\textsuperscript{th} centuries. They were, the Prussian Academy of Sciences (1700) in Berlin; the St. Petersburg Academy (1725), which is known as Russian Academy of Sciences since 1999; the Royal Danish Academy of Sciences (1742) in Copenhagen; the American Philosophical Society (1743) in Philadelphia; and the Royal Society of Edinburgh (1783). The Royal Astronomical Society was founded in 1820 in

---


London. The British Association for the Advancement of Science was founded in York in 1831 with the primary object of promoting science. In America, the Smithsonian Institution was established for the “increase and diffusion of knowledge” in Washington, DC in 1846. The American Association for the Advancement of Science was founded in 1848 in Pennsylvania. In 1863, the US National Academy of Sciences was established in Washington, D.C. The British Astronomical Association, the senior national association of amateur astronomers in the UK, was founded in London in 1890.

1.4 Technology in the 18th and 19th Centuries

1.4.1 Weaving Machines

In 1733, English inventor John Kay (1704-1779) patented a wheeled flying shuttle for the hand-loom which accelerated weaving and thus was a key factor in the Industrial Revolution. James Hargreaves (1720-1778), an English weaver, invented a multi-spool spinning frame known as ‘spinning jenny’ in 1764. Another Englishman, Richard Arkwright (1732-1792) also patented a spinning frame in 1768. English inventor Samuel Crompton (1753-1827) in 1779 invented the spinning mule, a machine which spun yarn suitable for use in the manufacture of muslin. In 1785, Edmund Cartwright (1743-1823), an Englishman, invented the mechanized power loom. In 1790, Eli Whitney (1765-1825), an American, patented the cotton gin, a machine that quickly and easily separates cotton fiber from the seed. Joseph M. Jacquard (1752-1834), a Frenchman, in 1800 invented the mechanical programmable loom.33

1.4.2 Steam Road Vehicles

A French inventor Nicolas-Joseph Cugnot (1725-1804) built the first steam-propelled three-wheeled vehicle in 1769. William Murdoch (1754-1839), a Scottish engineer, developed Britain's first steam road locomotive in 1784. Oliver Evans (1755-1819), an American inventor, in 1805 built the first amphibious vehicle, a steam-powered vehicle able to move on road as well as in water. Josef Bozek (1782-1835), Czech engineer and inventor built a steam-car in 1815. English inventor Walter Hancock (1799-1852) built a number of steam-powered three-wheeled road vehicles between 1824 and 1836.34

1.4.3 Steam Locomotives

Thomas Newcomen (1664-1729), an English ironmonger and Baptist lay preacher, combined the ideas of basic steam engines of English inventor Thomas Savery (1650-1715) and French inventor Denis Papin (1647-1712), to create the first practical steam engine for pumping water in 1712. James Watt (1736-1819), a Scottish inventor, in 1765 redesigned the steam engine making it more efficient than Newcomen's engine and capable of powering a wheel, thus allowing a greater number of applications such as powering a loom in textile factory, powering paper mills, draining mines, and running a steam locomotive.

British inventor and mining engineer Richard Trevithick (1771-1833) built the first full-scale railway steam locomotive in 1804. Locomotion built in 1825 by British civil and mechanical engineer George Stephenson (1781-1848) was the first public steam locomotive in the world, which moved through a distance of 12 miles (about 19.5 km) between Stockton and Darlington. The most advanced steam locomotive, Rocket was built in Newcastle upon Tyne

in 1829 by Robert Stephenson and Company. By 1830, railway lines laid in England grew to 98 miles (about 158 km). Use of railway was primarily made for transportation of men and materials essential for industrialization.

Belgium, after breaking with the Netherlands in 1830, gave importance to adopting rail transport for stimulating industrial revolution in the new country. The first Belgian steam-powered railway was operated between Mechelen and Brussels (about 24 km) in 1835. By 1843, Belgium had a railway network, constructed by the Belgian State Railways that connected the major cities, ports and mining areas, and also linked to the neighboring countries.

The first German steam-hauled locomotive Eagle, which ran between Nurberg and Furth in 1835, was built by Robert Stephenson and Company in Newcastle, England. By 1840s, major cities of Germany were connected by rails. The first Italian railway line covering a distance of 4.5 miles (about 7 km) between Napoli and Portici was opened in 1839. The first railway in the Netherlands operated between Amsterdam and Haarlem in 1839.

Ireland's first railway opened between Dublin and Kingstown, a distance of 6 miles (about 9.5 km), in 1834. In Poland, Warsaw and Pruszków, at a distance of 9 miles (about 14.5 km), were connected by rail in 1844. First railway in Hungary connected Pest and Vác – a distance of 26 miles (about 42 km) – in 1846.

The first Austrian railway line connected a distance of 15 miles between Vienna with Wagram in 1837. The first railway in Switzerland was a 10 miles line connecting Zürich with Baden in 1847.

The first steam-powered Canadian railway was operated outside Montreal in 1836. The first passenger train in British India was inaugurated in 1953 between Bori Bunder in Bombay and Thane covering a distance of 21 miles.

John Stevens, an American inventor designed and built a steam locomotive
that hauled several passenger cars in Hoboken, New Jersey in 1825. The first public carrier railways operated in the Baltimore and Ohio Railroad. A British made steam locomotive ‘John Bull’ was operated in 1831 in New Jersey. In 1831, a railroad between Boston and Providence was opened.35

1.4.4 Steamboats

Steamboats or steamships were used extensively for transportation of men and material from one place to another, before invention of trains, automobiles and air planes. James Watt (1736-1819) a Scottish inventor developed an engine run by steam in 1769. Five years later, Claude de Jouffroy (1751-1832), a French inventor, built Palimpede, the first working steamboat with rotating paddles. In 1802, a British Baron, Thomas Dundas (1741-1820) commissioned Charlotte Dundas, the first practical steamboat. Robert Fulton (1765-1815), an American engineer, built Clermont, the first commercially successful steamboat, in 1807. By 1900, there were about 30 steamboats operating in the world, which came down to less than 10 by 1930.36

1.4.5 The Automobile

French inventor Francois de Rivaz (1752-1828) developed first internal combustion engine powered by a mixture of oxygen and hydrogen in 1807. Siegfried Marcus (1831-1898), a German-born Austrian inventor built the first automobile in which internal combustion engine was fueled by gasoline. However, Karl Benz (1844-1929), a German engineer, was the first person to design and develop a practical gasoline-powered automobile


in 1885. He was granted patent for automobile in 1888 and production of the vehicle started immediately thereafter. During the remaining years of the 19th century, automobiles were developed by Gottlieb Daimler (1834-1900) and Wilhelm Maybach (1846-1929) in Germany; by Frederick William Lanchester (1868-1946) in 1895 in Britain; and also by John William Lambert (1860-1952) and Henry Nadig (1808-1860) in USA in 1891.  

### 1.4.6 Submarine

The first submarine torpedo boat Turtle was built in 1776 by David Bushnell (1742-1824), an American inventor. An attempt was made by the crew of ‘Turtle’ in 1776 during American Revolutionary War to affix explosive to the underside of British Warship ‘HMS Eagle’ in New York Harbor, but was unsuccessful. Robert Fulton (1765-1815), an American inventor, then living in the French First Republic, designed and built the first practical submarine, the ‘Nautilus’ in 1801.

### 1.4.7 Electrical Telegraph

Italian physicist Alessandro Volta (1745-1827) invented the voltaic pile, an early electric battery. Danish physicist Hans Christian Oersted (1777-1851) in 1820 experimentally discovered that electric current creates magnetic field. Influenced by Oersted's discovery, André-Marie Ampere (1775-1836), a French physicist performed a series of experiments in 1820 to elucidate the exact nature of the relationship between electric current-flow and magnetism. These experiments led him to formulate laws of electromagnetism. British physicist and chemist Michael Faraday (1791-

---


1867) in 1831 discovered electromagnetic induction: the induction or generation of electricity in a wire by means of electromagnetic effect of a current in another wire. He also developed the first dynamo in the form of a copper disk rotated between the poles of a permanent magnet. American scientist Joseph Henry (1779-1878) had also discovered the phenomenon of electromagnetic induction in 1831, but Faraday was first to publish his results. Henry later developed electromagnetic relay, an electromechanical switch.

Samuel F.B. Morse (1791-1872), an American painter, traveled to Europe in 1832 and heard of Faraday's work on electromagnetic induction. He also learnt about Henry's electromagnetic relay. Several attempts were made by Europeans in the following years to develop telegraph. In 1835, Morse built the first American single-wire telegraph. He also developed the Morse Code, a method of transmitting textual information as a series of on-off tones. Morse patented his telegraph machine in 1837 and was able to send the first telegraphic massage “What hath God wrought” from Washington, D.C. to Baltimore in 1843, at an approximate rate of 10 words per minute.

1.4.8 Electrical Technology

Michael Faraday's work of 1831 on electromagnetic induction in England led to a chain of inventions in electrical technology in the 19th century, such as electric motor by English physicist William Sturgeon (1783-1850) in 1832; dynamo by French instrument maker Hippolyte Pixii (1808-1835) in 1832; power transformer by Englishman Lucien Gaulard (1850-1888) in 1881; single-needle telegraph by Pavel Schilling (1780-1837) in Russia in 1832; and telephone by Alexander Graham Bell (1847-1922) in 1876 in America. Thomas Alva Edison (1847-1931) operated the first

commercial electricity generating station in America in 1882, which provided direct current (DC) to its customers. Another American, Nikola Tesla (1856-1943) invented alternating current (AC) generator in 1888, and soon thereafter commercial AC supply began in the US.\textsuperscript{40}

Having surveyed the principal scientific and technological developments, we will now look at three major nineteenth and twentieth century wars.

### 1.5 Technological Innovations during the American Civil War

The American Civil War, fought during 1861-1865, was a conflict between the Northern states (the Union) and the Southern states (the Confederacy). It was the bloodiest war in American history that claimed lives of some 6.2 million soldiers in course of thirteen battles. Sectional strife between northern and southern states, on issues like states' rights, territorial disputes and slavery, emerged in the early 19\textsuperscript{th} century, grew more pronounced during 1850s and finally transformed into a war on 12 April 1861 with the attack on Fort Sumter, near Charleston in South Carolina.

The history of United States of America started with the 'Declaration of Independence', a statement adopted by Continental Congress on 4 July 1776, which announced that 13 American colonies, at war since 1775 with Great Britain, were independent states and thus no longer a part of the British Empire. The war of Independence (also called American Revolution) ended with American victory in October 1781, followed by the 'Treaty of Paris' in 1783, the formal British abandonment of any claims to the United States.

The constitution of United States was written in 1787 and ratified in 1789. For more than a century before the constitution was drafted, black African

slavery had existed in the North American English colonies. Whether slavery was to be permitted under the new constitution was a matter of conflict between the North and South. The constitution of the Union, however, ensured slavery throughout the USA. But by 1804 most Northern states, had effectively abolished slavery, while in the Southern states slavery grew and became an inextricable part of the economy and way of life.

Between 1776 and 1819, the country had grown from 13 states to 22 states, with 11 free-states and 11 slave-states. In an effort to maintain balance of power between free-states and slave-states in Congress, the United States Congress passed an agreement, known as “Missouri Compromise” in 1820. The agreement accepted Missouri as a slave-state and Maine as a free-state. The Congress, once again to avert a crisis between the North and South on the issue of slavery, passed a package of five laws known as “Compromise of 1850”. It defused the sectional conflict, although each side disliked specific provisions made under the agreement.

In 1854, the territories of Kansas and Nebraska wanted to become new states of the USA. But the issue left to be resolved was whether they would have slavery or not. The Kansas–Nebraska Act passed by Congress in 1854, which allowed people in the territories to decide of themselves whether or not to allow slavery within their boundaries. As a result violence erupted in the region and continued for a few years. Kansas was admitted to the Union as a free-state in 1861 and Nebraska also became a new free-state but in 1867.

On 16 June 1858, Abraham Lincoln was nominated by the Republicans as their candidate from the state of Illinois for the US Senate. Lincoln in his address cautioned the audience to the danger of division of the country between slave and free-states by saying “Every Kingdom divided against itself is brought to desolation; and every city or house divided itself shall not stand.” On 6 November 1860, Lincoln was elected President of USA as a Republican candidate. He won the election entirely on the strength of his
General Considerations on Scientific Discoveries, Technological Innovations and Modern Warfare

support from the Northern states.

The Southern states got tired of all the fighting and arguing on the issue of slavery and as a result decided to break away from the USA. Between December 1860 and February 1861, seven deep-south states seceded, starting with South Carolina, Mississippi, Florida, Alabama, Georgia, Louisiana and Texas. On 4 February 1861 these states formed “Confederate States of America” with Jefferson Davis as President. Within next two months four more Southern slave-states – Virginia, Arkansas, North Carolina and Tennessee – also joined the confederacy.

