HAROLD EDGERTON IN WORLD WAR II

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# HAROLD EDGERTON IN WORLD WAR II

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HAROLD EDGERTON IN WORLD WAR II

INTRODUCTION

Approximately twelve years before Hitler invaded Poland and World War II erupted, Harold “Doc” Edgerton, an avid young engineer who grew up in a small town in Nebraska, headed to the East Coast in 1926 to begin his graduate studies in electrical engineering at the Massachusetts Institute of Technology. He later became a professor at MIT, co-founder of EG&G, and owner of over 40 patents. In addition, he worked with Jacques Cousteau, searched for the Loch Ness monster, won an Academy Award, and was awarded the Medal of Freedom. He photographed everything from milk drops to circus performers to atomic explosions. Many MIT students recognize Edgerton’s work from the photographs hanging in the corridors of the Institute, such as “Shooting the Apple” in Figure 1. Although many consider his work art, he said, “Don’t make me out to be an artist. I am an engineer. I am after the facts. Only the facts.”

Edgerton possessed a keen interest in science and engineering. His unparalleled passion to master the unknown in these fields is what remained constant throughout his prolific career. In his unpublished autobiography, he recalled that one his most memorable moments was when he built his first radio during his early childhood. Even as a child, he had the gift for creating and building. Whether it was building a radio or making breakthroughs in flash photography, which is what he is most recognized for, Edgerton always put tremendous effort in his work. Today, he is often recognized for his fascinating photographs of falling milk drops and speeding bullets. This is just one dimension of Edgerton’s research and accomplishments, but it has stolen the public spotlight. The purpose of this project history is to shed light on Edgerton and his research beyond what is conveyed by these wonderful photographs, by examining his work around the World War II time period. The story begins in the late 1920’s at MIT.

Harold Edgerton was first introduced to stroboscopy while doing his doctoral thesis at the Massachusetts Institute of Technology. Through his research in stability of synchronous motors, he discovered that he could visually observe changes in angular motion due to disturbances of the system by using stroboscopic light. Edgerton was able to detect changes in the rotor’s rotation when the transmission lines connected to the generator were perturbed (Figure 3). This breakthrough helped him realize the tremendous power of strobe lights in allowing the human eye to view high-speed motion that had never before been observed. By 1937, Edgerton had already achieved a string of new

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1 http://web.mit.edu/museum/exhibits/flashes4.html
innovations using strobe photography to capture fast motion. He utilized his resources at MIT to further develop his strobe technology. Several other manufacturing and scientific laboratories at MIT turned to Edgerton to help them capture fast motion and effectively freeze time during this time period.

During the 1930s, he was developing a range of technologies including the strobe, the multi-flash, and the sensitometer for light measurements. As he shifted his focus towards more artistic applications of his tools outside of the lab setting, he faced obstacles in taking pictures in uncontrolled conditions where weather and light conditions became a concern. In these initial endeavors, Edgerton could not get enough reflection intensity because the light from his flash was absorbed by particles in the open air. These outdoor conditions decreased the effectiveness of his method, which had been very successful in taking close up photographs like the milk drop shown in Figure 3. Compared to the lab (Figure 4) and industrial settings, photography in an uncontrolled outdoor environment proved to be a challenge.

The true test came, however, in 1939 when Major George Goddard of the Air Force presented Edgerton with a project to develop nighttime aerial photography for reconnaissance endeavors. The war mobilization effort brought tremendous time constraints to Edgerton’s aerial photography research. He needed to make his aerial photography flash units reliable, and more importantly, he had to develop them quickly during these times of international crisis. His involvement in World War II ultimately expanded the scope of applications for his strobe technology, caused him to take his technology out of the laboratory setting, and introduced him to research in the area of national security after the war ended. In addition, there was a big change in scale and magnitude of the units he built during the war.

This project history will bring to the surface lines of influence World War II had on Harold E. Edgerton. The influences will be traced as Edgerton’s work progressed into the war era, followed by his work during the war and his post-war pursuits. As shown in the timeline below, a window of Edgerton’s life between 1927 and 1963 is studied to understand these influences from the beginning of his inventions. The period from 1927 to 1939 is the pre-war era, when

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4 Edgerton, *Moments of Vision*
5 http://web.mit.edu/museum/exhibits/flashinsp.html
Edgerton invented the electronic control of flash duration and electronic triggering of the flash. He perfected his technology in this time period through many engagements in the academic and industrial world.

The years from 1939 to 1944 were the active war years, when Edgerton served the Air Force with the technologies and competencies he developed during pre-war years and built upon them immensely. His experiences in these years were very influential on his research and shaped the trajectory his work would take. Between 1944 and 1947, Edgerton remained involved with the Army through his research at MIT. In 1947, Edgerton founded his company with two other partners and started his intense work with nuclear efforts in the United States. In 1963, after being involved with many military applications, Edgerton ended all association with such work and focused on his interests from before the war and intensified his underwater endeavors. A close scrutiny of these three periods gives an effective and vivid picture of changes in Edgerton’s work in terms of his work environment, the scale and magnitude of his technology, and the broadening of applications for his technology. Thus, an examination of Edgerton’s pre-war, wartime, and post-war efforts illuminates the influence that World War II had on his work.

**PRE-WORLD WAR II**

Between 1927 and 1939, Doc Edgerton moved from using the stroboscope purely as an observational aid, to creating a new school of technology based on electronic control of sudden power discharge into a flash tube. During this time, he built on his original work by improving the accuracy and the robustness of the system and varying it in terms of speed, flashing frequency and triggering mechanisms. In all cases and designs, the main goal was the same, aiding the human eye in seeing something it could not otherwise. Capturing a snapshot of a moment in time was the main goal of Edgerton’s technology before World War II. During this period all his designs contained a crucial ingredient, the basic strobe technology.

**THE BASIC STROBE CIRCUIT**

A great deal of Edgerton’s work evolved from his innovation to the stroboscope. Invented in 1832, the early mechanical stroboscope was simply a disk with slits at regular intervals. As an observer looked at a moving subject through the slits in the spinning disk, he could see successive stages of the subject’s motion. Edgerton’s innovations in the stroboscope were in the areas of electronic control and trigger mechanisms. His electronic stroboscopes could emit flashes of extremely short duration and at a high rate under precise control. The control mechanism defined the length of the flash. This was an important design parameter determined by the speed of the subject such that the photograph could capture an instant of the motion without blur. The trigger system was an accurate way of synchronizing the flashes with the motion of the subject. The fundamental technical purpose of a high-speed flash system, whether employed as a viewing device or a photographic tool, is to overcome the human eye’s inherent inability to “see” and therefore study fast motions as they occur. These motions would normally be a blur to the naked eye.
Figure 5 shows a circuit representation of Edgerton's strobe system. This basic circuit was adapted for all of his electronic flash applications. The charging resistor \( R_C \) limits the current flowing through the capacitors during charging. The trigger switch is initially open, and the trip capacitor \( C_1 \) is charged to a voltage \( V_s \). \( V_s \) is determined by the voltage divider composed of \( R_1 \) and \( R_2 \) and \( E \), the voltage of the power source:

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V_s = E \cdot \frac{R_2}{R_1 + R_2}
\]

When the switch closes, the energy in \( C_1 \) is pulsed into the spark coil, and a voltage is applied to the trigger electrode wrapped externally around the flash lamp. This excites the noble gas in the tube (typically xenon) and decreases the breakdown voltage of the gas. When the voltage across capacitor \( C \) is greater than the gas' breakdown voltage, the gas in the tube will ionize and create a brief flash of light.

Characteristics of the flash such as intensity, duration, and recharge time can be controlled by changing the values of the components in the circuit and the resistance of the tube (by using a different gas). The flash duration is approximately given by \( \frac{1}{2} \cdot R \cdot C \), where \( R \) is the resistance of the tube. Flash duration for Edgerton's electronic flash “ranged from 1/3,000 to 3/10,000,000 of a second.” The extremely short flash duration made possible by the electronic strobe is ideal for high-speed photography. The flash duration of the stroboscope allows the photographer to achieve exposure times much shorter than those permitted by a mechanical shutter, since the film is exposed only when the flash illuminates the scene. However, the light output of the flash has to be high enough to provide adequate light on the subject, and the subject has to be illuminated long and intensely enough so that the image will be well-exposed on the film. The desired flash duration should also be as short as possible to avoid blurring. These strobe parameters can be tailored to the applications for which the strobe is used. For example, the bullet photographs

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8 Edgerton, *Stopping Time*, 44.
require flash duration of 1/1,000,000 of a second, whereas hummingbird photos can be taken at 1/100,000 of a second. As a young researcher at MIT, Edgerton invested a lot of time in refining his electronic flash and utilizing it in a variety of applications.

**Pre-War Applications of the Stroboscope and Edgerton’s Work at MIT**

Edgerton’s research and his technological focus were influenced by changes that were taking shape at MIT. The head of the Electrical Engineering Department at MIT, Dugald Jackson promoted new research areas that branched off from the department’s main focus, power systems. The stroboscope was an example of the type of research that Jackson had in mind. Thus, Edgerton continued working at MIT following his graduation in 1931 to further his work on stroboscopes.

