SALVE REGINA UNIVERSITY

SENSING A CONTROL PROBLEM?

AUTONOMOUS UNMANNED COMBAT AIR SYSTEMS AND HUMAN CONTROL

A DISSERTATION SUBMITTED TO

THE FACULTY OF THE HUMANITIES PROGRAM

IN CANDIDACY FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

BY

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NEWPORT, RHODE ISLAND

MAY 2016

SALVE REGINA UNIVERSITY

GRADUATE STUDIES

This dissertation of Shawn A. Kalis, entitled "Sensing a Control Problem? Autonomous Unmanned Combat Air Systems and Human Control," submitted to the Ph.D. Program in partial fulfillment of the requirements for the degree of Doctor of Philosophy at Salve Regina University, has been read and approved by the following individuals:

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DEDICATION

To my wife Dawn and the Sensational Seven,
for the constant motivation to “keep walking!”

In memory of Captain Eric Shaw, Ph.D., USCG
1957-2016
My advisor, teacher, mentor, and brother in arms.

ABSTRACT

Military unmanned aerial system technology, remote sensing systems, and artificial intelligence all play critical roles in creating the possibility for completely autonomous unmanned combat air systems. The integration of these technologies is significantly affecting the human-technology relationship on the battlefield. Not only are these technologies decreasing the level of direct human interaction in warfare, they are also significantly increasing the physical distance between humans and machines. This increased distance raises questions regarding the ability of humanity to maintain control over autonomous weapons systems. The development of these autonomous technologies appears to validate the position of traditional technological determinists such as Martin Heidegger and Jacques Ellul, as well as contemporary thinkers such as Raymond Kurzweil, Stephen Hawking, and Elon Musk, who propose that artificial intelligence technology is not a thing that can be controlled, but rather an influence or force that transcends human ability to maintain control over, and that any sense of control is merely an illusion. This work defends the thesis that while integrated technologies are significantly contributing to the evolution of fully autonomous unmanned combat air systems, the existence and application of these technologies do not by default support the hard technological deterministic view that technology is a force or influence beyond human control, nor does the evolution of such technologies necessarily threaten humanity's ability to maintain control.

Chapter One: Introduction

> *"The emotional and moral disengagement of the cubicle warrior may increase in the future, due to a noticeable shift from controlling to monitoring."*
>
> — Lamber Royakkers and Rinie van Est

This dissertation defends the thesis that while the integration or blending of unmanned aircraft system technology, remote sensing systems, and artificial intelligence (AI) play a critical role in the evolution of the U.S. military's autonomous unmanned combat air system (UCAS), the existence and application of these technologies do not necessarily support a technological deterministic view that humanity's ability to maintain control is threatened or transcended. Instead, the findings, with regards to the particular issue of the autonomous UCAS, will reveal that they run counter to the traditional hard technological determinist claims that technology is moving beyond human control.

Technology evolving beyond human control and threatening to convert humans from active participants to passive recipients has been a concern for humans since the Luddites of the industrial revolution. The theme of technology taking control is popular in many genres of literature and film. In modern times, Stanley Kubrick's famous 1968 film *2001: A Space Odyssey*, inspired by Arthur C. Clarke's 1948 short story, "The Sentinel," poignantly introduced the topic of technology's challenge to human control with the HAL 9000, a heuristically programmed algorithmic computer that has artificial intelligence and acts as the antagonist in the story. In D.J. Caruso's 2008 film *Eagle Eye,* the Autonomous Reconnaissance Intelligence Integration Analyst (ARIAA) super-computer determines that humans are no longer capable of making correct decisions; therefore, it breaks away from human control to embark on a mission to protect the spirit of the Declaration of Independence by attempting to eliminate the executive branch of the U.S. government. One particular science fiction film extremely relevant to this study—because it depicts the struggle for control between humanity and technology that appears to be coming to fruition today—is Rob Cohen's 2005 film *Stealth*. The movie focuses on a runaway autonomous unmanned combat air vehicle (UCAV) called "EDI," short for the Extreme Deep Invader. EDI contains multiple remote sensing systems and is completely controlled by an artificial intelligence system with quantum processing and a neural network. The UCAS has the capability to outperform human pilots and, in the course of the film, develops self-awareness and refuses to obey human commands, becoming an adversary to human pilots. Film director Cohen, reflecting on the technology-humanity relationship, stated that he began to realize that "within the story, it contained one of the great issues of our time . . . that as technology develops to the point of independence, who is in control and what are the possibilities, and especially as applied to war . . . ?" (Fischer 2005).

On May 14, 2013, off the coast of Virginia, the Northrop Grumman Corporation and the crew of the aircraft carrier *USS George H.W. Bush* (CVN-77) brought Cohen's science fiction film one step closer to reality. On that date the Northrop Grumman X-47B Unmanned Combat Air System Demonstrator successfully completed its first autonomous catapult launch as part of the U.S. Navy's UCAS Carrier Demonstration (UCAS-D) program (Vergakis, 2013). Three days later this event was followed by the first carrier-based touch-and-go landings by an autonomous UAV, and on April 22, 2015, the X-47B conducted the first ever autonomous aerial refueling (Northrop Grumman

2015, 1). What was once purely science fiction appears to be developing into reality, and the questions still remain: "Who is in control?" and, "What are the possibilities?"

What Does It Mean to Be Human in the Age of Technology?

"It has become appallingly obvious that our technology has exceeded our humanity."
— Albert Einstein

The motivation for this examination is the desire to discover the impact that a specific human-technology relationship has on society and culture, and to apply the findings to help provide one of many possible answers to the question "What does it mean to be human in an age of technology?" This inquiry focuses on the element of control in the human-technology relationship, and the impact that the issue of control has on this relationship. Control has been a consistent theme in the evolution of humanity, as evidenced in the history of mankind's struggle to control one another, the elements, the environment, and even one's self. Examining the issue of control as it relates to the human-technology relationship is vital to understanding what it means to be human in an age of technology.

With this broad question in mind, this study will examine the technologies used in developing autonomous aerial weapon systems, like the X-47B UCAS, in order to address the human-technology control issue. Through an examination of the human-technology interface in the context of 21st-century warfare and unmanned weapon systems development, specifically the UCAS, this dissertation helps determine the impact that this evolving technology has on the human operator's ability to maintain control of the technology. Using the U.S. military's development of the UCAS as a case study, this work specifically examines the impact of the integrated technologies of the unmanned aircraft system, the remote sensing system, and AI technologies on the evolution of the UCAS. The impact of these integrated technologies on the human operator is examined to determine the level of influence on the operator's ability to maintain control of the technology. The specific question addressed is: *"Do these integrated technologies, in the specific form of a UCAS, support a technological determinist argument that humans are losing control, or have no control, over the technology?"*

There is a broad spectrum of viewpoints regarding the relationship between humanity and technology in the realm of control. One end of the spectrum asserts that technology is and always will be under the control of human beings and society; this falls within the broader philosophical category of social determinism. This position is held by philosophers such as Don Ihde, Jurgen Habermas, and Leila Green. The opposite end of the spectrum affirms that humans never had, and never will have, the ability to control technology; this position lies within the realm of the philosophical position of technological determinism. Philosophers such as Martin Heidegger, Jacques Ellul, and Raymond Kurzweil adhere to this view. Between both extremes lies a wide variety of opinions and positions on the influences of technology on humanity, and vice versa. Philosophers such as Langdon Winner, John McDermott, and Robert Heilbroner espouse varying views of the different degrees that technology and humanity influence each other. (This spectrum of viewpoints on the relationship between humanity, technology, and control will be addressed in greater detail in chapter two.) At the heart of the issue between the various human-technology relationship spheres is the question of control.

This study examines the hard technological deterministic position that the evolution of autonomous technology is an example of a force or influence that is beyond humanity's ability to control. *The position advanced in this dissertation is from a social deterministic view, that technology, while becoming more complex and autonomous, is a human creation, a tool that remains under human control.* While it is true that the unmanned aircraft, remote sensing, and AI integrated technologies are making indispensable contributions to the creation of autonomous UCASs, they do not appear to support the technological determinist's view that autonomous UCAS technology is actually evolving beyond human control.

The findings of this dissertation may be directly applied to discussions and initiatives addressing current and future military, political, and social implications of the use of autonomous unmanned weapon systems in modern warfare. The findings not only apply to current moral questions concerning the control of autonomous military technology, but also apply to U.S. policy questions concerning the use of such systems in the future. In addition, the findings of this dissertation may also be used by U.S. senior-level policy and military decision-makers who are directly involved with developing autonomous military technologies, providing information that can encourage them to keep the humanity-technology relationship in consideration in order "to work for a world that is harmonious, just, and merciful."[1]

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[1] In addition to encouraging students to seek wisdom and promote universal justice, the Salve Regina University mission statement encourages students "to work for a world that is harmonious, just, and merciful" (Salve Regina 2016).

Key Terms Defined

"Nothing has meaning without context."

— Joe Aldrich

In order to examine the issue of integrated unmanned aircraft, remote sensing, and AI technologies and their influence on humanity's ability to maintain control, a few key terms must be defined: *technology*, *unmanned aircraft system*, *remote sensing*, *artificial intelligence*, and *autonomy*. While there are many technical terms used throughout the course of this study, some of these terms are more problematic than others in that there is less unified agreement regarding their definition.

Technology

According to the Oxford English Dictionary, the word *technology* originates from the Greek τεχνολογία (technology), a combination of two words: τέχνη (téchnē) and -λογία (-logia). The meaning of τέχνη is the subject of much discourse and debate in the field of the philosophy of technology; however, in the context of the English vernacular usage of technology, most dictionaries and encyclopedias define τέχνη (téchnē) as art, skill, craft, or the way in which something is gained.[2] The word -λογία (-logía), is less debated in the field, and has the accepted meaning of "study of." Like many terms used and debated among scientists and philosophers, the word *technology* is defined in different ways. Cultural theorist Paul Virilio describes technology as a mystery in *Pure War*, stating that "any examination of technology immediately gives rise to

[2] The more complex definitions of τέχνη as articulated by philosophers of technology such as Martin Heidegger and Jacques Ellul, and the associated issues related to technological autonomy, will be addressed in later chapters.

misunderstandings" (Virilio 2008, 37). Stanford Professor Stephen J. Kline stated that, "In the late 20th century, there is only one thing most people agree about concerning technology—it is important" (Kline 1985, 215). However, despite the ambiguities and misunderstandings, there are enough commonalities that surface among theorists and practitioners that allow for a working definition sufficient for the purposes of this study. Economist John Kenneth Galbraith includes systemization and science in his definition in *The New Industrial State,* defining technology as "the systematic application of scientific or other organized knowledge to practical tasks" (Galbraith 2007, 14). Technology philosopher Carl Mitcham, in his book *Thinking Through Technology: The Path Between Engineering and Technology*, gives the simple definition of technology as "making and using artifacts," and then throughout the rest of his treatise demonstrates the "narrow and broad senses" of the term as used by engineers and humanities scholars (Mitcham 1994, 1-15). Philosophers Mary Tiles and Hans Oberdiek, in *Living in a Technological Culture*, include "ways of doing and making which are both affected by and affect ways of thinking" in their definition; they insist that artifacts, techniques, roles, and practical knowledge be included in the definition (Tiles 1995, 10). In *Science and Technology in World History*, History of Science professors James McClellan and Harold Dorn underscore the practical aspect of technology but separate it from science, which they state is "more theoretical and philosophical" (McClellan 2006, 47-54). Science and Technology philosopher Don Ihde emphatically states that "definitions are not neutral," and therefore gives technology a "middle-sized" definition, insisting that the definition contain three components:

> First, we shall insist that a technology must have some concrete component, some material element, to count as technology. And, second, a technology must enter into some set of praxes—'uses'—which humans may make of these components. And third, we shall take as part of the definition, a relation between the technologies and the humans who use, design, make, or modify the technologies in question. (Ihde 1993, 47)

The important point of Ihde's definition is that in addition to the application of knowledge in creating an artifact for practical purposes, there is a relationship between humanity and technology. Many definitions include Ihde's components, emphasizing the human-technology interaction in the application of science or knowledge to create a particular capability for a specific, usually practical, purpose. Therefore, assuming that there will be a relationship of some kind between the human and the technology created, the definition of technology used for this study is as follows: *Technology is the application of knowledge that produces an artifact or provides a capability for practical purposes.* The different philosophical points of view taken on the relationship between technology and humanity, especially as it is applied to the aspect of technological autonomy and control, will be discussed in more detail later in the study.

Unmanned Aircraft System

Among the many different types of unmanned military technologies, the pilotless aircraft has played a significant role, primarily because of its successes in the U.S. Global War on Terrorism and Overseas Contingency Operations in Iraq and Afghanistan. The official term used by the Department of Defense when referring to a craft in the air without a pilot onboard is unmanned aircraft (UA), which it defines as "an aircraft that does not carry a human operator and is capable of flight with or without human remote control" (U.S. Department of Defense Joint Publication (JP) 1-02 2010, 252). All of the associated technology needed to operate a UA is termed an Unmanned Aircraft System (UAS), which is officially defined as "that system whose components include the necessary equipment, network, and personnel to control an unmanned aircraft" (U.S. Department of Defense JP 1-02 2010, 252). A UAS that is used as a military weapon system is called an unmanned combat air system (DARPA 2004, 1; U.S. Navy 2014, 1). Other terms often used by the DOD, other services, organizations, and agencies to refer to UA and UAS technology include: drone, optionally piloted aircraft, remotely operated aircraft, remotely piloted aircraft, remotely piloted vehicle, unmanned aerial system, unmanned aerial vehicle, and unmanned combat aerial vehicle.[3] This study will predominately use the terms UA, UAS, and UCAS; however, some of the other terms may be used depending on source references and context.

Remote Sensing System

Remote sensing is a critical component of unmanned and autonomous systems operations because remote sensors operate as eyes to the external world for machines.[4] The most commonly accepted definition of remote sensing among practitioners in the field is the action of observing something from a distance, most often the earth, usually

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[3] Many of these terms substitute the use of "aircraft" with the word "aerial." While the only terms beginning with "unmanned" in the Joint Publication 1-02, *Department of Defense Dictionary of Military and Associated Terms* (8 November 2010, As Amended Through 15 January 2016) are for the Unmanned Aircraft and Unmanned Aircraft System, the publication itself uses the term "unmanned aerial vehicle (UAV)" elsewhere in the document (see page 107 under the definition for imagery or the section entitled "Abbreviations and Acronyms," where UAV is defined as "unmanned aerial vehicle" numerous times). The earlier 12 April 2001 (As Amended through 31 October 2009) edition of JP 1-02 contained definitions for "remotely piloted vehicle" and "unmanned aerial vehicle," but these have been removed from the 2010 edition. This illustrates that many of the earlier terms previously used are still popular and are used to describe airborne craft without a pilot physically onboard.

[4] The term "remote sensing" was first used in the U.S. by Evelyn Pruitt of the U.S. Office of Naval Research in the 1950s and "is now commonly used to describe the science—and art—of identifying, observing, and measuring an object without coming into direct contact with it" (Graham 1999, 1).

from the air or space, using special instrumentation that measures reflected energy (e.g., heat from the sun radiating off an object) or emitted energy (e.g., heat from a car engine). The U.S. Geological Survey defines remote sensing as the "process of detecting and monitoring the physical characteristics of an area by measuring its reflected and emitted radiation at a distance from the targeted area (U.S. Geological Survey 2012). The National Geospatial-Intelligence Agency (NGA), the U.S. Department of Defense's National Functional Manager of imagery and geospatial intelligence (GEOINT), describes remote sensing as:

> . . . acquiring information about an object or target using a device that is *not in physical proximity with the object under study*. Remote sensing occurs through an interaction between some form of electromagnetic energy (natural or man-made) and objects and phenomena on or above the earth or below the earth's surface. Remote sensors can employ a number of technologies including electronic, optical, electro-optical, chemical, or mechanical systems, either individually or in combination. The information can be recorded or analyzed in either imagery or non-imagery formats using digital or analog means. (U.S. National Geospatial-Intelligence Agency 2006, 19; emphasis added)

Remote sensing information is categorized into two types: literal and nonliteral. Literal information is classified as visible imagery, e.g., a black and white (panchromatic) or color image that gives the viewer a literal or actual depiction of the object or scene (U.S. NGA 2006, 19). Nonliteral remote sensing consists of systems that collect data using sensors that produce information that cannot be interpreted by the human eye and cognitive systems, i.e., it is not recognizable as a literal depiction of the object or scene (U.S. NGA 2011, 17). Examples of nonliteral remote sensing include synthetic aperture radar (SAR), infrared (IR), and hyperspectral imagery (HSI), techniques that will be described in detail later in this study.

The definition of remote sensing used for this study is as follows: *the process of acquiring literal and nonliteral information about an object or target on, above, or below the earth or water using sensors onboard an unmanned aircraft (UA).* The remote sensing hardware, software, and aerial sensor technologies used to collect data; the data transmission and communication hardware and software used to transmit and receive commands and remote sensing data to and from the sensors onboard a UA; the hardware and software used to process, analyze, exploit, store, and disseminate remote sensing data; as well as all of the associated infrastructure and personnel required to operate the sensors and manipulate the data, together comprise the remote sensing system.

Artificial Intelligence

Within the computer science community there is little debate that English mathematician Alan Turing was one of the first persons to focus on the computer programming aspects of artificial intelligence (AI). Work on creating intelligent machines began in earnest in the post-World Word II era, and Turing gave a lecture to the London Mathematical Society in 1947 that included the subject of machines and intelligence (Turing 1986, 106). Soon after, computer programming research in the field of AI significantly increased (McCarthy 1998, 3).[5]

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[5] In contemplating artificial intelligence, Turing addressed the concept of whether machines could think in an article in the journal *Mind* in 1950. In the article, he addresses the question not by defining the terms “machine” or “think,” but by re-describing the problem using a modified version of a popular three-person guessing game—replacing one player with a computer—that would test the machine’s ability to display intelligence that would be indistinguishable from that of a human player. His game became known as the “Turing Test.” (Turing 1950, 433, 434) The Turing Test has been at the heart of many philosophical discussions about artificial intelligence and can be seen referenced in many computer science works on the topic as well. A good example of the types of discussions generated can be seen in NYU cognitive science professor Gary Marcus’s *The New Yorker* article titled “What Comes After the Turing Test?” (Marcus 2014).

Like technology, the term "artificial intelligence" poses some significant challenges, especially with the word *intelligence* as a component. The word *artificial* is less problematic as it is usually accepted to mean man-made as opposed to occurring naturally. However, one of the most significant issues with determining an acceptable working definition of artificial intelligence is settling upon an acceptable definition of human intelligence. Cognitive scientist Marvin Minsky, pioneer researcher in the field of AI and founder of the MIT AI Laboratory, readily admits that there is "no generally accepted theory of 'intelligence'" (Minsky 1960, 4), and futurist Ray Kurzweil underscores this statement by reaffirming that "there appears to be no simple definition of intelligence that is satisfactory to most observers" (Kurzweil 1992, 18). Because this study focuses on computerization of human intelligence in relation to autonomous weapon systems and control, the definition for intelligence developed by computer scientists John Laird, Allen Newell, and Paul Rosenbloom, early pioneers in a Defense Department AI research project called SOAR, is important to consider.[6] The goal of the SOAR program was to develop an AI software system capable of solving problems and learning in ways similar to human beings. The team stated that the goal of its efforts in working to create a cognitive architecture was to "provide the foundation for a system capable of general intelligence behavior," the characteristics for which they described as the ability to:

> (1) Work on the full range of tasks, from highly routine to extremely difficult open-ended problems, (2) employ the full range of problem solving methods and

[6] "SOAR: An Architecture for General Intelligence" was the 1986-1991 artificial intelligence and psychology research effort supported by the Computer Sciences Division and the Personnel and Training Research Programs, Psychological Sciences Division, Office of Naval Research; the Defense Advanced Research Projects Agency (DARPA); Air Force Avionics Laboratory; National Institutes of Health; and the Sloan Foundation. The specific work cited here is from Technical Report AIP-9 (Laird 1987).

> representations required for these tasks, and (3) learn about all aspects of the tasks and its performance on them. (Laird 1987, 1)

This early definition of intelligence is closely aligned with one agreed on by 52 experts in intelligence and allied fields and published in a 1994 *Wall Street Journal* statement entitled "Mainstream Science on Intelligence."[7] The definition agreed on in that statement, and the one which will be used for this study, is as follows:

> Intelligence is a very general mental capability that, among other things, involves the ability to reason, plan, solve problems, think abstractly, comprehend complex ideas, learn quickly and learn from experience. It is not merely book learning, a narrow academic skill, or test-taking smarts. Rather, it reflects a broader and deeper capability for comprehending our surroundings—"catching on," "making sense" of things, or "figuring out" what to do. (Statement, 1994)

With this definition of intelligence as the baseline, a working definition for artificial intelligence suitable for this study can be constructed.

It is also generally accepted by members of the AI community that computer and cognitive scientist John McCarthy first coined the term artificial intelligence when organizing the 1956 Dartmouth Summer Research Conference on Artificial Intelligence. However, despite the early use of the term and subsequent progress made in the field, there is still no commonly accepted definition for artificial intelligence (Murphy 2000, 15). John McCarthy defines it as "the science and engineering of making intelligent machines, especially intelligent computer programs" (McCarthy 1998, 2). Minsky also sees AI as making machines do things that require human intelligence (Minsky 1968, 23), and Kurzweil defines it in a similar manner, although he emphasizes the controversial

[7] The "Mainstream Science on Intelligence" article was written by professor of psychology Linda Gottfredson and signed by her and 51 other university professors specializing in intelligence (Statement, 1994).

nature of trying to define AI due to the difficulties of defining intelligence. British psychologist Michael Eysenck underscores the complexities of this human-technology relationship with his definition of AI by emphasizing that this is an activity that attempts "to develop complex computer programs that will be capable of performing difficult cognitive tasks" (Eysenck 1990, 22).

As with technology, there are many theories associated with AI, and like technology, there are enough commonalities to allow us to form a working definition for this study. Again, assuming that there will be a relationship of some kind between the human and the technology created, the definition of artificial intelligence used for this study is: *Artificial intelligence is the creation of computer software and hardware that allows a machine to perform functions that would require intelligence when performed by a human being.* The degree to which a machine can do this without human intervention is addressed in the following definition of autonomy.

Autonomy

The root of the word *autonomy* is derived from ancient Greek and means "having its own laws," from the words *autos*-, meaning "self," and *nomos*, meaning "law."[8] As with the definitions of technology and AI, autonomy is problematic in that there is no

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[8] Autonomy for this study is initially approached ontically in order to provide a working definition that focuses on autonomous weapon systems as technologies that are real, currently exist, and are used in the United States Department of Defense. This definition focuses on the concept of self-governance as applied to technological autonomy and the ability of a machine to use artificial intelligence in order to operate independently from human control. The ontological arguments associated with the development and evolution of autonomous weaponry is addressed in the chapter on technological determinism. In that section and elsewhere, the moral philosophical elements offered in the Kantian sense, i.e., the values and desires associated with an agent's capacity to impose the moral law on oneself, will be discussed; however, a comprehensive study of the arguments related to technological autonomy in relation to a moral law are beyond the scope of this study.

agreement when applied to technological systems. Dictionary definitions of autonomy underscore self-government, independence, and self-determination, especially in terms of existence, e.g., being independent or self-governing. These are also key elements when defining machine autonomy. Engineer and computer scientist Robin Murphy defines technological or robotic autonomy as a system that "can adapt to changes in its environment (the lights get turned off) or itself (a part breaks) and continue to reach its goal" (Murphy 2000, 4).