On 4 March 1861, Abraham Lincoln was inaugurated as the 16th President of the United States of America. On 12 April 1861, Confederate forces attacked a US Military installation at Fort Sumter, in South Carolina and that started the American Civil War – a bloody conflict between the Union and the Confederates. Ulysses S Grant (1822-1885) and Robert E Lee (1807-1870) were the generals of the Union and the Confederate forces, respectively.

The Federal Government of USA, called the Union, led by President Abraham Lincoln fought against the Confederates in thirteen battles during 1861-1865. The Union was supported by twenty Northern free-states (namely, California, Connecticut, Illinois, Indiana, Iowa, Kansas, Maine, Massachusetts, Michigan, Minnesota, Nevada, New Hampshire, New Jersey, New York, Ohio, Oregon, Pennsylvania, Rhode Island, Vermont, and Wisconsin) and five border states (namely, Delaware, Kentucky, Maryland, Missouri and West Virginia).

James Ford Rhodes (1848-1927), a self-taught eminent American historian, had written the "History of the Civil War 1861-1865" in three volumes in 1895, 1899 and 1904, respectively. In 1917, based on a fresh study of the subject, Rhodes produced another book titled ' A History of the Civil War, 1861-1865, which was published by the MacMillan Company. In his classic history, Rhodes had emphasized slavery and anti-slavery as the primary
causes of the war. In 1918, Rhodes's chronicle of the war was awarded the 2nd Pulitzer Prize for History.\textsuperscript{41} The perceptions of the American Civil War have, however, changed over the years.

James M. McPherson's book titled, \textit{Battle Cry of Freedom: The Civil War Era}, published in 1988, is considered as the best single volume history of that period by most of the historians. The treatise encompasses the economic, social and political pressures that led to the armed conflict and its outcome.\textsuperscript{42}

A detailed account of the political activities of the Union and the Confederate forces, as also on the battles of the war that divided America between the North and the South is available in a book by Bruce Catton.\textsuperscript{43} Peter Cozzens has traced the Civil War through 26 key battles and campaigns -- those with the most casualties and troops engaged, most strategic significance, or most remarkable tactics.\textsuperscript{44}

The course of the Civil War is intimately linked with refinement, development and utilization of new technologies. Historians have claimed that the Civil War was the first modern war, where technology outpaced tactics.\textsuperscript{45} They have considered to the utilization of the rifled musket, superior artillery, railroads, steamships, submarines, telegraph, balloons, photography etc. in the war as its modernity. Paddy Griffith, a noted historian, however, opined that the superior weapons developed during this


1.5.1 Weapons

Although the American Civil War started with old-fashioned infantry charges and cavalry attacks, many new technologically advanced weapons were brought into use by both the Union and the Confederates during the course of the war. Evolution of improved manufacturing methods during 1815-1865, as an impact of Industrial Revolution in the United States, created varied and broad improvement in field artillery weapons of the Civil War. Major weapon developments included the invention of the percussion cap; of the rifled gun and cannon barrels; of cylindro-conical bullet; of pistols and revolvers; of rapid firing guns; etc.

The percussion cap ignition system was invented by Scottish Clergyman Alexander John Forsyth (1768-1843) in 1805 and introduced later in warfare in 1850. It was a crucial invention as it enabled muzzle-loading guns to fire reliably in any climatic condition of the battle field.

Rifling of the musket barrel was another great improvement which increased range and accuracy of gun fire. Rifled breech-loading guns were also extensively used in the wars. Claude-Étienne Minié (1804-1879), a French Army officer, invented the Minié Ball in 1847 and the Minié rifle in 1849, which came into prominence in Crimean and Civil war. The rifle was designed to allow rapid muzzle-loading (loading of the gun from the forward open end of the gun's barrel) of rifles and therefore had widespread use as a mass battlefield weapon. The Minié ball is a spin-stabilised, muzzle-loading rifle bullet used in the Minié rifle. Several models of rifled cannons were used in the Civil War. Samuel Colt (1814-1862), an American inventor,


47 Hazlett, James C., Edwin Olmstead and M. Hume Parks. *Field Artillery Weapons of*
had developed a practical 'revolving gun' or revolver and patented it in USA in 1836. Colt's revolver was a practical adoption of 'revolving flintlock'. The Colt Army Model of 1860, a six-shot revolver of .44 caliber was favorite of the Union, while the confederates preferred Colt Navy Model of 1861, a .36 caliber revolver.

Richard Jordan Galting (1818-1903), an American inventor, developed a rapid-fire weapon called 'Galting gun' in 1861. These guns were very large and heavy and hence mounted on wheels. Galting guns were used mostly by the Union forces in the war. It was a forerunner of the modern machine gun.

1.5.2 Ironclad Battleships

'The Napoleon', commissioned by France in 1850, was the first steam-powered battleship in the world. The first ironclad battleship 'La Glorie' was launched by the French Navy in 1859. The British Royal Navy developed its ironclad battleships 'Black Prince' and 'Warrior' in 1861 and 1862. Ironclad ships were first utilized in the Crimean War and it transpired that they were formidable adversaries for traditional wooden warships of that time.

With the beginning of civil war in America both the belligerent sides developed steam-powered ironclad warships – 'CSS Virginia' by Confederate States Navy, and 'USS Monitor' by United States Navy. These two ironclad warships, supported by a fleet of wooden ships, fought a fierce battle near Virginia on 8-9 March 1861. A few wooden warships of both the sides were destroyed, but the ironclad warships survived opponents attacks and the result of the battle remained indecisive. While 'Virginia' was scuttled by the Confederates in May 1862, the 'Monitor' was lost at sea in December.

1.5.3 **Submarine Boats**

During the American Civil War the confederates built small, steam-powered submarines called 'Davids', one of which attacked battleship 'USS New Ironsides', off the coast of Charleston on 5 October 1863, but could not sink it. On 16 February 1864, another Confederate submarine ‘Hunley’ successfully sank ‘USS Houstonic’ off the Charleston coast. But the submarine too sank after completing its mission. The Union Navy also possessed a submarine warship ‘Alligator’ built in 1862 by French inventor Brutus de Villeroi (1794-1874). The ‘Alligator’ made two attempts to destroy enemy targets but never succeeded. It was lost off the North Carolina coast during a storm in 1863.

David Bushnell is credited for building the first water mine in the world. Like his submarine, his mines when used against the British fleet during American Revolutionary war in 1778 were proved ineffective. During the American Civil War the confederates used water mines extensively against the Union. The Confederates sank 27 vessels by mines, a high success rate, compared to sinking 7 Federal vessels by gunfire.\(^{49}\)

1.5.4 **Railways**

Many historians have opined that, one of the reasons for calling the American Civil War as the first modern war was because of extensive use of rail transportation for the first time in a major war. The war experience had further influenced the actions taken by the government in building and


running railway network in the United States in the years following the war.\textsuperscript{50,51,52}

By the time of the Civil War, the railroads had advanced in both Northern and Southern territories. The railways as a new mode of transportation were extensively used by both the belligerent sides. While the North had about 22,000 miles (about 35,400 km) of railroad, the South had about 9,000 miles (about 14,500 km) of railway track. The railways moved large number of troops and hauled heavy ammunition, ration and medicine for the army at the battle field much faster than ever before. The North had well-developed integrated and flexible railway network in serving the Union army's logistic needs over long distances.\textsuperscript{53} The Southern railroads in contrast were not so convenient for military operation. They mostly connected the hinterlands with the ports, without inter linkage and had three different track gauges limiting the ready ability to carry freights to long distances.\textsuperscript{54}

### 1.5.5 The Telegraph

The British made limited military use of telegraph for the first time at Varna during the Crimean War in 1854. By 1860, telegraph lines were laid in most of the eastern states of America. When Lincoln arrived for the


\textsuperscript{51} Hodges, Robert and Peter Dennis. \textit{American Civil War: Rail Road Tactics}. New York: Osprey Publishing, 2009.


inaugural in 1861, there were no lines connecting the War Department or the White House. He realized the great importance of electrical communication for the military and in May 1861 established the US Military Telegraph Corps. Telegraph operators were engaged in large numbers to assist the Union Army with technical expertise to transmit and receive messages. By 1862, more than 4,000 miles (about 6,500 km) of telegraph lines were laid for the benefit of Union Army. Throughout the period of Civil War, Lincoln extensively used telegraph in an unprecedented manner to communicate with his commanders stationed in the battlefields.55

1.5.6 Balloons

Balloons were the first mechanism in air warfare for gathering useful military information from a height over the battlefields. The first successfully flown hot air balloons were built in France around 1783 by Joseph–Michel Montgolfier (1740-1810) and his brother Jacques–Etienne Montgolfier (1745-1799). During American Civil War, both Union and Confederate armies used balloons for reconnaissance.

Thaddeus Lowe (1832-1913), a professor of chemistry and an early balloon enthusiast, was appointed as the Chief Aeronaut of the Union Army Balloon Corps in 1861. His balloon the ‘Union’ ascended to about 1,000 feet (about 300 meters) near Arlington, across the Potomac River from Washington, D.C. From his balloon he telegraphed information on location of Confederate troops. The Union army in turn fired at the Confederate army accurately, without seeing them – the distance between the two troops was about three miles (about 5 km). The Union subsequently built a fleet of six more balloons. John LaMountain (1830-1878), another aeronaut also worked for the Union aerial reconnaissance at the same time. Due to

several conflicting issues, the Union balloon corps was dissolved in August 1863. The Confederates also operated balloons for military reconnaissance, but with very limited success. They stopped using balloons after August 1863.\textsuperscript{56}

\subsection*{1.5.7 Photography}

A comprehensive photographic documentation of the battle scenes was done for the first time during American Civil War (1861-1864). The wars caught on camera before the American Civil Wars, were the Mexican-American War (1846-1848) and the Crimean War (1854-1856), but not so extensively.

In 1839, Louis-Jacques-Mandé Daguerre (1787-1851) in France, in collaboration with Joseph Nicéphore Niepce (1765-1833), invented photography by producing image of an object on a metal plate. He photographed a Paris street scene from his apartment window using a camera obscura and his invented daguerreotype process. The same year, William Henry Fox Talbot (1800-1877), an Englishman developed a photographic process that produced paper negatives and prints. During the next twenty years, much before the civil war, photography was developed to a great extent in Europe and America. In 1847, during Mexican – American War few daguerreotypes were taken of army officials and troop movements. The British Government, during Crimean War, sent several photographers to document the war. Only one of them, Roger Fenton (1819-1869), could take some 350 images, but were mainly portraits.

During the course of the American Civil War, more than 3,000 photographs were taken by the northern photographers - Mathew Brady (1823-1896),

\begin{flushright}
\footnotesize\textsuperscript{56} “Balloons in the American Civil War.” \textit{US Centennial Flight Commission}. Web. 20 April 2011.
\end{flushright}
Alexander Gardner (1821-1882), George Barnard (1819-1902), Timothy O'Sullivan (1840-1882), and James F. Gibson (1828-1905), and the southern photographer - George S. Cook (1819-1902). Photography of activities in the battlefield was an extremely difficult and time consuming process then. The photographers had to follow the armies in different location to take photographs of battle scenes. They carried bulky cameras, heavy equipment, hazardous chemicals and even the darkroom in the battlefield by wagons. However, the photographs, for the first time in history, gave a chance to the citizen of the country to have a glimpse of the carnage actually took place in the battlefields.

In 1866, George N. Barnard released wartime photographs in 'Photographic Views of Sherman's Campaign' and Alexander Gardner published his photographic work in 'Gardner's Photographic Sketchbook of the American Civil War'. But both the works initially had very limited success. Mathew Brady, despite his significant photo-documentation of the Civil War, had also very hard time. After several requests, his negatives of wartime photographs were bought by US Congress in 1875. These invaluable comprehensive photographic records of American Civil War had been archived in the US.57

1.6 Technological Innovations during the First World War

The Great War of 1914-1918 or the First World War was centered on Europe, involving world's great powers, assembled in two belligerent allies the Allies and the Central Powers. It claimed lives of about 9 million soldiers and 13 million civilians. It is said to be the second deadliest war in Western history.

57 “Photography and the Civil War: Bringing the battlefront to the home front.” Civil War Preservation Trust. Web. 10 March 2011.

The Great Powers of the world in 1914 were the German Empire, Austria-Hungarian Empire, Kingdom of Italy, British Empire, Russian Empire, French Third Republic, the United States, Empire of Japan, and the Ottoman Empire. According to a military agreement made in 1882 between Germany, Austria-Hungary, and Italy, each nation promised mutual help in the event of attack on any two other nations. The alliance, known as Triple Alliance, lasted until the beginning of World War I in 1914. An alliance among Great Britain, France and Russia, named as Triple Entente, was formed in 1907. This alliance was supported during World War I by various agreements with Japan, the United States, Portugal and Brazil. They fought against the Central Power made up of the German Empire, Austria-Hungarian Empire, Ottoman Empire, and the Kingdom of Bulgaria.