Edgerton’s plan to stay at MIT coincided with the 1929 Great Depression, which negatively impacted the entire nation. In the early 1920’s, Karl Compton, who later served as president of MIT from 1930-1948, began promoting his vision for the Institute to become the hotbed of scientific and technological developments, rather than being an industry-focused technical university. The association with industry was very strong at this time. For example, the advisory committee in charge of the engineering department’s curriculum was composed of leaders in the industry from companies including GE, Edison Illuminating Co. of Boston, American Telephone and Telegraph Co. of Boston, and Westinghouse. These corporations benefited from this relationship since they had direct access to MIT’s people and wealth of knowledge, which they could channel to their projects. Although Compton wanted to change the Institute's relationship to industry, the Depression halted his plans. MIT maintained its close ties with American industries to sustain its financial situation and provide resources for growth. President Compton stressed concern about MIT’s dependence on corporate America:

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10 Ibid 70.

11 Ibid, 43.
MIT’s over-dependence on industry, and more specifically on medium size corporations in technologically stable industries, had led to a strong emphasis on practicality and immediate utility in engineering education. It had transformed the Institute into a trouble-shooting agency for industry and thwarted its autonomy.  

Despite Compton’s concern, during the Depression years MIT had no choice but to promote consulting for industry in order to survive. This influence of corporate America on MIT research was reflected in Edgerton’s consulting work with companies that wanted to utilize his stroboscope. Thus, his ingenuity in applying his technology to numerous applications was fostered by MIT and its role during the Great Depression.

In 1931, with jobs scarce due to the Depression, MIT graduate Kenneth Germeshausen came to Edgerton seeking a research position. Edgerton convinced department head Jackson to hire Germeshausen as an assistant without pay and assigned the former student to projects involving use of the strobe to find problems in industrial machinery. Herbert Grier joined Edgerton in a similar fashion in 1933. Together, they established an informal partnership over the years. One of their first consulting jobs was with a paper mill company in which the machinery moved too fast to observe the cause of the defects. Using the stroboscope and high-speed motion pictures, they were able to observe the motion of the machine and see where the defects were forming. The stroboscope was also useful to engineers who sought to observe fast machinery while in operation. With Edgerton and his colleagues’ help, companies such as the Russell Box Company and the Foster Winding Machine Company utilized Edgerton’s stroboscope to record high-speed motion of their machinery in action. Figure 7 shows a thread machine captured in action by the stroboscope. For this type of work Edgerton licensed his patent to General Radio Company in 1935 to build the hand-held Strobotac (Figure 8). This 12-pound strobe unit could flash up to 14,400 times a minute.

In addition to industrial clients, Edgerton also cooperated with other departments within MIT. Figure 9 shows his work for the Mechanical Engineering department in which he examined the movement of air through the blades of a fan. In one of his reports to the Electrical Engineering department, Edgerton listed the “Class of Customers” he had for his stroboscope units and work between January 1933 and October 1935. He mentioned 26.6% of his work is for clients in

15 Wildes, 147.
16 Wylie, Francis. Unpublished article for Smithsonian. Harold Edgerton Papers, Box 5, Folder 1, p. 3
educational fields. The remaining clients are in industry, with 17.1% in general machinery, 9.6% in automotive and engine, 7.4% in textiles, and 3.2% in metallurgy and metal products.

With numerous successes in MIT laboratories and in industry, Edgerton established the stroboscope as a valuable scientific tool. However, machines were not the only subjects Edgerton was photographing during the 1930’s. At one point, MIT Professor Charles Stark Draper confronted Edgerton and said: “Why don’t you do something useful with it besides fooling around with motors?… The whole world is moving.” Edgerton heeded Draper’s advice:

I looked around and there was a faucet right next to where I worked. So I just moved the strobe over and took a picture of this water coming out of the faucet. That was the first picture I ever took except for a motor.

Edgerton began applying his stroboscope to various fast-moving phenomena in his surroundings. His images of speeding bullets, sporting events, and milk drops revealed that Edgerton had a flair for applying his technologies to multiple disciplines and applications. The “ability to construct fruitful analogies between fields” is an important mode of creative thinking. Much like Thomas Edison, who applied his expertise in telegraphy to make improvements in his electric light model, Edgerton used analogies with familiar devices like the motor and the strobe to deal with specific, wide-ranging problems he encountered. In a speech to a chemistry class in 1936, Doc explained that “there are a great many different ways to use the method [stroboscopic light], and I feel that we have hardly learned how to use the tool yet.” Hence, Edgerton possessed a remarkable ability to conceive countless design variations for various disciplines based on his expertise in strobe photography. This unparalleled talent was one of the reasons why the members of armed forces sought Edgerton’s expertise to improve aerial photography.

**EDGERTON’S COGNITIVE STYLE**

In addition to Edgerton’s talent in applying his technology, his cognitive style, illustrated by his incessant work ethic and meticulous nature, also made him a prime candidate for the aerial national security project. He was very passionate about his work. He once said, “If you don’t wake up 3 o’clock in the morning wanting to do something then you’re wasting your time.” During the 1930’s Edgerton and his colleagues diligently worked on perfecting the electronic stroboscope. They experimented with various gases for the flash tubes in order to create a brighter and faster flash. The nature of this work was much like Edison’s light bulb work, involving many trials and various materials. Edgerton also worked on triggering and timing devices in order to provide precise control of the flash. This shows not only that he was an

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17 Harold Edgerton Papers, Box 70 Folder 2.
18 Edgerton, *Flash!*, 130.
incessant worker, but that he was also intellectually curious and creative and wanted to "get to the bottom of things." Edgerton once said, “If you’re working with anything — anything — you want to understand it. You’ve got to see it and record it and learn all about it.”

Edgerton was not a theorist, but rather worked primarily from the hands-on approach. His model for success was trial and error. “If you weren't actively testing your ideas, you were wasting time. For Doc, learning by doing was most important.” He was not afraid of trying things and finding a problem, but rather embraced the findings and tried again and again until the project was refined to his satisfaction. In a draft of his autobiography, remembering his long hours as a technician working on power transmission poles, he writes “Some of these working habits have stood me well in my life. Whenever I have a job that must be done, I think of my linemen friends who taught me the secret — keep going!” He was a stickler for performance. After he came up with the design, he had to test everything he thought up. He always wanted to get to the very bottom of things, to understand everything about it. Edgerton was not just a genius tinkering in his lab. At the request of others and his own intellectual curiosity, he applied his basic idea of electronic flash to many areas.

Edgerton was also very meticulous. In the MIT Archives are around 160 boxes of his work and personal belongings. He recorded daily his activities, ideas, and findings. For example, Figure 10 shows two pages out of his date book. Records of places he went, work he had done and even the weather on a few days are all written down carefully by Edgerton. In his lab notebooks, Edgerton dated everything he wrote down and used the same kind of bounded and numbered institute laboratory notebook for his records. He wrote everything down from names of people he met, to the trip that he and his graduate students took, to circuits and ideas. Figure 11 presents a sample of the many notebook pages found.

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22 Exploring the Art and Science of Stopping Time: The Life and Work of Harold E. Edgerton
23 Harold Edgerton Papers, Box 152 Folder 13.
24 Exploring the Art and Science of Stopping Time: The Life and Work of Harold E. Edgerton
In his notebooks, Edgerton gave detailed explanations using many diagrams and photographs. There are signatures of his colleagues and graduate students stating that they had heard and understood Dr. Edgerton explain the concept or circuit on the page. Doc also pasted photographs, pamphlets, and fliers onto the pages. He worked hard, always on several projects at the same time. There are even napkins and hotel notepad pasted onto the notebooks with ideas and diagrams of circuits. This shows that he worked all the time, even while traveling or eating.

Not only was Edgerton persistent, meticulous and intellectually creative, he also knew the importance of demonstrations to the success of his technology. Edgerton approached Kodak about marketing his electronic flash, but Kodak refused saying they

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25 Harold Edgeton Papers, Box 51 Folder1, page 22.
26 Edgerton, Flash!, 158.
wouldn’t be able to sell more than 50 of the cameras based on his idea. So Edgerton decided to market his technology his own way, by taking pictures of well-known events like the track meet in Boston Garden. The picture in Figure 12 was the first flash photo to be sent over the AP wire. Edgerton also equipped photographers with his camera and flash so they could take stopped-motion pictures of stars like Joe Louis in his boxing match in Figure 13. For industrial applications of Edgerton’s electronic flash, General Radio agreed to build the Strobotac. The prototype was outfitted in a suitcase, and Edgerton brought the unit with him on a family vacation to demonstrate at factories and companies in order to build demand. Edgerton also gave many talks and lectures to promote his stroboscope. He created an exhibit for MIT at the New York World’s Fair (Figure 14) exposing even more people to his technology.

Edgerton’s technical expertise as well as his cognitive style brought him to the attention of the armed forces, and as a researcher at MIT, Edgerton was prepared to provide his services during World War II.