The Department of Defense (DOD) also includes the capability and freedom to self-direct and make choices in its definition, although the DOD does emphasize that the human-technology relationship is "defined by policy and operational requirements" (Stone 2011, 3). The DOD Unmanned Systems Integrated Roadmap FY2011-2036 draws a clear distinction between an automatic and an autonomous system and the level of human interaction involved with each. The distinction is described here as follows:

> Automatic systems are fully preprogrammed and act repeatedly and independently of external influence or control. An automatic system can be described as self-steering or self-regulating and is able to follow an externally given path while compensating for small deviations caused by external disturbances. However, the *automatic system is not able to define the path according to some given goal or to choose the goal dictating its path*.
>
> By contrast, autonomous systems are *self-directed toward a goal* in that they *do not require outside control*, but rather are g*overned by laws and strategies that direct their behavior*. Initially, these control algorithms are created and tested by teams of human operators and software developers. However, if machine learning is utilized, autonomous systems *can develop modified strategies for themselves by which they select their behavior*. An autonomous system is *self-directed by choosing the behavior it follows* to reach a human-directed goal. (Unmanned Systems Integrated Roadmap FY2011-2036, 43; emphasis added)

DOD Directive 3000.09, *Autonomy in Weapon Systems,* also makes this distinction, defining an autonomous weapon system as: "A weapon system that, once activated, can select and engage targets without further intervention by a human operator. This includes human-supervised autonomous weapon systems that are designed to allow human operators to override operation of the weapon system, but can select and engage targets without further human input after activation" (U.S. Department of Defense Directive 3000.09 2012, 13). The FY2013-2038 Unmanned Systems Integrated Roadmap echoes these definitions, also stating that automatic systems require human control, and autonomous systems are able to make decisions and react without human interaction (U.S. Department of Defense Unmanned Systems 2013, 68).

This distinction given by the DOD is important, first because it differentiates between automatic "fire and forget" weapon systems, such as cruise missiles or guided munitions, and unmanned or autonomous weapons systems, such as the X-47B UCAS. Second, because it clearly states that an autonomous system is *self-governing* in the context of its operating environment, i.e., it does not require human intervention for processing and responding to the environment and developing *modified strategies* to achieve its human-directed goal. This definition of autonomy exhibits the elements of AI previously given by the SOAR team: the ability to (1) work on a range of tasks, (2) employ problem-solving methods, and (3) learn about all aspects of the tasks and its performance on them. While both automatic and autonomous systems operate independently of external influence or control, only the autonomous system applies AI in order to adapt to its environment without human interaction.

Like the different degrees of intelligence, there are different degrees of autonomy, usually described in levels or scales that are based on the amount of human interaction. As there is no agreement on the definition of autonomy, the levels vary from organization to organization. The National Aeronautics and Space Administration (NASA) uses a scale with eight levels divided into four categories, with the lowest level consisting of the human who gathers and processes all data and makes all the decisions, and the highest level where computers not only gather and process all the data but also *do not allow any human interaction* (Proud 2005, 1).

The National Institute of Standards and Technology (NIST) provides the following definitions of *autonomy* and *autonomous* for unmanned systems (UMS):

> Autonomy – A UMS's own ability of integrated sensing, perceiving, analyzing, communicating, planning, decision-making, and acting/executing to achieve its goals as assigned by its human operator(s) through designed Human-Robot Interface (HRI) or by another system that the UMS communicates with.
>
> Autonomous – Operations of a UMS wherein the UMS receives its mission from either the operator who is off the UMS or another system that the UMS interacts with and accomplishes that mission with or without further human-robot interaction (HRI).
>
> Fully autonomous – A mode of UMS operation wherein the UMS accomplishes its assigned mission, within a defined scope, without human intervention while adapting to operational and environmental conditions. (Huang 2008, 15-22)

Using these definitions, the NIST places UMS into levels of autonomy (LoA) based upon varying levels of Human Independence (HI). The eleven-point LoA scale ranges from zero (the UMS has 0% HI) to level 10 (the UMS is "approaching" 100% HI) (Huang 2007, 20).

In the Department of Defense Unmanned Systems Integrated Roadmap FY2011-2036, the levels of autonomy are divided into four levels, as defined in table 1.

Table 1. Four Levels of Autonomy

Level	Name	Description
1	Human Operated	A human operator makes all decisions. The system has no autonomous control of its environment although it may have information-only responses to sensed data.
2	Human Delegated	The vehicle can perform many functions independently of human control when delegated to do so. This level encompasses automatic controls, engine controls, and other low-level automation that must be activated or deactivated by human input and must act in mutual exclusion of human operation.
3	Human Supervised	The system can perform a wide variety of activities when given top-level permissions or direction by a human. Both the human and the system can initiate behaviors based on sensed data, but the system can do so only if within the scope of its currently directed tasks.
4	Fully Autonomous	The system receives goals from humans and translates them into tasks to be performed without human interaction. A human could still enter the loop in an emergency or change the goals, although in practice there may be significant time delays before human intervention occurs.

Source: U.S. Department of Defense Unmanned Systems Integrated Roadmap FY2011-2036, 46.[9]

This study uses the DOD Directive 3000.09 definition—a weapon system that, once activated, can select and engage targets without further intervention by a human operator—along with the description in four levels.

Humans and Technology in 21st-Century Warfare

"Killer robots seem to be everywhere."

— Armin Krishnan

The improvements that the U.S. military has made in unmanned systems technology, particularly the unmanned aircraft systems, have significantly changed operations on the battlefield from the second half of the 20th century into the early 21st century. The U.S. Department of Defense today deploys unmanned combat aircraft systems (UCASs) throughout the Iraq and Afghanistan Theaters of Operation.

[9] The most current Unmanned Systems Integrated Roadmap, FY2013-2038, refers back to the FY2011-2036 Roadmap for the definition of the four levels of autonomy (U.S. Department of Defense Unmanned Systems 2013, 137).

Additionally, the U.S. Department of Homeland Security (DHS) deploys unmanned aircraft along the U.S. borders to assist in efforts to stop illegal aliens, drug traffickers, and terrorists from infiltrating the country. According to Peter Singer, Senior Fellow and Director of the Twenty-First Century Defense Initiative at the Brookings Institution, unmanned systems are being employed at levels that are rapidly increasing, and robotic technology is “truly changing war as we once knew it” (Singer 2009b, 203).

The technology of these sophisticated unmanned aircraft are integrated, or blended, with the technologies of advanced intelligence, surveillance, and reconnaissance (ISR) remote sensing systems, artificial intelligence technologies, and high-tech weaponry to create a formidable weapon system that has contributed to numerous battlefield successes in the late 20th and early 21st centuries (U.S. Air Force Fact Sheet: MQ-9 Reaper Unmanned Aircraft System 2015). However, one important negative aspect of this integrated technology is its tendency to increase the physical and technological distance between the human operators and the weapon system. The evolution of the UCAS and the associated increase in separation between the human and the machine directly affects human security in at least two ways. First, the ethics and morality of participants in 21st-century combat are impacted. Combatants and noncombatants alike are being further distanced from the traumatic effects of warfare by the ever-increasing physical, emotional, and psychological gaps created by unmanned systems and autonomous weapons technology, e.g., the technology that allows an operator to find and kill a human “target” that has little or no resemblance to an actual human being. As the physical, emotional, and psychological gaps increase, policy makers may be more willing to use autonomous systems to increase the level and duration of the force employed, and as warfare becomes more remote and "cleaner," there may be less public resistance to supporting such wars. The second way human security is affected by the evolution of the UCAS is the decrease in the human ability to directly interact with and potentially maintain control of the technology; as the weapon system becomes more autonomous, it becomes less dependent on direct human involvement and more capable of self-direction and self-control.

In the search to discover what it means to be human in the modern technological era, some scholars believe that completely autonomous weapon technology is not only serving to distance humans from the machinery of warfare, but is ultimately causing humankind to lose control of the technology, to the point where humans will eventually become subservient. To some, we are now witnessing an extreme version of Jacques Ellul's statement that "Man as a worker has lost contact with the primary element of life and environment" (Ellul 1964, 325). It is now possible for modern warriors to not only engage in battle without ever stepping foot on the battlefield, but also to allow machines to autonomously conduct operations to find, fix, target, track, and possibly even eliminate combatants. In his treatise on "Human Techniques" in *The Technological Society*, Ellul stated that "[Work] calls for different qualities in man. It implies an absence, whereas previously it implied a presence" (Ellul 1964, 320). The absence Ellul refers to has significantly increased in the work conducted by technology associated with 21st-century warfare, as increasing numbers of today's warriors practice their trade remotely, sometimes thousands of miles away from the battlefield, having no direct physical contact with the weapons they wield in battle or the combatants they target. Today technology exists that could allow a machine to make crucial life or death decisions independent of humans.[10]

The UCAS is one example of 21st-century military technology that, ostensibly, has the very real potential to completely separate the human from the war machine. These sophisticated systems allow pilots to fly over enemy territory to conduct armed intelligence and reconnaissance missions to seek and destroy targets without ever leaving the continental United States. The next generation of these systems is already being developed by the DOD to create more autonomous versions of the UCAS. Ellul, underscoring that *technique* has enabled man to accomplish things never before possible while simultaneously causing him to lose touch with reality, stated that:

> The machine's senses and organs have multiplied the powers of human senses and organs, enabling man to penetrate a new milieu and revealing to him unknown sights, liberties and *servitudes.* He has been liberated little by little from physical constraints, but he is all the more *the slave* of abstract ones. He acts through intermediaries and consequently has lost contact with reality [emphasis added]. (Ellul 1964, 325)

Today the crew of a UCAS operates in war "beyond human endurance in noise, movement, enormity of means, and precision of machines" (Ellul 1964, 320). The integrated technologies of the UCAS allow combatants to see targets at night, through bad weather, from miles above the battlefield; targets that are not visible to the human eye alone. The artificial intelligence systems onboard can not only fly and navigate the aircraft but also process vast amounts of data to recognize targets, automatically track

[10] The U.S. Navy's MK-15 Phalanx Anti-Ship Missile (ASM), aircraft, and littoral warfare threat close-in weapon system (a radar guided fast-reaction 20-millimeter gun) is currently deployed onboard naval vessels and is capable of "autonomously performing its own search, detect, evaluation, track, engage and kill assessment functions" (U.S. Navy 2013b).

them, and make decisions at speeds that are well beyond human capabilities. To some observers, the modern warrior is quickly becoming more of a spectator than a participant.

The technology of 21st-century warfare not only creates a new operating environment for the warriors, it also modifies their very "essence" (Ellul 1964, 325). In the words of RAF Wing Commander Pete York, referring to modern UAS warriors, "An overweight computer geek with green hair who misspent his youth playing 'war' games on a PlayStation© may make a better UAS Controller than an athlete" (York, 2008). The integrated technology of the UCAS on the 21st-century battlefield has brought about significant changes in the human-technology relationship in regard to U.S. military aircrews and their aircraft, and it underscores the question of what it means to be human in the highly technological environment of 21st-century warfare. There appears to be a new level in the warrior's evolution, from the pilot who was "completely one with his machine . . . immobilized in a network of tubes and ducts," to one whose senses "have been replaced by dials which inform him what is taking place," to today's UCAV operators, who have been removed from the machine altogether, connected only in a "cyber" sense, through sophisticated unmanned aircraft technologies, highly sensitive remote sensor systems, and human-like AI capabilities (Ellul 1964, 326). This new level of warrior evolution appears to be predicted by Ellul, Heidegger, Kurzweil, and other technological determinists, as the technology of modern warfare contributes to a new kind of dehumanization in warfare, a kind where some of the humans are completely removed from the environment and the machinery of warfare altogether, and a kind of dehumanization where humans seem to be losing control.

Focus of the Study

> *"When killing at a maximum range, one can pretend they are not killing human beings, and thus experience no regret."*
>
> — D. Grossman

Approaching the issue from a historical perspective that spans the era from World War I to 2015, this study addresses the following question: *Does the presence and influence of the integrated technologies of unmanned aircraft systems, remote sensing systems, and artificial intelligence, found in the development of the autonomous UCAS, support a technological deterministic view that humanity's ability to maintain control is threatened or transcended?*

The transition from theoretical concept once thought to be pure fiction (like manned flight) to an operational reality (like aircraft) has been accomplished many times and in many different ways throughout history, and the evolution of autonomous weapon systems is no exception. The idea that robotic weapons could become completely autonomous once belonged to the realm of science fiction; however, fully autonomous weapons appear to be coming to fruition in the modern U.S. military, as evidenced by the progress being made in unmanned weapon systems like the XB-47. This evolution toward complete autonomy can be seen with clarity by technological determinists who examine the U.S. military's current research, development, and deployment of unmanned and near-autonomous weapon systems. Consequently, even a cursory survey of modern military history reveals the significant technological leaps in unmanned aircraft, remote sensing, and artificial intelligence technologies. Notable examples taken from the period of this study are: remotely piloted and semi-autonomous aircraft, rocket, and missile technology; radar technology; and electro-optical, infrared, and hyperspectral imagery. Each of these technologies were developed and deployed for specific military purposes; however, each has had significant societal and cultural implications as well. The development of the unmanned and autonomous technologies of the 21st-century is built upon a foundation of technical functionality and significant societal change, and the possible development of actual autonomous weapons may cause us to reach a point in the history of war that has, up to this time, only been described in science fiction writings: total robotic warfare.

One would be hard-pressed to dispute the idea that there is some level of human dependency on even the most rudimentary forms of technology, e.g., pipes to carry water and sewage, power grids to carry electricity, or computer technology to enable systems to regulate flows of water and electricity. However, as suggested by some technological determinists, what must be pondered is the nature and level of influence technology has upon humanity. When discussing the influence that the integrated technologies of unmanned aircraft, remote sensing, and AI have had on the nature and influence of autonomous military technology, the questions can be further narrowed to the following: Can humans maintain complete control over such technology, or is the technology really evolving into an independent "entity" that will operate completely autonomously, outside of human control? If military technology is becoming autonomous, what responsibilities do humans have, if any, and how might they—if they should—mitigate the momentum?

The intent of this study is to focus on the technological capabilities in order to develop a deeper understanding of the role of unmanned aircraft, remote sensing, and artificial intelligence-integrated technology in the development of autonomous military weapon systems, particularly the development of the autonomous UCAS. A comprehensive examination of all of the elements associated with the creation of all unmanned weapon system technology is not possible in one dissertation, neither is it possible to discuss all of the non-technical factors of human interpersonal and group power relationships that affect the aspects of control. Therefore, this examination only focuses upon the influence that the integrated technologies have had on the evolution of the autonomous UCAS, and the possibility of these technologies evolving to a point beyond human control. The examination will occur in the context of the arguments associated with the theory of technological determinism related to the nature of technology and technological systems in order to discern the impact on humanity's ability to maintain control of such weapons.

Finding an answer to this study's question not only contributes to the ongoing technological determinism debate by providing additional evidence to one side of the human control issue, it also helps clarify the realities of autonomous UCAS system development and the responsibilities humans have in correctly defining and communicating the relationship between humanity, technology, and the issue of control.

Rationale as to the Question's Validity

> *"Something big is going on in the history of war, maybe even in the history of humanity itself."*
>
> — Peter W. Singer

The research question of this study focuses on the influence of integrated or blended unmanned aircraft, remote sensing, and artificial intelligence technologies on the evolution of the autonomous UCAS, and the findings help determine the true impact on humanity's ability to control such weapons in the context of the technology itself. The validity of this area of inquiry is underscored by the reality of current autonomous technology development efforts within the DOD. Additionally, the continuing debates among military leaders, politicians, and scholars concerning the definition of AI and autonomy, as well as their expressed concerns regarding the use and potential impact that autonomous technology has or can have upon armed conflict, society, and culture highlights the validity of this subject matter.

Military unmanned aircraft systems are able to conduct missions quietly, from high altitudes, over long distances, and over extended periods of time. These unmanned aircraft are outfitted with the latest intelligence, surveillance, and reconnaissance technologies, including remote sensing technology, which helps orient the machinery in relation to the earth, and to detect, monitor, track, and locate individuals, equipment, buildings, and various modes of transportation. The remote sensing technology onboard the unmanned aircraft allows human activity on the earth to be monitored unknowingly, and persistently, at all hours of the day and in all weather conditions. The capabilities of these remote sensing systems are proven, and specific capabilities include electro-optical (EO), full-motion video (FMV), infrared (IR), Synthetic Aperture Radar (SAR), and other surveillance technologies (U.S. Air Force Fact Sheet: MQ-9 Reaper Unmanned Aircraft System 2015).

In addition to remote sensing capabilities, the UAS utilizes AI technology to help with onboard navigation and flight control systems, the remote sensing systems, and the delivery of a wide variety of lethal weapons, allowing for semi-, or near-autonomous, operations. These capabilities make the UCAV a fearsome system that provides "a unique capability to autonomously execute the kill chain (find, fix, track, target, execute, and assess) against high value, fleeting, and time-sensitive targets (U.S. Air Force Fact Sheet: MQ-1B Predator, 2012). A key aspect of these combined or "integrated" high-tech systems is that they accomplish their missions without humans onboard, and are becoming increasingly capable of performing more functions without any direct human interaction once initiated.

The U.S. Department of Defense has been actively investigating the feasibility of the future application of *completely autonomous* UCAVs for combat missions, thereby asking "Whether completely autonomous UCAVs could be used in combat roles?" The results of some studies indicate that the technology required to create completely autonomous UCAVs could indeed be developed in the near future and used in combat (Hariharan 2008, 9).[11]

The successes of the UCAS have also opened the door for the creation of completely autonomous systems within the long-range strike (LRS) arena. The 2006 Quadrennial Defense Review (QDR) initially identified a need to establish long-range and long-loiter capabilities for strike and surveillance, and it revealed a threefold plan to modernize and reconfigure the USAF strategic bomber force for conventional LRS

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[11] During the United States Geospatial Intelligence Foundation's October 2011 Geospatial Intelligence Symposium*,* attended by more than 4,000 participants, the commercial L3 Corporation displayed the *MOBIUS*, the "optionally piloted aircraft system" (OPAS). In the unmanned mode, this system can conduct "fully-autonomous" operations once the commands are uploaded. According to the L3 representatives, *MOBIUS* is able to conduct "hands-free takeoffs and landings," including taxiing to and from the runway, flying to the area of operation, conducting remote sensing operations, conceivably *delivering a weapons payload*, returning to base, and taxiing to a hanger *with no human involvement*. These capabilities have already been demonstrated by the military and will be discussed in the following chapters.

missions (U.S. Department of Defense QDR 2006, A-4).[12] First, the existing force of B-52, B-1, and B-2 bombers would be fully modernized "to support global strike operations"; second, the DOD would develop "a new land-based LRS capability to be fielded by 2018"; and third, the goal was set to increase U.S. LRS capabilities by 50 percent by the year 2025, *"with 45% of the LRS force being unmanned"* [emphasis added] (U.S. Department of Defense QDR 2006, 46).

In the 2014 QDR, the DOD upheld portions of the 2006 Review as it emphasized the need to continue to invest in long-range strike capabilities and determined that U.S. forces will require the ability to exploit, extend, and gain advantages in unmanned systems to maintain the ability to project power (U.S. Department of Defense QDR 2014, x, 20).[13] The DOD also recognizes that the "increasing precision, persistence, and *autonomy* of unmanned systems hold great promise" and determined to examine the application of UAS technologies to a number of different operational areas, including "ISR, fighters and *long-range strike aircraft* . . ." (U.S. Department of Defense QDR 2010, 41; emphasis added). Finally, military leaders understand that the sophisticated technologies of automated and autonomous systems have a wide range of commercial, industrial, and military applications that pose a range of new challenges to the DOD (U.S. Department of Defense QDR 2014, 7).

The effort to create the next-generation LRS bomber is well under way, and a number of major contractors have already created designs and are currently vying for the

[12] The Quadrennial Defense Review (QDR) is a congressionally mandated review of the Department of Defense, which focuses on U.S. military doctrine, strategy, and priorities.

[13] As stipulated in the 1997 National Defense Authorization Act (NDAA), the QDR is conducted every four years.

lead position as the next-generation LRS bomber manufacturer (Clevenger 2015, 1). Whoever is chosen to lead the effort will have the privilege of taking UCAS technology to the next level of achievement should the government remain true to its projection that part of the LRS force has the capability to be unmanned. The plans to incorporate more unmanned or "optionally manned" strategic bombers, along with the autonomous system research and development efforts of the DOD, make this a valid issue worth studying in the contexts of the evolution of technological autonomy, technological determinism, and control.[14]

The ongoing debates among academics, politicians, and military leaders concerning the amount of human control that should be exercised over such integrated technology, as well as the discussions centered around the implications of autonomous military technology on humanity, also underscore the validity of this dissertation's area of inquiry. Noel Sharkey, professor of AI and robotics at the University of Sheffield, UK, in 2007 underscored the growth in U.S. robotic technology and warfare:

> The U.S. military has massive and realistic plans to develop unmanned vehicles that can strike from the air, under the sea, and on land. The U.S. Congress set a goal in 2001 for one-third of U.S. operational ground combat vehicles to be unmanned by 2015. More than 4,000 robots presently serve in Iraq, with others deployed in Afghanistan. The U.S. military will spend $1.7 billion on more ground-based robots over the next five years, several of which will be armed and dangerous. (Sharkey, 2007)

As the rapid growth and ubiquitous presence of unmanned systems since 2007 indicates, unmanned and robotic technology and its application to warfare remain a pertinent topic of discussion and debate. In addition, the debate is carried one step further as discussions

[14] While the DOD has not revealed the planned future capabilities of the long-range strike bomber, there is some conjecture that an "optionally manned" capability—i.e., one that could operate as a UAV or manned platform—is on the list (Seligman 2015, 1; Weisgerber 2015, 2).

about the possibility of completely autonomous military technologies increase, as highlighted by Robert Sparrow, School of Philosophy and Bioethics, Faculty of Arts, Monash University, Victoria, Australia:

> Most existing versions of these technologies still require some level of human supervision. However, the need for such supervision is steadily decreasing as computing and sensor technology improves. It appears increasingly likely that robots will eventually be entrusted with decisions about target identification and destruction.
>
> Beyond these weapons, which are already on the drawing board, lies the prospect of weapons systems that possess genuine 'artificial intelligence.' According to a number of writers in the field, before the end of the century—and according to some, well before this—machines will be conscious, intelligent entities with capacities exceeding our own. Given that the military constitute[s] a major source of funding for research into artificial intelligence, it seems inevitable that such AIs will be put to work in military contexts. (Sparrow, 2007)

With the growing concern over the possibility of machines becoming intelligent enough to one day achieve the ability to think, make decisions, and operate independently from humans, the question of whether humanity can lose control over such technology remains valid.

Originality of the Topic and Expected Contribution

> *"As president, I believe that robotics can inspire young people to pursue science and engineering. And I also want to keep an eye on those robots, in case they try anything."*
>
> — President Barack Obama

There are a number of studies that examine the automation of military weapons technology, the integration of artificial intelligence into weapon systems, and what constitutes true autonomy. Additionally, there are numerous scholarly works about the relationship between humanity and technology that address the philosophy of technological autonomy, the power politics associated with control of weapon technology, the issue of human responsibility for such technology, and the subsequent impact on humanity. However, there is currently no study that specifically examines the presence and influence of UCAS-integrated technologies and their impact on the technological deterministic view that humanity's ability to maintain control of the technology is threatened, or has already been transcended. This dissertation offers an interdisciplinary, technology- and humanities-focused study on UCAS-integrated technology and its influence on the debate regarding human control of technology.

This examination contributes to the scholarly debate surrounding the relationship between technology and humanity by examining the issue of technological determinism and human control over autonomous technology. Specifically, it examines the role that unmanned systems, remote sensing, and AI technologies play in supporting the evolution of autonomous unmanned aerial weapons systems, and it seeks to discover whether these technologies are actually contributing to the loss of human control over the technology. *The intent is that the findings of this study will defend the thesis that while the integration or blending of UAS, remote sensing systems, and AI technologies play a critical role in creating the environment needed to produce a completely autonomous UCAS, the existence and application of these technologies do not necessarily support the technological deterministic view that humanity's ability to maintain control is threatened or transcended.* Additionally, it is hoped that these findings will contribute to a better understanding of the impact that these technologies have had, and will continue to have, on the human-technology relationship, thus fostering a better understanding of what it means to be human in an age of technology.

Methodology

> *"The future of how you use these unmanned systems or remotely piloted systems is really unlimited. We need to open our minds and think more about [the] capability and impact we are going to achieve as opposed to how we've done business in the past."*
>
> — Lt. Gen. David Deptula

This study employs an interdisciplinary, qualitative analysis of historical and contemporary literature and follows the U.S. military's development of unmanned combat aerial system technologies from World War I to 2015. The relationships between the UCAS technologies and the human operators were closely scrutinized. Rigorous research methods were employed, including close readings of unclassified primary and secondary sources that included U.S. Government documents, academic and commercial scientific and technical papers, and historical writings from all sources on the development of the UCAS in its historical and social context.

Additional primary and secondary sources examined include publications, scholarly articles, dissertations, research papers, scholarly and popular Web-based materials, and electronic media. A review of primary and secondary sources that specifically addressed the writings of Heidegger, Ellul, Kurzweil, and other contributors to the theories of technological determinism was also conducted. Special emphasis was given to Heidegger's philosophy of the "essence" of technology, along with Ellul's philosophy of "technique" and Kurzweil's theory of "Singularity," to determine the impact these technological deterministic theories have on the UCAS-human relationship.