Historians are of the opinion that the causes of World War I are complicated and intertwined. They, however, consider 'militarism', 'alliances', 'imperialism' and 'nationalism', as major root causes for the war. Such simple interpretation of origins of the First World War has recently posed challenging questions. Annika Mombauer has presented the current views of the significance and meaning of the origins of the First World War. James Joll and Gordon Martel have dealt with major theories, including the question of secret diplomacy, political/philosophical ideas, military plans, economics and internal conflicts within different countries, etc. for finding the origins the Great War.

Militarism is the trend of a country towards development of army and military forces for national defense and also for protection of colonial interests. At the beginning of the 20th century, arms race had begun in


Europe. The armies of France and Germany were doubled in number between 1870 and 1914. Expansion of naval force also became competitive between Great Britain and Germany. Further, much before the actual conflict took place, the great powers had drawn complete plans for military mobilization, which awaited a go ahead signal. Alliances and treaties between European powers gave them a sense of security. But it was inevitable that in the event of a conflict between two countries, many more would join either sides and give it a shape of a great war.

Rivalry between European imperialist powers was one of the important causes that culminated in World War I. They thought it was all right to go for war to grab more territory and power in turn. By 1900, the British Empire had extended over five continents covering a quarter of the world. As a part of the Empire, the British ruled over Canada, India, South Africa, Egypt, Australia and New Zealand. They made huge amounts of money from these countries and their military presence was established almost all over the world. France had control over large part of Africa compared to German territories in the same continent. Due to industrialization, these European countries were also keen to acquire more and more territories to have continuous supply of raw materials from their colonies and to market finished products.

The nationalism or patriotism of various European countries also contributed to the beginning as well as continuance of World War I. Nationalism motivated them to compete for the largest army and navy, in order to prove their dominance and power. Nationalist movements had resulted in unification of Italy in 1861 and that of Germany in 1871. Nationalism of the Slavic people in Bosnia and Herzegovina created problems for Austria-Hungary and the Balkans, as they desired to be a part of Serbia.

The spark that initiated the chain reaction, which resulted in the explosion of
the Great War in Europe, was due to assassination of Franz Ferdinand (1889-1914), the heir of Austria-Hungarian throne, and his wife on 28 June 1914 during their visit to Sarajevo, a city of Bosnia in the south-east corner of the Austria-Hungarian Empire. The killer, Gavrilo Princip (1894-1918), was a Serbian nationalist belonging to Bosnian Black Hand Gang. Austria-Hungary was convinced that Serbia had conspired against them for the murder. Immediately after the assassination, Germany pleaded its full support to Austria–Hungary and motivated them to attack Serbia. On 28 July 1914, Austria-Hungary declared war on Serbia. Russia, in turn, when approached by Serbia for military help, ordered mobilization against Austria-Hungary. On 31 July 1914, Germany asked Russia to stop mobilization. Russia ignored German advice by saying that their mobilization was only against Austria-Hungary and not against any other nation. At the same time France declared that in the event of Russo-German conflict, it would act in its own interest and started military mobilization. On 1 August 1914, Germany declared war on Russia and after only two days, on 3 August, it declared war on France. The Germans decided to attack France through neutral Belgium and invaded Belgium on 4 August. As a result, Britain declared war on Germany and Austria-Hungary. Japan, having a military agreement with Britain, declared war on Germany on 23 August. Australia, Canada, India, New Zealand and the Union of South Africa, being colonies and dominions of Britain, offered military support to the Allied force. United States declared its policy to remain neutral. Italy too remained neutral. Thus World War I began.

A concise and insightful history of the First World War, focusing on its causes, the main events of the war and its consequences, has been written by Michael Howard.\textsuperscript{62} John Keegan's book is a passionate history and overview of the Great War.\textsuperscript{63}


This war of the early twentieth century has been drawing attention of the historians, even in the twenty first century. One such example is David Stevenson's re-examination of the underlying dynamics of the causes, course and impact of this 'war to end war'.

1.6.1 Machine guns

Machine guns are fully automatic mounted or portable firearm that can fire rounds of ammunition in quick succession from a magazine or a belt. All the super powers of World War I including the US had developed machine guns at some stage before or during the war. Machine guns were extensively used by belligerent armies during the war.

Hiram Maxim (1840-1916), an American-born British inventor developed the first self-powered machine gun, known as Maxim gun in 1884. The gun was first used during the First Matabele War fought during 1893-1894 between British South African Company and Matabele people in Rhodesia. The Maxim gun was thereafter used in the Anglo-Aro War (1901-1902), a conflict between British Empire and Aro confederacy in southeastern Nigeria.

The British Vickers gun was an improvement on Maxim gun of 1884 and was adopted for military use in 1912. It was a water-cooled machine gun which weighed 20 kg and could fire 450 rounds per minute. Madsen machine gun was developed by W.O. Madsen in 1896 and was adopted by Denmark in 1903. It was used by Russian Army during Russo-Japanese War (1904-1905) and also by the German army in 1914.

The Hotchkiss machine gun was adopted by France in 1900 and various models of the gun were produced until, a gas powered, air-cooled model was introduced in 1914. A further improved version of the gun appeared in

1915; it weighed 23 kg and could fire 600 rounds per minute. The gun's effective range was about 3,800 meters. The Chauchat, a French light machine gun, was developed in 1907 and modified in 1915. France produced 250,000 Chauchats during World War I, and used it throughout the war. St. Etienne gun, a heavy machine gun, produced by France in 1907, was withdrawn from service in 1916, due to difficulties experienced in its operation.

During World War I, Germany widely deployed Bergmann MP18 gun, a sub-machine gun that used 9-mm ammunition rounds loaded via a 32-round magazine. Bergmann MG-15nA machine gun was adopted by Germany in 1915. Its range was 400 m, and was often compared with British Lewis light machine gun. Maschinengewehr 08, German army's standard machine gun adopted in 1901, was similar to Maxim gun of 1884 in design. It used 7.92-mm ammunition, to fire at a rate of 250 rounds per minute to a range of 400 meters. An improved version of this machine gun was the Parabellum gun, which weighed only 10 kg and could fire 700 rounds per minute. It was introduced in service towards the end of 1914. A modified version of this machine gun, the Spandan gun was introduced in 1916. This 12-kg gun used 7.92-mm ammunition which could be fired at a rate of 500 rounds per minute.

Fiat-Revelli was the first mass produced machine gun of Italy. This 17-kg, 6.5-mm caliber, water-cooled gun was designed in 1908 and brought into use of Italian army in 1914. It could fire 400 rounds per minute up to a distance of 1,500 meters accurately. World's first genuine sub-machine gun Villar Perosa was introduced in the Italian army in 1915. The gun could fire 300 rounds per minute accurately to a distance of 800 meters.

The American Browning gun, similar to the Maxim gun and Vickers gun, was developed by John Moses Browning (1855-1920) in 1910 and adopted by the US army following America's entry into the World War I in 1917. In 1918 Browning developed an automatic rifle which was used by the American forces in the final year of the war. The gun was air cooled, gas
operated, magazine fed and used 0.30 inch ammunition. Its firing rate was 550 rounds per minute at 600 yards (about 550 meters).

At the start of the First World War, American Expeditionary Force (AEF) adopted the Colt-Browning machine gun. It was the first successful gas-operated machine gun designed by Browning. It was modified in 1917 to produce the Marlin gun, a 0.30-inch light machine gun. Marlin gun was air-cooled, gas operated, and could fire 650 rounds per minute.

Colonel Isaac Newton Lewis (1858-1931) of US Army designed the Lewis gun, an early light machine gun, in 1911. It was used widely by the British from 1915 onwards. This air cooled gun weighed 12 kg and could fire 500–600 rounds per minute up to 600 meters.

The only machine gun developed by Russia was the ‘Pulemyot Maxima’. This water-cooled, 7.62-mm machine gun was developed in 1910 and was similar in design to the Maxim gun. It could fire 250-300 rounds up to 2,700 meters.\footnote{Bruce, Robert. \textit{Machine Guns of World War I: Live Firing Classic Military Weapons in Colour Photographs}. Ramsbury, Marlborough Wiltshire: The Crowood Press Ltd., 2008.}

### 1.6.2 Flamethrowers

The first modern flamethrower, Flammenwerfer, was invented by German engineer Richard Friedler in 1901. These powerful weapons used pressurized air, carbon dioxide or nitrogen to push oil through a nozzle, which was ignited by a charge, producing a jet of flame. Flamethrowers were mainly used to clear enemy soldiers from the trenches. Richard Friedler developed two types of flamethrowers – the smaller version Kleinflammenwerfer was a portable one carried by one person, and the larger version Grossflammenwerfer was suitable for transportation, also by a single person. From 1911 onwards, the German army deployed
flamethrowers in three specialised battalions. They used it first against French trenches at Malancourt, north of Verdun on 26 February 1915. The Germans made a surprise attack with the flamethrowers on the British troops at Hooge in Flanders on 30 July 1915. The French also used their portable one-man flamethrower, Schilt, a superior build to the German models, in trench attacks against the Germans during 1917-18. The Germans too produced an improved lightweight model of flamethrower, Wex, in 1917. The British army used ‘Liven Large Gallery Flame Projectors’, developed by a Royal Engineers officer William Howard Livens, in the Battle of Somme in 1916 and also in an offensive in 1917 near Diksmuide, Belgium.66

1.6.3 Tanks

The advent of tanks to counter the ills of trench warfare brought in a new era of mechanized warfare and profoundly altered the land warfare tactics. The longstanding need for armored self-propelled weapons with ability to move powerfully in any terrain was met with the development of the tank. The First World War also witnessed the first-ever tank-versus-tank battles. In 1915, ‘Holt’ tractors were introduced by British and French armies to haul artillery and other supplies to the battle-fields. The vehicle ran on continuous caterpillar tracks instead of wheels, and thus provided contact with a large surface of the ground. This innovation was adopted at the time of design of military tanks.

The ‘Little Willie’, constructed by Britain in 1915, was the first completed prototype tank in history. The 16.5-ton tank had a crew of six and could cross a trench of 5-foot (about 1.5-meter) width. The ‘Schneider CA1’ was the first French tank introduced in 1915, while ‘St. Chamond’, developed in

1916, was the second French tank. The French light tank ‘Renault FT-17’, introduced in 1917, was the most revolutionary in tank design history. It was in service from 1917 till 1945. This 6.5-ton light tank had two crew members and moved at a speed of 7 km/hour. The ‘Holt’ gas-electric tank, built during 1917-1918, was the first prototype tank of USA. This 25.4-ton tank carried six crew members and moved at a speed of 10 km/hour. ‘Sturmpanzerwagen A7V’ was the first German attempt at a tank in 1917. It, however, had limited success in World War I. The six-ton tank M1917 was USA’s mass produced efficient tank, which was extensively used in World War I. Great Britain developed the maximum number of tanks between 1916 and 1918, known as Mark I to Mark X, which served varied military purposes.\textsuperscript{67,68}

\textbf{1.6.4 Battleships}

\textbf{Battle-cruisers}. Developed in the first decade of the 20th century, they formed part of navies of Britain, Germany and Japan in First World War and were primarily used as fast and hard hitting battleships. Great Britain introduced several battle-cruisers between 1908 and 1916, under the classes ‘Invincible’, ‘Indefatigable’, ‘Lion’, ‘Queen Mary’, ‘Tiger’ and ‘Renown’. Germany also brought into service a few battlecruisers between 1911 and 1917, belonging to ‘Von der Tann’, ‘Moltke’, ‘Seydlitz’, ‘Derfflinger’, and ‘Hindenburg’ classes.

\textbf{Dreadnoughts}. The predominant battleships of the early 20\textsuperscript{th} century were the dreadnoughts. The first of its kind, ‘HMS Dreadnought’ was built by the British Royal Navy in 1906. It had two revolutionary features: an all-big-gun armament and driven solely by steam turbines. By


1914, the British Navy had 19 dreadnoughts and 13 under construction, Germany had 13 battleship similar to dreadnoughts and seven under construction. Other countries which had introduced battleships of dreadnought class in 1914 were USA (8), France (8), Austria-Hungary (2), Italy (1), and Japan (4). Britain subsequently produced improved dreadnought ships, namely, ‘Queen Elizabeth’, ‘Warspite’, ‘Barham’, ‘Valiant’, and ‘Malaya’, all of which served during First World War.