**WORLD WAR II**

During the period from 1927 to 1939, Edgerton's work at MIT and in industry resulted in a maturation of his basic stroboscopic technology and in the development of the aspects of his cognitive style. However, this period of unencumbered research during which Edgerton explored and developed his interests ended in 1939, when his involvement in the war effort began. As it did for most people of academia of that era, the Second World War had a great impact on Edgerton and marked the start of period of a change in his career. Edgerton's direct involvement in the war effort also had a significant influence on the direction of his technology and research and the form, which those works took. Thus, Edgerton's work during World War II explains the new trajectories that his research followed in the aftermath of the war.

27 Edgerton, *Moments of Vision*, p. 82.
28 Harold Edgerton Papers, Box 51 Folder 3, p.148.
**WORLD WAR II CHANGES RESEARCH AT MIT**

To understand the reasons behind Edgerton’s direct involvement in the war effort, it is important to understand the environment and time period in which he lived and worked. In particular, it is helpful to examine MIT’s attitude towards the military during World War II. As soon as the United States entered the war, MIT transformed from an industry-dependent institute, to an entity increasingly funded by the federal government. In Compton’s eyes, MIT needed to mobilize all of its resources and intellectual power to help in the war effort:

> We are fortunate to serve as an institution whose objective in respect to national needs is so clear-cut and constructive… In a time of military crisis, technological efficiency in production as well as in design of instruments of defense and offense is the basic element of national defense… We should make [best evaluation of national importance] possible by postponing less urgent research projects, by internal rearrangement of teaching schedules, and by carrying out a more than normal per capita burden of work.29

Both the students and the staff redirected their research and goals to meet the needs of the war effort. In line with what was expected of MIT, Edgerton was ready to contribute. Major Goddard, the leader of the aerial reconnaissance team from Wright Field in Dayton, Ohio visited Edgerton during the summer of 1939 and presented him with the project of developing an electronic flash unit for nighttime aerial photography. For Edgerton, this opened a whole new dimension to his research that was grander in scale than his pre-war consulting endeavors.

**AERIAL RECONNAISSANCE PHOTOGRAPHY**

The original impetus for soliciting Edgerton’s involvement in World War II was the need for a more advanced system of nighttime aerial photography. Aerial reconnaissance was a tactical operation used by the Allied forces to track enemy movements of supplies, weapons, and their locations. During WWII, the Germans anticipated aerial reconnaissance operations. As a result, much of the their movements occurred at night, under the blanket of darkness. Hence, there was a need for nighttime aerial photography.

**WORLD WAR I AERIAL PHOTOGRAPHY**

Aerial photographs were first being used for reconnaissance during World War I. After the war, development of cameras for aerial photography continued as nations began to see the importance of aerial reconnaissance. In an army wide general memo, Captain Lynfold Bright wrote,

> The importance of air reconnaissance cannot be overemphasized and its effect upon the enemy’s morale cannot be overstressed, let alone the military importance of the information obtained through these night photographs.30

By 1928, the Royal Air Force was using aerial cameras that could photograph regions up to 4 square miles from 30,000 feet, beyond the reach of anti-aircraft guns. These cameras were equipped with electrical heating systems to prevent the shutters from freezing at high altitudes.31

29 Burchard, 6.
30 Harold Edgerton Papers, Box 77 Folder 2.
The technological advancements in the United States’ aerial photography research coincided with research in Europe.

**FLASH BOMB**

In the United States, Major George Goddard played a critical role in the advancement of aerial photography. As aerial reconnaissance photography grew more prevalent, the military learned to move at night in order to avoid being seen by enemy reconnaissance operations. In order to be able to track enemy movements at night, Goddard began to investigate night aerial reconnaissance methods. He took the first night aerial photograph in the U.S. (Figure 15) over Rochester, NY in 1925, using the flash bomb technique he invented. A bomb of magnesium powder was dropped from an airplane and triggered the camera shutter to coincide with the flash caused by the bomb’s explosion. The time at which the flash bomb detonates was regulated by a time-delay fuse. When the flash illuminated the ground below, a photocell fixed to the plane would trigger the shutter of the camera. While flash powder made night aerial photography a reality, it was not an ideal solution. The flash powder was dangerous due to the risk of the bomb igniting while still on the plane. Goddard narrates many incidences in his book *Overview: A Lifelong Adventure in Aerial Photography* indicating the dangers involved with the powder of the flash bomb as well as the primitive release mechanism. In addition, the number of photographs that could be taken was limited by the amount of explosive powder carried on the plane. In an article published in the Journal of Physical Society of America, Edgerton described the disadvantages:

In spite of apparent success, the flash-bomb method of night photography had several disadvantages. The flash bomb is dangerous because the powder is easily ignited. The number of reconnaissance operations is restricted since the number of bombs that can be carried is limited. The plane can operate only at a given altitude because the time-delay fuses are set before take-off [for the bombs] to be dropped from a pre-determined altitude.34

Because the flash bomb fuses are set before take-off, this system has no flexibility in the operating altitude. For this reason, inclement weather may cause problems for night photography using flash bombs. Encountering unexpected clouds may prevent the operators from being able to photograph at the pre-set altitude. However, they cannot

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33 Harold Edgerton Papers, Box 80 Folder 6.
simply fly below the clouds, since the flash bomb would not explode at the right time. Inclement weather in the form of wind or rain may also be problematic, since they could blow the flash bomb off course or prevent the flash powder from igniting.

Anticipating increased use of nighttime aerial reconnaissance in World War II, it was clear to officials in the armed forces that a safer and more versatile aerial photography technology was needed. Edgerton was asked by Goddard to adapt his stroboscope technology for use in nighttime aerial photography. In theory, the electronic flash system addressed most of the disadvantages of the flash bomb:

- The equipment was inherently non-explosive.
- The electronic nature of the flash meant that it could provide a reusable and limitless source of light.
- The light source itself was controlled internally and was contained within the reconnaissance aircraft, meaning that it could be operated at any altitude.

These advantages were inherent to the flash equipment itself. However, the size of the system needed to accomplish aerial reconnaissance was much greater than the systems for close-up photos like those used to analyze milk drops and motors.

**EDGERTON JOINS THE WAR EFFORT**

Because of the possible advantages of an electronic flash, Goddard approached Edgerton in 1939 with the proposition to develop a more advanced night aerial reconnaissance than the flash bomb:

> While my photoelectric system automatically opened the camera shutter when the bomb went off and therefore assured greater photographic dependability, the disadvantages remained and even though the Ordnance people worked long and hard at overcoming them, I began looking for a better method by which to light up the sky. I found it at MIT at the electroscopic laboratory of Dr. Harold Edgerton. I knew that Dr. Edgerton and his assistants had come a long way in methods of generating bright light using electricity.36

**DEVELOPMENT OF ELECTRONIC FLASH FOR NIGHT AERIAL RECONNAISSANCE**

Edgerton’s work on his flash technology during the war focused primarily on creating strobe equipment that could generate a flash with enough power to illuminate a target more than a mile away and withstand the amount of energy such a flash would generate. At first glance, it would seem as if the technology used to take pictures from miles in the sky would differ greatly from that used in Edgerton’s pre-war work in sports photography and industrial consulting. However, a comparison of a pre-war handheld unit (Figure 18) with a wartime aerial flash system (Figure 19) shows that the basic architectures were nearly identical. In both units, the system architecture is comprised of a flash bulb, the camera used to take the pictures, a power source

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35 Harold Edgerton, "The Past, Present, & Future of High Speed Photography."
and capacitors to store the energy discharged in the flash, and a control unit to trigger the system and control the delay between the camera and flash.

Thus, the wartime innovations in electronic flash development for reconnaissance were a mere extension in scale of pre-war flash equipment. However, this work was not trivial, and Edgerton’s wartime efforts included scaling his electronic flash components to be able to produce the power necessary to generate beams of high enough intensity to illuminate the ground below and optimization of the overall system design.

**SYSTEM DESIGN**

While the basic electronic flash technology remained similar to that of the smaller pre-war units, the design of the aerial flash unit and its layout within the reconnaissance aircraft were developed to accommodate the specific constraints of aerial photography.

**Figure 20** shows a high-level circuit diagram of one of the flash systems documented by Edgerton in November 1943. Similar to the basic strobe circuit in [Figure 5](#), the main idea is charging a large capacitor and releasing the power suddenly into the flashtube. As an addition, in the large aerial flash system, the “ON” switch prepares the light filaments of the bulbs, warms them up for operation, and starts the flash bulb cooling system that is composed of a

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37 Edgerton, *Electronic Flash, Strobe*, 113.
38 Harold Edgerton Papers, Box 77 Folder 5.
simple air blower. The cooling system is necessary since the sizes of the flash units are large and exposed to high levels of energy. This preparation is usually done on the ground prior to take off since it draws very little current.

Once at the desired altitude, the pilot simply pushes the “PHOTOGRAPH” button to charge up the capacitors. This switch connects the battery to the power inverters where DC current is changed to AC current. As soon as the voltage across the capacitor reaches 4,000 volts, a relay triggers the camera shutter, which in turn triggers the firing of the flash. While the “PHOTOGRAPH” button is depressed, this series of events continues with a delay determined by the charging speed of the capacitors.