Another specific component was the examination of the writings of a wide range of authorities on the subject of autonomous military weaponry, particularly the writings of Ronald Arkin, renowned authority on computing, robotics, and autonomous systems, and Peter W. Singer, one of the foremost authorities on 21st-century warfare and military robotics.

This dissertation is composed of six chapters. Following the introduction, chapter two provides a literature review and evaluation of the concepts introduced. The review addresses the subjects of unmanned aircraft systems, remote sensing, AI, UCAS systems, and the human-technology relationship with regard to unmanned weapons, technological determinism, and technological autonomy, the development of autonomous weapons systems, and the changing nature of 21st-century warfare as asserted by Singer and others. Additionally, this chapter will highlight any omissions or gaps in the literature and areas where not enough information exists and which require further investigation.

The following four chapters provide a historical background into the philosophical perspectives of technological determinism and technological autonomy, the development of UAS technology, the history and development of remote sensing and AI technologies, the integration or blending of these technologies into the UAS, and the issue of human control of the UCAS and future autonomous systems.

Chapter three studies the philosophical perspectives of technological determinism, technological autonomy, and the issue of the human ability to control technology. The chapter focuses on the philosophers, historians, and authors who have made significant contributions to understanding the humanity-technology relationship as it applies to the evolution of technology, the meaning of technological autonomy, and the current efforts to develop autonomous unmanned combat aircraft systems. It examines the technological determinists' arguments of technological autonomy in order to gain an understanding of the issues associated with control. In addition, the different philosophical positions regarding technological determinism are examined in order to understand the historical and contextual issues regarding the debate over technological autonomy as applied to weapon systems.

The fourth chapter provides a brief historical overview of the development of unmanned flight and aircraft technology prior to World War II, and then moves into a more in-depth examination of unmanned aircraft technological development from the Second World War into Operation Iraqi Freedom (2003). The study defines and explains the human-systems integration related to unmanned flight and provides an overview of the progress and challenges associated with the military application of unmanned aircraft technology. This chapter provides the foundation to understand the current development and use of unmanned aircraft in warfare and the subsequent levels of autonomy associated with unmanned combat aircraft systems, as well as the research and development activities associated with the planned development of the fully autonomous UCAS. This chapter is foundational to understanding the current development and use of the UCAS.

Chapter five examines the history of remote sensing, computer-controlled flight, and artificial intelligence technologies as the necessary precursors that enabled the development and evolution of the unmanned aircraft into the unmanned combat air system and, subsequently, autonomous unmanned combat air systems. The chapter begins with an examination of traditional early remote sensing technologies and swiftly moves to the technologies used during World War II: literal (optical) imagery, infrared, and radar. The study then moves into the more advanced technologies developed during and after the war and applied to unmanned aircraft, including the thermal infrared, synthetic aperture radar, and multi- and hyperspectral technologies that are used in 21st-century warfare. World War II provides the background for the departure from traditional literal technologies, which is briefly discussed in order to give context to the development of the nonliteral technologies used in the prelude and subsequent operation of the First Iraq War in 1990 and beyond. The development of computer-controlled flight technology follows, with particular application to unmanned aircraft systems. The evolution and integration of remote sensing, computerized flight, and AI technologies, and their application to the battlefield environment, up to 2015, will be discussed to demonstrate how the technology is widening the gap between the operators and the weapon systems. This chapter underscores the contribution made by the remote sensing, computer-controlled UAV, and AI-integrated technologies in preparing the way for the development of completely autonomous weapon systems. The convergence of these technologies and their relationship and contribution to the evolution of autonomous unmanned combat aircraft systems becomes a critical theme for the remainder of this study.

The final chapter will critically examine the previously discussed technological determinists' arguments in light of current and projected developments in UCAS technology to determine the impact on human control over these systems. Included in this analysis will be the current technological limitations, the current laws associated with the development of autonomous technology (including international laws and treaties), the law of armed conflict, and the rules of engagement (ROE) associated with warfare. In addition to technological capabilities and the rule of law, moral and ethical elements of humanity associated with technology will also be briefly evaluated to provide an answer to the research question: *Does the presence and influence of the integrated technologies of unmanned aircraft systems, remote sensing systems, and artificial intelligence, found in the development of the autonomous UCAS, support the technological deterministic view that humanity's ability to maintain control is threatened or transcended?*

Reflecting on the question's answer and its implications, the findings and the conclusion, with regard to the particular issue of autonomous UCAS technology, will support the thesis that while the blending of military UAS technology, remote sensing systems, and AI play a critical role in creating the environment needed to produce a completely autonomous UCAS, they run counter to the technological determinist claims that the existence and application of these technologies support the view that humanity's ability to maintain control is threatened or transcended. The findings of this study provide a better understanding of the extent to which UA, remote sensing, and AI technologies have contributed to the creation of the autonomous UCAS, the extent of autonomy these integrated technologies can actually achieve, and the level of control humans have over this particular technology. The findings, as related to the technological determinism debate associated with technological autonomy, integrated technologies, and control of the autonomous UCAS—and which have not been examined in any other scholarly work—will contribute to a better understanding of what it means to be human in the age of 21st-century technology. This chapter will also provide some recommendations for responsible citizens that will focus on education, knowledge application, and participation.

Potential Areas of Concern for This Investigation

"The first to speak in court always seems right until his opponent begins to question him."
— King Solomon

The first potential area of concern for this study is the use of definitions. Technology, intelligence, artificial intelligence, autonomy, and technological autonomy are all highly esoteric and greatly debated terms in the academic and scientific communities, and a potential obstacle is the possibility of a wrong understanding of the meanings of these terms as applied to unmanned aircraft systems, autonomy, and human control. Every attempt has been made to develop working definitions that conform to the most widely accepted understandings of these terms within their associated fields; however, it is possible that wrong interpretations have led to inaccurate applications to the issues examined in this study. Additionally, with the exception of a brief foray into the etymology of some words, only English definitions are used. There is the possibility that using only English will contribute to misunderstandings of the terms used.

Related to the use of English words in the definitions is the issue of heavy use of published works in English. The foreign works referenced in this study are English translations—for example, the works of Heidegger and Ellul, which originated in German and French, respectively. Every effort was made to access primary and secondary sources in any language that contained material related to this examination, and translations of other languages were also consulted, opening the possibility that key issues were mistranslated or that important works relevant to this study were missed altogether.

A third area of concern is that an unknown amount of data related to autonomous combat aircraft systems is held by the U.S. Department of Defense as well as by the governments of various other nations consulted for this study. As the amount and quality of this data is unknown, there is no way to accurately assess the potential impact on the findings. While the introduction of such data could very well have altered the conclusion, the intent of this examination is to reach a more general audience than those who have access to such information.

Another area of concern is the danger of making assessments and conclusions based on a relatively limited amount of material and a limited number of case studies. While every effort was made to be as comprehensive as possible, it is not feasible, in the information age, to examine every piece of applicable literature on every topic covered in this examination.

Similarly, the content under examination is highly complex, in both the technological and philosophical arenas. The technology associated with next generation unmanned aircraft, the phenomenology behind remote sensing technologies, the mathematics and computer languages associated with AI technology, and the biology and psychology related to the human brain and cognitive processes—where much still remains to be learned and understood and which remain outside the limits of current technology to achieve— make it impossible to predict future outcomes of research and development in all of those areas. Additionally, the complexity of the philosophical and social systems affiliated with concepts such as autonomous technology, determinism, being, agency, human-machine interface, and human-human interaction are all areas of continuing study, thought, and debate with many unknown and unanswered questions.

Therefore, because it is not conceivable to address all of these areas, it is acknowledged that the possibility exists of misunderstanding the scientists, technologists, philosophers, theorists, academicians, and practitioners who are authorities in these areas. However, these concerns were noted and addressed by a careful, thorough, comprehensive, and interdisciplinary analysis of current technologies—within the realm of existing science focused on a specific weapon technology—along with the current philosophies associated with technological determinism. The methodology applied to this study helps to mitigate the impact of these potential areas of concern in order to develop the best possible conclusions.

Chapter Summary

Chapter one introduced the subject matter for this dissertation by addressing the broader problem of discovering what it means to be human in the age of technology. This was accomplished by asking the following question: *Does the presence and influence of UAS, remote sensing systems, and AI integrated technologies, found in the development of the autonomous UCAS, support a technological deterministic view that humanity's ability to maintain control over the technology is threatened or transcended?* The chapter also highlighted that the conclusion of this study would defend the thesis that while the integration of the previously mentioned technologies plays a critical role in creating the environment needed to produce a completely autonomous UCAS, the existence and application of these technologies do not necessarily support the technological deterministic view that humanity's ability to maintain control is threatened or transcended. The chapter then provided supporting definitions of the key terminology used throughout the study and introduced the primary areas associated with finding an answer to the dissertation question: the relationship between unmanned aircraft systems, remote sensing, AI, and the development of autonomous systems. The issues of technology and humanity in 21st-century warfare were introduced, along with some of the philosophical challenges and issues that will be addressed and are associated with technological determinism, control, and the humanity-technology relationship as argued by Heidegger, Ellul, Kurzweil, and others. An explanation of the methodology used for this dissertation was given, and the potential obstacles and concerns that may impact the investigation were discussed.

Chapter Two: Literature Review

"Our review of the literature says this appears to be bigger than in the past."
— Bob Dietz

Chapter Introduction

This chapter provides a review of the literature used in this investigation. As an interdisciplinary examination this study draws from the fields of philosophy, history, science, sociology, and political science. The review addresses the scientific, technological, and humanities perspectives of unmanned systems, remote sensing, artificial intelligence, autonomous technology, unmanned combat air systems, and robotic warfare by primarily evaluating the writings of leading experts in these fields serving in academia, government, and industry. It also addresses the philosophical perspectives of technology, autonomy, control, and technological determinism through the writings of key thinkers and philosophers who have written about technology, and provides a focus on those who have written from a hard technological determinism perspective, including Martin Heidegger, Jacques Ellul, Ray Kurzweil, Paul Virilio, and others. Finally, the chapter addresses omissions, gaps in the literature, and areas where not enough information exists, requiring further investigation.

While there is a significant amount of data on military weapon systems, artificial intelligence, robotics, and next generation warfare, there is a comparatively smaller amount of material addressing the evolution of technological autonomy specifically related to unmanned aircraft weapon systems, the philosophy of technology related to lethal autonomous weapons, and technological determinism as it relates to the control of autonomous weapon systems. Smaller still is the pool of information available that specifically addresses military applications of remote sensing—especially nonliteral remote sensing—related to the unmanned combat air system (UCAS), and lethal autonomous UCAS weapon technology and development in relation to human control. One contributing factor to the scarcity of information in the latter group is likely the fact that much of it is still classified by the U.S. Department of Defense and not available to the general public. However, the past and current states of research and development associated with unmanned aircraft systems and unmanned combat air systems provided sufficient information to address the research question of this study.

Introduction to the Literature Used

The material used for this investigation was divided into five broad groups, which were further divided into subcategories. The first group covers the areas of the philosophy of technology, determinism, and control, and are further subdivided into the categories of social determinism, soft technological determinism, hard technological determinism, and the relationship and interactions between technology, humanity, and control.

Group two focuses on the development of unmanned flight and is comprised of the subcategories of history and development of unmanned flight, unmanned vehicles and systems, and military application of unmanned flight.

The third group concentrates on works related to the development of aerial remote sensing, beginning with the history and development of remote sensing and remote sensing systems, followed by works on aerial remote sensing, and ending with writings on the military applications of aerial remote sensing.

Group four examines the literature related to computer, artificial intelligence (AI), and autonomous technology development, and is broken down into categories of the history and development of computer technology, autonomous aircraft systems development, development of artificial intelligence, and military applications of autonomous unmanned combat air systems.

The final group examines political, legal, and ethical literature related to lethal autonomous weapon systems, beginning with the areas of political and legal elements related to autonomous UCAS development and finishing with works on the moral and spiritual elements of autonomous UCAS development.

While research into all groups and subcategories was conducted, the majority of material included in this literature review is comprised of the works specifically cited within this study.

The Philosophy of Technology, Determinism, and Control

> *"Whereas the short-term impact of AI [artificial intelligence] depends on who controls it, the long-term impact depends on whether it can be controlled at all."*
>
> — Stephen Hawking

Anthologies

The readings in the first group address the writings of 20th- and 21st-century philosophers who wrote about technological determinism, a necessary foundation for a discussion of human control of autonomous weapon systems. Beginning with a valuable anthology of differing perspectives is David Kaplan's editorial work on the *Readings in the Philosophy of Technology*. Kaplan provides an extensive set of readings that range from early philosophers like Heidegger to contemporary thinkers like Kurzweil. Topics include such wide-ranging areas as ontology, politics, ethics, human nature, science, gender roles, agriculture, nature, and the environment. The work not only provides multiple perspectives and applications of the field of study, but specific articles, such as Heidegger's "The Question Concerning Technology," Don Ihde's "A Phenomenology of Technics," Hans Jonas's "Technology and Responsibility," and Hubert and Stuart Dreyfus's "Why Computers May Never Think like People," all of which provide excellent foundational material directly related to the technology-humanity relationship and the issue of control. A deficiency of this particular work, as far as this study is concerned, is the lack of discussion on the relationship between the military, or weapon systems technology, and humanity. With the exception of the Dreyfus article, which dedicates half a page to the discussion, the military-technology-humanity relationship is only mentioned fleetingly throughout the book.

A second important anthology is the *Philosophy of Technology: The Technological Condition*, edited by Robert Scharff and Val Dusek. Like Kaplan's work, this is a collection of historical—beginning with Plato and Aristotle—and contemporary writings, covering some of the same material as Kaplan, including some of the same articles. A difference in this work is the additional detail in the foundational works related to the philosophy of technology, as well as a more focused discussion on the ontological aspects of technology and its relationship to humanity. This can be seen in the section dedicated to the different perspectives of Heidegger's writings on technology. However, with the exception of four pages in John McDermott's article "Technology: The Opiate of the Intellectuals, with the Author's 2000 Retrospective" dedicated to the

Vietnam War, this anthology also is lacking in references or discussions on issues related to military technology and the impact on humanity.

The collected works of Merritt Roe Smith and Leo Marx, editors of *Does Technology Drive History? The Dilemma of Technological Determinism,* helps to specifically introduce the concept of technological determinism. The work provides a good introduction, providing many different perspectives on the technology-humanity relationship, dealing with questions of whether technology can be autonomous, if it can be controlled, and to what extent autonomous technology influences humanity in the political, social, cultural, and economic spheres. A wide variety of stances taken toward technological determinism are identified and included in order to help define the issues regarding human control in relation to technology. The important contribution of this work is the introduction and explanation of these various positions, underscoring the wide variance among different scholars and philosophers with regard to the cause and degree of influence technology has in the humanity-technology relationship. Of particular interest in this anthology are the works *Technological Determinism in American Culture* by Merrit Roe Smith, *Do Machines Make History?* By Robert L. Heilbroner, and *Three Faces of Technological Determinism* by Bruce Bimber, each of which underscores the different and disparate perspectives of the technology-humanity relationship and the issue of control.

Social Determinism

In the realm of social determinism, John Dewey's work, *Reconstruction in Philosophy,* addresses issues and problems associated with social change, including social change brought about by technology. Dewey proposed the idea that philosophy and moral practice needed to be reconstructed to correctly and cogently respond to a changing world and new circumstances. Dewey emphasized that it is not some mystical force or power that determines the direction of society, but rather the choices of humanity, their intentions, volitions, and desires. Because Dewey did not create a work exclusively on technology, but rather includes extensive discussions on technology in his many discourses on the history of philosophy, metaphysics, and social thought, Larry Hickman's work *John Dewey's Pragmatic Technology* proved helpful in coalescing Dewey's thoughts on technology and relating them to the discussion of autonomy and control.

Continuing in the same vein of social control of technology, Jurgen Habermas's *Toward a Rational Society* addresses the relationship between humanity and technology in the context of the social life-world, i.e., the experiential world of humanity. There Habermas analyzes the relationship and differences between technology and human social life, explaining the impacts of technology on advanced industrial society as the result of social interests and human decisions, not independent, autonomous technological advancements (Habermas 1970, 59). This work is used to introduce the opposing position from the hard technological determinists' view. Habermas supports a more human, social influence, a position that highlights the complexity and multifaceted human elements contributing to the influences involved in the human-technology relationship, which refutes the idea that technology is an independent force or influence.

Among those who maintain that technology is still subordinate to society and human control is professor John McDermott, author of *Technology: The Opiate of the*

Intellectuals. McDermott sees technology not as an autonomous force, but as an "institutional system" of control that one group of people in society uses to control another (McDermott 1997, 90). Using the Vietnam War as an example, McDermott states that the greatest threat to society is not autonomous technology, but an elite group of people who manipulate and use technology to achieve the political goal of maintaining control (McDermott 1997, 90). Here the control issue in the humanity-technology relationship is such that one group of people exercises control over another by using technology as a manipulation tool.

While focused on communication technologies, Leila Green's *Technoculture: From Alphabet to Cybersex* demonstrates the complexity of the relationship between technology and humanity, arguing that technology is not neutral, but also that it is not an independent force operating outside or above humanity. Instead, Green writes, technology is closely linked to society. She demonstrates this by emphasizing the human involvement in the acceptance and adoption of new technologies as displayed in various ways by different technology cultures—industry, media, information—that interact and result in the wide disparities between cultures. Green underscores that it is not only society that is in control, but specifically the power holders of society that determine technology's influence.

Don Ihde's *Technics and Praxis* provides the middle ground between pure social determinism and technological determinism with a transformative approach. He emphasizes that neither the social nor technical approach is adequate to properly explain the relationship between humanity and technology and the corresponding influences, and offers instead a transformative perspective, where a nonneutral technology transforms rather than determines human experiences. Using different tools, he demonstrates how technology inclines humanity toward particular directions, with subsequent successes and consequences based on the experiences humanity has with the technology. Ihde's position gives more influence to technology than the social determinists, but still refrains from supporting the position that technology alone controls the direction of society.

Soft Technological Determinism

Political scientist Langdon Winner demonstrates the soft technological deterministic view by leaning closer to technological autonomy in *Autonomous Technology: Technics-out-of-Control as a Theme in Political Thought*. He views technology as a tool, but a tool that is illogical and erratic, one that has moved beyond human control because humanity has become indifferent toward it, as evidenced by society's willingness to follow where it leads. While technology may have moved beyond human control because of apathy, Winner believes humanity still has the capability of controlling technology because it is a tool.

The soft position is also illustrated by Robert Heilbroner in his article "Technological Determinism Revisited," found in Smith and Marx's *Does Technology Drive History*? Heilbroner emphasizes that technology plays a determinative role in the context of certain soft political and social preconditions, particularly economics, and imposes itself upon humanity. However, like Winner, he places a substantial amount of responsibility for the direction that technology takes squarely in the hands of humans.

Hard Technological Determinism

The theory of technological autonomy, or technology approaching a state of human-level autonomy, is possible, and only works if technology is reified. One of the pivotal intellectuals responsible for promoting the idea of reified technology is the world-renowned German philosopher Heidegger, whose life's work was the pursuit of understanding "being" or "existence." No discussion on autonomous unmanned combat air systems would be complete without including the ontological issues addressed by Heidegger in *Being and Time* and *The Question Concerning Technology.*

Heidegger is known for his work in the areas of ontology and the "essence of truth." *Being and Time* is his pivotal work, and it is a phenomenological analysis focused on understanding human existence. This is important for this study because it addresses the relationship between technology and humanity. While *Being and Time* is an extremely difficult book to understand due to the technical subject matter and the unique terminology Heidegger created in an attempt to communicate his understanding and perspective, the study of the human-technology relationship that he undertakes is instrumental in demonstrating the complexity of defining technological autonomy when comparing it to human autonomy. One of the many important contributions of this book is Heidegger's ability to draw attention to, and ask questions concerning, existence and the relationship between humanity and technology in the context of being and existence. This approach provides foundational material for technological determinists who embrace the idea that technology is a self-existent entity acting autonomously as a free agent apart from humanity. Heidegger's argument for technology having an existence that is manifested is important to address when considering the possibility of a machine's autonomous existence, or being, apart from humanity.

A follow-on work of Heidegger that focused specifically on the humanity-technology relationship is *The Question Concerning Technology,* a foundational piece that addressed technological autonomy. In this work Heidegger stated the purpose for writing his essay was to ask questions concerning technology, questions that focus on the relationship between humanity and technology, opening humanity to the existence of an "essence," or an agency imputed to technology, which he then described (Heidegger 2009, 9). His essence is an important concept for technological determinism and autonomy because it offers an explanation for why technology, *techné*, should not be viewed solely as a tool, instrumentally, but as something greater, an influence or force—a cause—with the reality of independent existence.[15] Hard technological determinists see this concept of independent existence of *techné* as part of the process of technological evolution where technology becomes more autonomous. As technology moves toward the possibility of true autonomy it questions the relationship between humanity and technology, particularly in the area of control. A little more time is spent on Heidegger in chapter three due to this focus on the ontological aspects of technology.

Similar to Heidegger, Ellul defines the agency imputed to technology as *Technique*. In his work *The Technological Society*, Ellul takes a strong stand for autonomous technology becoming an independent entity that could work its way beyond human control, stating that *Technique* is "external to man" and has "become autonomous" (Ellul

[15] Martin Heidegger is a difficult and technical philosopher. The views and opinions expressed in this study hardly scratch the surface of understanding the full meaning of Heidegger's works.

1964, xxv, 6). Ellul attributed agency to technology by stating that *Technique* possesses autonomy and directly impacts humanity, identifying it as artificial, self-determining, and independent of human intervention (Ellul 1962, 10; 1964, 141). As *Technique* becomes more efficient it decreases the need for human involvement, eventually evolving beyond human control. The hard technological determinists may see the process of efficiency associated with *Technique* as including the process of technological evolution, where technology is driving humans to depend more on the weapon system technology and less on human operators.

Technology, Humanity, and Control

In *A First Year in Canterbury Settlement With Other Early Essays,* Samuel Butler includes an 1863 letter he wrote to the editor of the *Press* in Christchurch, New Zealand, titled "Darwin Among the Machines." This short article, written under the pseudonym of Cellarius, introduces the concept that inspired his work *Erewhon,* a novel that contains three chapters about the evolution of machine consciousness by Darwinian selection. The article is important because it introduces the concept of technological determinism, comparing the fast evolution of technology against the slow progress of organic evolution, eventually culminating in the superior state of the machine over humanity, or an early form of Kurzweil's singularity.

As robotic autonomy evolves, the issues of human-machine relationships and control over technology come to the forefront, with some thinkers defending the position that technology will one day evolve beyond human control. With regard to this thinking, the paper "The Coming Technological Singularity: How to Survive in the Post Human

Era," by Vernor Vinge, is important because it defines the term *singularity*—a previously undefined word first used by mathematician John Von Neumann in 1958. The paper includes within the definition of singularity the idea of computers that are conscious and superhumanly intelligent. This particular term is eventually expounded on further by computer scientist and international authority on artificial intelligence Ray Kurzweil in *The Singularity Is Near: When Humans Transcend Biology*.

Kurzweil first addressed the issue of machine evolution in *The Age of Intelligent Machines*. This work provided the background required for understanding the development of artificial intelligence and the impact on humanity. Starting with the early creation of machines and artificial intelligence, Kurzweil traced their development up to the present, focusing on machines with superior capabilities due to exponential increases in speed and memory. He raised the question of whether AI represents the next stage of *evolution* (Kurzweil 1992, 218). In his work *The Age of Spiritual Machines: When Computers Exceed Human Intelligence,* Kurzweil saw AI fundamentally altering the way we live, with computers exceeding the memory capacity and computational ability of the human brain due to the exponential pace of a "human-sponsored variant of evolution, technology" (Kurzweil 1999, 14). Of course, such development brings into question how humans will be able to control such technology. In *The Singularity Is Near,* Kurzweil aligned himself with the hard technological determinists by continuing to examine the theory of technological evolution. His focus was on the "singularity" mentioned previously by Von Neumann and Vinge, in which human achievements merge with technology to produce a new entity that far exceeds the current capacity of both humans and technology. Kurzweil maintained that we are in what he termed Epoch Five, the beginning of the singularity, and that still to come is the robotics revolution, where "human-level robots with their intelligence derived from our own, will be redesigned to far exceed human capabilities" and will eventually lead us into a union of human and machine—a new species comprised of human biology (genetics) and computers, artificial intelligence, nanotechnology, etc.—resulting in a new level of consciousness and intelligence (Kurzweil 2005, 205).