Pre-dreadnoughts. Pre-dreadnought battleships built between 1889 and 1908 were possessed by Great Britain (48), and Germany (24). Other allied countries of Great Britain and Germany also had pre-dreadnought ships, which were used during First World War. Pre-dreadnoughts replaced the ironclad warships of 1870s and 1890s. ‘USS Texas’ launched in 1892 was the first pre-dreadnought battleship. Such battleships were built from steel, protected by hardened steel armor and carried a main battery of heavy guns supported by a secondary battery of lighter weapons. ‘HMS Majesty’, British battleship of this class was introduced in 1895.69

1.6.5 Torpedo Boats

Torpedo boats, small but fast vessels to carry torpedoes into battle, were introduced during the American Civil War. In Russo-Japanese War (1904-1905), the Imperial Russian Navy deployed many torpedo boats to launch torpedoes in three major battles. The Imperial Japanese Navy too launched torpedoes and deployed torpedo boat destroyers (TBD) which were invented in 1892 by British Royal Navy. During the WW1 Britain and its allies deployed 420 torpedo boats and torpedo boat destroyers, while Germany and its allies used 178 torpedo boats and destroyers.70

1.6.6 Submarines

In 1888, the Spanish Navy launched the first fully capable military submarine 'The Pearl' which could fire torpedoes under the sea and move at a speed of 10 knots. French Navy also launched a fully functional military submarine 'Gymonte' in the same year. Next development was Ireland's 'Holland VI' submarine of 1896 which made use of internal combustion power on the surface and electric battery power for submerged operations. In 1900, US Navy purchased this submarine and named it as 'USS Holland'. Germany completed its fully functional military submarine 'Forelle' in 1903. They sold this vessel to Russia in 1904, for use in Russo-Japanese war. German Imperial Navy's first U-boat design 'U1' was commissioned in 1906. In 1914, at the start of the war the super powers of Europe had significant number of submarines with their Navies: Great Britain (77), Russia (58), France (62), Germany (48), and Ottoman Empire (7). All of them lost a number of submarines during the First World War.71

Table 1.1 Comparison of combined fleets of operation between the Entente and Central Power during First World War

<table>
<thead>
<tr>
<th>Fleets in operation</th>
<th>Great Britain and Allies</th>
<th>Germany and Allies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-dreadnoughts</td>
<td>54</td>
<td>45</td>
</tr>
<tr>
<td>Torpedo boats and Torpedo boat destroyers</td>
<td>420</td>
<td>178</td>
</tr>
<tr>
<td>Submarines</td>
<td>179</td>
<td>44</td>
</tr>
</tbody>
</table>

1.6.7 Aircrafts

In 1903, Wilbur Wright (1867-1912) and Orville Wright (1871-1948), the American engineer brothers, created the first powered airplane in the

---

World. They had been running the 'Wright Cycle Company' in Dayton, Ohio since 1892, for manufacture of bicycles. Between 1900 and 1902, they built and flew three biplane gliders. Development of propeller and engine enabled them to build a powered airplane. On 17 December 1903, their 'Flying Machine', with Orville at the controls made a short flight of 12 seconds and covered a distance of 120 feet (about 36.5 meters) at Kitty Hawk in North Carolina. Wilbur too flew on the same day for 59 seconds at Kill Devil Hills near Kitty Hawk. Their airplane of 1905 could remain airborne for over 35 minutes and in 1908 their airplane remained afloat for 2 hours and 20 minutes. In 1909, Wright brothers founded the 'Wright Company' to build and sell airplanes in the United States. They also licensed various manufacturers to produce airplanes of their design in Europe and also taught many officers to fly an airplane.

Louis Bleriot (1872-1936), a French aviator and engineer built a monoplane, an aircraft with one set of wing surfaces, in 1905. In collaboration with Morane Saulnier (1881-1964), another French man, he designed an advanced monoplane 'Blériot XI' in 1908. Louis Bleriot crossed the English Channel, from Calais to Dover, in 36.5 minutes by his 'Bleriot XI' in 1909.

As the aircrafts gained stability in flights, many countries decided to use aircrafts for warfare. During Italian-Turkish War (1911-1912), Italy used airplanes for military reconnaissance and bombing. During first Balkan War (1912-1913), the Bulgarian Air Force bombed Adrianople in Turkey. The Greek Air Force dropped bombs over the Dardanelles, a narrow strait in northwest Turkey connecting the Aegean Sea to the Sea of Marmara, which incidentally was the first naval-air cooperation in history. Effective use of aircrafts in these two wars drew attention of armies worldwide and great importance was given for fast development of aircrafts for military operations. 1914 to 1918 was a period when very rapid technological development in design and development of military aircrafts occurred. From slow moving, unarmed, fragile aircrafts they evolved into fast, agile, sturdy
deadly fighters and bombers. Ninety five military aircrafts were produced during World War I by Austria-Hungary, France, Germany, Great Britain, Italy, Russia and United States (Table 1.2) of which 41 were reconnaissance aircrafts, 52 were fighters and 25 were used as bombers. Germany established its superiority over others by producing 37 different aircrafts and they used their planes only during World War I. Other six countries used aircrafts, as detailed in Table 1.3, of their own designs, as well as of others during the war.

In 1914, Germany produced three reconnaissance aircrafts, namely, ‘Albatros B.I’, ‘Aviatik B.I’ and ‘Hansa-Brandenburg B.I’. They designed and developed new aircraft in the following years under the series Albatros, Aviatik, Fokker, Gotha, AEG and Hansa-Brandenburg, to serve German Air Force as trainers, fighters, bombers and reconnaissance aircrafts.


‘Farmann MF.11 Shorthorn’ was an early-war French aircraft used for reconnaissance and bombing. In 1915, France produced three more bombers, namely, ‘Breguet br. M5’, ‘Caudron G.4’ and ‘Voisin Type 5’. ‘The Brequet br.14’, introduced in 1917, was the single most important aircraft in the whole course of the war. This biplane was a fighter, bomber and also served for reconnaissance. The ‘Caudron R.11’, which appeared in 1918 was a reconnaissance, bomber and escort aircraft of the French Air Force.

‘Nieuport Nie.11’, produced in 1915, was the first true Allied fighter of World
War I. In a year, this aircraft was improved in performance and named as ‘Nieuport Nie.17. Two more fighter aircrafts, Harriot HD.1’ and ‘SPAD S.VII’, were introduced by France in 1916. The ‘SPAD S.XII’, a cannon-armed biplane fighter aircraft was introduced in the war in 1917.

Austria-Hungarian aircrafts; ‘Lohner B.VII’ and ‘Lohner C.I’ developed in 1915 and 1916 respectively were reconnaissance planes. Three versions of ‘Lloyd (C.II, C.III and C.IV)’ produced in 1915 were also used for reconnaissance. The ‘Hansa-Brandenburg C.I’ and Hansa-Brandenburg D.I’ were fighter aircrafts of 1916. The ‘Aviatik D.I’ and ‘Phonix C.I’, produced by Austria-Hungary in 1917, were also fighter planes. The last reconnaissance fighter aircraft which entered in service in 1918 was the ‘Ufag C.I’, a two-seater, 230-horsepower, biplane.

Developed in 1915, Italian ‘Caproni Ca.1’ was the first useful heavy bomber in the world. Italian bomber ‘Caproni Ca.3’ was launched in 1917. ‘Ansaldo A1 Balilla’ (Hunter) biplane was first Italian fighter aircraft.

First introduced in 1913, the Sikorsky Ilya Mouromets series of aircrafts were the world's first four-engine bomber aircrafts in operation.

The ‘Aeromarine 39’, developed in 1916 by USA, was a versatile two-seater aircraft for land-based and seaplane training. The ‘Aeromarine 40’ of 1918 was a flying boat. ‘Standard J-1’ of 1917 was used by the US army as a trainer, while ‘Vought VE-7 Bluebird’ launched during the same year was fighter-cum-training aircraft. The ‘Martin MB-1’, the first American-designed two-engine heavy bomber came into operation in 1918.
Table 1.2 Military Aircrafts developed during First World War

<table>
<thead>
<tr>
<th>Country of Origin</th>
<th>1914</th>
<th>1915</th>
<th>1916</th>
<th>1917</th>
<th>1918</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Austria-Hungary</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td></td>
<td>9</td>
</tr>
<tr>
<td>France</td>
<td>1</td>
<td>5</td>
<td>3</td>
<td>6</td>
<td>1</td>
<td>16</td>
</tr>
<tr>
<td>Germany</td>
<td>3</td>
<td>6</td>
<td>8</td>
<td>14</td>
<td>6</td>
<td>37</td>
</tr>
<tr>
<td>Great Britain</td>
<td>1</td>
<td>4</td>
<td>5</td>
<td>12</td>
<td>3</td>
<td>25</td>
</tr>
<tr>
<td>Italy</td>
<td>1</td>
<td>1</td>
<td></td>
<td>1</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Russia</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>United States</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

Table 1.3 Aircrafts used in combat during First World War

<table>
<thead>
<tr>
<th>Name of the country using aircrafts</th>
<th>Country of origin of aircrafts</th>
<th>Total No. of aircrafts used during WW I</th>
</tr>
</thead>
<tbody>
<tr>
<td>Austria-Hungary</td>
<td>Austria-Hungary</td>
<td>France</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td>France</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>Germany</td>
<td>37</td>
<td></td>
</tr>
<tr>
<td>Great Britain</td>
<td>10</td>
<td>25</td>
</tr>
<tr>
<td>Italy</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>Russia</td>
<td>11</td>
<td>1</td>
</tr>
<tr>
<td>United States</td>
<td>8</td>
<td>8</td>
</tr>
</tbody>
</table>

1.6.8 Chemical Weapons

In August 1914, Germany invaded Belgium and subsequently attacked France. At that time the French made the first use of a chemical as a weapon by firing grenades of tear gas (xyllyl bromide) on the German
army. The effect, however, was insignificant. In October 1914, German troops fired shells filled with chemical irritants against the British positions at Neuve Chappelle in France. During the Second battle of Ypres, on 22 April 1915, the German Army discharged 180 tons of chlorine gas on allied trenches. As a result the French and Algerian troops fled and allowed an opening of about 8 to 9 km in the Allied line. The Germans conducted a second chlorine gas attack at Ypres on 24 April on Canadian troops and the third attack on 2 May on British troops. Chlorine is a toxic gas that irritates the human respiratory system. Chlorine gas inhaled at concentrations above 30 ppm reacts with water and cells in human body, and in turn changes into hydrochloric acid and hypochlorous acid. On 25 September 1915, the British army made its first chemical weapon attack on German troops with chlorine gas at the battle of Loos in France.

On 19 December 1915, Germany attacked British troops at Wieltije near Ypres with chlorine and phosgene gases. In March 1916, phosgene gas shells were fired on French troops in Verdun by the Germans.

Phosgene is a toxic gaseous compound of carbon, oxygen and chlorine, with the chemical formula COCl₂. It is produced by passing carbon monoxide and chlorine through activated coal or charcoal. Phosgene is an industrial reagent, used in synthesis of organic compounds including pharmaceuticals and production of dyes. Phosgene, when inhaled, reacts with water in the lungs and creates hydrochloric acid and carbon monoxide. It is deadlier than chlorine gas, but has a drawback that symptoms of attack on respiratory tract of the affected persons appear about twenty-four hours after inhaling.

The chemical warfare reached its peak with the use of mustard gas by Germany in July 1917 in Ypres region of Belgium. Mustard gas, chemically known as bis-(2-chloroethyl) sulfide, is a compound of carbon, hydrogen, chlorine and sulfur, with the chemical formula C₇H₈Cl₂S. It was not specifically a killing agent, but was used to disable the enemy and pollute the battlefield. The gas was a lung irritant, skin blistering agent and
remained active on the battlefield soils for many days. In 1916, German scientists, Wilhelm Lommel and Georg Wilhelm Steinkopf jointly developed a method for large-scale production of mustard gas.

During the period between 1915 and 1918, both Allies and Central Powers used tear gas, chlorine gas, phosgene gas and mustard gas as chemical weapons to attack their opponents.\textsuperscript{72}

\subsection*{1.7 Technological Innovations during the Second World War}

World War II was a global conflict involving most of the nations of the world and was fought during 1939-1945 between the Allies and the Axis powers. The Allies were primarily a group of three nations, namely United Kingdom, Soviet Union and the United States, who were also supported by France, China, Canada, Australia and others. The opposing Axis powers were formed by Germany, Japan and Italy, who were supported by Hungary, Romania, Bulgaria and other like-minded countries. The battles of World War II were fought in Europe, the Pacific, the Atlantic, South-East Asia, China, Middle-East, Mediterranean, Africa, and briefly in North America. It was a modern war, which mobilized available resources and the population of the belligerent nations and took place on land, in air, on sea surface and under the sea.