The placement of the flash unit was another aspect of the system architecture design. When Edgerton worked with stand-alone stroboscope units in his pre-war research, this was not an issue, but now the whole unit had to be embedded in the plane. Bombers including the A-20 and the B-24 were modified so that both the flash unit and the condensers housing the large energy-storing capacitors could be located in the aircraft’s bomb bays. This was the logical location for these components since the bomb bays afforded the most space in the airplane for the bulky condensers and its doors provided a way to install the flash within the plane while giving it an opening to the outside world. Given the condensers’ placement in the bomb bay, the camera was placed at either the nose or tail of the plane to provide maximum separation from the flash unit in order to minimize the loss of contrast caused by placing a flash and camera in close proximity to one another.

In a letter dated September 10, 1943, Edgerton relates to Colonel Baisley his findings through his trials with one of the pilots in an A-20, suggesting two possible installations methods:

> It seems possible from the available data that the flash unit for the A-20 can be modified to be used on the bomb shackles in the rear bay beneath the tank since the tank is in the upper portion of the bomb bay.

Figure 21 shows one of Edgerton’s sketches of the installation.

40 Harold Edgerton Papers, Box 78 Folder 2.
The circuit and the layout design considerations were very technical and experimental in nature. The theory behind the requirements of the circuit and the size of the system was derived from basic electronic flash theory, which determines the parameters of the system.

**THEORY FOR FLASH LIGHT SOURCES**

The challenge facing Edgerton was the need for increased light energy output of the flash equipment. The output of a flash, measured in candlepower, is integrated over the effective flash duration to determine the total output, or CPS, measured in candle-power-seconds. The required total output in nighttime aerial photography is determined by two factors:

- The altitude at which the plane is flying, measured in feet. This determines the distance between the flash and the subject.

- The lens aperture used in the camera, which determines how much light the lens lets in. This value, measured in f-stops, is the focal length of the lens divided by the lens-opening diameter. The aperture value becomes larger as the diameter decreases, and less light is allowed to reach the film. This affects the flying altitudes where larger aperture values call for being closer to the ground in order to capture enough light to expose the film.

The combined effect of these two elements is called the Guide Factor (Equation 1, below). The Guide Factor is proportional to the amount of light energy needed to be output by the flash adjusted by the effect of the reflector (Equation 2). This relationship is due to the inverse square brightness law ([Figure 22](#)), which states that the area covered by a light source increase as the square of distance from the light source. As a result, the intensity of light per unit area decreases as a square of distance. The light energy output (CPS) is directly related to the electrical energy (E_{elec}) provided to the flash bulb and the bulb’s efficiency in transforming the electrical energy to light energy (Equation 3).

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41 Harold Edgerton Papers, Box 78 Folder 2.
Edgerton used the above calculations to determine the circuit requirements that would provide the electrical energy for the bulb.

\[
E_{\text{Elec}} = \frac{1}{2} \text{Capacitance} \cdot \text{Voltage}^2
\]

Edgerton also had to consider timing of the energy build-up and discharge to ensure short flash duration at high speeds in order to avoid blurring of images. These calculations are determined by changes to the capacitors and resistors that determine the time constant of a circuit.

**TECHNICAL ISSUES**

Despite the advantages of flash equipment for aerial photography, electronic-flash systems were not without drawbacks. The weight of the system, the lack of shadows in pictures taken with electronic flash, and possible fogging of the film were the main disadvantages in Edgerton’s technology.

As explained in the section Theory for Flash Light Sources, for a plane operating at higher altitudes, the intensity of the flash required illuminating the target increases quadratically as altitude increases. Since the power of an electric flash is directly proportional to the capacitance of the circuit, operation at higher altitudes requires the number of condenser units (Figure 23) containing the capacitors to also increase quadratically. Because the weight of the condensers dominates the equipment, Edgerton noted “the weight of the flash equipment increases as the square of the altitude at which photographs are made.” Edgerton’s initial calculations showed that the equipment required for the operation of the flash at altitudes suitable for reconnaissance flights would weigh several tons. However, while he initially saw this as a limiting constraint,

Goddard was completely unimpressed by the very considerable weight of the proposed nocturnal photoflash equipment. He knew that the new airplanes, then on the drawing board, would have no trouble carrying such heavy equipment.

42 http://universe.colorado.edu/tango/figures.taf?function=number&number=6.10
44 Harold Edgerton Papers, Box 136.
46 Edgerton, Electronic Flash, Strobe, 289.
Another issue in the use of electronic flash units in nighttime aerial photography involved the amount of separation in distance between the flash bulb and the camera itself. A light source placed too closely to the camera would result in “back-scattered light from the source caus[ing] fog on the film, which reduces contrast.”47 Similarly, a light source placed in close proximity to the camera resulted in a picture without shadows. Shadows were useful in determining the height of objects. Flash bombs were superior to the electronic flash in this regard, as the separation they provided after being dropped from the plane was enough to produce distinctly shadowed objects. The inability of the electronic flash units to produce shadows in the photographs was unavoidable due to the self-contained nature of the equipment and the limited dimensions of the airplanes. Table 1 summarizes the advantages and disadvantages of the flash bomb and electronic flash. Figure 24 shows two aerial photographs, one taken with flash bomb technology and the other with Edgerton’s electronic flash.

<table>
<thead>
<tr>
<th>Flash Bomb</th>
<th>Electronic Flash</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Advantages</strong></td>
<td><strong>Disadvantages</strong></td>
</tr>
<tr>
<td>• Shadows indicate heights of</td>
<td>• Number of photos per flight limited by flash bombs</td>
</tr>
<tr>
<td>subjects</td>
<td>on board</td>
</tr>
<tr>
<td>• Lighter equipment</td>
<td>• Explosive material</td>
</tr>
<tr>
<td></td>
<td>• Operation at fixed altitude</td>
</tr>
<tr>
<td></td>
<td>• Problematic in inclement weather</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Advantages</strong></td>
<td>• Easy and safe to use</td>
</tr>
<tr>
<td>• Lighter equipment</td>
<td>• Non-explosive</td>
</tr>
<tr>
<td>• Easy and safe to use</td>
<td>• Unlimited number of photos per flight</td>
</tr>
<tr>
<td>• Non-explosive</td>
<td>• Operates at a range of altitudes</td>
</tr>
<tr>
<td>• Unlimited number of photos per</td>
<td></td>
</tr>
<tr>
<td>flight</td>
<td></td>
</tr>
</tbody>
</table>

Table 1: Comparison of Flash Bomb and Electronic Flash

Figure 24: Photos Taken with Flash Bomb48 (left) and Electronic Flash49 (right)

48 Harold Edgerton Papers, Box 80 Folder 6.
In light of the advantages and disadvantages of the flash bomb method and the electronic flash method, these two technologies served well under different conditions. Edgerton reiterates this point, “Contrary to a first impression that these two distinctly different methods are competitive, they complement each other in tactical uses.” His biggest challenge was not with the flash bomb. Rather, it was with developing a technology quick enough to meet the urgent demands of the armed forces. This is where Edgerton’s work ethic excelled. In a letter written to Edgerton in 1941, Lt. F.O. Carroll explained,

The probability of widespread use of flash unit for night photography is rapidly increasing and it is indicated that the need for it will be urgent. It is therefore recommended that the full size unit be developed with all possible haste.

THE SIX ELECTRONIC FLASH MODELS

By the end of 1939, Edgerton had tested a quarter-scale prototype of his aerial flash in a B-18 bomber over Boston, resulting in the first photograph using aerial electronic flash techniques. By March of 1941, Edgerton had begun testing his full-scale system over Boston, with MIT as the subject of some of his first aerial photographs. Edgerton used these as initial demonstrations to Goddard, who commended Edgerton for his work in August 1941:

Your flash development for aerial photography has received excellent recognition by the War Department. They really believe that this development has tremendous possibilities, and I feel that you should do everything possible to expedite the completion of the second unit.

Besides his experimental trials between 1939 and 1942, Edgerton produced six different flash units for use in aerial night photography, numbered D-1 through D-6. See Figure 25 for the development and operation timeline for all models as well as a representation at the altitudes.

![Figure 25: Timeline for Electronic Flash Development](image-url)


51 Harold Edgerton Papers, Box 77 Folder 10.
they operated at.

Each of his first three models surpassed the previous one in the amount of energy released per flash. There is significant improvement from one model to the next, but D-1 represents the greatest leap in technology when compared to his pre-war strobes. A visual comparison of images of the Milk Drop and Stonehenge (Figure 26) illustrates the change in the magnitude of flash intensities. Figure 27 gives a quantitative analysis of the energy per flash of the systems developed up to 1943.

The Strobotac, which was used during his consulting practices was held in close proximity to the subject and did not require high light intensities. The Strobotac released 0.135 watt-sec per flash, unlike the aerial photography units where the smallest energy level was 342 watt-sec, which was approximately 2,500 times as powerful. The largest flash unit was about 250,000 times more powerful than the Strobotac. Goddard also recognized the challenge this application presented: “They had succeeded in producing an electric flash system for nothing larger than a small hand-held Graflex camera, and what I was asking for was a jump from candlelight to sunlight.”