The incredible speed at which this technology appears to be evolving is also addressed by Virilio in *Pure War*. His work of dromology—the logic and impact of speed—addressed the issues of technological autonomy and technological determinism by focusing on the impact that the speed of technological developments have upon humanity. Much of Virilio's work is relevant to this discussion because he focused on the military-industrial complex and the subsequent militarization of science, i.e., that humans are "disappearing in the technology and automation of the war-machine" (Virilio 2008, 33). His thesis about the relationship of speed and technological development also addressed the impact of technological evolution on society and the issue of humanity's ability to maintain control. He writes: "No more illusions about technology. We do not control what we produce" (Virilio 2008, 76). In *Future War,* an interview of Virilio conducted by James Der Derian, director of the University of Sydney's Centre for International Security Studies, Virilio expounds upon an idea similar to Kurzweil's, that humanity is on the verge of a new epoch in human history, a third industrial revolution, called "transplantation," in which technology will be anthropomorphized—that is, where technology will no longer be just around the body, but *within* the body as well, resulting in a biomachine, similar to Kurzweil's new human-technology entity.

While not prolific writers on this specific topic, three important contemporary thinkers—Stephen Hawking, Elon Musk, and Bill Gates—gained notoriety by using the media, a public academic symposium, and a popular social media site to convey their thoughts on the dangers of artificial intelligence. BBC reporter Rory Cellan-Jones's video interview of Hawking, "Stephen Hawking Warns Artificial Intelligence Could End Mankind," brought into the public sphere the world-renowned theoretical physicist's concern that technology is advancing to the point in which humanity will no longer be able to control it. In a similar manner, MIT Aeronautics and Astronautics Professor Jaime Peraire's moderated video session with Musk during the MIT AeroAstro 1914-2014 Centennial Symposium revealed the cofounder of Tesla Motors and founder of SpaceX had genuine concerns about the growing area of artificial technology, calling for national and international oversight to prevent things from getting out of control. And these sentiments were echoed by Microsoft founder Bill Gates during a Reddit Ask Me Anything session in January 2015. In the forum, Gates expressed his opinion that AI could become strong enough in a few years to be a concern—as well as his concern that people are not listening to the larger issues involved.

While it was not possible to explore every position and every work written on the subject, the literature used for this portion of the study proved essential for acquiring an appreciation of the various arguments and broad spectrum of stances taken with regard to the relationship and influences that exist between humanity and technology. The works selected also provide an important foundational understanding of the key elements related to the discussions and debates associated with autonomous weapon systems and human control, particularly the motivations for those who adhere to the hard technological determinist position. With an appreciation and strong foundation of the hard technological determinism position, the study turns to the past and current technological developments in unmanned aircraft, remote sensing, and artificial intelligence that contributed to the creation of the unmanned combat air system.

Development of Unmanned Flight

> *"A drone is often preferred for missions that are too 'dull, dirty, or dangerous' for manned aircraft."*
>
> — Nick Hahn

History and Development of Unmanned Flight

An essential reference tool used throughout this study is the Department of Defense (DOD) *Joint Publication 1-02, Department of Defense Dictionary of Military and Associated Terms.* As the Department of Defense is extremely large, consisting of multiple services, agencies, organizations, offices, and directorates, the terminology and definitions for similar things can be very different. This U.S. Department of Defense-level publication served as an official government source for approved military terminology, setting a standard for words, terms, and phrases used within the department and across the different military service branches. *Joint Publications* from different years were referenced throughout the study because terminology evolved within the DOD, and some terminology continues to be used even if it is no longer referenced in the most current publication.

Military Robots and Drones, by Paul Springer, assistant professor of comparative military studies at the Air Command and Staff College, was another reference handbook that provided detailed introductory information on a variety of topics related to the military application of unmanned systems. The work included topics on historical development, a detailed chronology, different international perspectives, and major issues and controversies, including human-machine-related issues associated with unmanned system development, biographical sketches of key developers, organizations related to unmanned systems development, and important documentation related to robotics, unmanned systems, and related policies. While not comprehensive in any particular area, this book provided an important stepping-stone for further research into many of the areas covered in this study.

Another valuable reference work was the *Biographical Dictionary of the History of Technology*, edited by Lance Day and Ian McNeil. This dictionary provided analytical biographies of more than a thousand historical persons who have had a significant impact in the development and advancement of technology. This work provided excellent material demonstrating the role of humans in the creation and advancement of different technologies. Each entry contained detailed biographical information on the individual, including the focus of their work and relevance of that work to their particular area of technological expertise and the impact they had in the development process.

War of the Aeronauts: A History of Ballooning in the Civil War, by Charles Evans, founding curator of the Hiller Air Museum, Redwood City, California, was an important work showing the value and numerous, differing military applications of the first aerial balloon forces used by both sides during the Civil War, activities that were instrumental in nurturing the growth of future military aerial operations. He clearly explains the role of pioneer aeronaut professor Thaddeus S.C. Lowe, and Lowe’s interaction with the new technology, including the control issues related to the early years of balloon operation. The work underscores the influence that Lowe and other aeronauts of the period had in adapting aerial operations for the military, activities that were key to developing future airborne intelligence collection and remote airborne sensing missions that would be adopted by future manned and unmanned aircraft.

Lawrence Newcome, former Air Force pilot and national UAV authority, wrote *Unmanned Aviation: A Brief History of Unmanned Aerial Vehicle,* an extremely useful survey of the historical development of the UAV, beginning with the 1918 Sperry Aerial Torpedo and ending with the Environmental Research Aircraft and Sensor Technology (ERAST) Program in 2002. Newcome's purpose for his book was to help stop the duplication of effort that has occurred in the UAV development programs by chronicling the evolution of the various systems (Newcome 2004, v). The work is short and covers much material; however, it is one of the only efforts to provide a semi-detailed chronological history of the UAV from shortly after the Wright brothers until 2002. While not intended to highlight the human-technology interaction during the development of unmanned systems, the issues, particularly those related to controlling unmanned flight, are clearly evident. Newcome's coverage of UAV military applications is especially helpful, with excellent coverage of the Vietnam War, but the combat application ends with the Bosnian Conflict, the period when proliferation of UAVs and autonomous operations was just beginning.

Radio engineer Benjamin Franklin (B.F.) Miessner's *Radiodynamics: The Wireless Control of Torpedoes and Other Mechanisms* provided insight into the context of the history and methods used in the early years of remote control development, including the valuable contributions made by Nikola Tesla. While Miessner's work focused on torpedoes, the concepts laid the foundations upon which radio-controlled aircraft would be developed and included the contributions of A.J. Roberts, the first person to apply the new technology to a dirigible balloon. This set the stage for future humanity-technology issues related to control that develop as pilots are removed from the airplanes, and the combination of mechanical and radio technology beginning to replace the human functions onboard.

Indispensable authoritative government documents related to the development and use of unmanned combat air systems came from the Department of Defense *Unmanned Aerial Vehicle Roadmaps*. During the early stages of DOD unmanned aerial vehicle development, the DOD created *Roadmaps* to provide a vision and direction for developing and employing Unmanned Aerial Vehicles (UAVs) and Unmanned Combat Air Vehicles (UCAVs). Included in the discussions of these roadmaps are the human-technology issues of unmanned aerial vehicle control, particularly in the context of weapon delivery. As the focus turned to the entirety of the system involved with UAVs, as well as the integration with ground, surface, and subsurface unmanned systems, the vision and direction evolved into the *Unmanned Systems Integrated Roadmap*. The purpose of the *Roadmap* is to provide an official, authoritative vision and strategy for the development, production, fielding, operational employment, and sustainment of unmanned systems technologies across the entire DOD. In addition to the employment of unmanned systems, the strategy addresses the future use of fully autonomous systems that can act outside human influence or control. While one might expect a government publication to be biased toward the use of unmanned systems, the *Roadmaps* provide a balanced perspective that include the pros, cons, dangers, and limitations of the human-machine relationship.

The Introduction to Unmanned Aircraft Systems, edited by aviation experts Richard Barnhart, Stephen Hottman, Douglas Marshall, and Eric Shappee, is an anthology similar to Paul Springer's work in that it contains a survey of a variety of topic areas from multiple authors. The difference is this book focuses on aircraft systems. However, it does not focus on military systems; instead it includes a wide variety of civil applications. Topics, many of which contain discussions directly applicable to the humanity-unmanned system relationship, include a brief history, regulatory and certification processes, UAV operations, autonomy, sensors and payloads, and sense and avoid systems. This book is another helpful tool in providing detailed introductory overviews with references to more detailed work for further research.

The architect of the NASA Aviation Safety Reporting System (ASRS), Dr. Charles Billings, a pilot and flight surgeon, wrote *Aviation Automation: The Search for a Human-Centered Approach,* a work directly addressing the human-technology relationship related to the automation of flight control systems. His work describes the development of aircraft automation and the effects on the human operators and managers of the system. While focused on automation of manned aircraft, he provides valuable information on the historical development of automations that had direct application to the development of future automated unmanned systems.

U.S. Air Force Fact Sheets, from the U.S. Air Force and National Museum of the U.S. Air Force websites, provide valuable historical and technical information on specific unmanned systems, as do specific electronic object descriptions, e.g., the *Henschel Hs*

293 A-1 Air-to-Surface Missile, from the Smithsonian National Air and Space Museum collections. The opportunity to visit and examine many of the unmanned combat air systems at the National Museum of the U.S. Air Force provided unique human-machine interactions, insights, and perspectives that could not be obtained from the fact sheets alone, e.g., firsthand observations providing perspective of the size differences between UAVs, such as the World War I-era *Kettering Bug* and the *Global Hawk* operating in the 21st century, or the payload capacity of the Vietnam-era *Lightning Bug* and the *Predator* used in the Global War on Terrorism.

Military Application of Unmanned Flight

John David Blom's paper, "Unmanned Aerial Systems: A Historical Perspective," written for the U.S. Army Combined Arms Center, provides a detailed historical description of the development of unmanned aerial vehicles for the U.S. Army. Beginning with 1917, Blom describes the Army's use of aerial platforms for reconnaissance, and then focuses his study on the development and integration of UAV technology for military applications, specifically as a support to Army ground units, from World War II to operations in Iraq and Afghanistan in 2007. While this resource is Army-centric, Blom's work provides valuable data on the human-UAV interaction during combat applications, as well as a detailed bibliography that provides valuable military-focused sources.

The Evolution of the Cruise Missile, by former Air Force pilot and history professor Kenneth Werrell, provides a comprehensive history of the origin and technical development of the cruise missile, an important element in the development of unmanned aircraft because of the initial intent of such aircraft to be used as flying bomb, e.g., the Sperry Aerial Torpedo and Kettering Bug. While the focus is on cruise missiles, Werrell's work provides valuable details on the early mechanical workings of the onboard mechanisms involved with reaching altitude and maintaining unmanned flight, contributions that would have bearing on the future human-technology issue of control.

Historians James Rife and Rodney Carlisle wrote *The Sound of Freedom: Naval Weapons Technology at Dahlgren, Virginia 1918-2006,* recounting the story of the U.S. Navy's research and development (R&D) effort at the Naval Proving Ground in Dahlgren. Included among the many types of naval ordnance and weapon technology testing was the attempt to develop automatic and remote-controlled aircraft that could serve as an unmanned weapon, i.e., the aerial torpedo, a forerunner of what would become cruise missiles and UAVs. Rife and Carlisle's work provides valuable insight into World War I and early World War II efforts to separate the human from the aircraft to create operational UAVs.

Naval Research Laboratory historian Angelina Callahan's article "Reinventing the Drone, Reinventing the Navy, 1919-1939" in the *Naval War College Review* was useful as it revealed the technical developments of the U.S. Navy's early radio-controlled unmanned aircraft efforts during the interwar period, including the failures associated with removing the pilot from the cockpit. An interesting aspect of the Navy's effort detailed by Callahan's article is the reuse of technology in failed projects for new R&D that contributed to the development of early UAVs during World War II.

The short article "The Queen Bees," by Robin Braithwaite, former RAF aircraft engineering technician, in the June 2012 issue of *Light Aviation*, provides valuable insight into the technology and operations of pre-World War II remote-controlled target drones. Braithwaite uses the last surviving airworthy *de Havilland DH.82B Queen Bee, LF858*, based at RAF Henlow, England, to not only provide a historical description of the *Queen Bee*, but also to describe radio control workings as well as the relationship to the mechanical linkages, an aspect of the technology that allowed this early drone to be controlled by humans on the ground.

Air Force pilot, historian, and professor Dik Daso wrote *Architects of American Air Supremacy: Gen. Hap Arnold and Dr. Theodore von Kármán,* providing insight into the founding and early development of the U.S. Air Force science and technology efforts. Daso's work provides a narrative of two key personalities involved with molding U.S. airpower technologies through World War II, providing valuable information into the Army and Navy unmanned combat aircraft programs code-named Operation Aphrodite and Project Anvil. The efforts clearly demonstrated the dangers inherent in the human-technology relationship, not only in the loss of aircraft as the technology was being developed, but also to the human pilots who lost their lives in the early years of weaponizing remote-controlled aircraft, i.e., the flying bombs that were precursors to later military efforts to create cruise missiles and unmanned aircraft.

The chapter "History," in Richard K. Barnhart's *Introduction to Unmanned Aircraft Systems*, was written by Army aviator Charles Jarnot, and provides a survey of unmanned aircraft systems, from the ideas introduced by Tesla in the 1890s to the operational deployments of the *Pointer* and *Pioneer* UAVs used in the 1991 Desert Storm operation. In regard to the human-technology relationship, Jarnot provides important insights into why the Department of Defense decided to keep pilots in the loop of unmanned aerial systems, despite the technical capability to conduct autonomous operations. The weakness of this work was the minimal amount of references, requiring additional research to verify the accuracy of some of the historical references.

The article "A Brief History of Early Unmanned Aircraft," in *The Johns Hopkins APL (Applied Physics Laboratory) Technical Digest*, by APL staff members John F. Keane and Stephen S. Carr, provides an insightful historical survey on the early development and military application of UAVs. An interesting aspect of this article is the recognition and brief discussion of how the technological developments used in the creation of cruise missiles and UAVs were intertwined, although the discussion does focus on the UAV. The human-technology interaction is inherent in this work, starting with World War I, where Keane and Carr describe the early development of UAVs for three specific missions: 1) as aerial targets, which removed the human from the danger of being wounded or killed while towing targets; 2) nonlethal intelligence, surveillance, and reconnaissance missions, so human pilots could avoid being shot down; and 3) as unmanned combat air vehicles (UCAVs), where armed UAVs could deliver weapons in hostile territories. A key contribution of this work, unlike many other UAV histories, is the valuable information provided on the role of UAVs during the Korean War.

The most comprehensive historical work on Vietnam-era unmanned aerial vehicle combat operations, and the one that addressed many of the different issues associated with the human-UAV relationship in the most detail, was *Lightning Bugs and Other Reconnaissance Drones: The Can-Do Story of Ryan's Unmanned Spy Planes* by William Wagner. This book is unique because of Wagner's insight and firsthand experience watching and participating in the development of military UAVs, and his experience gained because of his association with Ryan aeronautical, subsequently Teledyne-Ryan, since 1936. These companies were pioneers in the U.S. UAV market, manufacturing the Ryan 147 *FireBee* drones used by U.S. Air Force, Navy, and Army during the Vietnam War. Wagner's work gives firsthand accounts of the human-technology trials and tribulations encountered, starting in the late 1950s when, for the first time, technicians on the ground—or flying onboard control aircraft—replaced pilots by flying jet aircraft remotely to conduct a variety of military combat missions. The book chronicles the technological developments and evolution of the 19 different Teledyne–Ryan variants. The drawbacks of the book are the lack of references—it was written by a company that helped create the drones—and the lack of technical details on specific onboard systems, e.g., the working aspects of the autopilot, onboard computer, and remote sensing systems. This was most likely due to the classification levels of much of the information while the book was being written.

The sequel to *Lightning Bugs and Other Reconnaissance Drones* is *Fireflies and Other UAVs (Unmanned Aerial Vehicles)*, written by Wagner and cowriter William Sloan, another Ryan-Teledyne employee with roots in the late 1930s. This book covers the period of UAV development from the end of the Vietnam War until 1992. Like its predecessor, the work makes it easy to see the human-technology issues associated with the continuing evolution of the UAV programs, including the human political decisions that affected development of the associated technologies. A particularly interesting topic covered in this material was the history of the development and operational deployment of the Model 124I for the Israel Defense Force. As discussed later in the study, it was the Israelis who helped spark increased interest in, and had a significant impact on, the development of a UAV system that would transition into the U.S. Air Force *Predator*, one of the most prolific UAV systems used by the U.S. military. Because this is a historical narrative, the work suffers from the same deficiencies as Wagner's first work: lack of reference material and few technical details of particular onboard systems.

In the 1999 U.S. General Accounting Office report to the Secretary of Defense, *Unmanned Aerial Vehicles. DOD's Demonstration Approach Has Improved Project Outcomes*, Louis Rodrigues, director of Defense Acquisition Issues, provided valuable information on the DOD's adoption of the Advanced Concept Technology Demonstration (ACTD) strategy for assessing new UAVs. In the course of providing a positive report on the new strategy, the report gave a historical survey of the *Predator* technical development processes, the beginnings of the *Global Hawk* UAV program, the *RQ-3 DarkStar* program (subsequently cancelled), and brief surveys of previous (before the ACTD process) UAV programs, including the *Aquila*, *Pioneer*, and *Hunter*. The report also contains a list of programs that were started and canceled before completion. While not detailed, and not written to specifically address the human-technology issues, the report provides information that was difficult to obtain in other sources.

Smart Weapons by Hugh McDaid, a filmmaker, and David Oliver, former editor of *British Air Forces Monthly* magazine, provides a strong historical overview of the UAV technologies using official government sources such as the DOD and NASA. The work did not add new insights into the human-technology relationship previously discussed, but it did provide historical coverage that ranged from Langley's steam-powered, unmanned heavier-than-air flying machine in 1896 to the *RQ-1 Predator* missions during the 1996 NATO air campaign in Bosnia. It also included mention of some of the programs that have since been discontinued, such as the *HiMAT* mini jet fighter and the *RQ-3 DarkStar* UAV; these programs are not often covered in other works. This book is also a strong introductory source of information on the programs of other countries, such as Russia and China. (There is an extensive web links list in the appendix, but many sites were dated and no longer viable.)

Development of Aerial Remote Sensing

> *"The idea of aerial military surveillance dates back to the Civil War, when both the Union and the Confederacy used hot-air balloons to spy on the other side, tracking troop movements and helping to direct artillery fire."*
>
> — Michael Hastings

History and Development of Remote Sensing

Albert Van Helden's 1977 article "The Invention of the Telescope," in *Transactions of the American Philosophical Society*, was an important reference for the introduction of remote sensing and a vital contribution showing the impact of the earliest form of remote sensing technology and the lasting effect on humanity and the art of war. Van Helden, who had a technical background and spoke five languages, began this project with the original intent of translating Cornelis de Waard's 1906 work *De uitvinding der verrekijkers*, a history on the origin of the telescope. However, during the translation process, Van Helden uncovered many other primary documents collected by Waard and decided to translate all of them. His work became a definitive reference in English for the origin of the first precision optical instrument that can be considered "the prototype of modern scientific instruments" (Van Helden 1977, 5). In a discussion of the influence of remote sensing technology and its impact on humanity, particularly with regard to the issue of control, it was important to begin with references from Van Helden.

His work helps explain the telescope's important contribution to the science of observation and the future military applications that were put into effect almost immediately after its introduction.

Richard Dunn, curator of the History of Navigation at the National Maritime Museum, Greenwich, wrote *The Telescope: A Short History*. Despite the name, the book's 192 pages, which include many pictures and illustrations, chronicle the evolution of the telescope from the pre-telescope era to space-based astronomical telescopes. An important contribution to this study was Dunn's specific attention to the speed with which Galileo, soldiers, and sailors recognized the important military applications of the instrument, particularly for aiding in celestial navigation and observation of the battlefield, uses that set a firm foundation for the development of military remote sensing systems.

In the Internet article "Remote Sensing," Steve Graham, from the NASA Earth Observatory, provides a brief introductory overview of U.S. remote sensing. The Earth Observatory is part of NASA's Earth Observing System (EOS) Project Science Office located at NASA's Goddard Space Flight Center in Greenbelt, Maryland. The site does not address the human-technology issue directly, but it does provide official definitions, descriptions, history, timelines, accomplishments, and descriptions, in laymen terms, of the science, theories, and methods related to U.S. Government remote sensing activities. The site also provides links to other NASA sites. Graham does not address the human-technology issue directly, but the material serves as an excellent launching point for further research.

The U.S. Department of the Interior's U.S. Geological Survey website contains a Science Topic tab that holds a Remote Sensing anthology, a helpful place to visit after reading the NASA remote sensing article. This site is valuable for researchers as it contains a wealth of information, almost 250 articles and links to other sites at the launching point alone, providing excellent government material on many aspects of remote sensing, from aerial photography to hyperspectral imaging. The information comes in report or product (images, photos, data, etc.) form. Each link leads to still more links, usually with additional downloadable material available. In addition, each site contains subtopics and related topic sites, e.g., clicking the microwave imaging link on the remote sensing page brings you to downloadable data display software. On that page there is a Special Sensor Microwave/Imager (SSM/I) subtopic link, as well as links to geography and radar imaging under the related topics section. This site provides an excellent resource to find examples of the remote sensing technologies discussed in this study.

Remote Sensing of the Environment: An Earth Resource Perspective, by Dr. John R. Jensen, Carolina Distinguished Professor of Geography at the University of South Carolina, introduces the fundamentals and a brief history of remote sensing. The work spanned from Gaspard-Felix Tournachon's first aerial photograph taken from a balloon in 1858 to the use of remote sensing systems onboard UAVs today, emphasizing the literal and nonliteral capabilities, e.g., optical, thermal infrared, multispectral, and Light Detection and Ranging (LIDAR). Jensen conducts a thorough review of the nature of the electromagnetic spectrum, discussing electromagnetic radiation and how the reflected or emitted energy in the visible and nonvisible portions of the spectrum are collected using a variety of remote sensing instruments, to include those that are placed on aircraft. The discussion demonstrates how these technologies not only replicate human vision, but far surpass it, and how the storage systems have roles similar to the human brain, storing and retrieving the data collected. When talking about the advantages of remote sensing capabilities, Jensen underscores one of the greatest advantages of passive, nonliteral remote sensing as collection against targets without their knowledge, as it "does not disturb the object or area of interest" being sensed (Jensen 2007, 7). While the work emphasizes the use of remote sensing for biophysical or socioeconomic information purposes, it does demonstrate why these clandestine capabilities are vitally important for the success of unmanned military ISR operations.

John R. Schott, professor of imaging science and director of the Digital Image and Remote Sensing Laboratory at the Rochester Institute of Technology, also deals with the fundamental issues in the field in *Remote Sensing: The Image Chain Approach*. Like Jensen, Schott explains the electromagnetic spectrum and reviews the nature of electromagnetic radiation, reflected and emitted energy, and the visible and nonvisible bands, tools, and procedures required to extract literal and nonliteral data using a variety of sensors. He also examines different applications of remote sensing, including nonliteral spectral image analysis and processing. Schott's work emphasizes the utility of remote sensing technology's ability to extract data that is beyond human sensory capability, for instance multispectral data, where "the human's ability to quantify becomes even more restricted compared to the potential information content . . . one area where machines are much more adept than humans" (Schott 2007, 26).

Virginia Tech Geography Professor James B. Campbell and Forest Resources and Environmental Conservation Professor Randolph H. Wynne have written an excellent foundational, yet very detailed, introductory textbook on remote sensing and image processing titled *Introduction to Remote Sensing, 5th ed*. The authors start with definitions, a short history of the development of remote sensing starting with photography in the 1800s, quickly move through military applications during the major wars, and then move into civil applications. Like other works on the subject, the textbook then focuses on basic physics of electromagnetic radiation and covers image acquisition from aerial photography to LANDSAT satellite systems, analytic techniques, and applications specifically in the plant, earth, and hydrospheric sciences. While Campbell and Wynne provide excellent coverage of the science and sensors associated with both the literal and nonliteral remote sensing systems, there is a noticeable lack of information related to military applications, and only three pages on unmanned aerial vehicle remote sensing systems. However, the human-technology-related elements outlined in this study, while not specifically addressed as such, are inherent in the subject matter.