Germany faced severe economic crisis after World War I. Further, there was a negative impact on German economy due to Wall Street crash in the US, from whom funds used to flow to Germany. The Nazis offered radical solutions to overcome the setback in Germany and as a result they came to power in 1933 with Adolf Hitler as the Chancellor.

The first of a series of conflicts of the Second World War started when on 1 September 1939, Germany invaded Poland. Following the invasion, Britain

and France declared war on Germany on 3 September 1939. On 10 May 1940, Germany launched invasion of Western Europe by attacking the Netherlands, Belgium and France. Further, in a small-scale invasion, Italy attacked France on 10 June 1940. The Empire of Japan invaded French Indo-China during 22-24 September 1940. On 22 June 1941, Germany invaded the Soviet Union. On 7 December 1941, in a surprise pre-emptive military action, the Empire of Japan attacked Pearl Harbor, in Hawaii, which is a territory of the United States. Japan also attacked British installations on the same day at Singapore and Hong Kong. On 8 December, Japan declared war on the United States and British Empire. The United States, in turn, declared war on Japan, the third Axis power. Germany and Italy, the other two Axis powers, declared war on United States on 8 December 1941. On the same day, the United States responded by declaring war on Germany and Italy. Thus by that time all the major Allies and Axis nations were involved in the war.

On 7 June 1942, the Japanese Navy lost a three-day battle to US Navy at Midway island in the Pacific Ocean. In the same year German forces in Africa were defeated by Anglo-American forces. On 2 February 1943, German forces were defeated by the Soviet Union at Stalingrad. On 10 July 1943, the Mediterranean island of Sicily, under Italy, was invaded by armed forces of the UK, US and Canada. On 25 July, the Italian dictator, Benito Mussolini stepped down from the post of Head of Italian Armed forces. On 3 September 1943, the Allied troops invaded mainland Italy and after five days on, 8 September 1943, Italy signed an unconditional armistice with the Allies. On 25 August 1944, after four years under German occupation, Paris was liberated by the Allied forces and the Germans surrendered. On 7 February, the British Prime Minister Winston Churchill, US President Franklin D Roosevelt, and Premier of the Soviet Union, Joseph V. Stalin drew up plans for the final phase of war against Germany. On 14 February 1945, British and US bombers devastated the city of Dresden in Germany. On 12 April 1945, Franklin Roosevelt died and Harry S. Truman was sworn in as US President. On 21 April 1945 Russian army captured a few outlying
suburbs of Berlin. Seven days later, Benito Mussolini, the dictator of Italy until 1943, was killed by Italian Partisans. Only three days later Germany announced that Adolf Hitler was dead. On 7 May 1945, General Gustav Jodi declared unconditional surrender by Germany and thus brought an end to six years of war in Europe. The US dropped atomic bombs on Hiroshima and Nagasaki in Japan on 6 and 9 August 1945. On 2 September 1945, Japan surrendered unconditionally, which finally brought an end to World War II.\textsuperscript{73,74}

Ernest Mandel has critically examined the role of science, technology, logistics, weapons and propaganda played in the Second World War.\textsuperscript{75}

1.7.1 Radar

Radar is a device that detects position, movement and nature of remote objects, such as aircraft, ship, motor vehicles etc., by means of radio waves or microwaves reflected from the target. The term radar was coined in 1940 by the US Navy as an acronym for radio detection and ranging. Radar were developed by nine nations of the world, independently and secretly during the period between 1934 and 1939. They were called by various names in those countries. The countries that developed radio detection systems were Germany, Great Britain, the United States, Soviet Union, France, Italy, Japan, Hungary and the Netherlands. Four commonwealth countries: Australia, Canada, New Zealand and South Africa received basic information on radar from Great Britain and then developed radar indigenously. Hungary developed radar during World War II. However,


\textsuperscript{74} Dear, I.C.B. (General Editor) and M.R.D. Foot (Consultant Editor), \textit{The Oxford Companion to World War II}. New York: Oxford University Press, 2005.

during the course of World War II, France, the Netherlands, Italy and Hungary lost control on their radar. Finland used German radar during the war. By the end of the war three Allied countries – the United State, Great Britain and Soviet Union, and two Axis countries – Germany and Japan had wide varieties of land-bases, sea-based and airborne radar. The United States and Great Britain possessed the most advanced and effective radar that helped them to win the war.76, 77

James Clerk Maxwell (1831-1879), a Scottish mathematician and physicist, formulated four mathematical equations in 1864, the basis for modern electromagnetic theory, which state that (i) time-varying magnetic field produces an electric field, (ii) an electric current and/or time-varying electric field produces a magnetic field, (iii) an electric charge is a source for electric fields, and (iv) magnetic fields only exist in closed loops and no point source exists for them.78 In 1880s, Heinrich Rudolf Hertz (1857-1894), a German physicist, simplified and formalized Maxwell's equations into a more compact and symmetric form. Hertz experimentally proved that electricity can be transmitted by electromagnetic waves and such waves can be reflected and refracted. In 1886, while carrying out experiments on radio waves, he noticed that surrounding objects interfered with the waves. The observation inspired many physicists worldwide to explore the possibility of detection of objects located at a considerable distance by means of radio waves. This was the first step towards development of radar in future.79, 80


79 Hertz, Heinrich. "Ueber die Beziehungen zwischen den Maxwell'schen
1.7.1.1 German Radar

In 1904, Christian Hulsmeyer (1881-1957), a German experimenter, demonstrated his “Telemobiloscope”, an anti-collision device for ships that worked as primitive radar, in the harbor of Rotterdam, in presence of an international gathering of shipping experts. He claimed that the device could detect remote metallic ships in darkness, fog or rain and thus could avoid ship disasters. His invention, however, did not create much interest in Germany. When Hulsmeyer sought for financial support from the German Navy for production of his device, Admiral Alfred von Tirpitz (1849-1930) replied “Not interested. My people have better ideas!” Hulsmeyer spent his personal 25,000 Marks for the project, but had to abandon his plan very soon.81, 82

Richard Scherl and Hans Dominik, in Germany during World War I, devised a technique for wireless detection of remote objects, called “Strahlenzieler” (Raypointer) and showed it to the Imperial German navy. The apparatus was considered to be of no importance to the war effort by the Navy.83

In 1923, Reichsmarine, the German Navy (1919-1935) formed the Nachrichtenmittel Versuchsanslalt (NVA) or Experimental Institute of

**References:**


Communication system in Kiev, primarily to conduct research for development of sonar. In 1933, Rudolph Kunhold (1903-1992), a German physicist and Scientific Director of NVA had designed a radio-detection system. In January 1934, two amateur radio operators and designers of radio communication devices, Paul-Ginther Erbslöh (1905-2002) and Hans-Karl Freiherr von Willisen (1906-1966) had formed a new company in Berlin, called Gesellschaft für Electroakustische and Mechanische Apparate (GEMA). On Kuhnhold’s request they agreed to take up the radio-detection project at GEMA, and began work on a Funkmessgerät für Untersuchung (radio measuring device for reconnaissance). Under Kuhnhold’s guidance GEMA developed a prototype experimental radar and on March 20, 1934, it could detect movement of a ship at a distance of seven miles, in presence of German naval officers, in Kiel harbor. The officials were impressed and granted funds to GEMA for production of such radar.84,85

With funding from Kriegsmarine, for development of radar for naval use the GEMA in 1936 produced a Dezimeter Telegraphie (DeTe-I) system for surface search of objects which could be used on ship-board as well as installation on ground. Another version of Dezimeter Telegraphie (DeTe-II), a ground-based air warning system was developed by GEMA in 1938. Both the radar systems were called the Seetakt. GEMA development another ground based radar called Freya by early 1939.86

Wilhelm Tolmé Runge (1895-1987) a German electrical engineer joined Telefunken’s Radio Research Laboratory at Berlin in 1923 and became its Director in 1935. He then initiated an internally funded project on radio-based object detection system. With the help of an experimental set up, a transmitter-receiver of 0.5 watt output operating at 600 MHz, he could

detect movement of a flying aircraft. The German Air force (Luftwaffe) provided funds to Telefunken in 1936 for development of radio-detection system.\textsuperscript{87}

In late 1938, Telefunken received a contract from Luftwaffe to develop ground based gun laying radar. They demonstrated a precision gun-laying radar Wurzburg (FuMG 62) in 1939 and another giant version of the radar called Wurzburg-Riese (FuMG 65) in 1941. Wilhelm Runge at Telefunken was given responsibility by the Luftwaffe, in early 1941, to develop radar for night-fighting. Three versions of airborne radar code-named Lichtenstein were developed by Telefunken between 1942 and 1943. It is to be noted that none of the radar used by Germany during the Second World War operated in the microwave frequency range. German Luftwaffe introduced its airborne surveillance microwave radar Berlin (FuG240) in April 1945. It was probably based on British Royal Air Force radar H2S, installed in a British aircraft they had captured during the war. Only 25 units of FuG240 was manufactured by Telefunken and used in German night fighter Ju88 G-6.\textsuperscript{88}

<table>
<thead>
<tr>
<th>Function/Type of Radar</th>
<th>Name of Radar [Introduced in]</th>
<th>Range (Km)</th>
<th>Wavelength (cm) [Frequency (MHz)]</th>
<th>Peak Power (Kw/w)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ground based or ship board surface search</td>
<td>Seetakt (DeTe-I) [1936]</td>
<td>11-20</td>
<td>60 [500]</td>
<td>7 Kw</td>
</tr>
<tr>
<td>Ground based air warning</td>
<td>Seetakt (DeTe-II) [1938]</td>
<td>-</td>
<td>240 [125]</td>
<td>7 Kw</td>
</tr>
<tr>
<td>Ground based air warning</td>
<td>Freya [1939]</td>
<td>130</td>
<td>240 [125]</td>
<td>15 Kw</td>
</tr>
</tbody>
</table>


General Considerations on Scientific Discoveries, Technological Innovations and Modern Warfare

<table>
<thead>
<tr>
<th>Ground based gun laying</th>
<th>Wurzburg [1939]</th>
<th>29</th>
<th>50 [600]</th>
<th>7-11 W</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ground based gun laying</td>
<td>Wurzburg-Riese [1941]</td>
<td>70</td>
<td>50 [600]</td>
<td>7-11 W</td>
</tr>
<tr>
<td>Airborne night fighter</td>
<td>Lichtenstein [1942]</td>
<td>0.1 - 0.15</td>
<td>62 [484]</td>
<td>1.5 Kw</td>
</tr>
<tr>
<td>Airborne surveillance</td>
<td>Berlin (FuG240) [1945]</td>
<td>0.5 - 9</td>
<td>10 [3000]</td>
<td>15 Kw</td>
</tr>
</tbody>
</table>

1.7.1.2 Radar in Great Britain

Robert Alexander Watson-Watt (1892-1973), a Scottish physicist is credited to develop the first practical radar for Britain. Watson-Watt received BS degree in Electrical Engineering in 1912 from University of St. Andrews in Scotland. He was a teacher at University of Dundee during 1912-1915. After serving at the Wireless Station of British Air Ministry’s Meteorological Office for many years in various capacities, in 1933 he became Superintendent of the Radio Department of National Physical Laboratory in London.

In early 1930s the Air Ministry, a department of the British Government, responsible for coordinating affairs of the Royal Air Force, became worried about the possibility of German air attack. H.E. Wimperies, Director of Scientific Research in the Air Ministry appointed Henry Tizard, as the Chairman of its Aeronautical Research Committee in 1933. Tizard was an English chemist and had served the Royal Air Force from 1918 to 1919. Wimperies expected that under the leadership of Tizard, recent advances in science and technology would be utilized to develop new methods to fight against hostile German aircrafts.

It was rumored at that time that Nazi Germany had developed “death-ray”, a kind of radio-wave weapon, capable of destroying human lives. In January
1935, H.E. Wimperies, advised Watson-Watt to explore the possibility of developing a radio-wave weapon specifically to use against German bombers. On 12 February 1935, Watson-Watt sent a confidential memorandum entitled “Detection and Location of Aircraft by Radio method” to the Air Ministry. He, however, made it clear that production of “death-ray” to kill people or to create inconvenience to air-pilots was impossible. Watson-Watt and his assistant Arnold Wilkins (1907-1985) on 26 February 1935 secretly installed an experimental set up in a field at Daventry in Northamptonshire and showed to a limited number of Air Ministry officials that detection of movements of a British bomber was possible from a distance of about eight miles. The British Government encouraged concerned departments engaged in defense research to initiate radar development programs on priority. A Radar Research Station at Orfordness in England was set up by Air Ministry in 1935. The research group, headed by Robert Watson-Watt, moved to nearby Bawdsey Research Station in 1936. They subsequently moved to Dundee, Scotland with a new name of Air Ministry Research Establishment (AMRE), which was again renamed as Telecommunication Research Establishment (TRE) in 1940. The Air Defence Experimental Establishment (ADEE) at Biggin Hill also worked for radar development from 1936. Henry Tizard led the team there. ADEE was renamed as Air Defence Research and Development Establishment (ADRDE) in 1939. Both TRE and ADRDE moved to Malvern in 1942 and operated independently.89,90

The first British ‘Radio direction finding’ (RDF) system for detection and location of targets was built at Bawdsey Manor in May 1937. By September 1939, the Royal Air Force had a chain of 18 Air Ministry Experimental Stations (AMES Type 1 Radar Stations) called ‘Chain Home’ (CH), established along the south and east coasts of Britain, primarily to detect attack at the sea or from the air. These fixed base unidirectional radar

operated at 1.2 m wavelength radio-waves for 24 hours. They could detect aircrafts, flying only at high attitudes, but not the presence of ships on the sea and air planes at lower altitudes.