Looking at the units themselves, the differences in magnitude can be better visualized. Figure 8 showed the Strobotac unit manufactured by the

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52 Harold Edgerton Papers, Box 77 Folder 10.
53 Synthesized from “Night Aerial Photography – A Technical Story” ORDWES Laboratory, Wesleyan University, July 1, 1954. Harold Edgerton Papers, Box 79 Folder 8.
55 Harold Edgerton Papers, Box 79 Folder 5.
56 Synthesized from Harold Edgerton Papers, Box 62 Notebook 14, p. 39.
57 Goddard, 244
General Radio Company in 1935 under Edgerton’s patent. The Strobotac can be compared to the aerial flash units shown below. Figure 28 shows a D-3 system installed in an A-26 bomber and the flash is being operated on the ground. Figure 29 shows two reflectors right before installation.

In his first three units, there is an increase in energy per flash. Edgerton had to create systems with greater energy output to enable flights at higher altitudes. Goddard explains, “Great altitude to a reconnaissance pilot in World War II was money in the bank, it meant he had a much better chance of coming home safely.” Delivering for this specific goal, Edgerton bettered his system along this dimension provided that he could ready the units in time for successful operations. Much like Draper’s missile guidance system with increasing accuracy, Edgerton could believe in a trajectory for his first three units. Table 2 shows the final specifications of these systems by the end of 1943:

<table>
<thead>
<tr>
<th></th>
<th>D-1 Flash</th>
<th>D-2 Flash</th>
<th>D-3 Flash</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operation Altitude with f/1.5 Camera</td>
<td>1,000 ft</td>
<td>5,000 ft</td>
<td>20,000 ft</td>
</tr>
<tr>
<td>Energy per Flash</td>
<td>460 Watt-sec</td>
<td>3,000 Watt-sec</td>
<td>43,200 watt-sec</td>
</tr>
<tr>
<td>Capacity</td>
<td>75 µF 3500 Volts</td>
<td>375 µF 4000 Volts</td>
<td>5,400 µF 4000 Volts</td>
</tr>
<tr>
<td>Weight</td>
<td>150 lb</td>
<td>500 lb</td>
<td>5,400+ lb</td>
</tr>
</tbody>
</table>

Table 2: Specifications of Three Major Edgerton Flash Units

However, the end of 1943 marks a shift as the models that follow the D-3 no longer increase energy released per flash but rather are specific solutions to applications required by the army. These customized solutions led to the D-4, D-5 and the D-6, which were modified versions of the

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59 Harold Edgerton Papers, Box 79 Folder 5.
60 Goddard, 307
61 Harold Edgerton Papers, Box 77 Folder 4.
D-2 Flash. Table 3 shows the specifications of the new units. D-4 was designed to be a lightweight unit for low altitude flights in the South Pacific. D-5 incorporated use of standard power inverters, which were also used in other navigational equipment like early radar. D-6 was an improved version of D-5 that could work at higher plane speeds with less time required between flashes.

<table>
<thead>
<tr>
<th>Operation Altitude with f/1.5 Camera</th>
<th>D-2 Flash</th>
<th>D-4 Flash</th>
<th>D-5 Flash</th>
<th>D6-Flash</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>500 lb</td>
<td>362 lb</td>
<td>1,400 lb</td>
<td>1,500 lb</td>
</tr>
</tbody>
</table>

Table 3: Specifications of Edgerton Flash Units Modified from D-2

Once the D-3 allowed photography from an altitude of 20,000 feet, it was no longer necessary to pursue improvements along this dimension. Therefore subsequent models represented improvements of the D-2 flash along other dimensions, including power requirements and allowable plane speed.

One of the reasons the D-2 was the model in operation the longest was because it accommodated alterations for specific purposes. In most cases, the manufactured D-3 models were reassembled into D-2 models. Edgerton was personally involved in the re-engineering process when he took a D-3 from Italy to England to be made into three D-2 flash units. After D-Day, sixty D-2 units were ordered making it the most manufactured unit produced by the General Electric Company.

D-2 may also have lasted so long because it fostered a good trade-off between weight and altitude. Table 4 shows the planes that were available for reconnaissance and the units they could carry. The table shows that the D-3 could only be used with an A-26, a luxurious requirement during war times when planes with high bomb capacity were always being utilized in attack fronts. Although the D-2 could not operate at the altitudes as high as the D-3, it was nonetheless, more manageable. D-2’s superiority over the D-1 is the ability to operate at higher altitudes without a big impact on the weight of the unit by making more use of the plane’s power supply.

<table>
<thead>
<tr>
<th>Plane Model</th>
<th>Bomb Capacity</th>
<th>Admissible Flash Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>B-18</td>
<td>2,000 lb</td>
<td>♦♦</td>
</tr>
<tr>
<td>B-25</td>
<td>4,000 lb</td>
<td>♦♦</td>
</tr>
<tr>
<td>A-20</td>
<td>4,000 lb</td>
<td>♦♦</td>
</tr>
<tr>
<td>A-26 (aka B-24)</td>
<td>6,000 lb</td>
<td>♦♦♦</td>
</tr>
</tbody>
</table>

Table 4: Types of Planes and Flash Units They Could Carry

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62 Harold Edgerton Papers, Box 79 Folder 8, 27-29.
63 “Night Aerial Photography – A Technical Story”
Edgerton’s war research was used during the China-Burma campaign in 1943. Figure 30 reveals a blown up bridge in Burma. A captured Japanese officer said the following about the Edgerton light unit: “Oh! What can we do now! With his bright blinking eyes streaking across the dark canopy of night, the devil himself has compromised our last and now unfaithful mistress of security.”

The technology Edgerton developed during World War II also played an important role in the D-Day invasion of Normandy. Edgerton recalled, "The clouds were down about 1,000 feet and the flash bombs couldn’t be used at all because they were designed to be working at 10,000 feet." However, photographs taken using his aerial electronic flash enabled the Allied forces to discover that the Germans were completely unprepared to defend an attack at Normandy. Figure 31 shows this historical photograph. The focus of the photograph is of a main road artery that runs through the city. This photograph shows that the road is clear with no German supply vehicles in the area.

**BROADENING OF APPLICATIONS OF STROBE TECHNOLOGY**

In addition to huge increase in the magnitude that the aerial flash project brought to Edgerton’s original strobe technology, the war also broadened its range of applications. Edgerton’s close cooperation with the military and the numerous wartime needs of the U.S. military during the war led him to apply his original stroboscopic technology to a number of other, completely new applications. These included development of technologies for the photography of ballistics tests and the use of strobes as aircraft beacons.

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65 Edgerton, *Electronic Flash, Strobe*, 293.
66 Harold Edgerton Papers, Box 77 Folder 2.
67 Edgerton, *Moments of Vision*, 138
68 Exploring the Art and Science of Stopping Time [CD-ROM]
BALLISTIC TESTING

While nighttime aerial reconnaissance was Edgerton’s main focus during World War II, he also spent a great deal of time during the war traveling to testing centers like the one located in Aberdeen, Virginia to photograph military ballistics tests. This work built upon Edgerton’s pre-war efforts in developing ultra-high speed movie cameras and the high-speed multi-flash, during which time Edgerton had also gained experience in the specific area of ballistics. Prior to the war, Edgerton had photographed bullets as they left the barrel of a pistol. He was able to show that, contrary to what was previously thought, the “kick” of a fired pistol when it was shot did not affect the trajectory of a bullet, as the gun did not begin its jerk upwards until well after the bullet had left the barrel.

Aware of Edgerton’s pre-war work in this area, the Army approached him about applying it to the war effort. Edgerton quickly signed on and, at the same time that he was doing his work with the aerial flash, also photographed a wide variety of ballistics tests throughout the war. Much of this work involved photographing the impact of certain types of shells against armor. However, while Edgerton’s work with the aerial flash focused on maximizing the power and intensity of the flash, the ballistics had a different focus. The aim of this work was to increase the accuracy with which the flash and camera were triggered. It was imperative in ballistics testing to capture the moment of impact at the exact instant it occurred.

This focus is apparent in the work Edgerton did during this time with sound as the triggering mechanism for his photographs. In early ballistics tests during the war, the impact of the shell being photographed with the armor was used to trigger the flash. However, this method resulted in pictures that were often of poor quality or that were obscured by the flash caused by the initial impact of the bullet with the target. In an earlier notebook entry from November 9, 1940, Edgerton states that he “again considered the use of a stroboscope with a sound pick up,”70 indicating that the technique had not been used before. However, in this entry, he discusses using this sound-triggering mechanism in the context of diagnosing problems with looms in the textiles industry, not in ballistics photography. No mention is made of its possible use in ballistics testing, and his earlier tests during the war all use the contact of the bullet itself with the target as the triggering mechanism. There is no evidence of the use of the sound technique in his ballistics photographs prior to the war. This application of the technology is first seen on November 10, 1943. In his notebook, he draws a diagram of

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69 Harold Edgerton Papers, Box 52 Notebook 14.
70 Harold Edgerton Papers, Box 52 Notebook 11.
71 Harold Edgerton Papers, Box 52 Notebook 11.
the setup he uses, in a microphone is placed in front of the target and the sound wave created by
the bullet is used to trigger the flash. Clear photographs showing the instant that the shell pierces
the armor result (Figure 32). Thus, Edgerton’s work on increasing the accuracy of the triggering
of his flash for this wartime application resulted in the development of a technique, microphone
triggering that is still in use today.