The “Multispectral Imagery” chapter in the *Air University Space Primer*, with a foreword by Air Force Colonel James G. Lee, the Air University Space Chairman, offers an excellent reference source for Multispectral Imagery (MSI). The *Primer* provides a history of MSI from its growth out of the infrared technology of the 1960s to its use on LANDSAT 7 in 1999. This is followed by a detailed discussion on theory, starting with the basics of the electromagnetic spectrum related to MSI, demonstrating the capabilities of the technology that are well beyond human sensory capabilities and ending with discussions on orbital characteristics and space environmental effects on the technology. The work also explains the military applications of MSI, including mission planning, thermal signature detection, terrain analysis, image mapping, navigation, and targeting, providing historical examples of its use during military missions and engagements. The chapter ends with a discussion on the availability of the data and the finished products (reports, images, etc.) produced by MSI systems.

Getting the Message Through: A Branch History of the U.S. Army Signal Corps by Rebecca Robbins Raines, historian at the U.S. Army Center of Military History, documents the history of the U.S. Army Signal Corps from the Civil War through its participation in the 1990-1991 Persian Gulf War. This work was important to include because the advancement of military signals technology greatly impacted the future development of both unmanned flight and remote sensing. At the start, this technology was intimately united with the human in the form of Morse code keys, earphones, microphones, etc. However, as the technology improved, the signals themselves would be used to operate machines remotely, enabling the removal of humans from the communications loop. This work demonstrates how communications technologies replicate human vocal and hearing capabilities, allowing information collected aloft to be quickly transmitted to the ground. In addition, this technology became a remote sensing capability in itself, used to collect radio and radar transmissions. Radar, an offshoot of radio, evolved from signals technology, enabling the creation of a number of different types of remote sensing capabilities, including the advanced synthetic aperture radar used by the military today to create images at night and during inclement weather.

Aerial Remote Sensing

A helpful resource for providing an introductory overview of the history of aerial remote sensing is geography professor Paul Baumann's Geo/SAT 2 instructional module *History of Remote Sensing, Aerial Photography*. This online module from the Department of Geography, State University of New York, College at Oneonta, provides a historical overview, from Joseph Niepee's first photograph in 1827 to the 1960 shoot-down of American pilot Gary Powers in the U-2 reconnaissance plane over the Soviet Union. There is a significant amount of data on the evolution of airborne imagery technology; however, the impact of automation on the human-technology relationship is only briefly mentioned, as this was not the purpose of the module. A major drawback of this material was the lack of any references, requiring tedious research to find the primary source material for the relevant topics for this study.

John Tennant's article "Aerial Photography," in the 1903 *The Photo-Miniature* magazine, provides a wealth of information on pre-World War I-era technology, addressing in an indirect way many of the opportunities and challenges brought about by human-technology interaction. The article includes a brief description of the new capability, and how it can be used from balloons, kites, large buildings, and perhaps even via Langley's "gigantic aeroplanes" should the secret of flight, from Tennant's perspective, ever be uncovered (Tennant 1903, 144). His work also discusses some potential applications, including meteorology, cartography, surveying, and use in warfare, moving into discussions of specific pieces of camera equipment and methods of exposure and development. A historical timeline is provided with key pioneer contributions. A noteworthy section addressing the human-technology interface deals with the sensation of flying and the particular issue of vibration while trying to photograph. Also contained within the work are numerous—and very clear—aerial photographs.

Military Applications of Aerial Remote Sensing

Dr. R.C. Olsen, a physicist at the U.S. Naval Postgraduate School, focuses on the military and intelligence applications of remote sensing systems in *Remote Sensing from Air and Space.* In addition to covering the basics of the electromagnetic spectrum and physics behind literal imagining sensing technology, Olsen provides information on nonliteral sensing technology, including both thermal infrared and radar, e.g., explaining the difference between literal (normal, visual information) and nonliteral (metadata found within the data from the electromagnetic spectrum), "Infrared imagery differs from visible in two big ways: thermal infrared works at night, and mid-wave infrared (MWIR) and long-wave infrared (LWIR) data allow for nonliteral information [to be seen and collected]" (Olsen 2007, 20-21).

Unlike Campbell and Wynne's work, *The Phenomenology of Intelligence-Focused Remote Sensing, Volume 1: Electro-Optical Remote Sensing*, by Howard Evans, James Lange, and James Schmitz, is focused on the military and intelligence applications of remote sensing phenomenology and sensor systems. Created under a cooperative research and development agreement between industry and the Air Force Institute of Technology, the authors, all PhD remote sensing scientists, provide an in-depth, graduate-level look at the science—the same science discussed in the three previous works—behind the sensing and the direct application to intelligence collection and analysis. The work quickly covers the history and evolution of military remote sensing, then dives deeply into the science and phenomenology, covering the electromagnetic spectrum from the visible through the nonliteral imagery bands, making references and comparisons to the human capabilities that the technology replicates and surpasses. It then addresses advanced technical intelligence collection systems, the associated data processing systems, and military intelligence analysis and exploitation techniques. While it is a wealth of information, this work also is a highly scientific approach that is filled with mathematical formulas.

Civil War aviation expert professor Frederick Stansbury Haydon's *Military Ballooning During the Early Civil War*, first published in 1941 as *Aeronautics in the Union and Confederate Armies, Vol. 1*, is a comprehensive work on the creation of the U.S. Balloon Corps and the Confederate military's balloon operations during the Civil War. His book explains the value of aerial observation during warfare, as well as the different methods used for transmitting information observed from the air to the ground, including communications technology in the form of Morse code. His work also is important for refuting the oft-repeated statement that aerial photographic reconnaissance began during this conflict. The interesting human-technology issues addressed in this work include the challenges of controlling the balloons, the training of the soldiers responsible for operating the balloons, and the various degrees of acceptance by the military of the new technology.

James B. Campbell's article "Origins of Aerial Photographic Interpretation, U.S. Army, 1916 to 1918," in *Photogrammetric Engineering & Remote Sensing*, was key to understanding the impact of integrating photography with aircraft. Using official histories and archival materials, Campbell describes the development of military airborne photointerpretation in the U.S. Army during World War I, showing how "within a few years of intense innovation, the camera and the airplane were integrated to form, arguably, the most effective intelligence resource of the conflict" (Campbell 2008, 77). His article also highlights the close initial involvement of the human with the technology, as demonstrated through manual flying, handheld cameras, and film development, followed by the subsequent introduction of early automated camera capabilities, removing the observer and allowing pilots to fly and photograph, thus beginning the human-technology separation process.

The impact of the development of mosaics—overlapping vertical photos aligned together—and stereoscopes, a device used to view two separate images simultaneously created from aerial imagery, was explained in Dan Gettinger's article "The Ultimate Way of Seeing: Aerial Photography in WWI." Writing for the Center for the Study of the Drone at Bard College, Gettinger points out that these capabilities enabled early human "pattern of life" analysis using soil displacement or shadows to help identify human activity related to trench building, artillery battery emplacements, and troop movements. The article underscores technology's replacement of the human and horse, as aerial photoreconnaissance replaced the traditional methods of cavalry reconnaissance. This short article also had some excellent WWII-era photographs complementing the written material.

A History of Air Warfare, edited by John Andreas Olsen, is a collection of 16 essays written by various airpower historians and authorities that covers the history of air warfare from WWI to 2006. While lacking in the technical details of the intelligence, surveillance, and reconnaissance capabilities, the book does a very good job at following the progression and integration of airborne reconnaissance in aerial operations, from the early photoreconnaissance missions of World War I to the MQ-1 Predator missions in Operation Iraqi Freedom, demonstrating the steadily increasing separation of the human from the battlefield due to the remote sensing capabilities.

In *A Radar History of World War II: Technical and Military Imperatives*, Louis Brown, physicist-emeritus at the Carnegie Institute, described the historical development and revolutionary impact that radar had on warfare. This particular surveillance technology increased the range of nonliteral coverage even further beyond the physical limitations of the human eye, introducing a highly effective remote sensing capability that significantly changed the way wars were fought (Brown 1999, 6). This innovative technology no longer required the weapon systems operator to visually see the enemy combatants they were targeting; instead, the targets picked up beyond visual range were displayed in the form of electrical dots or blips on a radar screen. The technology began to replace the human requirement to find, track, and target the enemy from long distances. Eventually this technology was put on aircraft and then on unmanned aircraft.

The previously mentioned *Lightning Bugs and Other Reconnaissance Drones: The Can-Do Story of Ryan's Unmanned Spy Planes* by Wagner, and the sequel *Fireflies and Other UAVs (Unmanned Aerial Vehicles),* by Wagner and Sloan, also provide exhaustive histories of the military applications of aerial remote sensing by UAVs during and after the Vietnam War. These are included in the narratives describing UAV development during those time periods.

Frank Strickland, senior officer of the CIA's Directorate of Science and Technology, wrote the article "The Early Evolution of the Predator Drone" as an unclassified extract in *Studies in Intelligence*. This article provided detailed information on the development history of the *GNAT 750* unmanned aerial vehicle and its evolution into the *Predator*, the U.S.'s first operational long-endurance unmanned aerial vehicle. The importance of this article, besides the firsthand account of Israel's Abraham "Abe" Karem and his team's contribution to the design and development of the systems, was the chronicling of the success of integrating unmanned aircraft, remote sensing capabilities, and the ability to stream live video from a platform over Europe to Washington, D.C. The impact on the technology-humanity relationship was revolutionary for UAV operations, for neither the UAV pilot nor the intelligence analysts who exploited the full-motion video were required to be in the same area of the world as the UAV to conduct their missions.

In the Congressional Research Service (CRS) 2003 report "Unmanned Aerial Vehicles: Background and Issues for Congress," CRS research associate Elizabeth Bone and specialist in national defense Christopher Bolkcom provided Congress a detailed description of America's UAV programs. While focused on program status and financial issues for each of the operational UAVs, this document provides an excellent historical overview of UAV development and a significant amount of factual data on all of the individual UAV programs, ending in 2003.

The CRS 2012 Congressional report "U.S. Unmanned Aerial Systems," by Jeremiah Gertler, specialist in military aviation, provides detailed data about the legacy, new (*MQ-9 Reaper* and *Global Hawk*), and future (*X-47B* and *Airships*) systems, and additional discussion of autonomous operations, including a ten-step autonomous capability level (ACL) chart that ranges from remotely guided to fully autonomous swarm. An important topic in this report is one underscoring the significant gap between human control and fully autonomous control deals with multiple UAV or swarm capabilities. For example, according to the report, on the autonomy scale, in order for a UAV to achieve maximum use when flown by one pilot, it should be at least at level 8; however, the *Global Hawk* platform, the most autonomous operational UAV, flies only at a 2.5 (Gertler 2012, 20). If the "see and avoid" technology were developed to allow a UAV to operate autonomously, that would potentially raise the ACL to only a level of 4.

The working definition for Intelligence, Surveillance, and Reconnaissance (ISR) is found in the *Joint Publication 1-02* mentioned above: "an activity that synchronizes and integrates the planning and operation of sensors, assets, processing, exploitation, and dissemination systems in direct support of current and future operations" (U.S. Department of Defense JP 1-02 2010, 169). This integrated intelligence and operations function includes the use of remote sensors. ISR operations using remote sensors provide accurate, relevant, and timely intelligence to combat commanders and senior-level decision-makers, providing them with much needed information and the situational awareness necessary to successfully plan, make decisions regarding, and carry out military operations. An important discipline of ISR, and one that collects, analyzes, and disseminates an enormous amount of remote sensing data, is Geospatial Intelligence, known within the intelligence community as GEOINT.

Title 10 U.S. Code §467 Definitions provides the U.S. Government's definition for GEOINT: "the exploitation and analysis of imagery and geospatial information to describe, assess, and visually depict physical features and geographically referenced activities on the Earth. GEOINT consists of imagery, imagery intelligence, and geospatial information."

The National Geospatial-Intelligence Agency (NGA) produced the *National System for Geospatial Intelligence, Geospatial Intelligence (GEOINT) Basic Doctrine, Publication 1-0,* providing guidance on all matters related to GEOINT. This important publication states that the military services, as part of the National System for Geospatial Intelligence, conduct GEOINT-related ISR missions, with the U.S. Air Force being the lead service conducting airborne GEOINT missions. The Air Force, as a prime developer and user of ISR remote sensors, also provides doctrine and guidance on the use of these systems. The relevance to UCAS development is not only the integration of the ISR payload, but also the capabilities which can give "sight" to a machine through the various remote sensing imagery technologies.

Air Force Doctrine Document 2-9, Intelligence, Surveillance and Reconnaissance Operations describes the two primary imagery intelligence types affiliated with GEOINT today: the optical, or *literal*, image and the non-optical, or *nonliteral*, image. The nonliteral imagery includes infrared, multispectral, and radar imagery, all of which are collected by remote sensors that detect emissions in the nonvisual portion of the electromagnetic spectrum (U.S. Air Force Intelligence, Surveillance and Reconnaissance Operations Doctrine Document 2-9 2007, 23).

Computer, AI, and Autonomous Technology Development

"Computers, like automobiles and airplanes, do only what people tell them to do."
— Bill James

History and Development of Computer Technology

Jack B. Copeland, director of the Turing Project at the University of Canterbury, New Zealand, is co-director, along with Diane Proudfoot, of AlanTuring.net*,* a large repository of digitized original documents written by Turing and other pioneers in the fields of computing and artificial intelligence. Within the net is an article written by Copeland, "A Brief History of Computing." This piece provides foundational information on the origin of computing and computing machines, starting with Babbage in 1828. It covers the evolution from analog through mechanical, electro-mechanical, electronic, and digital, ending with a brief discussion on high-speed memory. The article is short but provides a quick review or primer prior to launching into the archives of the site. Copeland is also editor of the anthology *Colossus: The Secrets of Bletchley Park's Codebreaking Computers,* which contains numerous articles derived from previously classified documents focused on the first electronic computer built by the British Secret Service during World War II. The relevant information derived from Copeland's materials is the speed at which the computer revolution takes place, and the important role it plays in military intelligence.

Robert Sedgewick and Kevin Wayne's book *Algorithms, 4th edition*, is considered a leading textbook on the subject. Beginning with the fundamentals of basic programming, it surveys the most prevalent and important computer algorithms used today. The work is important for this study because, as an authoritative book used by many colleges and universities, it defines computer program as a finite and deterministic method to solve a problem. It also defines algorithm as a finite set of logical rules followed in order to solve a mathematical problem, thus laying the foundation for an argument that computers are finite calculating tools and not sentient creations or beings capable of human autonomy.

Lawrence Bernstein and C.M. Yuhas's article "Design Constraints That Make Software Trustworthy," in the 2008 Institute of Electrical and Electronics Engineers (IEEE) Reliability Society Annual Technology Report, provides suggestions for constraints on software design to attempt to increase the probability of creating a more reliable software. A key element of this article focuses on the human-machine interface and the significant issues associated with software failures that cause crashes and lost data. The authors' point is that constraints need to be introduced because humans cannot ensure the outcome of even the small changes they make to software, outcomes that can range from unexpected, strange behavior to hang-ups and crashes, results that can occur even when fixes and upgrades are introduced, providing significant obstacles to AI development.

In "ESC.Java2 as a Tool to Ensure Security in the Source Code of Java Applications," found in *Software Engineering Techniques: Design for Quality*, Aleksy Schubert and Jacek Chrzaszcz address software checking tools like ESC/Java2 that can be used to ensure source code security properties of Java programming language applications. The pertinent information for this study is the human element. The authors explain the difficulty with software bug detection, citing that even the tools and techniques employed to detect software errors may have errors in them as well. After providing a case study for their tool, they write that the techniques employed in their case study are still quite time-consuming and could use additional tool support, and that the end result is only certain bugs and source code deficiencies can be discovered. This also illustrates the complexity of the human-machine relationship in coding and the issues affiliated with creating reliable AI software.

Paul Springer's *Military Robots and Drones*, referenced in the Development of Unmanned Flight section above, also provides introductory material on robotics, autonomy, and artificial intelligence related to unmanned aerial vehicles and autonomous weapon systems.

Development of Artificial Intelligence

Artificial intelligence and robotics expert Dr. Ronald C. Arkin, in *Behavior-Based Robotics,* introduces the principle of intelligent behavior-based autonomous robotic systems, highlighting the application of the integration of knowledge and behavior-based learning in autonomous robots. He also emphasizes the importance of sensors in artificial intelligence, stating that enabling advances in robotic and sensor hardware has made it feasible to test the behavior-based robotics community's hypothesis that sensing and acting within the environment is important to AI-related robotics research (Arkin 2000, 15). Arkin demonstrates that robots, combined with prior knowledge models (deliberate reasoning) and representational world models (using incoming sensor data), are more capable of making decisions and adapting to a dynamic environment such as a battlefield (Arkin 2000, 20).

Dr. Robin Murphy, director of Texas A&M University's Center for Robot-Assisted Search and Rescue and a foremost expert on robotic research, addresses AI robot applications involving sensing in *Introduction to AI Robotics*. Murphy discusses what she calls the three paradigms of AI robotics: hierarchical, reactive, and hybrid deliberative/reactive, explaining the importance of sensors in the deliberative/reactive paradigm, e.g., computer vision and range sensing, needed to allow a machine to operate autonomously, i.e., without requiring recourse to a human operator (Murphy 2000, 4).

The article "Building Watson: An Overview of the DeepQA Project" in *AI Magazine*, by David Ferrucci, et al, is a comprehensive account of the research and development activities involved with the building of IBM's Watson deep question-answering (DeepQA) computer before it beat the reigning human champion on the TV quiz show *Jeopardy*. The article is germane to this study because the computer Watson—along with being something of a cultural phenomenon—is a technological accomplishment that has revolutionized QA processing, resulting in many helpful applications in the fields of medicine, business, and even military intelligence. The authors explain the workings of DeepQA, demonstrating the complexities in the programs, algorithms, hardware, natural language processing, machine learning, and parallel processing required to rapidly understand a question, and then find, sort, order, and retrieve answers from large amounts of unstructured data. The article describes the three-year research and development process the team of 20 researchers used to achieve success, highlighting their work in integrating multiple algorithms, using more than 100 different techniques for analyzing natural language, identifying sources, finding and generating hypotheses, finding and scoring evidence, and merging and ranking hypotheses. The article also describes Watson's limitations as well as the restrictions it operated under to compete against the humans, e.g., no questions containing audio-visual components and no special instruction questions requiring explanations before being asked. The accomplishment of performing at human expert levels in terms of precision, confidence, and speed on the *Jeopardy* game were real and unprecedented, but the authors' article underscored that even Watson's accomplishments remain a long way from achieving true AI that would replicate human cognition.

The frequently asked questions page on the "Deep QA Project" page of IBM's research website was an excellent source for clarification on Watson, as it was published prior to the *Jeopardy* competition. The company explains that Watson is not an AI computer like the iconic HAL in the movie *2001: A Space Odyssey*, but more like the *Star Trek* computer where humans obtain precise answers to questions via an interactive dialogue with a computer that uses natural language processing. As previously mentioned, Watson searches through large quantities of digitally encoded unstructured information—information from disparate sources like natural language documents, intranets, reference books, textbooks, technical reports, blogs, and more—to "rapidly answer and rationalize open-domain natural language questions confidently, quickly and accurately, a capability once considered the exclusive domain of human intelligence" (IBM 2015b, 1). The company admits the difference between computers and humans, explaining that computers find it very difficult to do what humans do naturally, i.e., "deal with variety, ambiguity, subtlety, breadth and expressiveness of human language and meaning" (IBM 2015b, 1). Related to this is the "What Is Watson?" page, a site providing helpful video tutorials that explain how Watson works, as well as its capabilities and limitations.

The paper "Scalable Models for Patterns of Life," written by J.T Folsom-Kovarika for the Proceedings of the Twenty-Fifth Innovative Applications of Artificial Intelligence Conference, focuses on the dificulties modeling human patterns of life, i.e., the observable patterns of regularity associated with human interactions. Folsom-Kovarika writes that unlike other types of modeling, pattern of life modeling must take into account individual human behaviors as well as collective human emergent patterns. Because human interactions consist of so many variables and complexities, computational modeling of the patterns of life represents a significant technological challenge for artificial intelligence researchers. The article offers suggestions on how to approach the problem, but concludes with a solicitation for contributions from many fields of AI to help meet challenges.

The article "Computing Machinery and Intelligence Amplification" in *Computational Intelligence: The Experts Speak*, edited by David Fogel and Charles Robinson, provides an explanation of the difference between AI and intelligence amplification. Referring to Turing's 1950s article "Computing Machinery and Intelligence," authors Steven K. Rogers, senior scientist for Automatic Target Recognition and Sensor Fusion at the Air Force Research Laboratory, and Matthew Kabrisky, Kenneth Bauer, and Mark Oxley, professors at the Air Force Institute of Technology, emphasize that Turing's article did not address whether a machine would be conscious if it passed his imitation game (known as the Turing Test). Instead of focusing on machine consciousness and the "illusion of intelligence," the article focuses on measuring how much value a computer brings to a given application. This they define as *intelligence amplification*, which they consider to be a more realistic goal than artificial intelligence (Rogers 2003, 34). A key componet of intelligence amplification is the concept of qualia, or a human's "internal perception of the basis set used to represent the variety of stimuli encountered . . . upon which we construct our world model, allowing for the representation of the infinite variety of stimuli we sense into a small number of clusters, qualia, of relevant things" (Rogers 2003, 31). The examples given to illustrate qualia include the word for the color red, which is used to describe a specific portion of the electromagnetic spectrum; or a word like jealousy, which is the quale of a specific social situation. According to the authors, the more qualia (clusters) that a computer creates and is able to meaningfully manipulate, the more intelligent it will be perceived to be. Their idea is important in the discussion of the human-technology relationship because, as they explain, human self-awareness is the quale resulting from the activity in the internal thinking about oneself, and because it is a quale, it will always be unexplainable—an important aspect of why artificial intelligence remains significantly different than human intelligence.

Neuroscientist Dr. David Eagleman provides a layman's understanding and valuable insights into the symbiotic relationship between the physiology of the human brain and the person in *The Brain. The Story of You*. The book demonstrates how the brain impacts living, and how living impacts the brain's function, explaining how the brain rewires and adjusts itself to adapt to changes caused by living, e.g., a catastrophic injury. A key point of the book related to this study is the emphasis on the lack of understanding regarding the relationship between the physical mechanics of neurons and networks in the brain to thoughts, feelings, and emotions. It is this lack of understanding that contributes to the wide gap between human and artificial computer intelligence.

This concept of minimal understanding of human cognition and the relationship to computers is also addressed by computer scientist, iRobot cofounder, and Rethink Robotics founder Rodney Brooks. He disseminated the article “Artificial intelligence is a tool, not a threat” on his company’s Rethink Robotics blog site, “Rethinking Robotics,” providing a counter-perspective to those who champion the dangers of developing artificial intelligence. He posits the idea that those who are fearful of losing control of AI, or of a malevolent AI takeover, have fundamental misunderstandings of the nature of the progress being made in AI development. Brooks also emphasizes that such naysayers do not realize how far we actually are from creating volitional or intentional AI. Brooks stresses that the technical difficulties of connecting an IBM Watson to an existing functional industrial robot is enormous, and poorly understood. Citing the complexity of the human brain and how little we know about it—even the brain of a simple creature such as a worm—Brooks reminds readers of the difficulty of simulating the human cerebral cortex. He emphasizes the difficulty of creating evil robots is compounded by the need to program in an understanding and awareness of the world, as well as the ability to create robots that are mobile and dexterous enough to outwit and manipulate humans. To accomplish such a feat, Brooks believes it would require “deep thought and hard work from thousands of scientists and engineers. And, most likely, centuries” (Brooks 2014, 1).

An article highlighting the disagreement among members of the computer science community in regard to how soon artificial intelligence could be developed is Stuart

Armstrong and Kaj Sotala's "How We're Predicting AI—or Failing To" in *Beyond Artificial Intelligence*. The authors' research looked at the various predictions that have been made about AI coming to full fruition while using a database of 95 AI timeline predictions, spanning from Turing in the 1950s to 2012. The predictions, whether made by experts or nonexperts, had poor results, with expert predictions contradicting each other considerably. The duo's final conclusion was that expert predictions ranged widely, were not in agreement, and were systematically made 15 to 25 years into the future, providing strong evidence that any future AI timeline predictions would be uncertain. While the paper looked specifically at AI timelines, it did not define AI, leaving it to the reader to assume that the AI being predicted was defined the same by all who made their predictions.