Subsequently, to overcome the failure of detecting lower targets by Chain Home, another type of AMES radar called Chain Home Lower (CHL) was developed by Britain during the war. The movable radar operated on a wavelength of 1.5 m and could detect aircrafts at ranges up to 30 miles flying at a height of 500 ft. Both CH and CHL radar were operated simultaneously for tracking enemy aircrafts during World War II.\(^{91,92}\)

By June 1940, all of Western Europe was under the control of Hitler’s Germany. Luftwaffe, the German Air force, undefeated till then, waged air attack on Britain on 10 July 1940. The objective of the campaign was to gain control over the British Royal Air Force. However, towards the end of this war, known as ‘Battle of Britain’, on 31 October 1940, the Germans had to incur greater loss in terms destroyed aircrafts, and missing, captured or killed air crews, compared to Britain. The Chain Home radar provided information on early warning and raid locations to the British Fighter Command on time which enabled them to take every necessary step to fight the German Air Force and finally win the battle. This was the very first example of influencing the course of air warfare by deployment of radar.\(^{93}\)

Table 1.5 presents a list of some notable British radar systems developed and used during the war. Description of microwave radar, Type 271, ASV Mk III, AI Mk VII and H2S, is given in Chapter 2, Section 2.11 of this thesis.

---


Table 1.5 Notable British Radar of Second World War

<table>
<thead>
<tr>
<th>Function/Type of Radar</th>
<th>Name of Radar [Introduced in]</th>
<th>Range (Km)</th>
<th>Wavelength (cm) [Frequency (MHz)]</th>
<th>Peak Power (Kw/W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early warning</td>
<td>Chain Home [1937]</td>
<td>200</td>
<td>600-150 [20-50]</td>
<td>200</td>
</tr>
<tr>
<td>Early warning</td>
<td>AMES Type 15 [1941]</td>
<td>180</td>
<td>150 [200]</td>
<td>100</td>
</tr>
<tr>
<td>Naval air warning</td>
<td>Type 281 [1940]</td>
<td>220</td>
<td>350 [85]</td>
<td>350</td>
</tr>
<tr>
<td>Naval surface warning</td>
<td>Type 271 [1941]</td>
<td>25</td>
<td>10 [3000]</td>
<td>70</td>
</tr>
<tr>
<td>Airborne surface vessel</td>
<td>ASV Mk II [1940]</td>
<td>58</td>
<td>170 [176]</td>
<td>7</td>
</tr>
<tr>
<td>Airborne surface vessel</td>
<td>ASV Mk III [1943]</td>
<td>160</td>
<td>10 [3000]</td>
<td>50</td>
</tr>
<tr>
<td>Airborne intercept night fighter</td>
<td>AI Mk VII [1940]</td>
<td>5</td>
<td>10 [3000]</td>
<td>5</td>
</tr>
<tr>
<td>Airborne ground mapping</td>
<td>H2S [1942]</td>
<td>24-48</td>
<td>10 [3000]</td>
<td>25</td>
</tr>
</tbody>
</table>

1.7.1.3 Radar in the United States

Nikola Tesla (1856-1943), an Austrian-born American electrical engineer in 1900 suggested a system for detection and location of objects with the help of reflection of radio waves. Tesla explained the concept as “when we raise the voice and hear an echo in reply, we know that the sound of the voice must have reached a distance wall or boundary, and must have been reflected from the same. Exactly as the sound, so an electrical wave is reflected, and the same evidence can be used to determine the relative position or course of a moving object such as a vessel at sea.”
Unfortunately, Tesla did not get any funding to materialize the plan.\textsuperscript{94, 95}

In 1922, Albert Hoyt Taylor (1879-1961), an electrical engineer and Leo C. Young (1891-1981) a radio engineer with the U.S. Naval Aircraft Radio Laboratory, while conducting radio communication experiments, noticed interference in their signal due to movement of a wooden ship in the Potomac River. Their system had separate transmitter and receiver at fixed sites on opposite sides of the river. Taylor reported this observation to the Bureau of Engineers and suggested that the technique could be used to detect enemy vessel irrespective of darkness, fog or smoke screen.\textsuperscript{96}

US Army's first radar system SCR-268 for tracking aircraft for the purpose of directing searchlights against the aircraft and also for laying guns was introduced in 1938. It was, however, replaced by much smaller and more accurate microwave radar SCR-584 that was produced as a collaborative effort of the British and American scientists in 1943. Mobile early warning radar SCR-270 developed in 1940 were used throughout the Second World War. In 1940, the first US shipboard search radar CXAM were installed on battleship \textit{USS California}, aircraft carrier \textit{USS Yorktown} and three cruisers \textit{USS Chicago}, \textit{USS Northampton}, and \textit{USS Pensacola}. CXAM radar was improved as SK in 1941.\textsuperscript{97} Microwave radar, SCR-520, SCR-720, SCR-584, AN/APS-6, AN/APS-15 and AN/CPS-1, were all developed by scientists at the Radiation Laboratory of Massachusetts Institute of Technology and had played a crucial role in enabling Allied forces to win the war.


\textsuperscript{96} Watson, R.C. Jr. 2009. p 30.

Table 1.6 Notable American Radar of Second World War

<table>
<thead>
<tr>
<th>Function/Type of Radar</th>
<th>Name of Radar [Introduced in]</th>
<th>Range (Km)</th>
<th>Wavelength (cm) [Frequency (MHz)]</th>
<th>Peak Power (KW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tracking of aircraft</td>
<td>SCR-268 [1938]</td>
<td>36</td>
<td>146 [205]</td>
<td>75</td>
</tr>
<tr>
<td>Mobile early warning</td>
<td>SCR-270 [1940]</td>
<td>230</td>
<td>300 [100]</td>
<td>100</td>
</tr>
<tr>
<td>Shipboard search</td>
<td>CXAM [1940]</td>
<td>160</td>
<td>75 [400]</td>
<td>-</td>
</tr>
<tr>
<td>Airborne search and interception</td>
<td>SCR-520 [1941]</td>
<td>3-9</td>
<td>10 [3000]</td>
<td>40-60</td>
</tr>
<tr>
<td>Airborne search and interception</td>
<td>SCR-720 [1942]</td>
<td>3-16</td>
<td>10 [3000]</td>
<td>100-150</td>
</tr>
<tr>
<td>Airborne search and interception</td>
<td>AN/APS-6 [1943]</td>
<td>160</td>
<td>3 [10000]</td>
<td>40</td>
</tr>
<tr>
<td>Auto-tracking gun laying</td>
<td>SCR-584 [1943]</td>
<td>29</td>
<td>10 [3000]</td>
<td>300</td>
</tr>
<tr>
<td>Airborne ground mapping</td>
<td>A/APS-15 [1943]</td>
<td>39</td>
<td>3 [10000]</td>
<td>1</td>
</tr>
<tr>
<td>Early warning (microwave)</td>
<td>AN/CPS-1 [1944]</td>
<td>380</td>
<td>10 [3000]</td>
<td>700</td>
</tr>
</tbody>
</table>

1.7.1.4 Radar of the Soviet Union

Glavnoe Artilleriisko Unpravlenie (GAU), the Main Artillery Administration and an engineering service of the Red Army in Soviet Union in early 1930s asked the Central Radio Laboratory (Tsentral 'naya
radiolaboratoriya, TSRL) of Leningard to develop a ‘radiolokatory’ or radio-location device for detecting enemy aircraft at night or hidden by the cloud. Mikhail Aleksandrovich Bonch-Bruyevich (1888-1940), Head of Radio Technology Department of TSRL, on 3 January 1934, with the help of an experimental set up detected presence of an aircraft at a distance of about 600 meters by using radio-wave of 50 cm wavelength. In 1936, a radio-locating system, codenamed Zenit was exhibited by Laboratory of Electromagnetic Oscillations (LEMO), of the Ukrainian Institute of Physics and Technology, at Kharkov, which could detect a target at a distance of 3 Km. In 1937, Pavel K. Oshchepkov (1908-1992), could detect movement of a target at a distance of about 17 Km by a pulse radio-location technique.98

By the year 1940, LEMO developed a three-coordinate radio-location system which could provide information of range, altitude and azimuth for a target aircraft located at a distance of 25 Km.99 Samuel Rabinovich (1909-1988) and his group in 1940 created the first practical radar station RUS-2 (also called “Redoubt”), near Moscow. It detected more that 200 German bombers, when Germany invaded Soviet Union 1941. Other important developments were ship borne air warning radar Redut-K (1940) and Gyuis-1 (1944), and airborne night fighter radar Gneis-2(1942). Description of notable radar developed by the USSR during the Second World War is presented in Table 1.7.100

---


Table 1.7 Notable Second World War radar of the USSR

<table>
<thead>
<tr>
<th>Function/Type of Radar</th>
<th>Name of Radar [Introduced in]</th>
<th>Range (Km)</th>
<th>Wavelength (cm) [Frequency (MHz)]</th>
<th>Peak Power (KW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gun directing</td>
<td>Zenit [1938]</td>
<td>3</td>
<td>60 [500]</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mobile early warning</td>
<td>RUS-2 [1940]</td>
<td>100</td>
<td>400 [75]</td>
<td>40</td>
</tr>
<tr>
<td>Shipborne air warning</td>
<td>Redut-K [1940]</td>
<td>100</td>
<td>400 [75]</td>
<td>50</td>
</tr>
<tr>
<td>Airborne night fighter</td>
<td>Gneis-2 [1942]</td>
<td>4</td>
<td>150 [200]</td>
<td>-</td>
</tr>
<tr>
<td>Shipboard air warning</td>
<td>Gynis-1 [1944]</td>
<td>40</td>
<td>140 [214]</td>
<td>80</td>
</tr>
</tbody>
</table>

1.7.1.5 Radar in Japan

Kinjiro Okabe (1896-1984), a professor of physics at the University of Osaka was the first person in Japan to detect movement of an aircraft, from a distance by electronic method. In 1936, he developed a bi-static system, with a separated transmitter and receiver of radio wave and detected the interference of radio signals due to passage of an aircraft between the two. In 1938, Mastasugu Kobayashi, the Manager of the Vacuum Tube Department of Nippon Electric Company (NEC) noted similar interference of the direct radio signal and the reflected radio signal from an aircraft. Kobayashi suggested to the ‘Army Science Research Institute’ that this phenomenon might be used as an aircraft warning system. NEC

then proceeded to develop an RRF system called Bi-static Doppler Interference Detector (BDID) and the first such unit called ‘Ko’ was produced in 1940. It operated between 4.0 – 7.5 MHz (75-40 m) and could detect presence of an aircraft at distances up to 500 km. The equipment was not a radar in true sense. Radar equipment capable of detecting and ranging objects or targets by the use of radio wave was known as Radio Range Finder (RPF) in Japan. During the course of World War II, Imperial Japanese Army and Imperial Japanese Navy ran completely separate and parallel RRF development programs. Brief description of such radar is given in Table 1.8 and Table 1.9. As a result in many cases they developed almost similar radar. Further, in most cases the later version of radar was hardly better than its predecessor. Although, from 1941 until the end of the war, Japan designed and manufactured land-based, ship-borne and airborne meter and centimeter wave radar and used those in the war, they could not beat the Allied radar, developed and produced during the same period of the war.