As a result of the success of this work with shells and armor, the Army also asked Edgerton to photograph
explosions to characterize their effects. This application also placed a great premium on the
accuracy of the triggering, as the nature of an explosion meant that the photographer would only
have one chance to capture the instant of explosion. For instance, in a test he conducted at the Army
testing facility in Aberdeen, Virginia on April 18, 1943,73 Edgerton overestimated the time it took for a
bomb to actually explode after it has been triggered. As a result, he miscalibrated his flash and was left
with pictures of the bomb before it actually exploded. Edgerton worked throughout the war on circuits and
techniques, which allowed him to increase the accuracy of his triggering mechanisms. This work
laid the groundwork for one of his main post-war applications of his existing technology: photography
of atomic explosions. Thus, the example of ballistics photography is an example of a pre-war
application, high-speed photography, that found a new, unanticipated application due to the
needs of the Army during the war and that remained a continuing area of work for Edgerton after
the war.

AIRCRAFT BEACONS

Edgerton’s close collaboration with the Army Air Corps and his creative problem-solving nature
also provided a springboard for the development of other non-photographic novel applications of
strobe technology as a result of wartime needs. The growing success of the aerial flash program
drew the attention of the army, and he was encouraged to find additional applications for his
original strobe technology. Later in the war, in 1944, Expert Consultant to the Secretary of War,
Edward Bowles wrote:

For some time you have been engaged in research on and the development of this
equipment, which has now reached a stage at which it is adapted for operational military use… While you are engaged in this project, it is desired that you take every opportunity
to examine into other possible applications of this equipment.

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72 Harold Edgerton Papers, Box 52 Notebook 14.
73 Harold Edgerton Papers, Box 52 Notebook 14.
74 Harold Edgerton Papers, Box 80 Folder 2.
One such application that Edgerton developed during the war was the aircraft landing beacon. During his time in England conducting tests of the aerial flash unit, Edgerton noticed that pilots returning from nighttime test flights often had a difficult time finding their landing field, due to both the darkness and the overcast skies common to the area. The need became apparent for a system of high-intensity beacons to allow pilots returning from nighttime reconnaissance missions to identify their home airfields. Edgerton described the problem in a post-war description he wrote of his wartime work in his autobiography:

I was at… Chalgrove airfield, where a night photo squadron was based… Often there was a problem to get them home, due to atmospheric conditions. For example, on clear nights, a heavy ground fog often appeared which covered the airfields. On other nights, the cloud layers were very low. A standard rotation beam airport beacon was of some help, but inadequate for the job.

Edgerton felt that his aerial flash unit could be used for this purpose, as a light that could illuminate a target from miles in the sky could also be turned around and be used to signal an airport’s positions from miles away. Showing his creativity and hands-on approach, Edgerton quickly jury-rigged one of his aerial flash units for use as a landing beacon. He reasoned that a technology that could illuminate target on the ground from miles in the sky could also be used to indicate the position of a airport to pilots flying in from miles away. While the illumination provided by this system was more than adequate for the application, Edgerton found as he did additional work on the system that the primary concern in this application was not the maximization of flash intensity, as it was in the aerial strobe project. Instead, he found that the main objective was to maximize the longevity of the equipment and minimize the power consumption of the lamp, as the beacon would need to continually flash for extended periods. As such, use of the aerial flash was not ideal for this application, as the system discharged large amounts of energy in each flash, which both consumed large amounts of power and caused the equipment used to deteriorate quickly.

Edgerton next proposed a system whereby a number of smaller strobe lamps would be arranged in a circle, pointed outwards, and triggered in series, one after another. Such a system had the effect of closely approximating the coverage of the single large, power-consuming aerial flash lamp while consuming only a fraction of the power. Figure 34 shows one of Edgerton’s initial drawings of such a system. As this system proved most efficient and durable, the Army eventually commissioned Edgerton to produce beacons in this style, using three smaller lamps. Beacons of this type are still in use in airports today. The aircraft beacon is one of the first examples of the use of strobe

Figure 34: Edgerton’s Innovative Design for Aircraft Landing Beacons

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75 Harold Edgerton Papers, Box 1 Folder 8.
76 Harold Edgerton Papers, Box 52 Notebook 13.
technology in non-photographic, non-imaging applications. Thus, Edgerton’s involvement in the war with the aerial flash afforded him opportunities to apply his technology in ways that he did not envision before the war.

**EDGERTON’S WORKING STYLE DURING THE WAR**

At the end of the war period, the Secretary of War requested Edgerton to investigate further applications of his technology, indicating that the armed forces were pleased with Edgerton's work. He successfully designed and deployed six models of electronic flash units for aerial photography; however, his technical ability was not the only factor in his success in this project. His working style which can be observed in his activities before World War II, specifically the ways in which he conducted his research and presented his work to others, contributed to his success.

**CONDUCTING RESEARCH**

Edgerton was very diligent in the way he put his ideas on paper and into graphical representation. Like his lab notebooks in the pre-war era, Edgerton consistently records information about the experiments that he carries out for the Air Force. This is needed to both determine his next steps and facilitate his regular reports to the army officers. Many of Edgerton’s documents from the war times found in the MIT Archives were in forms of correspondence between Edgerton and people in the field or people back at MIT who helped him with his work. Figure 35 shows part of a letter Edgerton wrote to Grier during test flights at Wright Field in summer of 1942. The letter relates the events that happened during the tests as well as technical information. Similar to his pre-war lab books where he jotted down ideas as they came to him, he uses these correspondences to scribble rough circuits or system diagrams. In this particular example, he sends Grier a piece to work on before his arrival at MIT to speed up the project.

One significant change in the way Edgerton carried out his research was the setting where he did his experiments. Prior to war, he was dealing with small-scale projects where either, he would prepare up his equipment and setting or he would be operating a mobile stroboscope unit into another closed setting like a manufacturing plant, or a machine room. Figure 36 shows an

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77 Harold Edgerton Papers, Box 78 Folder 1.
example of a lab set up where Edgerton could control all the parameters that could influence the effectiveness of his equipment. In such a situation, the experiment can be repeated many times until the desired results are obtained. When compared to the air force bases where he did his work, this is a big change. He was in an environment where he did not have access to resources of his lab. Goddard recalled when Edgerton arrived in Chalgrove, Britain with some reconnaissance pilots:

He was a great improviser so instead of beefing to the Commanding Officer, he immediately went to the base dump and scoured a number of large wooden airplane and glider crates. In a few days, he and his men were sitting in a comfortably equipped office containing stoves, desks, chairs, filing cases, and a nanny! This was typical of the Doctor for he was a man of action and always got the job done with distinction.

The men at Chalgrove marveled at his unbouding energy as they saw him in coveralls clinging in and out of airplanes and dashing to his machine shop and about the field on personnel training schedules.

His resourcefulness often also allowed him to make fast progress despite difficulties. When a shipment of flash tubes arrived broken, he went to Siemens Company in England and asked them to manufacture some xenon bulbs. As xenon was not readily available in the UK, Siemens turned him down. Edgerton managed to obtain 3 liters of xenon and returned to the company two days later, much to the surprise of Siemens' president. Yet, this was a different operating mode than he had at MIT, where he could walk down the hall to the spare parts room and browse and get whatever he needed.

Another challenge of working in the field was testing. Experimentation of his equipment required the installation in a plane, flying the plane and testing the quality. This process took a long time, and could only be repeated at night. Edgerton was present and onboard inmost of these trial flights. Each flight test would require installing the equipment in the plane, take-off, taking of the pictures and recording of the parameters, landing and deinstallation. It was a time consuming and expensive process unlike any in lab tests. Besides, reflecting how hard it is to conduct tests and have them run smoothly each time, Edgerton’s letters have a tone of accomplishment in each. Each letter shows a modification or an improvement that he designs to better his technology. This shows how passionate and excited he was about his work and involvement with the war effort. John Burchard in his accounts of MIT in WWII says:

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79 Goddard,329-30
80 "Edgerton, Killian, Duncan 3 April 1978" [Audio tape] Harold Edgerton Papers, Box 143.
The important thing to remember is that these men were ready - that they did not wave magic wands - and that the reason that they were ready was that as free men in a free institution they had been permitted to proceed on projects which caught their imagination without any insistence on the part of their superiors that they be able to forecast a pay-off.

Edgerton’s excitement about his work is also observed through the amount of thinking he puts into his products and their perception by others.

PRESENTING HIS WORK

Working on photography and motion pictures before the war, Edgerton had a vehicle for demonstrating his work to others. His audience in the pre-war years included people from academia, clients from industry and manufacturing companies who built under Edgerton’s patents. However, none of these demonstrations were at as great a scale as those he had during the war.