Autonomous Unmanned Combat Air System Development

In *The Robotics Primer*, Maja Mataric, professor of computer science and neuroscience and director of the Center for Robotics and Embedded Systems at the University of Southern California, explains basic robotic concepts, including the components, control and control architectures, sensors, navigation capabilities, and movement. Mataric emphasizes the importance of integrating sensing systems to create autonomous intelligent robots, defining a robot as a physical autonomous system that can sense its environment using sensors, and which can act—on the basis of its own decisions, and not controlled by humans—by using its senses in order to achieve specific goals (Mataric 2007, 19-21).

The U.S. Department of Defense Office of Technical Intelligence's 2015 *Technical Assessment: Autonomy,* focuses on the human-technology relationship by identifying research and development, as well as U.S. policy opportunities, to leverage weapon system autonomy for the military. The assessment acknowledges the advantages of creating systems that can act with greater independence from humans to assist them with understanding the surrounding environment, making decisions, and conducting missions more effectively. It describes the assistance role of autonomy in areas where it can augment or even replace humans to reduce risk and decrease costs. An important aspect of the assessment is the realization that the human-technology relationship has many variations in terms of manned and unmanned applications, as manned systems can integrate significant amounts of autonomy, e.g., the U.S. Navy's Phalanx anti-ship missile close-in weapon system, while unmanned systems can be almost totally human-controlled, as is the case with remotely piloted aircraft, watercraft, or vehicle (U.S. Navy 2013b).

Thomas Ehrhard and Robert Work, from the not-for-profit Center for Strategic and Budgetary Assessments, wrote the short but detailed and well-documented background paper, "The Unmanned Combat Air System Carrier Demonstration Program: A New Dawn for Naval Aviation?" The paper provides a historical overview of the Navy's Unmanned Combat Air System Carrier Demonstration (UCAS-D) program and defended the argument (to justify funding) that it is a strategic imperative that the Navy increase the range, persistence, and stealth of the Navy's carrier air wing. Ehrhard and Work provide justification for doing so in order to increase the carrier's reach, endurance, and survivability to ensure long-term operational and tactical relevance of the U.S.

Navy's carrier fleet. The authors also underscore the human-machine relationship, citing the different configuration possibilities of unmanned aircraft controlled remotely by human operators, by aircraft operating with autonomous flight control systems, or by a hybrid of the two. Particular emphasis is given to autonomous aerial refueling, due to the increased persistence it provides, enabling the UCAS to fly well beyond 3,000 nautical miles from the carrier, enabling the capability to strike targets at even longer ranges and thus qualifying it as a long-range strike system in accordance with the Department of Defense's long-range strategic goals.

"RQ-4 Global Hawk: High-Altitude, Long-Endurance Unmanned Aerial Reconnaissance System" is a detailed fact sheet maintained by Gemma Loochkartt of the Northrop Grumman Corporation. The material provides an operational history of the military's largest unmanned aircraft system from 2001 to 2007. Unclassified technical specifications on the aircraft's airframe, flight control systems, and remote sensing intelligence collection systems are provided, as well as an overview of the foreign nations that have purchased the system. While only briefly mentioned, it does explain the autonomous capabilites of the system and the role of the human ground-based operators, the latter primarily serving to monitor system status and provide retasking commands as necessary.

The Defense Advanced Research Projects Agency's (DARPA) *J-UCAS Overview* provides information on the Joint UCAS program, an effort between DARPA, the Air Force, and the Navy, the predecessor of the current Navy-only UCAS Demonstrator program. The overview provides data on the purpose of the program, which was to demonstrate the technical feasibility, military utility, and operational value of a networked system of high performance, weaponized unmanned air vehicles. Operational capabilities, system attributes, and development history of the participating Boeing *X-45A* and Northrop Grumman *X-47A* air vehicles also were covered. Particularly relevant to the human-technology relationship was the coverage of the Common Operating System, a capability developed to integrate the different system components of the UCAS, i.e., the aircraft platforms, onboard subsystems, sensors, weapons, communication systems, and human crews, to create highly autonomous operations. Also included was a description of the operational experimentation and assessments of the autonomous UCAS.

The "U.S. Air Force Fact Sheet: Boeing *X-45A* J-UCAS," the Boeing Corporation's *X-45* Joint Unmanned Combat Air System website, and the Northrop Grumman *X-47B* UCAS website, provide authoritative and factual histories, news releases, and valuable data on technical specifications of the X-45 and X-47 programs as well as system capabilities of the platforms.

Supporting Mataric's position, the report "Autonomous Military Robotics: Risk, Ethics, and Design," prepared by Patrick Lin, George Bekey, and Keith Abney for the U.S. Department of the Navy, Office of Naval Research, defines an autonomous robot as "a powered machine that (1) senses, (2) thinks (in a deliberative, non-mechanical sense), and (3) acts, having the capacity to operate in the real-world environment without any form of external control, in some areas of operation, for extended periods of time, once activated" (Lin 2008, 4). This report underscores the criticality of integrating sensor systems with artificial intelligence in creating completely autonomous unmanned robotic weapon systems.

Computer programmer Manuel de Landa, in *War in the Age of Intelligent Machines,* addresses the evolution of autonomous weapon system technology in light of the transfer of intelligence from humans to machines. Taking a historical approach, de Landa demonstrates how technological autonomy has evolved, slowly replacing the command and control responsibility of the human combatant and paving the way for the potential to have completely autonomous weapon systems in future wars.

Dan Dudgeon, senior staff member in the Lincoln Laboratory Machine Intelligence Technology Group, and Richard T. Lacoss, leader of the group, address the subject of automatic target recognition (ATR) in the *Lincoln Laboratory Journal* article "An Overview of Automatic Target Recognition." One purpose of their discussion is to provide reasons why ATR, an essential element of artificial intelligence, is so difficult to achieve. Dudgeon and Lacoss begin by defining ATR as the use of computer processing to detect and recognize target signatures in sensor data. They then move to the chief difficulties in the development, which include detecting and recognizing targets in environments filled with various kinds of clutter, recognizing the difference between detecting a target and identifying it, imperfect sensors, sensor data quality, and the difficulties with developing recognition algorithms. The remainder of the paper focuses on a number of different approaches being undertaken to try and overcome the difficulties.

The U.S. Air Force's *Autonomous Horizons*: *System Autonomy in the Air Force—A Path to the Future, Volume I: Human Autonomy Teaming* addresses the significant potential advantages of developing unmanned systems and autonomous software to meet future challenges presented by potential high-tech adversaries. The first of three volumes provides the Air Force direction and guidance required to meet the challenges of developing autonomous systems for operations. An important aspect of the approach is the human-machine relationship, where autonomous technology works synergistically with airmen as a part of an effective human-autonomy team. The work summarizes the challenges of the human-autonomy working relationship, including the issue of trust, and provides a comprehensive definition for autonomy, which includes a degree of self-government and self-directed behavior, with human engagement for decisions. The guidance enforces Department of Defense Directive 3000.09, which requires that autonomous and semi-autonomous weapon systems be designed to allow humans to exercise judgment when the use of force is involved.

Political, Legal, and Ethics Literature

> *"It can be said that international law is simply unprepared for the particular ethical challenges that are posed by AW [autonomous weapons], especially when seen from the long-term perspective."*
>
> — Armin Krishnan

Political and Legal Elements Related to Autonomous UCAS Development

While Kurzweil and the DOD focus on the future impact of technological evolution on humanity, Peter W. Singer, director of the 21st Century Defense Initiative, explores the evolutionary progress of robotics as it relates to the U.S. defense establishment in *Wired for War*. He focuses on unmanned and robotic weapons as they are being used in areas like Iraq and Afghanistan, examining the profound effects the evolution of this technology is having on both combatants and senior-level decision-makers. He also raises the question of whether humans will be able to "maintain control of the wars and weapons" created by such complex and fast-moving technology (Singer 2009, 204). Singer conjectures that one of the main issues in the human-machine relationship will be the decision of how much control is given to the machines. "If the first step of technology's effect on command and control is to force officers to learn to lead troops fighting from home bases, and the second is to make generals have to figure out when to intervene directly in the battle or not, the final step may be figuring out just which command roles to leave to people and which to hand over to machines" (Singer 2009, 357). Singer's work is thought-provoking and asks critical questions directly related to political power bases and the use of autonomous technology in warfare.

Dr. Armin Krishnan, author of *Killer Robots: Legality and Ethicality of Autonomous Weapons,* also addresses the rapidly growing automation of warfare and the possibility that humans could potentially be excluded from the decision-making cycle in future robotic weapon systems: "The more complex and intelligent these machines become, the harder it will be to control their behavior" (Krishnan 2009, 58). Krishnan focuses his attention on both the technological and human, i.e., legal and ethical, issues connected to the use of robotic weapon systems, examining both the opportunities and limitations of technological autonomy.

The stated purpose of the *U.S. Department of Defense Directive 3000.09: Autonomy in Weapon Systems*, is twofold: first, to establish DOD policy and assign responsibilities for the development and use of autonomous and semi-autonomous functions in weapon systems, including manned and unmanned platforms; second, to establish guidelines designed to minimize the probability and consequences of failures in autonomous and semi-autonomous weapon systems that could lead to unintended engagements. These purposes focus on the humanity-technology interaction, with the intent to safely optimize autonomous weapon system employment and operations in warfare. The directive emphasizes the role of rigorous hardware and software verification and validation along with realistic developmental and operational system testing and evaluation to minimize unintended consequences. The military chain of command and associated responsibilities are clearly portrayed, with the goal of ensuring that all elements and aspects associated with autonomous system development and employment allow human commanders and operators to intervene in the use of force and employment of munitions. Also included are directives to take appropriate care to operate the systems in accordance with the law of war, applicable treaties, weapon system safety rules, and applicable rules of engagement.

The U.S. Department of Defense Joint Publication 1-04, *Legal Support to Military Operations*, is another important document that provides guidance on the use of unmanned and autonomous weapon systems. This document is prepared under the direction of the Chairman of the Joint Chiefs of Staff and reviewed by the General Counsel (Chief Legal Officer) of the Department of Defense. The publication provides joint doctrine to guide the activities and performance of the U.S. armed forces during military operations, emphasizing that it is DOD policy that all DOD members comply with the law of war during all armed conflicts. Specific law of war principles addressed include: military necessity (allowable actions under international law to quickly defeat an enemy), unnecessary suffering (prohibition of means and methods that cause unecessary suffering), distinction (differentiation made between combatants and noncombatants and military objectives and protected places), and proportionality (ban on attacks that cause civilian damage, injury, or loss of life disproportionate to the military advantage gained). This guidance assists with limiting the negative effects of technology when employed against humanity.

International Committee of the Red Cross's *Protocol Additional to the Geneva Conventions of 12 August 1949, and Relating to the Protection of Victims of International Armed Conflicts (Protocol I)* is an amendment protocol to the 1949 Geneva Conventions. *Protocol I* relates to the protection of victims of international conflicts that are not declared acts of war, but rather "armed conflicts in which peoples are fighting against colonial domination, alien occupation or racist regimes." The *Protocol* considers these to be international conflicts, and reaffirms and applies the international laws of the original Geneva Conventions of 1949 to such conflcits. The *Protocol* also adds clarifications and new provisions to accommodate the unique aspects of post-World War II modern international warfare. The work is applicable to this study as many of the conflicts that the U.S. military's UAVs and UCAVs have participated in fall under this category of conflict.

Air Force Pilot James Dawkins, Jr. wrote *Unmanned Combat Aerial Vehicles: Examining the Political, Moral, and Social Implications,* a thesis for the Air University. Dawkins provides greater clarity on the political, moral, and social issues surrounding UCAV employment to help decision-makers more effectively address the implications of this new technology. Directly addressing the humanity-technology relationship, he first addresses the politcian's temptation to use UCAVs to employ the option of force first, before considering all other options, because of the lower potential for in-country involvement and friendly casualties. He then examines UCAVs in light of currently accepted laws, principles, rules, and norms that govern the use of weapons of war, including just war principle and the laws of armed conflict. His third point addresses the new dynamic created by unmanned warfare, the transition from close quarters combat to one centered on the act of killing from a distance, emphasizing that this should be addressed by leaders to prevent military members from viewing their activities as a job rather than a military profession. He culminates the study recommending that strategists delve deeper into these issues as related to UCAV technologies and applications.

Directive 5000.1: *The Defense Acquisition System, Defense Acquisition Guidebook* provides direction for the U.S. Defense Acquisition System to manage the nation's technology, program, and product support investments made to support national security and the armed forces.[16] In the context of autonomous unmanned combat air systems, the guidebook's additional supplement E1.1.1 directs program managers responsible for overseeing developments or acquistions to pursue international armaments cooperation to the maximum extent, consistent with U.S. national security goals. Supplement E1.1.15 directs that acquisition and procurement of DOD weapons and weapon systems be consistent with all domestic laws and treaties and international agreements, customary international law, and the law of armed conflict, with the requirement for legal reviews to ensure compliance.

The United Nations Office at Geneva, Convention on Certain Conventional Weapons, also referenced as the Inhumane Weapons Convention, is sometimes referred to by those seeking to restrict the use of unmanned and autonomous weapon systems.

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[16] The full title is Directive 5000.1: *The Defense Acquisition System, Defense Acquisition Guidebook, Enclosure 1, Additional Policy, E1.1.1 (Armaments Cooperation) and E1.1.15 (Legal Compliance)*, May 12, 2003 (certified current as of November 20, 2007).

They do this as an interim solution while the international community works to establish specific conventions for unmanned and autonomous weapon systems. The purpose of this convention is to ban or restrict the use of specific types of weapons that are considered to cause unnecessary or unjustifiable suffering to combatants, or that affect civilians indiscriminately, such as mines, booby traps, blinding laser weapons, and explosive remnants of war.

The United Nations Office at Geneva Convention on Certain Conventional Weapons, 2015 Meeting of Experts on Lethal Autonomous Weapons Systems (LAWS), was a forum in which participants engaged in dialogue on questions related to emerging LAWS technologies. While not reaching definitive conclusions, the meeting produced more than 120 documents and presentations from multiple nations, providing detailed information on a variety of LAWS-related topics. Topics discussed included charateristics of LAWS, technical issues, possible challenges to international humanitarian law due to increasing degrees of autonomy, overarching issues, and a way ahead. The meeting clearly illustrated the complexities associated with the issues accociated with LAWS, and with finding consensus on definitions, development, employment, and proliferation of these systems.

Department of Defense Directive 2311.01E, *DOD Law of War Program*, updates the policies and responsibilities associated with ensuring DOD compliance with the U.S. law of war obligations.[17] The directive also clarifies the responsibilities of the Secretary of the Army in the role of DOD executive agent responsible for investigating and

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[17] The full title is Department of Defense Directive 2311.01E, *DOD Law of War Program*, May 9, 2006 (Incorporating Change 1, November 15, 2010, and certified current as of February 22, 2011).

reporting reportable incidents against U.S. personnel. This document makes it policy for all members of the DOD to comply with the law of war during all armed conflicts and in all military operations. It ensures that U.S. law of war obligations are observed and enforced by the DOD components as well as DOD contractors. The directive also provides detailed responsibilities for senior DOD leaders.

United Nations, International Court of Justice, *Statute of the International Court of Justice*, *Chapter II, Competence of the Court, Article 38* is a statute annexed to the Charter of the United Nations; its main objective is to organize the composition and functioning of the Court. Chapter two deals with the competence of the court, and article 38 provides the primary sources of international law the court uses.

U.S. Air Force Lieutenant Colonel Anthony Lazarski's article "Legal Implications of the Uninhabited Combat Aerial Vehicle," in *the Aerospace Power Journal*, addresses the legal issues involved with operating UCAVs in international airspace. It underscores the need for the U.S. to understand these issues before it develops, deploys, and employs UCAVs. The article considers the rules that govern flight operations in national and international airspace, the law of war, and rules of engagement.

Moral and Ethical Elements of Autonomous UCAS Development

Like Krishnan's *Killer Robots* and Singer's *Wired for War* previously mentioned, Ronald Arkin also addresses the issue of control in *Governing Lethal Behavior in Autonomous Robots.* In the context of artificial intelligence in autonomous weapon systems and ethics, he explores the idea of developing an "artificial conscience" to be used in governing autonomous robotic weapon systems (Arkin 2009c, 42). He addresses the relationship between the human operator and the evolution of weapons technology, focusing on the issues "regarding the ethical quandaries surrounding the deployment of autonomous systems capable of lethality" in relation to the law of war and rules of engagement (Arkin 2009c, 5). Citing various studies, Arkin argues that humans' emotional and psychological state makes them, on the one hand, reluctant to "shoot to kill," and on the other, prone to behaviors that result in violations of the law of war and atrocities. He believes that military robotic weapon systems could be programmed to be more efficient and behave more ethically on the battlefield compared to humans. While he presents possible ways that this could be achieved, he admits in the end that it is impossible to tell whether ethical military robots may ever really come into existence.

In "Terrorists Are Made, Not Born: Creating Terrorists Using Social Psychological Conditioning," in *Cultic Studies Review*, social and organizational psychologist Anthony Stahelski describes a process for conditioning humans. While the focus of his article is on the conditioning of terrorists, the five phases of conditioning he describes apply to other groups in various degrees as well, including military organizations. The process he describes methodically removes members from one group and associates them with another, eventually leading to a distancing between groups and, finally, demonizing each other. The application to this study occurs when UCAS technology seperates combatants via phase 3, other-deindividuation (stripping away the personal identities of enemies), and phase 4, dehumanization (identifying enemies as subhuman or nonhuman) of the conditioning process. Stahelski's five phases are important to understand to help unmanned systems operators obtain the knowledge to recognize when technology is contributing to the deindividuation and dehumanizing processes and to take action to prevent it from coming to fruition.

Jean Otto and Bryant J. Webber wrote the article "Mental Health Diagnoses and Counseling Among Pilots of Remotely Piloted Aircraft in the United States Air Force" for the *Medical Surveillance Monthly Report.* Their work focused on and compared mental health and post-traumatic stress disorder cases between manned aircraft and unmanned aircraft pilots. The results revealed that there was no significant difference in the rates of mental health diagnoses between the two types of pilots, suggesting that each group has similar mental health risks. The study also revealed that both groups expeienced the catalysts that lead to mental health issues differently, demonstrating that the human-technology interface of the UAV pilots caused a different set of real and impactful stressors.

In the previously mentioned Office of Naval Research report titled "Autonomous Military Robotics: Risk, Ethics, and Design," Lin, Bekey, and Abney provide a preliminary investigation into ethical issues related to autonomous military systems. Their study addressed a wide range of topics, including the use of autonomous systems, risk and ethics, law of war and rules of engagement, ethical and social issues, and recommendations for future courses of action, to name a few. They offer a number of possible solutions to address each area, but conclude that the use of autonomous military systems represents a new era in warfare, and that the systems are more than just additional military assests because they are meant to replace humans. Consequently, there are unique ethical and social questions that need to be, and should be, answered well ahead of the operational deployment of autonomous robotic systems in order to limit irrational fears, prevent accidents, avoid inhibiting research progress, and keep from threatening national security interests.

Omissions and Gaps in the Literature

As this study takes an interdisciplinary approach, it required exposure to a large body of disparate material, allowing for the possibility of gaps or omissions during the research. A concerted effort was made to use the most prominent positions, whether for or against a particular stance, to ensure a fair assessment and that the most important aspects of an issue were brought to the forefront. With regard to the philosophy of technology and technological determinism, only a few of the most prominent thinkers were examined, giving a representative sample of the primary positions taken on the subject of human control and technological evolution.

This study was also limited to the U.S. military's unmanned combat air systems and does not take into account unmanned ground, surface, and subsurface systems, all of which have unique characteristics, and presumably unique circumstances and problems, that could have been considered and may have impacted the outcomes and findings regarding control systems and human involvement. This is a recommended area for future study and investigation, with an emphasis on determining if the differences in system domains have an impact on the development of autonomous systems, and if development in these other domains could contribute to the evolution of artificial or autonomous capabilities beyond human control.

Similarly, because this study was confined to U.S. systems, with few references to foreign systems, there is a gap in the UCAS development history, particularly from technologically savvy nations that are considered potential adversaries to the U.S., as other autonomous system capabilities likely exist that could also impact the findings. While the political, legal, ethical, and moral aspects of this problem could change dramatically from one nation to another based on religious and cultural differences, the specific technological issues and shortcomings related to computer programming and algorithm development, especially in the realm of replicating human cognition and emotion, are most likely ubiquitous in nature. However, while there may be commonalities across the globe with regard to the shortfalls affecting current software and algorithm development that would result in the same or similar conclusions, additional study is needed to determine the veracity of the premise.

While a concentrated effort was made to research the current status of U.S. military unmanned combat air systems and the state of development in artificial intelligence, the entire field of related classified government efforts remained untouched, and, as with the Manhattan Project, the F-117 Stealth Fighter, and other past and current classified programs, there may be technological breakthroughs that have not made their way into the information domain of the general public.

With few exceptions, only the military research, development, and acquisition processes, or the civilian efforts related to military programs, were examined for this effort. The equivalent efforts in the academic and commercial industry environments not related to the military, such as those systems being created for law enforcement, agriculture, energy, emergency management, sports, media, and others, were not addressed either, leaving open the possibility that these other venues are making progress in autonomous systems that could have a different outcome than those in the DOD. This too is an area that could be explored with further research.

Finally, as the concluding argument of this study focused on the technological, political, and legal issues associated with autonomous unmanned combat air systems, only a brief discussion of the moral and spiritual dimensions of the argument was given. The various religious, moral, and ethical philosophies and perspectives that guide various societies, and the impact that these have on the issues of using autonomous unmanned weapon systems, is another important area that deserves more in-depth research.

Chapter Summary

As mentioned in chapter one, the interdisciplinary approach taken by this study required familiarity of historical, scientific, technological, and humanities literature related to five primary areas: philosophy of technology, unmanned aircraft systems, remote sensing systems, computer and artificial intelligence technology, and legal, moral, and ethical writings associated with autonomous weapon systems. This review addressed the philosophical perspectives of technology, autonomy, control, and technological determinism through the writings of key thinkers and philosophers who have offered valuable material about technology, autonomy, and control, with a focus on those who have written from a hard technological determinism perspective, including Martin Heidegger, Jacques Ellul, Ray Kurzweil, Paul Virilio, and others. The technical areas incorporated the writings of leading experts and authorities in each field, from across academia, government, and industry. In addition to the primary works of literature referenced in this chapter, the bibliography presented at the end of this work contains additional literature related to this topic that was included or consulted during the research and writing phase.

This chapter also addressed some omissions, gaps in the literature, and areas that warrant further investigation.

Building on this foundation of the relevant literature researched and examined, chapter three begins the study with an overview of the various positions taken on the human-technology relationship in the context of technological evolution and control. This will provide the reasoning behind, and define, the argument of the hard technological determinists. Once described, the stage will be set for the following chapters on the evolution of each of the technical systems associated with the composition of the unmanned combat air system—demonstrating the continuous human involvement and control of the development processes—and the support for the argument against the premise that humans are losing, or have lost control of, the technology.

Chapter Three: Technology, Determinism, and Human Control

"Technology makes it possible for people to gain control over everything, except over technology."

— John Tudor

Chapter Introduction

Chapter three examines the technological determinists' argument that technology is an autonomous entity, or independent agent, outside of human control.[18] It begins with an overview of the development of various philosophical perspectives on technological influence and control, focusing on select philosophers who have made significant contributions to the philosophy of technology, particularly the technological determinism argument. The humanity-technology relationship is then examined as it applies to the evolution of technology and the state of being of technology, particularly ideas that view technology as an independent entity or agent.

As mentioned in chapter one, it is important to make a distinction between viewing technological autonomy instrumentally, as purely the operation of a machine or tool under human control, and viewing it ontologically, as a non-instrument or metaphysical entity or agent that exists independent of human control. This distinction is important because it has a significant impact on the arguments related to the control of technology. It is the ontological arguments associated with the development and

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[18] The definition of an agent used for this study is from *The Stanford Encyclopedia of Philosophy*: "An agent performs activity that is directed at a goal, and commonly it is a goal the agent has adopted on the basis of an overall practical assessment of his options and opportunities. Moreover, it is immediately available to the agent's awareness both that he is performing the activity in question and that the activity is aimed by him at such-and-such a chosen end" (Wilson 2012, 3).

evolution of technology, as expressed by hard technological determinists, which are addressed in this chapter.