**Table 1.8 Radar used by the Imperial Japanese Army during the Second World War**

<table>
<thead>
<tr>
<th>Function/Type of Radar</th>
<th>Name of Radar</th>
<th>Range (Km)</th>
<th>Wavelength (cm) [Frequency (MHz)]</th>
<th>Peak Power (KW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detection of presence of aircraft</td>
<td>BDID [1941]</td>
<td>700</td>
<td>750-375 [40-80]</td>
<td>0.1-0.4</td>
</tr>
<tr>
<td>Ground based target tracking</td>
<td>Tachi - 1 [1943]</td>
<td>20</td>
<td>150 [200]</td>
<td>5</td>
</tr>
<tr>
<td>Ground based target tracking</td>
<td>Tachi - 2 [1943]</td>
<td>40</td>
<td>150 [200]</td>
<td>10</td>
</tr>
<tr>
<td>Ground based target tracking</td>
<td>Tachi - 3 [1944]</td>
<td>40</td>
<td>416-357 [72-84]</td>
<td>50</td>
</tr>
<tr>
<td>Static early warning</td>
<td>Tachi - 6 [1942]</td>
<td>300</td>
<td>441-375 [68-80]</td>
<td>10-50</td>
</tr>
</tbody>
</table>

Table 1.9 Radar used by the Imperial Japanese Navy during the Second World War

<table>
<thead>
<tr>
<th>Function/Type of Radar</th>
<th>Name of Radar [Introduced in]</th>
<th>Range (Km)</th>
<th>Wavelength (cm) [Frequency (MHz)]</th>
<th>Peak Power (KW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Portable ground early warning</td>
<td>Mark I Model 3 [1943]</td>
<td>145</td>
<td>205-182 [146-165]</td>
<td>10</td>
</tr>
<tr>
<td>Shipborne air and surface search</td>
<td>Mart II Model 1 [1942]</td>
<td>145</td>
<td>162-143 [185-210]</td>
<td>5</td>
</tr>
<tr>
<td>Shipborne surface search and fire control</td>
<td>Mart II Model 2 [1942]</td>
<td>35</td>
<td>10.5-9.6 [2857-2125]</td>
<td>2</td>
</tr>
<tr>
<td>Ground search light and anti-aircraft fire control</td>
<td>Mark IV Model 1 [1943]</td>
<td>48</td>
<td>150 [200]</td>
<td>30</td>
</tr>
<tr>
<td>Ground search light and anti-aircraft fire control</td>
<td>Mark IV Model 2 [1944]</td>
<td>48</td>
<td>150 [200]</td>
<td>30</td>
</tr>
<tr>
<td>Airborne ship-search</td>
<td>Mark VI [1943]</td>
<td>69</td>
<td>214-187.5 [140-160]</td>
<td>3-6</td>
</tr>
</tbody>
</table>

1.7.1.6 Radar in Italy

Guglielmo Marconi (1874-1937) an Italian inventor conceptualized radio-based detection technology in early 1920s. In a paper presented to a joint meeting of the 'American Institute of Electrical Engineers' and the 'Institute of Radio Engineers' in New York City, Marconi on 20 June 1922 made a clear forecast on utilization of radio-detection system for military purposes. In 1933, Marconi at his laboratory at Cornegliano, in Genova,
developed "Radioecometro" a continuous wave Doppler detection system operating at 330 MHz (91cm), that used a German (Barkhausen-Kurz) vacuum tube for both in the transmitter and receiver, and was able to detect disturbances in the reflected signals due to movement of the target. Marconi demonstrated his radio-detection device to Benito Mussolini (1883-1945), Head of the Government of Italy in 1935 in presence of Military authorities. As it was not powerful enough for immediate use for military purposes, Mussolini directed further development of Marconi’s system at the Royal Institute for Electro-techniques and Communications (RIEC) or Regio Instituto Electrotecnico a delle Communicazioni. RIEC was a part of ‘Italian Naval Academy’ (INA) in Livorno.

The first Italian ‘telemetro radiofonico del rivelatore', [Radio-Detector Telemetry] (RDT) for military use was developed in 1936 by Lieutenant Ugo Tiberio (1904-1980) a physicist and radio-technology instructor at Italian Naval Academy and Nello Carrara (1900-1993), a physics instructor at RIEC. This device called EC-1 had a frequency-modulated transmitter operated at 200 MHz (1.5 m) with a single parabolic cylindrical antenna. The EC-1, however, was unable to provide information on range of its target, which was essential for military use of a radio-detection system. In 1937, Alfeo Brandimarte, a captain of Naval Weapons, joined the group of Tiberio and Carrara and as a result the first Italian pulsed RDT system EC-2 was created. Further work of the group resulted in production of a high power, high frequency RDT, which operated at 425 MHz (70cm) and released 10 KW output power. Two versions of EC-3 were also developed -- one for shipboard and another for coastal defense.

During 1938, RDT became a non-priority project and came to an end before World War II. In 1941, when Italy entered the war, they had no RTD in operation.\textsuperscript{106,107}


\textsuperscript{107} Watson, R.C. Jr. 2009. p 341-344.
1.7.1.7 Radar in the Netherlands

In 1927, the Dutch Parliament constituted a “Committee for the Applications of Physics in Weaponry” which was headed by G.J. Elias, a professor of physics at the Delft University of Technology. A Laboratory was set up at “Meetgebonw” (Measurements Building), initially to conduct radio-transmission experiments. Dutch engineers J.L.W.C. Von Weiler and S. Gratama in 1938, developed an “electronic listening equipment”, which was a gun laying radar operated at a wavelength of 50 cm, having a range of 20 km. The navy ordered for production of ten such radars. To keep the development secret, the work was split over two universities and two companies. By May 1940, four radars were produced. When the Germans invaded the Netherlands on May 10, 1940, Dutch radar operators could track the planes, but unfortunately had nothing to shoot at them with. Only a day before, Holland’s surrender to the Nazis, Von Weiler escaped to Great Britain with detailed documents of the radar and two mainframes. He continued to work there on radar, in collaboration with British Colleagues till 1944.108, 109

1.7.1.8 Radar in France

In 1934, a “radio-detection system” was developed by French engineers Emile Girardean (1882-1970) and Henri Gutton (1905-1984) at Campagne Generale de Telegraphie Sans Fil (CSF). It was patented in France in July 1934 as a “New system of location of obstacles and its applications”. The device was operated at a continuous wavelength of 16...
General Considerations on Scientific Discoveries, Technological Innovations and Modern Warfare

... cms and could detect targets at a distance of 12 nautical miles. In 1939, Girardean and Maurice Ponte (1902-1983) a physicist, built radio-detection systems for defence of Paris against air attacks. In a parallel attempt, Pierre David at the Laboratori National de Radioelectricite (LNR) initiated research on a detection technique known as “barrage electromagnetique” (electromagnetic curtain) and his device was tested by the Defense Aerienne de Territorie (Defence of Air Territory) in 1936. But it could not detect aircrafts on many occasions. By 1938, David developed an improved pulse-modulated detection system with a peak power of 12 KW at 50 MHz frequency (6.0m). Both types of radio-detection devices, developed by CSF and LNR were deployed when Germany invaded France on May 10, 1940.110

1.7.1.9 Radar in Hungary

Work for development of a ‘radio-location’ device (radiolokacio) was started in Hungary in 1942, when Zoltan Lajos Bay (1900-1992), a physicist and Chief Engineer of IZZO, a Hungarian electrical and telecommunication firm, was advised by the Minister of Defense to produce radar for the Army. The first radar developed in 1942 by Bay and a team of physicist, engineers and technicians was called Sas (Eagle). The device operated at 120 MHz (2.5m) and had a range of 500 Km. It was installed atop Mount Janos and a second Sas unit was installed at another location in Hungary. However, there is no record available on regular use of the radar.111

The radar developed by all the nine countries prior to Second World War operated mostly in VHF range, i.e., 30 MHz to 300 MHz frequency band. Attempts were, therefore, made to increase the operating frequency or, in other words, to use shorter wavelengths, in order to get greater accuracy.

and better resolution. In 1940, John Randall (1905-1984) and Henry Boot (1917-1983) in Birmingham University invented the 'cavity magnetron', a high-powered vacuum tube that generated microwaves using the interaction of a stream of electrons with a magnetic field. With such cavity magnetron the British produced light-weight radar transmitters that could generate RF pulses at 3 GHz with an output power of 15 kW. This was a great achievement, as it contributed a 10-fold improvement in operating frequency over the German radar of that time.

In 1940, a seven-member team of British Technical and Scientific Mission, led by Henry Tizard (1885-1959), who was the Chairman of British Aeronautical Research Committee, visited USA and disclosed technical details of the cavity magnetron to their American counterpart. The Radiation Laboratory was set up at Massachusetts Institute of Technology in Cambridge, USA in October 1940 to develop microwave radar system, while British Admiralty carried out extensive research on microwave radar development in England at the same time. As a result of such collaborative effort, MIT in 1943 created the SCR-584 anti-aircraft microwave radar, one of the most efficient radar used during World War II. Both the British and the Americans used it extensively in the War. Chapter 2 of the thesis gives details of development of microwave radar during the Second World War.

Another significant achievement of the British and the Americans was the Radio Proximity Fuse (RPF). It is a fuse that detonates a war head when the target is within some specified region near the fuse. RPF was installed at the front of a bomb. It was a massive breakthrough in technology which paved the way for miniaturization of electronics, prior to solid state electronics. By 1945, 22 million radio proximity fuses were produced.

1.7.2 Anti-aircraft Guns

As airplanes became effective weapons during the First World War, the need for artillery to fire from ground and shipboard was felt by all the warring nations. During the war, field artilleries up to 90-mm caliber were initially converted to serve as anti-aircraft weapons. This, however, was an inadequate arrangement. But great progress was made during the inter-war years, in development of range finders, gun laying mechanisms, rapid-firing time fuses, etc. As a result, many of the strong military powers of that time made remarkable progress in developing anti-aircraft guns prior to and during World War II.

In 1930, Bofors, a Swedish defense firm, designed the 'Bofors 40-mm gun', an anti-aircraft (AA) auto-cannon, which could fire 0.9 kg projectiles, 120 rounds per minute, up to a height of 3.2 km. This medium-weight gun was used extensively by most of the Western Allies and also by the Axis forces during World War II.

Throughout the Second World War, German forces used their '2-cm Flak 38 anti-aircraft cannon', which was first produced in 1934. Their next significant development was the '88 mm Flak 36 gun' of 1936, which was used as anti-aircraft and anti-tank artillery. During the war, Germans further developed 10.5-cm Flak 38, 12.8-cm Flak 40, 5.0-cm Flak 41 and 3.7-cm Flak 43 anti-aircraft guns. The 'Möbelwagen', produced in 1943, was the first German built self-propelled anti-aircraft gun. It was developed on the chassis of Germany's 1939 Panzer IV tank. Germany produced two improved versions of Möbelwagen, known as 'Wirbelwind' and 'Ostwind', in 1944. The 'Kugelblitz' developed in 1945, had a fully enclosed rotating turret, which previous self-propelled anti-aircraft German guns did not have.

Japan used its 'Type 10 120-mm anti-aircraft gun' as a coastal defense gun from 1921 to 1945. They also used 'Type 11 75-mm anti-aircraft gun' from 1922 to 1940, and 'Type 88 75-mm anti-aircraft gun, produced in large numbers, during 1927-1945. The Japanese Navy used the 'Type 96 25-mm
AT/AA gun', a dual-purpose weapon, from 1936 to 1945. The most common Japanese anti-aircraft gun was the 'Type 98 20-mm AA machine gun', more than 2,500 of which was produced and used throughout the war. In 1942, Japan produced 'Type 2 20-mm AA machine gun', based on German Flak 38. They further produced the 'Type 4 75-mm AA gun' in 1944 for use in World War II.

During World War II, Britain primarily used its 'QF 3.7-inch anti-aircraft gun' which was an equivalent of German 88-mm Flak gun. The Royal Navy used its 'QF 2 pounder MK VIII naval gun' between 1930 and 1940. In 1938, the British Royal Navy introduced 'QF 4.5-inch MK I-V anti-aircraft naval gun', which was used throughout the war.

In 1932, Italy designed the 'Breda model 35' 20-mm anti-aircraft gun and put it in service in 1935. In 1925, Norway developed the 7.5-cm L/45 M/16 anti-aircraft gun, which was in use during World War II. 'Orelikon 20-mm cannons' developed by Switzerland in 1927 was also used, on a limited scale, as an anti-aircraft gun during the war.

In 1939, the Soviet Union developed a 37-mm automatic air defense gun M1939 (61K) and used it in Second World War. The same year, they also produced a 88-mm air defense gun M1939 (52K). Soviet Union's light self-propelled anti-aircraft gun ZSU-37 was introduced in 1943.