Although Edgerton had Goddard’s support, he had to demonstrate his technology to the decision makers and potential users of the equipment. The first demonstrations came as he developed the unit and flew it over MIT in 1941. Figure 37 shows a photograph of the Institute.

Edgerton also arranged a dramatic public demonstration of his technology for British military personnel using Stonehenge as his subject. One can also see this type of heterogeneous engineering demonstrated in Thomas Edison at his Menlo Park Laboratory. Thomas Edison used his Menlo Park demonstration to unveil his electric lighting system to the public and generate enthusiasm. Similarly, Edgerton picked a prominent British landmark to influence the officers to use and support the electronic flash. Edgerton recalled in an interview:

Six more senior officers and me were the decision makers. I was the only defender of the xenon flash… (I wanted to show them what it could do. No pilot wanted to fly for me.) They thought they did not have a target. At conclusion, we suggested that let’s get a target. And they got excited. I said the Stonehenge. Worked well.

81 Burchard, 204.
82 Harold Edgerton Papers, Box 77 Folder 2.
83 Israel, p. 187.
84 “Edgerton, Killian, Duncan 3 April 1978"
This demonstration was successful in building enthusiasm and support for his electronic flash equipment. However, Edgerton’s job was not done after convincing the decision makers to allocate resources for nighttime flash photography. He also had to gain the favor of the pilots and technicians who would be using the equipment.

Working with the pilots, Edgerton had to overcome some psychological obstacles, “My biggest problem was the fighter pilots. They came there to fly and fight. They did not want to have anything to do with flying a camera around.” Edgerton soon figured out how to motivate them. When he discovered a nudist camp in England, he kept the coordinates secret, and only the few pilots that flew for him learned the location.

Edgerton also used his documentation of the equipment, and the actual artifacts to gain the interest of the men in the field. Edgerton was allowed to train the soldiers only once. Therefore, at all times, his units were accompanied by documentation to train the people. The first page of an operating manual about D-2 usage in A-20’s he sent to the army contains a picture of an officer holding the control.

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“Edgerton, Killian, Duncan 3 April 1978"
unit, showing that his device is manageable (see Figure 39). The flash is not installed and depicts the device abstracted from the complications of the plane and connections.

The manual continues by introducing the objectives of the technology. Whenever the army asked him to build a flash unit, he would be told the desired height of operation. Moreover, when tests were conducted with these units, and recordings were made, the most consistent information recorded by the pilots is the altitude of flight. Edgerton, aware of this concern about height, mentions that exact information in the first sentence of his product manual: “…highly effective for military purposes at altitudes up to 10,000 ft…”

He continues his introduction with a very social approach to the usability of the device. Edgerton uses this kind of “soft” approach in many situations, and he is also aiming to kindle some ease in the operator that the device is simple to use:

This device produces, at the touch of a button under the control of the pilot, lightening-like flashes of intense actinic value for night, dusk, or dawn aerial reconnaissance.

Next he touches on issues that the pilots are most concerned with, their security while flying and flashing the system and questions around being an open target to the enemy:

The new technique promises greater chance of avoiding antiaircraft defenses… The flash is virtually silent… The brevity of the flash gives the enemy little advance notice… There is no explosive hazard.

Edgerton then adds the points around the ease of use of the system:

Once the apparatus is synchronized, it requires no further adjustment. The equipment has been designed to be installed or removed easily.

![Figure 40: Aerial Electronic Flash Control Unit](image)

The control unit, shown in Figure 40, is operated with one button only and the control settings are extremely simple and self-explanatory. This is ideal for a pilot to use especially when the rest of the plane equipment he needs to operate is extremely complex. He uses the black box idea to abstract the pilot from all the connections and complications of the actual setup.

The rest of the operating manual is geared towards technicians who will be maintaining and fixing the equipment when Edgerton is not with them. At this level, Edgerton provides a semi-detailed blue print, shown in Figure 20. He proceeds to present a cookbook of the

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88 Harold Edgerton Papers, Box 78 Folder 8.
89 Harold Edgerton Papers, Box 78 Folder 6.
installation process with step-by-step instructions, “…emergency bomb release should be checked. Two other cables must be installed… install a No. 17 flashtube before lifting the unit into the airplane. Hold the tube vertically…”

Following the instructions, Edgerton includes detailed descriptions of the power supply, the flash bulb with details that are needed to fix or disassemble the unit. These three main sections of the manual form a document where the level of details are very well balanced and organized. This shows how much Edgerton thought about making his unit attractive in terms of usability and operation friendly.

In addition to the operating manual, Edgerton also uses graphic aids and photographs to ease the explanation of the technology in his correspondences and documents. Figure 41 shows a very high-level installation of the equipment and basic specifications. This document is geared towards the pilots who would like to understand the modifications made to the plane or senior officers who would like to get a general idea and associate the terminology with the actual equipment.

INTERACTION WITH PEOPLE

Even though Edgerton was very successful in educating through his documents, his desire for hands-on teaching lead him to arrange for a group of enlisted men to come to MIT for training in flash technology during August of 1943. Not only did Edgerton teach them in a better-equipped environment but also he was also able to get to know them better during the training. In his talk with John Duncan, Edgerton recalls the extraordinary experience during the war, “I still get letters from these fellows. We took one guy from South Carolina skating, he has never seen ice before.”

In addition to the stories Edgerton narrates, excerpts and pictures in his lab notebooks display his enthusiasm,

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90 Description and Operating Manual Lamp-Electric Flash Type D-2 For Use in an A-20 Airplane December, 1943. Harold Edgerton Papers, Box 77 Folder 4.
91 Harold Edgerton Papers, Box 137.
92 “Edgerton, Killian, Duncan 3 April 1978"
about being a part of the Army and the war effort. In one of his lab notebooks, he describes the prelude to a reconnaissance mission. He lists all the military personnel involved and their roles in the mission and the entry contains little technical writing. Many of the accounts in his lab notebook during this period contain narration of the day’s events. This highlights his interest in people and the nature of his relationships. This interest is also evident in the numerous pictures of co-workers, military officers, and students pasted in his notebooks (see Figure 42, HEE standing in the middle holding a large reflector). His positive attitude and passion for his work are main thrusts to his success during the war.

As the war ended, he resumed his role as a professor at MIT, asking the army for aerial units to be used for education losing no time to get back to his passion for teaching:

I should like to recommend that a complete D-5 unit be permanently assigned to MIT for use in educational and experimental work in night photography... There is one K-19 camera, two intervalometers, two spare condenser banks for D-2, and several other small items here at MIT... I suggest that this material likewise be permanently assigned to the institute for the educational and development projects, which will undoubtedly come up in the future.

Harold Edgerton enjoyed his work and also the people with whom he worked. From the way he conducted research to how he presented his work to actually working with people Edgerton continued his style from his pre-war years. His working style during the war definitely contributed to his overall success.

With the end of World War II in 1945, Edgerton ended his involvement with his main wartime project, the nighttime aerial flash. However, the work he did during the war had the effect of increasing the magnitude and scale of his technology, broadening the range of applications that he applied it to, and further expanding and developing the methods with which he did his work. In addition, his wartime work in many ways shaped and defined over the trajectory of much of his work after the war, especially by creating networks that stuck with Doc in the post-war era and shaped a significant part of his work till 1963.

**POST-WAR**

Most of the influences and changes traced in Edgerton’s work up till this point involve the same basic technology – the electronic flash. From the early milk drop photographs to the aircraft beacon, all the applications involved the short and powerful (and sometimes periodic) discharge

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93 Harold Edgerton Papers, Box 53 Notebook 15, p. 6.
94 Wildes, p. 150.
95 Harold Edgerton Papers, Box 78 Folder 6.
of electricity through a gas tube, causing a bright illumination. The period of time towards the end of the war and following the war represents a significant deviation from this model. He delved into applications that did not necessarily involve commercial, artistic, or observational photography or illumination. Some of the more notable applications that sprung from his technology in the 10 to 15 years after the war were:

- Firing systems for nuclear bombs,
- Methods for photographing nuclear explosions, and
- Side-scan sonar for underwater exploration.

In 1947, Edgerton, Germeshausen, and Grier formed EG&G (named from the first letter of each man's last name). EG&G became a leading government contractor for testing and designing nuclear weapons. The work he did at EG&G was unlike the work he had prior to the war. It is thus a pertinent example of a new research path of Edgerton’s.

**EDGERTON, GERMESHAUSEN, & GRIER, INC.**

**EG&G BEGINNINGS**

In the early 1930's, Edgerton, Germeshausen, and Grier worked together to solve problems in industry using the stroboscope. Grier recalls the division of labor in early days of the partnership:

> [The partnership] was an effort to achieve, as a group, more than we could as individuals. Doc, in particular, was a full time professor and trying to promote the stroboscope essentially in his spare time. Germeshausen was the researcher who undertook the actual development of tubes that could be used over and over again, and my role I guess, was the putting together of equipment we could use.