A short explanation of the difference between social determinism and technological determinism is given to set the context for the different philosophical positions taken in the debate of where control of autonomous aerial weapon systems fits in the humanity-technology relationship. In addition, an overview of some of the key technological determinists' positions provides a foundation for the discussions, in following chapters, on integrated or blended technologies in the development of autonomous unmanned combat aerial systems and the ability for humans to control them. The hard technological determinist view of technology, autonomy, and control will be the primary areas of emphasis in order to gain the best possible understanding of the argument that humans are losing control of, or never had control over, autonomous UCAS technology.

The Philosophy of Technology and Determinism

"Today we are almost totally dependent on the products of science and technology."
— James Burke

The debate over humanity's ability to control autonomous military technology such as the unmanned combat aerial system centers on the theory of technological determinism and is associated with one particular aspect of the problem: the amount of influence and control technology has over humanity. In other words, it asks the fundamental question: Does technology drive humanity and social change, or is the reverse true? It would be difficult to refute the idea that there is some level of human dependency on even the most rudimentary forms of technology, e.g., a bucket to carry water, a knife, or a writing implement. However, what can be questioned is the nature of technology itself and the level of influence and control it has on society as a whole. When discussing the nature and influence of technology, the questions can be further narrowed to the following: Is technology really only an *instrument* that humans have control over—and complete control at that—or is it an independent agent, entity, or force that works autonomously, outside of human control? If it is autonomous or not yet autonomous, but becoming autonomous, what responsibilities do humans have and how should they interact with technology?

The subjects of social and technological determinism bring to the table numerous views regarding the relationship between technology and humanity, particularly as it relates to control. There are far too many viewpoints and related variations to examine all of them in any single study; therefore, this examination focuses on arguments regarding technological determinism and the relationship between human control and technology. Nonetheless, to better understand the context of technological determinism, it is important to understand the opposing arguments of the social determinists.

Social Determinism: Societal Control of Technology

As introduced in the first chapter, social determinism asserts that technology is under the control of human beings. Adherents of this theory believe that technological development, and the subsequent changes to society brought about by the use of technology, is the product of human decision-making and activity, i.e., humans are in control, ultimately determining the direction of technology and the effects of its impact on social change. The power, control, and influence associated with technology are not properties of its autonomy but rather the by-products of "power relations and the decisions of elites, or groups of people in power" (Ihde 1993, 100). Social determinists take a pragmatic approach, seeing the humanity-technology relationship instrumentally; technology is only a neutral instrument or tool manipulated by humanity, and the degree of power it has is directly proportional to the strength and power of its user.

John Dewey: Technology as an Instrument of Society

American philosopher John Dewey was a pragmatist who rejected the idea that history supported the concept of an independent or autonomous technological force determining the direction of society; rather, he emphasized that man was the toolmaker:

> He is distinguished as the toolmaking animal. This has held good since man was man; but till nature was construed in mechanical terms, the making of tools with which to attack and transform nature was sporadic and accidental. . . . When chemical fertilizers can be used in place of animal manures, when improved grain and cattle can be purposefully bred from inferior animals and grasses, when mechanical energy can be converted into heat and electricity into mechanical energy, man gains power to manipulate nature. Most of all he gains power to frame new ends and aims and to proceed in regular system to their actualization. (Dewey 1920, 71-72)[19]

Referring to the "growth of the new technique of industry" and the impact on society, Dewey underscored human control: "Modern states, in other words, are regarded less as divine, and more as human works than they used to be; less as necessary manifestations of some supreme and overruling principals, and more as contrivances of men and women to realize their own desires" (Dewey 1920, 43-44).

[19] Pragmatist philosophers claim that "an ideology or proposition is true if it works satisfactorily, that the meaning of a proposition is to be found in the practical consequences of accepting it, and that unpractical ideas are to be rejected" (McDermid 2006, 1).

Clarifying Dewey's pragmatic and instrumental approach to technology in *John Dewey's Pragmatic Technology*, Larry Hickman, Director of the Center for Dewey Studies at Southern Illinois University, describes Dewey's perspective on the technological deterministic arguments of Karl Marx and Jacques Ellul, particularly the idea of whether humanity has a choice:

> Taken together, Dewey's reconstruction of three concepts—necessity, cause and effect, and freedom—sharply undercuts the naïve realism exhibited by both Marx and Ellul. Dewey meets the question of whether choice exists with an argument that might be called "transcendental." The very fact of asking that question indicates that choice at some level has in fact been exercised, for the term "choice"—like the terms "necessity," "causality," and "freedom" – is itself a technical artifact, the product of a procedure in which choice has been exercised in the context of inquiry. . . . It follows from Dewey's remarks on the doctrine of necessity that he rejects all claims that there are inevitable laws operative in history. (Hickman 1990, 158)

As previously shown, Dewey found unacceptable the idea that there is an overall direction to history because of external supernatural forces, whether personal or impersonal; he rejected both the judgment that history has provided us with laws that are intrinsically "dynamic," as well as the judgment that history involves "single-" or "multiple-" factor causal accounts (Hickman 1990, 159). Dewey further argued that it is the free will decisions made by society that determine the direction of society's technological progress, not some impersonal technology's determining force, and any claim to the contrary was a "philosophical fallacy" (Hickman 1990, 162).

Jurgen Habermas: Technology and the Life-World

Another proponent of the idea that progress and social influence are not determined by some independent technological force, but rather by social conditions, is philosopher Jurgen Habermas. In 1970, Habermas refuted the idea posed by German sociologists Hans Freyer and Helmut Schlesky that "recognizes technology as an independent force" whose processes obey "immanent laws" (Habermas 1970, 58). Refuting Freyer's argument of autonomous progress and Schlesky's thesis that technological potentialities "command their own practical realization," Habermas contended that their assertion of technology as independent of the social "life-world" was erroneous.[20] Arguing that technology did not operate outside of human control, he stated that:

> It is clear that this thesis of the autonomous character of technical development is not correct. The pace and *direction* of technical development today depend to a great extent on public investments: in the United States the defense and space administrations are the largest source of research contracts. I suspect that the situation is similar in the Soviet Union. The assertion that politically consequential decisions are reduced to carrying out the immanent exigencies of disposable techniques and that therefore they can no longer be made the theme of practical considerations, serves in the end merely to conceal preexisting, unreflected social interests and prescientific decisions. As little as we can accept the optimistic convergence of technology and democracy, the pessimistic assertion that technology excludes democracy is just untenable. (Habermas 1970, 59)[21]

[20] The term *life-world*, which is the English translation of the German *Lebenswelt*, was first used by Hugo von Hofmannsthal in 1908 and later by Georg Simmel in 1912; however, it didn't become popular until Edmund Husserl's *The Crisis of European Sciences and Transcendental Phenomenology* was published in 1936 (Føllesdal 2010, 27). A difficult term with various interpretations, Husserl first used the term in his earlier writings to mean the natural world and the natural subjects interacting in life (Føllesdal 2010, 27). However, he later defined it by differentiating the world of experience from the scientific, "mathematically substructed world of idealities," stating that it is the world of actual experience, "the only real world, the one that is actually given through perception, that is ever experienced and experienceable (sic)—our every-day life-world . . . the world constantly given to us as actual in our concrete world-life" (Husserl 1970, 48-49, 51). In *The Theory of Communicative Action, Volume Two*, Habermas defines the life-world as "the intuitively present, in this sense familiar and transparent, and at the same time vast and incalculable web of presuppositions that have to be satisfied if an actual utterance is to be at all meaningful, i.e. valid or invalid" (Habermas 1987, 131). He further defines the term by quoting Alfred Schutz and Thomas Lukmann's meaning: "the unquestioned ground of everything given in my experience, and the unquestionable frame in which all the problems I have to deal with are located" (Schutz 1973, 4). It is this experiential world of humanity that Habermas asserts influences technology, and is influenced by technology, but is not controlled by technology.

[21] Habermas defines democracy as "the institutionally secured forms of general and public communication that deal with the practical question of how men can and want to live under the objective conditions of their ever-expanding power of control" (Habermas 1970, 57).

Habermas admits that new technological capacities can arise and develop without human preparation, as a by-product of technology, but he states that the "direction of technical progress is still largely determined today by social interests," i.e., society (Habermas 1970, 60). He distinguished between the life-world and technological control, and views technology not as a single instrument, but as a system, as "scientifically rationalized control of objectified processes . . . the system in which research and technology are coupled with feedback from the economy and administration." While Habermas describes the relationship between technology and humanity as intertwined, he is clear that technology is not an independent, autonomous agent acting upon and controlling humanity.

John McDermott: Technology as an Institutional System

Philosopher John McDermott also was a proponent of the idea that technology is a system subordinate to human control. He sees technology not as an autonomous force but as an "institutional system" of control that one group of people uses to control another (McDermott 1997, 90):

> Technology, in its concrete, empirical meaning, refers fundamentally to systems of rationalized control over large groups of men, events, and machines by small groups of technically skilled men operating through organized hierarchy. (McDermott 1997, 77)

According to McDermott, the greatest threat to society is not autonomous technology, but an elite group of people who manipulate and use technology to achieve the political goal of maintaining control.

The views expressed by Dewey, Habermas, and McDermott are key components of the social determinists' argument that it is erroneous to view technology as an independent, autonomous force or entity operating outside of human control and influence. This idea of an erroneous point of view is also held by social determinist Leila Green.

Leila Green: Social Processes and Technology

According to Leila Green, professor at the School of Communications and Multimedia, Edith Cowan University, Perth, and author of *Technoculture: From Alphabet to Cybersex*, technology only has influence on society if it is accepted by society and then integrated into society; "social processes determine technology for social purposes" (Green 2002, 8). Like Habermas, Green underscores that technology does not operate outside of human influence, arguing that technological determinists do not take into consideration all of the facts, and further states that those who believe in the idea of technology beyond human control do not properly apply the societal "checks and balances," such as law, regulation, legislation, and social sanction (Green 2002, 9). She argues that it is society, particularly the power-wielding elite members, which actually control the direction and impact of technology:

> When we discuss the social determination of technology, it is easy to imply that this is a democratic, inclusive way to develop technology. Such a perception is generally erroneous, however, since some visions of the future are more inclusive than others. The visions which tend to attract funding anticipation and active commitment from the societal elites who have power in western society are those visions which offer these elites the greatest benefits. In fact, it is arguable that population wide "progress" is only ever an accidental spin-off of some powerful group's self-interest. Technology is developed as a result of specific choices made by influential power brokers representing a limited range of social elites. (Green 2002, 9)

Like McDermott, Green emphasizes that it is not technology that is in control determining the course of history, but society's power brokers. She specifically identifies three types of elite power brokers: politicians, corporations, and the military, emphasizing that it is the priorities of these spheres that determine the purpose, ultimate use, and overall influence of technology on humanity (Green 2002, 9-10).

Don Ihde: Technology a Non-Neutral Instrument

Moving more toward the technological deterministic view, but still maintaining a distance through a praxis-focused and instrumentally-centric view, philosopher Don Ihde describes different views of the humanity-technology relationship. Seeing technology as non-neutral, his "magnification/reduction transformation" approach is a middle ground between pure social determinism and total technological determinism, and provides a strong segue into technological determinism.[22] According to Ihde, technology is not deterministic, but rather transformative, and the transformations brought about by the "mediating position" of the instruments of technology impact humanity by causing them to "experience an environment or world in a new or technological way" (Ihde 1993, 112). His conclusion is that the technological instruments are neither socially nor technologically determined. Ihde explains:

> By projecting a state of affairs from the non-neutrality structure of instrumental transformations, I have suggested that a straightforward social determinism such that instruments might be thought to embody just any human aim or interest is not adequate. Instruments embody human aims and interests in certain ways, ways in keeping with the necessarily transformational characteristics of the amplification-reduction structure. On the other side, no technological determinism in the hard

[22] In *Philosophy of Technology,* Ihde gives the following example to define the magnification/reduction transformation approach he describes in his work *Technics and Praxis*:

> For every enhancement of some feature, perhaps never before seen, there is also a reduction of other features. To magnify some observed object, optically, is to bring it forth from a background into a foreground and make it present to an observer, but it is also to reduce the former field in which it fit, and—due to foreshortening—to reduce visual depth and background. Such non-neutral transformations belong to all technologies (Ihde 1993, 111).

> sense is adequate either, since technics in its telic dimension provides only a base for inclination rather than determination in any hard sense. (Ihde 1979, 48)

Ihde emphasizes that technology does not determine society's course of action, but it does transform society through "latent telic [purposeful or defined] inclinations which are made possible through instruments" (Ihde 1979, 42). He gives the example that the inclination produced by the pen resulted in writing in the "old style of belle letters," in contrast with the inclination of the typewriter as writing in "short, clipped sentences of speed typing" (Ihde 1979, 57; 142).[23] The technologies of the pen and typewriter did not determine humanity's creation of long or short, or slow or fast, sentences, but were merely technological inclinations. Society develops and determines how instruments are to be used, but, according to Ihde, the instruments' inclinations are what influence and transform the society.

Social determinists do not view technology as independent institutional systems, technological systems, or economic force fields manipulating society beyond human control (all stances taken by soft technological determinists later in this chapter), but rather as tools used by humans to manipulate society; they view humans as in control, with the ability to make decisions and take actions that affect the impact of technology on society. The opposing idea, that technology is innately autonomous, or has the inherent capacity to become autonomous, and is therefore impossible for humanity to control, falls within the realm of a theory known as "technological determinism."

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[23] In his later work, *Technology and the Lifeworld: From Garden to Earth*, Ihde comments on the inclination of the word processor, which not only slightly increased speed of composition over the electric typewriter, but also introduced a focal temptation produced by the ease of the editing processes, resulting in more malleable and unfixed projects (Ihde 1990, 142).

Technological Determinism: An Ontological View of Technology

Defining technological determinism is difficult because there is no agreed-upon definition by scholars embracing or critiquing the theory. As stated by political scientist Bruce Bimber, "Technological determinism exists in enough different incarnations that the label can easily be attached to a range of views" (Bimber 1994, 80). While there may be no single definition for technological determinism that all can agree on, a common theme among the various descriptions often arises, and includes the idea that technology, or technological development, is a prime catalyst for societal change. In other words, contrary to the idea of social determinism, technology is *what moves and shapes all elements of society in such a way as to determine its course or direction.* This will be the definition used for this study.

A brief survey of history reveals the human tendency to create technologies that are influential enough to direct the course of humanity's future, or at least to make such an impact upon the happenings of humanity that society has a difficult, if not impossible, time changing or correcting the subsequent course of events; the moldboard plow, gunpowder, the clock, the printing press, and nuclear fission are all relevant examples that profoundly affected the course of human history.[24] While his stance as a determinist is under debate by scholars,[25] Karl Marx's statement that "The windmill gives you

[24] The statement "human tendencies to create technology" is problematic because part of the debate over the extent of technology's influence over humanity includes the philosophical concept that technology is an independent agent, entity, influence, or essence that has its own existence, and is therefore not *created* by humankind but is only *discovered, revealed, reacted to,* or *unleashed*. Thinkers such as Martin Heidegger, Jacques Ellul, and Raymond Kurzweil are proponents of such a view. This concept will be examined in more detail later in this chapter.

[25] To see examples of scholarly disagreement over Marx's status as a technological determinist, see Bruce Bimber's "Three Faces of Technological Determinism" in *Does Technology Drive History*? *The Dilemma of Technological Determinism,* edited by Merritt Roe Smith and Leo Marx (Smith 1994, 87-89).

society with the feudal lord: the steam-mill, society with the industrial capitalist" illustrates the type of determining influence that technological determinists believe technology has on society (Marx 1920, 119). The apparent autonomous or near-autonomous momentum and the deterministic features displayed by technology has caused scientists, technologists, philosophers, theologians, and historians to exam this apparent "technological determinism" in an attempt to: (a) verify its existence; (b) discover its root cause or causes; and (c) formulate a response to it, depending on where one stands in the technological determinism continuum.

Technology, Humanity, and Control

While the concept of technological determinism dates back to the Industrial Revolution, the phrase is credited to 20th-century American economist Thorstein Veblen, who wrote about the influence of technology upon economics (Ellul 1964, xviii). In his 1921 book, *The Engineers and the Price System*, Veblen foreshadows future discussions on the subject of technological determinism:

> The foundation and driving force of it all [the industrial system] is a massive body by technological knowledge, of a highly impersonal and altogether un-businesslike nature, running in close contact with the material sciences, on which it draws freely at every turn—exactingly specialized, endlessly detailed, reaching out into all domains of empirical fact.
>
> Such is the system of productive work which has grown out of the Industrial Revolution, and on the full and free run of which the material welfare of all the civilized peoples now depends from day to day. Any defect or hindrance in its technical administration, any intrusion of nontechnical considerations, any failure or obstruction at any point, unavoidably results in a disproportionate set-back to the balanced whole and brings a disproportionate burden of privation on all these peoples whose productive industry has come within the sweep of the system. (Veblen 1921, 132-133)

The dependence on technology mentioned by Veblen has grown through the years, leading humanities intellectuals and scientists to question the level of that dependency. More than thirty years ago, in a television series titled *Connections,* science historian James Burke provided another perspective on the influence of technology on humanity, giving an update to Veblen's perspective and opening the doors of this issue to the general public. In the series, Burke invited the common person to consider their reliance and dependency on technology. He provided this perspective:

> As the technological support systems which underpin our existence become more complex and less understandable, each of us feels less involved in their operation, less comprehending of their function, less confident of being able to cooperate without them. . . . In the face of all this most of us take the only available course: we ignore the vulnerability of our position, since we have no choice but to do so. . . . We seek security in the routines imposed by the technological systems which structure our lives: into periods of work and rest. In spite of the fact that any breakdown in our interdependent world will spread like ripples in a pool, we do not believe that the breakdown will occur. Even when it does . . . our first reaction is to presume that the fault will be rectified, and that technology will, as it always has, come to the rescue. . . . The first man-made harvest forced mankind from total and passive dependence on the vagaries of nature, and at the same time tied him forever to the very tools that set him free. (Burke 1978, 4-5, 10)

The degree to which society is tied to and controlled by its tools really depends on how one views technology. According to Merritt Roe Smith, history of technology professor at MIT, adherents of the theory of technological determinism usually fall into one of two categories: "soft" determinists and "hard" determinists.[26] The soft determinists are those who promote the idea that "technological change drives social change but at the same time responds discriminatingly to social pressures" (Smith 1994,

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[26] Some theorists do not embrace the idea of a "soft" versus "hard" form of technological determinism. Bruce Bimber, commenting on G.A. Cohen's standard for defining technological determinism, states that technological determinism "does not admit 'hard' and 'soft' versions of determinism, for a so-called soft determinism cannot be determinism at all" (Bimber 1994, 87).

2). In other words, technology is one among many enabling factors that is responsible for social change, but it can be manipulated, guided, and directed by human intervention; it provides the opportunity for social change but does not force it (White 1978, 28). This position is close to the social determinist stance previously discussed, with the difference that the social determinists do not accept the idea that technology is an independent agent, entity, or force that can be "manipulated, guided, and directed," but rather only an instrument or system that is used by humans.

Soft Technological Determinism: Humanity's Influence and Technology's Control

Political scientist Langdon Winner takes a similar stance to McDermott's, resisting the idea that technology is completely rational and autonomous. While leaning toward the idea of autonomy, Winner sees technology as more irrational and unpredictable and describes it as "tools without handles or, at least, with handles of extremely remote access" (Winner 1977, 13). His position is that humans have become apathetic toward technology; they have "come to accept an overwhelmingly passive response to everything technological," failed to consider consequences, and willingly submitted to *the control of technological systems* [emphasis added] (Winner 1977, 324). Like McDermott, Winner places much of the responsibility for what happens with technology in the hands of humans, but he views technology as a system that can control humanity if left unchecked.

Another approach taken by soft determinists is more economic-based, a position taken by economist Robert Heilbroner. His explanation for the reality of technological determinism also focuses on the role that humans play in the equation, with the difference being that it involves economics. He agrees that technology plays a large role, but only in the context of the marketplace:

> Machines make history by changing the material conditions of human existence . . . There must be a systematic reduction of complexity of cause into simplicity of effect, enabling us to explain how the development of new machineries of production can alter the social relationships constitutive of feudalism into those of capitalism, or those of one kind of capitalism into those of another kind. . . . The mechanism is, of course, economics, in the sense of a force field in which a principle of "maximizing" imposes order on behavior in a fashion comparable to the magnet and the gravitational pull of the sun. . . . At the risk of belaboring the obvious, economics accomplishes this remarkable feat by ignoring all effects of the changed environment except those that affect our maximizing possibilities. In this way, changes in technology, like changes in the weather or in our social situations, are depicted as loosening or tightening of constraints on our behavior, and these altered constraints are then perceived as changing our actions in sufficiently regularized ways to enable us to speak of "laws" at work in the marketplace or in the enterprise. (Heilbroner 1994, 68-70)

Heilbroner, like McDermott and Winner, places a significant amount of responsibility for where technology goes in the hands of humans and "certain 'soft' political and social preconditions"; however, there is still an element of technology, a "force field" of some kind, that "imposes order on human behavior" (Heilbroner 1994, 73).

Unlike the instrumental or system view of the social determinists, the soft view of technological determinism sees technology as something more than just an instrument. When this idea grows beyond the ability of humans to control, it enters into the realm of the hard determinists.

Hard Technological Determinism: Technology's Independent Control

At the other end of the determinism continuum, the hard determinists adhere to a perception of technology as "an autonomous force, completely independent of social constraints" (Smith 1994, 2). This position upholds the theory that the ultimate direction or course that technology takes, and the subsequent impact on society and humanity, is inevitable and cannot be resisted due to the "state of technological development and laws of nature" (Bimber 1994, 83). A statement made by historian and author Henry Brooks Adams at the start of the U.S. Civil War demonstrates the early thinking behind hard determinism: "Man has mounted science, and is now run away with. I firmly believe that before many centuries more, science will be the master of men. The engines he will have invented will be beyond his strength to control" (Adams 1862, 290). It is from this notion that a technology can be created which will evolve beyond human control that the idea of true or actual technological autonomy springs forth.

This ontological view of technology, i.e., seeing technology as an autonomous being or entity that can act as its own agent, independently, and in a self-governing manner, becomes possible only when technology is reified.[27] Once it is reified, it results in its concretization, i.e., technology is no longer viewed as an abstract idea, concept, or descriptor, but as an actual entity, one with an existence of its own. This ontological understanding of technology as an entity or force with its own existence is foundational to the stance of the hard determinist, and a pivotal intellectual responsible for promoting the theory of technology as an independent, autonomous force, entity, or agent is the German philosopher Martin Heidegger.

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[27] Reification is the process or result of regarding something that is abstract as a material or concrete thing (*Encyclopedia Britannica* online, s.v. "reification," http://www.britannica.com/EBchecked/topic/496484/reification [accessed December 7, 2013]).

Martin Heidegger and the Essence of Technology

"We ask the question concerning technology when we ask what it is."
— Martin Heidegger

Heidegger's work included the pursuit of understanding "being" and "existence," and in a lecture delivered in 1954, "Die Frage nach der Technik"—or, The Question Concerning Technology—he connected the idea of "being" with technology. He proposed a theory that there is an "essence" behind technology that gives it existence apart from humanity, i.e., he reified the essence of technology, implying a non-neutral existence of this essence that is associated with technology but beyond mere instrumentality:

> The essence of technology is by no means anything technological. Thus we shall never experience our relationship to the essence of technology so long as we merely represent and pursue the technological, put up with it, or evade it. Everywhere we remain unfree and chained to technology, whether we passionately affirm or deny it. But we are delivered over to it in the worst possible way when we regard it as something neutral; for this Conception of it, to which today we particularly like to pay homage, makes us utterly blind to the essence of technology. (Heidegger 2009, 9)

Heidegger's writings brought to the forefront the idea that there is another aspect of technology, an *essence* of technology that is not a neutral instrument, an idea that forms the essential foundation for the premise that humans cannot control technology.