American heavy machine gun Browning M2HB produced since 1921 was extensively used in World War II. This, however, did not fulfill the requirement of the US Navy. In 1940, America introduced 90-mm anti-aircraft-cum-anti-tank guns and put into service their super-heavy 120-mm M1 anti-aircraft gun during 1944-1945.\(^\text{112}\)

1.7.3 Aircraft Carriers

First large-scale use of aircraft carriers was made by Japan, U.K. and the United States during World War II. In December 1941, when Japanese Imperial Navy attack the main naval base of the United States at Pearl Harbor, Japan had a fleet of carriers, consisting of ‘Hosho’, ‘Akagi’, ‘Kaga’, ‘Ryujo’, ‘Soryu’, ‘Hiryu’, ‘Shokaku’, and ‘ Zuikaku’. During the war they designed and launched four additional aircraft carriers. At the time of attack on Pearl Harbor, US had eight operational aircraft carriers – ‘Langley’, ‘Enterprise’, ‘Lexington’, ‘Saragota’, ‘Yorktown’, ‘Hornet’, ‘Wasp’, and ‘Ranger’. At the beginning of the war, British Royal Navy had ‘HMS Ark Royal’ aircraft carrier. The other aircraft carriers developed during the World War II by Royal Navy were ‘Illustrious’, ‘Indomitable’, ‘Unicorn’, ‘Colossus’, and ‘Implacable’. ‘KMS Graf Zeppelin’ was the only aircraft carrier launched by Germany in 1938, but it was never over 80% complete. The French Navy had ‘FR Bearn’, the only aircraft carrier, which was commissioned in 1927. Italy started construction of ‘Aquila’, an aircraft carrier in 1941, but it was never completed.\(^{113}\)

1.7.4 Missiles

In 1942, Germany developed a ‘Pilotless flying bomb’, ‘Vergeltungswaffe’ 1, also known as V-1, which was first launched at London on 13 June 1944. During 1944-1945, Germany fired 9,521 V-1 bombs on Southern England, but anti-aircraft gun fire from Royal Air Force fighter planes destroyed 4,621 of them. V-1 was a cruise style guided missile that was propelled by a pulse-jet engine and carried a one-ton warhead. It was 25-ft (about 7.6 meters) long and had wing span of 20 ft (about 6 meters). They were launched from a fixed ramp and could travel at a speed of about

350 mph (about 560 km/h). Flying at an average altitude of 2,000 ft (about 610 meters) they could cover a distance of about 155 miles (about 250 km).

Robert Hutchings Goddard (1882-1945), an American physicist built the world's first liquid-fuelled rocket in 1926. Wernher von Braun (1912-1977), a German engineer studied Goddard's designs and developed three rockets of 'Aggregat' series between 1933 and 1935. Goddard and Walter Riedel (1902-1968), another German engineer designed much larger 'Aggregat-4' in 1937. This ballistic missile, commonly known as V-2, was the first of its kind in the world and has been considered by experts as the second most significant technical innovation of the World War II, next only to the atomic bomb. V-2 was first launched at Paris on 6 September 1944. During 1944-45 the Germans launched over 3,000 V-2s on their enemies. The V-2 traveled faster than sound and thus the enemies did not get any information before the impact.\(^{114}\)

**1.7.5 Medicines**

Significant advances were made in medicine during World War II, which saved the life of thousands of soldiers in the battlefields. Blood plasma, the liquid component of blood, makes up about 55% of the total volume. It is the medium for blood cells to move through the body. It also performs many more useful functions of the body. Plasma was a vital element in treatment of the wounded soldiers in the battlefields. A project called 'Blood for Britain' was started in the United States with Charles Richard Drew (1904-1950), an African-American as its head in 1940 to collect blood in hospitals of New York and thereafter export it to Britain. Liquid plasma and whole blood were preserved and exported initially. Charles Drew and his team for the first time developed 'dried plasma', which was produced on a mass scale. Addition of distilled water to dried plasma

---

could form liquid plasma in only three minutes. Such plasma was given extensively to the wounded allied soldiers in Second World War.

In 1935, Gerhard Johannes Paul Domagk (1895-1964), a German biochemist discovered 'Sulfonamide', a new class of drugs for treatment of pneumonia, meningitis, gonorrhea, and other bacterial diseases. Use of sulfonamide powder on open wounds in human body prevented infection and thus greatly reduced mortality rate of soldiers during the war.

Alexander Fleming (1881-1955), a Scottish biologist and pharmacologist discovered the antibiotic penicillin in 1928. Penicillin is a life saving drug and has been very effective in treatment of syphilis, gangrene, and tuberculosis. Penicillin injections and tablets helped save countless lives during World War II.

Quinacrine, a synthetic anti-malarial drug was introduced in 1931 by the Germans. American chemists also succeeded in synthesizing Quinacrine in 1941. The drug was sold under the name of Atabrine in the form of tablets.

In 1925, a Hungarian chemist, Janos Kabay (1896-1936) developed a method to extract morphine from opium poppy straw. Morphine injection was administered as a pain killer to patients during the war.

Othmar Zeidler (1859-1911), an Austrian chemist while conducting research at the University of Strasbourg in France synthesized a chemical called dichlorodiphenyltrichloroethane, or DDT, in 1874. In 1939, Paul Hermann Muller (1899-1965), a Swiss chemist discovered the insecticidal qualities of DDT. Field trials showed that DDT was effective against common house fly, louse, Colorado beetle and mosquito. Muller patented DDT in Switzerland (1940), Australia (1943), and United States (1943).  

1.7.6 Atomic Bomb

German physicist Albert Einstein (1879-1955) propounded his Special Theory of Relativity in 1905 and as a part of this theory he made the intriguing point that large amount of energy could be released from a small amount of matter. This was expressed by the equation, \( E = mc^2 \), where \( E \) is the internal energy of the body, \( m \) is its mass, and \( c \) is the speed of light in a vacuum. When the atomic bomb developed later, it illustrated this principle.

In February 1932, through a series of experiments, British physicist James Chadwick (1891-1974) demonstrated the existence of the neutron, a previously unknown particle, in the atomic nucleus. Within nineteen months of discovery of neutron, in September 1933, the Austro-Hungarian physicist Leo Szilard (1898-1964) conceived an idea of using a chain reaction of neutron collisions with atomic nuclei to release energy. In July 1934, Szilard filed a patent application in England for developing atomic bomb, describing basic concept of using neutron induced chain reaction to create explosions. He also gave the concept of critical mass – the smallest amount of material required for a sustained chain reaction. A few months earlier, in May 1934, Italian physicist Enrico Fermi irradiated uranium with neutrons and produced the first transuranic element, and also achieved unknowingly, the world's first nuclear fission.

In December 1938, German chemists Otto Hahn (1879-1968) and Fritz Strassman (1902-1980) in Kaiser Wilhelm Institute for Chemistry at Berlin-Dahlem detected the element barium after bombarding uranium with neutrons. The result was interpreted as being nuclear fission by Austrian physicists Lise Meitner (1878-1968) and Otto Robert Frisch (1904-1979).

---


Frisch confirmed this experimentally on 13th January 1939.¹¹⁸


Another three physicists, Leo Szilard (1898-1964), Eugene Wigner (1902-1995), and Robert J. Oppenheimer (1904-1967), although were not associated directly with either of the two occasions, also heard about nuclear fission and realized that it might be possible to build a bomb. On 31 August 1939, Niels Bohr and John A. Wheeler (1911-2008) published a theoretical analysis of nuclear fission and predicted that uranium-235 is more fissile than uranium-238 and that the undiscovered element 94-239 (later known as plutonium-239) would be very fissile.

On 2 August 1939, Albert Einstein wrote a letter to the US President Franklin D. Roosevelt (1882-1945), wherein he suggested that US should initiate research for development of atomic bomb in a big way, as it would have vast destructive power. It is believed that the letter was largely written by Leo Szilard in consultation with fellow Hungarian physicists Edward

¹¹⁸ Frisch, O. R. "Physical Evidence for the Division of Heavy Nuclei under Neutron
Teller (1908-2003) and Eugene Wigner. The letter, however, was brought to the notice of President Roosevelt on 11 October 1939.

Meanwhile, on 1 September 1939, Poland was invaded by Germany, the Soviet Union and a small Slovak contingent. Although the battle ended on 6 October 1939 with decisive German and Soviet victory, as they divided and annexed the whole of Poland, it was the beginning of a series of conflicts that happened during World War II, between 1939 and 1945.

In March 1940, Otto Frisch (1904-1979), an Austrian-born British physicist and Rudolf E. Peierls (1907-1995), a German-born British physicist, while working in University of Birmingham, England, prepared a memorandum containing calculations about the amount of uranium required for creating an atom bomb. The memorandum reached Henry Tizard (1885-1959) an English chemist and Chairman of the Committee on the Scientific Survey of Air Defence, who in turn referred it to Military Application of Uranium Detonation (MAUD) committee formed by him on 10 April 1940. The MAUD committee consisted of George Paget Thomson (1892-1975), Marcus Oliphant (1901-2000), Patrick Blackett (1897-1974), Philip Moon (1907-1994), John Cockcroft (1897-1967), and James Chadwick (1891-1974). The committee considered that the scheme for a uranium bomb was practicable and likely to lead to a decisive result in the war. It recommended that the work should be continued on the highest priority in order to obtain the nuclear weapon in the shortest possible time. It further opined that collaboration with the United States, especially in the region of relevant experimental work, should be continued and extended.

In the US, Vannevar Bush (1890-1974), an American engineer and science administrator of National Defense Research Committee, was given the responsibility to coordinate the research activities on nuclear fission. Francis Simon (1893-1956) a German-born British physicist devised a method in December 1940 to separate uranium-235 from natural uranium containing

approximately 99.3% U-238 and 0.7% U-235. James Chadwick at that time realized that a nuclear bomb was not only possible, but also inevitable. In the same year American scientists, Glenn T. Seaborg (1912-1999) and Edwin McMillan (1907-1991) synthesized plutonium at the University of California at Berkeley. It was predicted later that plutonium-239 isotope would be the most useful for nuclear fission.

On 10 May 1940, Germany launched the invasion of Western Europe by attacking the Netherlands, Belgium and France. The battle of Netherlands lasted only from 10 to 14 May and Germany occupied the whole country on 17 May. Belgium surrendered unconditionally to Germany on 28 May 1940. The battle of France took place from 10th May to 25 June 1940 between the Allies and the Axis powers and the result was the decisive victory of the Axis.

On 7 December 1941, Japan, the third Axis power, attacked the US naval base at Pearl Harbor at Hawaii, which was totally unprepared for a battle. US President Franklin Roosevelt addressed the Congress on the next day to ask for a consent to declare war on Japan. The proposal was approved and US declared war on Japan on 8 December 1941. Three days later, Italian National Fascist Party Chief, Benito Mussolini (1883-1945) declared war on US. Adolf Hitler on the same day declared war on US stating that Germany was obliged to join with Italy to defend its ally Japan, under the Tripartite Agreement signed between these counties in September 1940. As a result, resolutions of war against Germany and Italy was passed in the US senate immediately and a new law was passed which allowed US servicemen to fight anywhere in the world.

A secret military research project to produce nuclear weapon, called the Manhattan Project, was initiated in Manhattan, New York in June 1942. The project eventually employed more than 130,000 people at more than 30 research and production sites across the United States, the United Kingdom and Canada with a budget of nearly two million US dollars. Details of the project is furnished in Section 3.5.1 of this thesis.
On 2 December 1942, Enrico Fermi and his team at the University of Chicago produced world's first controlled and self-sustained fission reaction. By 1943, three different designs of nuclear fission bombs had evolved under the Manhattan Project – (i) a uranium-235 gun-type bomb, (ii) a plutonium-239 gun-type bomb, and (iii) a plutonium implosion-type bomb. The first atomic bomb of the world, an implosion-type plutonium device, code-named 'The Gadget' was detonated by the United States Army on 16 July 1945 at a desert in New Mexico. The exploded bomb produced energy equivalent to the explosion of about 20 kilotons of TNT. Only two atomic bombs have ever been used in war – both detonated by United States over Japan near the end of World War II. 'Little Boy', a uranium-235 gun-type bomb was dropped on Hiroshima on 6 August 1945 by Boeing Super-fortress 'Enola Gay' aircraft of the US Army Air Force. 'Thin Man', a plutonium-239 gun-type weapon, was planned, but never produced due to technical inconvenience. 'Fat Man', a plutonium implosion-type bomb, similar to 'The Gadget' in design was detonated on Nagasaki on 9 August 1945.

1.8 Conclusion

Wars have always been an integral part of human civilization. In the Age of Tools, the era staring around 2000 BC and ending around 1500 AD, advancement of military technology was rather slow. However, with the advent of the modern age, which is believed to have commenced after the French Revolution, the nature of warfare started changing with ever accelerating rapidity. Inventions, innovations and discoveries -- product of human creativity and endeavor -- when exploited for development of the ultimate weapons, revolutionized warfare during the period from 1500 AD to the present time. The cases of the American Civil War, the First World War and the Second World War have been selected to highlight the interrelation of science, technology and war, during the period between 1861 and 1945.