Interestingly, their roles seem analogous to positions in a modern corporation. Edgerton was effectively the Chief Technical Officer, Germeshausen was the Chief Engineer, and Grier was the Chief Executive. Grier even mentions that Mrs. Edgerton was the “Chief Financial Officer” since she ran the accounts. They found agreement in division of labor and their talents were complimentary. Bernard O’Keefe, a navy officer, who also worked with the group at EG&G, recalls the effectiveness of their union:

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97 Wildes, p. 152.
98 “EG&G” [Audio Tape] Harold Edgerton Papers, Box 143.
They simply pooled their resources and worked together on whatever consulting or measurement problem came along. Throughout the thirties they prospered as their abilities became more widely known.

EG&G AND WORLD WAR II

According to Germeshausen, the war “permanently changed the direction of the partnership.” When the U.S. entered the war in December 1941, Edgerton, Germeshausen, and Grier were assigned to different projects. Edgerton spent most of his time developing systems for nighttime aerial reconnaissance. Germeshausen went to the MIT Radiation Laboratory, which dealt mostly with wartime radar development. There he developed a series of gas switching tubes for radar modulation. Grier went on to work at Draper Lab with the famous Stark Draper. However, both Grier and Germeshausen maintained a limited involvement with the nighttime aerial reconnaissance program. In particular, Grier was working at Raytheon on the construction of the aerial reconnaissance units. Grier’s work at Raytheon, ironically, set the tone for the direction of the partnership in the post-war era.

THE RAYTHEON CONNECTION

Los Alamos Scientific Laboratory, the U.S. headquarters for nuclear weapons research, needed high-energy capacitor banks, but they did not have time to develop their own. These capacitor banks were to be employed in the design of a firing set to trigger the explosion of an atomic bomb. Raytheon was building the firing sets, and was also making capacitors for Edgerton’s aerial photography project. Robert J. Oppenheimer, Los Alamos’ director, realized these capacitors would suit his project's needs. Because of Grier’s connection to Raytheon, Oppenheimer hired him as a consultant and commandeered the plant to build capacitor banks for Los Alamos. The schedule was so tight that they did their first full-scale test of the system at Tinian Island in the Marianas the day before it was used at Nagasaki.

The network between the night aerial photography project, Raytheon and Los Alamos that was established got Edgerton and his apprentices involved in the Manhattan project (Figure 46). They were able to carve a niche for themselves in the development of firing sets. This proved pivotal in the eventual formation of EG&G, and subsequently, in expanding the scope of Edgerton’s work.

FORMATION OF EG&G, INC.

After the war, the Atomic Energy Commission decided that the country had to maintain substantial research in nuclear technology. Los Alamos let a contract to MIT to continue firing set development with the three researchers. By this time,
the three of them had been working on firing set development for a while and had become prominent players in the nuclear world. Edgerton, Germeshausen, and Grier were therefore consulting again, now in the nuclear test and design business.

The formation of EG&G was influenced by a shift in MIT policy and by the Atomic Energy Commission. O'Keefe states:

James Killian, the MIT president, was not happy about the size of the project, since the Institute was going through one of its periodic attempts to divest itself of government contracts.101 According to John Burchard, this was because MIT was trying to re-deploy for peace after WWII. He stressed that since MIT had taken more active a role in the war than any other institution in the U.S., MIT staff was “more completely diverted from education.”102 Therefore the Institute took a harsh stance against military work immediately after the war. Nevertheless, since the Atomic Energy Commission (AEC) required their services, Edgerton, Germeshausen, and Grier had no choice but to move off campus to continue the work. EG&G incorporated in 1947:

At the end of the war MIT decided against having such highly classified work on campus. Since the Atomic Energy Commission wanted the work continued, the three partners formed a corporation and became a prime contractor to the AEC.103

Thus, it is evident that the impetus for the partnership's revival and subsequent officiation primarily sprung from an interplay between MIT’s attitude to military research and the government's nuclear effort, both directly related to World War II.

After incorporation and free from MIT’s pressure, the partners were free to undertake any government work they pleased. EG&G subsequently was asked to build a special firing set for a series of full-scale weapons tests that were to be undertaken at Eniwetok in the Marshall Islands in 1951. They were also tasked to deliver a network of timing signals for the experimenters who would be participating. This eventually became a big responsibility, requiring millions of dollars of submarine cable and instrumentation. The government then added neutron multiplication measurements and technical photography to their agenda and the corporation expanded rapidly.

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101 Ibid.
102 Burchard, p. 313
103 Wildes, 151
104 Edgerton, Moments of Vision, p. 169.
EG&G TODAY

Today, the U.S. government is still one of EG&G’s most important customers. The company's website states that it is a “leading provider of management and technical services to agencies of the U.S. government and commercial businesses.” It seems, however, that the bulk of its projects remain government-related. EG&G consists of four operational divisions:

- Defense Systems and Services
- Logistics
- Ranges & Installation
- Science & Engineering

Major customers include NASA, the Secret Service and The Departments of Defense, Energy, Transportation and Justice. Major commercial clients include Boeing and Lockheed Martin, which are also highly defense-related. EG&G’s two most recent contracts were for the US Air Force (estimated at $72 million) and the Naval Systems Air command, signifying their strong links to the military. What was once a small company solely in charge of nuclear triggering matured into a multi-million dollar corporation that specializes in a multitude of disciplines.

INFLUENCE ON EDGERTON’S WORK

The war brought a new dimension to Edgerton's research. Before the war he used his technology for high-speed photography and industrial consulting. These consulting projects were funded by private firms whose interest was in improving processes in order to increase profits. During and immediately after the war, however, the government became a major client of Edgerton, and their interest was primarily National Security. This resulted in his work taking on two separate trajectories. He continued his work in the electronic flash after the war, but EG&G also became a significant part of his research life.

CONCLUSION

WAR’S INFLUENCE IS COMPLEX

As Carl Von Clausewitz aptly put it, “War is a continuation of politics by other means.” This definition sounds simple and straightforward enough. However, huge socio-political implications accompany a state of war. The multi-faceted nature of war influences every individual in a myriad of fashions. Edgerton has been shown to be no exception.

CHANGE OF WORK ENVIRONMENT

The war made aerial reconnaissance a strategic requirement for the Allies. Edgerton’s nighttime aerial flash technology was an effective tactical means of meeting this requirement. This is precisely why Major Goddard first approached him, and how Edgerton eventually got involved in the war. He was “extracted” from his familiar, calm laboratory setting and taken into the battlefields in England and Italy, where conditions were uncontrolled and tumultuous. This represented a huge change in work environment.

105 http://www.egginc.com/html
**INCREASE IN SCALE AND MAGNITUDE**

Having become involved in the war, the most immediate effect Edgerton’s work experienced from the war was new technical requirements. Power was now the name of the game. Prior to the war, the aim of Edgerton’s strobe photography was to capture motions which occurred too fast to be observable to the naked eye. His chief concerns were accuracy of triggering and flash duration. Aerial reconnaissance, however, called for flashes 100 times more powerful than those before the war. The flashes had to sufficiently illuminate terrain thousands of feet away from the plane as opposed to a milk drop inches away from the camera. Thus, power, and consequently weight, of his flash units increased tremendously as a direct result of the war.

**BROADENING OF APPLICATIONS**

Edgerton’s newly formed link with the military also gave rise to new applications for his electronic strobe. The nighttime aerial strobe was the first in a number of wartime applications. Other examples included ballistics photography and aircraft beacons. The aerial selectronic flash may also have led to his development of the side-scan sonar. Hence, an obvious effect of the war was the ensuing broadening of applications.

**NEW AREAS OF RESEARCH**

The war also had an indirect, but not insignificant, influence on Edgerton’s work in the form of the relationships it engendered. The war formed a network between parties and organizations that began working together for the same cause. The aerial strobe project and Los Alamos were two separate entities that linked up because of their respective relationships with Raytheon. It was because of this connection that Los Alamos was able to tap the expertise of Edgerton and his associates. These relationships represented the beginning of a new research realm for Edgerton. A combination of MIT’s anti-military attitude and National Security Policy immediately after the war also facilitated the founding of EG&G, which was to undertake this new dimension of research and eventually become a major part of Edgerton’s legacy.

**A KEY FORCE IN EDGERTON’S LIFE**

In conclusion, war is a unique state of affairs that impacts all aspects of society. World War II’s influence on Edgerton’s work cannot be traced to one particular line or trajectory. The war changed everything from his work environment to the actual technology he researched. There is no doubt however, that it was a pivotal force in the life of the Harold E. Edgerton.
HOW WE CONDUCTED THE RESEARCH

A significant portion of our research was conducted at the MIT archives, where we examined all of Edgerton’s notebooks and materials that he had compiled and donated to MIT. The most challenging aspect of a project history on Edgerton is being able to focus on a single specific topic. Edgerton had such a prolific career that it is hard to choose a single path to study. By searching through these primary sources we were able to narrow our topic to events surrounding World War II, which the MIT Archives had well documented. We also interviewed Edgerton’s student, Professor Kim Vandiver, and Dr. James Bales of the Strobe Lab. They gave us insight on who Edgerton was on a personal level and also shed light on the technical side of Edgerton’s tools. All of the equipment demonstrated during the presentation were borrowed from the Strobe Alley.

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Please visit "Edgerton in World War II" online at:

APPENDIX A: TIMELINE