Heidegger is known predominantly for his work in the areas of ontology and the "essence of truth." His pivotal work *Sein und Zeit*—or "Being and Time"—was written in 1927 and is a monumental discourse focused on his attempt to "access being (*Sein*) by means of phenomenological analysis of human existence (*Dasein*) in respect to its temporal and historical character" (Korab-Karpowicz 2001, 1).[28] In *Being and Time*, one of the areas Heidegger covered was the relationship between the human, the instrument, and the concept of being. He explained his theories by defining the humanity-technology-being relationship as "readiness-to-hand" and "presence-at-hand," using a specific tool, a hammer, to demonstrate the interaction and level of the awareness of being between the tool and the user. According to Heidegger, tools, like hammers, are used and perceived instrumentally and are "ready-to-hand," i.e., the purpose of their being is understood, and the user gives little attention to its existence:

> The hammering does not simply have knowledge about [*um*] the hammer's character as equipment, but it has appropriated this equipment in a way that could not possibly be more suitable. In dealings such as this, where something is put to use, our concern subordinates itself to the "in-order-to" which is constitutive for the equipment we are employing at the time; the less we just stare at the hammer-Thing, and the more we seize hold of it and use it, the more primordial does our relationship become, and the more unveiledly is it encountered as that which it is—as equipment. The hammering itself uncovers the specific "manipulability" [*Handlichkeit*] of the hammer. The kind of Being which equipment possesses—in which it manifests itself in its own right—we call "readiness-to-hand" [*Zuhandenheit*] (Heidegger 1962, 98).

He writes that the carpenter uses a hammer without thinking about it, and does not contemplate its existence; in effect the technology—the hammer—is transparent to the carpenter because the carpenter is primarily focused on the work and not the tool (Heidegger 1962, 99). Applied to a UAS, this particular human-technology-being "readiness-to-hand" relationship can

[28] *Sein und Zeit* is a complex book, one that attempts to gain an understanding of being and existence, and any attempt to completely explain Heidegger's theories and ideas as he intended them would be a difficult endeavor for a work of this length (and, in truth, the focus of this work is centered on another topic). However, Heidegger does provide explanations for his terms and definitions, and he spends a great deal of time on the term *dasein*, or existence, from both ontical (physical, real) and ontological perspectives. The focus for this discussion is on Heidegger's description of the human-instrument-being relationship.

be seen when the systems operator uses the UAS as a tool to conduct a particular mission. The operator does not think about or consider the existence or being of the UAS; it is simply an instrument or tool being used to accomplish a specific task. However, Heidegger makes the argument that this readiness-to-hand is in effect a kind of "being" that the equipment (the hammer, or UAS) actually does possess in and of itself, and which it manifests in its own right (Heidegger 1962, 98). According to Heidegger, the reality of the instrument's or technology's existence only comes to the mind of the user when something goes awry, i.e., the instrument becomes unusable; it is at this point that the technology's being is actually considered. This is what Heidegger called "presence-at-hand."[29]

In making an application to a UAS, this means an operator would only really consider the unmanned aircraft's existence or being if the UAS malfunctioned (had a pre-launch maintenance issue or an in-flight emergency), became lost (was misplaced, stolen,

[29] Heidegger uses the term "presence-at-hand" for the term "existential" (being), and defines the term "existence" as "a designation of being," as *dasein* (Heidegger 1962, 67). Instruments become "present-at-hand" when they become noticeable through their "un-readiness-to-hand," i.e., their existence becomes visible to the user when they become unusable in three ways: they become damaged (are conspicuous), they are missing (are obtrusive), or they "stand in the way" of the user accomplishing a task (are obstinate) (Heidegger 1962, 102-103). According to Heidegger, "The modes of conspicuousness, obtrusiveness, and obstinacy all have the function of bringing to the fore the characteristic of presence-at-hand in what is ready-to-hand" (Heidegger 1962, 104). He sums up the importance of this relationship between "ready-to-hand" and "presence-at hand" in the context of being as follows:

> If, in our everyday concern with the "environment," it is to be possible for equipment ready-at-hand to be encountered in its "Being-in-itself" [in seinem "An-sich-sein"], then those assignments and referential totalities in which our circumspection "is absorbed" cannot become a theme for that circumspection any more than they can for grasping things "thematically" but non-circumspectively. If it is to be possible for the ready-to-hand not to emerge from its inconspicuousness, the world must not announce itself. And it is in this that the Being-in-itself of entities which are ready-to-hand has its phenomenal structure constituted.
>
> In such privative expressions as "inconspicuousness," "unobtrusiveness," and "non-obstinacy," what we have in view is a positive phenomenal character of the Being of that which is proximally ready-to-hand (Heidegger 1962, 106).

or crashed), or became a hindrance to accomplishing the mission (a part of the aircraft prohibits a sensor from properly collecting data, or the onboard computer system prohibits the operator from performing a certain task). As will be discussed in later chapters, for there to be an argument for the ability of humanity to lose control of UAS technology, the agency and autonomy of the UAS has to be considered a viable possibility, and the first step toward this consideration is recognition, or at least an awareness, of a machine's existence or being, or its "presence-at-hand."[30]

The Essence of Technology

Heidegger stated that humanity's free relationship with technology would be achieved only if the relationship opens our human existence to the *essence* of technology.[31] The underlying core of the definition of *essence* is the element or state of being, or the state of existence; therefore, when Heidegger talks about the essence of technology, he is referring to the "being" or "existence" of technology, *not in terms of an instrument*, but in terms of an independent entity or agent. He further expounds on the definition of *Wesen,* the German word for essence:

> If we speak of the "essence of a house" and the "essence of a state" we do not mean a generic type; rather we mean *the ways in which house and state hold*

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[30] It is important to keep in mind that this perspective of an essence or "being" of technology, or of the technological, is held in various degrees of intensity by the technological determinists. Only a representative sample of these varying viewpoints will be discussed in this dissertation.

[31] A key factor in understanding Heidegger's intent, and tying it to the idea that technology, or the force behind technology, is other than an instrument, is an understanding of the word *essence*. The word comes from the German *Wesen*, which when translated into English means "being, essence, suchness, or entity." The noun *Wesen* is derived from the verb *wesen*, which is translated "to be, to exist, to be available." The English word for essence is "a: the permanent as contrasted with the accidental element of being; b: the individual, real, or ultimate nature of a thing especially as opposed to its existence, e.g., a painting that captures the essence of the land; c: the properties or attributes by means of which something can be placed in its proper class or identified as being what it is" (Merriam-Webster Online Dictionary, s.v. "essence").

> *sway, administer themselves, develop, and decay—the way they "essentially unfold"* [*wesen*]. Johann Peter Hebel in a poem, "Ghost on Kanderer Street," for which Goethe had a special fondness, uses the old word *die Weserei*. It means the city hall, inasmuch as there *the life* of the community gathers and village *existence* is constantly in play, i.e., essentially *unfolds*. It is from the verb *wesen* that the noun is derived. *Wesen* understood as a verb is the same as *wahren* [to last or endure], not only in terms of meaning, but also in terms of the phonetic formation of the word. Socrates and Plato already think the essence of something as what it is that unfolds essentially, in the sense of what endures. (Heidegger 2009, 21)

The elements that Heidegger focuses on in regard to the definition of essence are the concepts of *being, life, existence,* and *unfolding*. He stresses from the beginning that one should not confuse the essence of technology with the physical instruments, the familiar concepts, or the activities associated with technology, i.e., what he defines as the instrumental and anthropological definitions of technology. Heidegger emphasizes that technology is not the same as the essence of technology, and applies this to the instruments of technology; i.e., the instruments of communication, transportation, or warfare are not what pervade and constitute, but rather they are the essence of the technology that exists and is all pervading.[32] In other words, there is an essence of being behind the circuitry, silicon boards, and ones and zeros that comprises the technological components of an unmanned aircraft system.

Another important point that Heidegger accentuates in his explanation of the essence of technology is that it is unique, and that it is the uniqueness of the essence of technology that separates it from the instrument, process, or system of technology. This uniqueness is why he states that "the essence of technology is by no means anything

[32] Heidegger uses the example of a tree to underscore the point that technology is not the same as the essence of technology: "When we are seeking the essence of 'tree,' we have to become aware that that which pervades every tree, as tree, is not itself a tree that can be encountered among all the other trees." He emphasizes that the individual tree, like an instrument, is not what pervades and constitutes, is not the essence, of what all trees actually are (Heidegger 2009, 9).

technological," and that until we realize that we are chained to our ordinary ideas and understandings of what we think technology is, we can't be freed to understand or experience the real essence of technology (Heidegger 2009, 9). He admits there is an instrumental definition for technology; however, he emphasizes that this is not the same as the essence of technology.

The important point of Heidegger's idea that is relevant to this study is that the essence of technology is not neutral, it is not just an instrument, and it is not something that is only manipulated *by* humans. Because this unique, mysterious essence of technology cannot be fully understood, but actually exists, and is the essence behind the instrument, it is something totally beyond humanity's ability to control.

This is the perspective with which hard technological determinists approach modern technology, and it is upon this understanding, or a derivative thereof, that they build their case that humanity has little or no control over technology.

Traditional Versus Modern Technology

Heidegger does not leave this in the abstract but applies his thinking on the essence of technology toward modern technology, underscoring the difference between "traditional" and "modern" technology by drawing the distinction as follows:

> The instrumental definition of technology is indeed so uncannily correct that it even holds for modern technology, of which, in other respects, we maintain with some justification that it is, in contrast to the older handicraft technology, something completely different and therefore new. (Heidegger 2009, 22)

With the distinctions drawn and modern technology described as "something new," the question is then asked: What is modern technology? Heidegger offers an answer, stating that "It too is a revealing" (Heidegger 2009, 13). However, the difference between the old, instrumental handicraft technology and new modern technologies is the focus on *the way* of revealing.[33] What makes modern technology unique is that the revealing is a "*Herausfordern*," or "challenging," which puts to nature the unreasonable demand that it supply energy, which can be extracted and stored, e.g., digging coal, ore, or uranium from the earth (Heidegger 2009, 13-14).[34] The revealing that occurs with modern technology only occurs when nature is challenged, i.e., the earth is ripped open, water flow is redirected or stopped, land is rearranged, or electrons are rearranged or redirected in the electromagnetic spectrum, etc. What modern technology does is *set-upon* nature, *ordering it* and *challenging it* to unlock, expose, and reveal its *reserves* of resources, or its *standing reserves* [*Bestand*] (Heidegger 2009, 14).

The key point for this discussion is that Heidegger emphasizes that modern technology is *not* a human endeavor, and that humans (nature) *are set upon by technology, which orders humanity* and *challenges humanity* to unlock, expose, and reveal the standing reserves of resources. In other words, the essence of modern technology influences, manipulates, and challenges humanity, and it is not humanity that manipulates the essence of modern technology. The idea that modern technology is not a human endeavor is a critical component of the technological determinists' argument that

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[33] Heidegger states that the essence of the old technology was a revealing in the sense of *poiesis*, or "bringing-forth," e.g., bringing-forth energy by reasonably and unobtrusively capturing the power of nature; e.g., the wind with a windmill, water with a watermill, etc. (Heidegger 2009, 13-14).

[34] While Heidegger uses the physical earth for his examples here, the implication is that the unreasonable demands that modern technology's *challenging* places upon nature to supply energy which can be extracted and stored can also be applied to other areas, such as extracting and storing energy from across the electromagnetic spectrum. In the information technology age, an application could also be made to the mathematical and scientific laws of the cyber realm. In addition to the physical environments of land, sea, and water, it is within the realms of the electromagnetic and cyber arenas that modern unmanned aerial systems operate, and hard determinists could make a case that technology sets upon, orders, and challenges humanity to unlock, expose, and reveal the standing reserves of resources in these other realms.

technology is not a passive instrument, but an active agent, and one that determines the actions and course of events through the directing or ordering of humanity.[35]

The Essence of Technology and Modern War Machines

Although this was very technical and lengthy explanation, it is important to address Heidegger in a discussion of unmanned weapon systems and human control, because Heidegger demonstrated in *The Question of Technology* that the essence of technology is nothing technological; that it is, instead, an entity or agent apart from the technological, that it is mysterious, it is beyond human control, and yet it interacts with humanity. According to the hard determinists' perspective, Heidegger's arguments can be seen coming to fruition in the technology of the modern battlefield, particularly the technology involved with unmanned and autonomous systems. Such technology is seen as a revealing and "enframing," as Heidegger called it, to extract the standing reserve of humanity, of unique human capabilities and human intellect, particularly in the realm of artificial intelligence. Additionally, the resources modern technology orders not only include extracting the natural elements required to manufacture machinery and

[35] Heidegger called this ordering "Gestell" or "enframing." This enframing is another key component of the essence of modern technology:

> Enframing means the gathering together of the setting-upon that sets upon man, i.e., challenges him forth, to reveal the actual, in the mode of ordering, as standing-reserve. Enframing means *the way of revealing that holds sway in the essence of modern technology* and that is itself nothing technological. On the other hand, all those things that are so familiar to us and are standard parts of assembly, such as rods, pistons, and chassis, belong to the technological. The assembly itself, however, together with the aforementioned stockparts, fall within the sphere of technological activity. Such activity always merely responds to the challenge of enframing, but it never comprises enframing itself or brings it about [emphasis added] (Heidegger 2009, 16).

Here Heidegger once again emphasizes that the essence of modern technology is itself nothing technological, and yet is inextricably tied to the instruments and activity of technology. Like traditional technology, the essence of modern technology involves a revealing, but unlike the *poiesis* of the traditional essence, which is a bringing-forth, modern technology is aggressive, consisting of a challenging-forth that requires ordering, or an enframing, to extract nature's standing reserve.

equipment, but could also be applied to the extraction of reserves of energy from the electromagnetic spectrum. Furthermore, the data, information, and knowledge that constitute computer technology can be ordered to include control systems that replicate birds in flight, sensors that replicate human sensory functions, and artificial intelligence that replicates human intelligence. The human activities and senses that remote sensors emulate—i.e., motion, seeing, smelling, and hearing—and the human intellect that artificial intelligence and agency emulate are areas in which the essence of technology is showing forth, and which will continue to be revealed, regardless of human activity.

Heidegger's concept of the essence or being of technology is fundamentally important to the hard determinists because it is required for defining technological autonomy as an agent of change through the evolution and influence of computer technology and artificial intelligence. In order for something to be autonomous it must act independently and be self-governing, and in order to make a case for the autonomy of technology, the transfer from technology as an abstract idea to technology as a concrete thing, essence, or being is important. Once the argument is made that technology has revealed itself to be a self-existing entity, force, or essence not under human control, proponents can begin to build a case for the reality of technological autonomy.

While Heidegger is a philosopher whose work is foundational, diving deeply into the ontological aspects of technology, there are a number of other important, well-respected adherents to the theory of technological autonomy. One of the most renowned is French philosopher Jacques Ellul.

Jacques Ellul and Technological Autonomy

"Technology is not an instrument that man can use as he likes."

— Jacques Ellul

Ellul, a near contemporary of Heidegger, also adhered to the idea that technology operates as an autonomous agent. He describes this behind-the-scenes activity as "Technique," defining it as "the totality of methods rationally arrived at, and having absolute efficiency (for a given stage of development) in every field of human activity" (Ellul 1964, ccv). Unlike Heidegger, Ellul did not consider the autonomous nature of Technique to be an essence of technology, but rather a "sociological phenomenon" (Ellul 1964, ccv). However, like Heidegger, Ellul underscored the point that Technique is not machinery, or technology per se, stating that "[T]echnique has enough of the mechanical in *its nature* to enable it to cope with the machine, but *it surpasses and transcends the machine* because it remains in close touch with the human order . . . [T]echnique integrates the machine into society" [emphasis added] (Ellul 1964, 5). Ellul diverges from the stance held by the soft determinists, who claim that technology's force is *created by* social structures, and defends the idea that all social aspects are situated in the technological system of Technique, and that it is incorrect to say that social factors, such as economics, politics, and culture are influenced or modified by Technique. Instead, he states that the social phenomena are "situated in it, a novel situation modifying all traditional social concepts" (Ellul 1962, 395).

The Intrinsic Nature of Technique

Akin to Heidegger, Ellul emphasized that Technique is not a thing or an instrument, but instead is its own “pre-existent” and “more or less determinative” reality wherein humans operate and within which “all human decisions are always made” (Ellul 1964, xviii). To Ellul, Technique has become the very environment where humankind now exists and is required to function, “which has supplanted the old milieu, viz. that of nature” (Ellul 1962, 394). He described this new technological environment as having the following characteristics:

> a. It is artificial;
> b. It is autonomous with respect to values, ideas, and the state;
> c. It is self-determining in a closed circle. Like nature, it is a closed organization which permits it to be self-determinative independently of all human intervention;
> d. It grows according to a process which is causal but not directed to ends;
> e. It is formed by the accumulation of means which have established primacy over ends;
> f. All its parts are mutually implicated to such a degree that it is impossible to separate them or to settle any technical problems in isolation. (Ellul 1962, 394)

Ellul identifies Technique as artificial, yet autonomous, self-determining, and independent of human intervention. It is not neutral, but rather its “own peculiar force” that does not bend to the will of the human, but operates independently of human intentions and objectives, concealing within itself an “intrinsic finality” that humanity cannot evade; “if there is a competition between the intrinsic finality and the extrinsic end proposed by man, it is always the intrinsic finality which carries the day” (Ellul 1964, 141). Ellul describes this non-neutral nature of Technology:

> For me, the non-neutrality of technology signifies that technology is not an inert, weightless object that can be used in any manner, any direction by a sovereign mankind. Technology has in itself a certain number of consequences, it represents

> a certain structure, certain demands, and it brings certain modifications of man and society, which force themselves upon us whether we like it or not. Technology, of its own accord, goes in a certain direction. I am not saying that this is absolutely irremediable, but rather, that in order to change this structure or redirect this movement we have to make a tremendous effort to take over what was thought mobile and steerable, we have to become aware of this independence of the technological system, which is opposed by the reassuring conviction of technological neutrality. (Ellul 1980, 155)

Technological Autonomy and Human Control

In emphasizing the intrinsic nature of Technique, Ellul is describing technological autonomy, a state of being where technology is an autonomous reality with respect to economics, politics, morality, and even spirituality, with its owns sets of laws and determinations (Ellul 1964, 133-134). He unequivocally states that Technique is truly autonomous, can do what it wills, and is neither good nor bad, admitting that this claim is an unrecognized "outrageous truth" (Ellul 1964, 134; Ellul 1980, 153). In describing the characteristics of technological phenomenon, he defines technological autonomy as follows:

> This means that technology ultimately depends only on itself, it maps its own route, it is a prime and not a secondary factor, it must be regarded as an "organism" tending toward closure and self-determination: it is an end in itself. Autonomy is the very condition of technological development. (Ellul 1980, 125)

Subsequently, with the realization that Technique is autonomous, Ellul addresses an important question related to the development of technological society: Is man able to remain master in a world of means (Ellul 1962, 398)? Like Heidegger, Ellul sees Technique as an autonomous entity existing outside of human control, developing and operating according to its own intrinsic rules, flowing with humanity's attempts to influence, direct, and control it, but always operating according to its own inherent processes and direction independent of the human (Ellul 1980, 135, 153). According to Ellul, humanity believes it has control of technology, but this is only an illusion.

> Now, it is technology that engulfs and determines the cultural forms, the "civilization." But this is neither accepted nor achieved.
>
> In other words, the behavior of human groups in regard to technology is according to traditional forms and relations. Man claims he still controls and uses technology. But in this way, he restrains what strikes him as threatening, frenzied, etc. We must therefore pay heed to these refusals, which grow more extreme as the movement [the attempt to curb technological growth] grows more rapid. (Ellul 1980, 298)

As technology grows, it increases in power, and with each technological breakthrough and advance this power becomes more efficient and effectual than any previous technology; as the power increases, the possibility of technology becoming "limitless and absolute" increases (Elul 1962, 401-402). As technology's power and influence grows, humanity participates less in its creation, and is "reduced to a level of a catalysts" (Ellul 1964, 135). According to Ellul, the ultimate end in the humanity-technology relationship is the replacement of the human by the technology.

> But this autonomy with respect to man goes much further. To the degree that [T]echnique must attain its result with mathematical precision, it has for its objective the elimination of all human variability and elasticity. It is a commonplace to say that the machine replaces the human being. But it replaces him to a greater degree than has been believed. (Ellul 1964, 135)

Ellul, Technology, and Modern Warfare

One example of Technique's influence upon humanity that determinists could cite is the distancing—and in some cases complete removal—of the human from the machine in the unmanned systems used by the U.S. military. Ellul writes that humanity not only operates in the new milieu of Technique, but that its very essence is affected, citing as an example modern work, which “calls for different qualities in man,” and “implies an absence, whereas previously it implied a presence” (Ellul 1964, 320).

The absence Ellul refers to appears to have significantly increased in the remote control technology of modern military operations. Some of today’s warriors practice their trade very remotely, thousands of miles away from the battlefield, never seeing the enemy they engage. The modern UAS has been successfully used since the Vietnam War, and more prominently since the first U.S. Gulf War, and is currently deployed throughout the world. Using highly sophisticated flight, sensing, and weapon technologies, these systems allow UAS crews to either remotely fly unmanned aircraft over foreign enemy territory, or monitor the flight status of unmanned aircraft following preprogrammed routes, to conduct intelligence and reconnaissance missions, and to seek and destroy targets without ever leaving the continental United States. Ellul wrote that Technique has enabled humans to accomplish things never before possible while slowly reducing them to observers and causing them to lose touch with reality.

> The machine’s senses and organs have multiplied the powers of human senses and organs, enabling man to penetrate a new milieu and revealing to him unknown sights, liberties and servitudes. He has been liberated little by little from physical constraints, but he is all the more the slave of abstract ones. He acts through intermediaries and consequently has lost contact with reality. (Ellul 1964, 325)

In this description, the hard technological determinists can see Ellul’s assessment of the modern warrior’s reduction to observer status realized in the unmanned systems operators of today, a perspective further underscored by Ellul:

> War is now beyond human endurance in noise, movement, enormity of means, and precision of machines; and man himself has become merely an object, an object to be killed, and prey to a permanent panic that he is unable to translate into personal action. Man is subjected by modern war to a nervous tension, a

> psychic pressure, and an animal submission which are beyond human power to support. (Ellul 1964, 320)

According to Ellul, the evolution of technology associated with warfare not only is creating a new operating environment and changing the roles of the pilots, but is also changing their very essence. Whereas before the pilot was integrated within the technology, "completely one with his machine . . . immobilized in a network of tubes and ducts" with senses that "have been replaced by dials which inform him what is taking place," today UAS pilots have been removed from the machine altogether (Ellul 1964, 326). Technique now allows the operators to remain connected to the physical machine through computer, communications, and remote sensing technologies. In the view of the hard determinists, the end result was predicted by Ellul; humans have lost control and have "lost contact with the primary element of life and environment" (Ellul 1964, 325). The Technique of modern warfare has contributed to a new level of dehumanization in warfare, a level in which humans are now completely removed from each other, the machines, and the environment altogether.

Technological Evolution and Human Control

> *"The Singularity is near. When Humans transcend biology."*
>
> — Ray Kurzweil

According to Ellul and other hard technological determinists, the ultimate end in the humanity-technology relationship culminates with technology's replacement of the human. The idea of technology evolving to a point surpassing humanity began in the early 19th century, on the heels of the Industrial Revolution, and continues to be a prevalent idea among some post-modern thinkers.

Richard Thornton, Samuel Butler, and Thinking Machines

One of the first Americans to write about the idea of machines evolving beyond human capacities was Richard Thornton in 1847. In a book containing a compilation of periodicals, the *Primitive Expounder*, he wrote about another editor's encounter with a new "thinking machine" that was "designed to supersede the necessity and labor of thinking" by doing mathematical calculations. Commenting on the new device, Thornton states:

> The Editor thinks that such machines, by which the scholar may, by turning a crank, grind out the solution of a problem without the fatigue of mental application, would by its introduction into schools, do incalculable injury. But who knows that such machines when brought to greater perfection, may not *think* of a plan to remedy all their own defects and then grind out ideas beyond the ken of mortal mind! (Thornton 1847, 281)

Shortly thereafter, in the novel *Erewhon*, first published in 1872, Samuel Butler expanded upon this idea, writing that machines would ultimately develop a "mechanical consciousness," and that humanity should not be deceived in finding comfort in the minimal amount of machine consciousness in current technology, as this would be a false security:

> Reflect upon the extraordinary advance which machines have made during the last few hundred years, and note how slowly the animal and vegetable kingdoms are advancing. The more highly organised machines are creatures not so much of yesterday, as of the last five minutes, so to speak, in comparison with past time. Assume for the sake of argument that conscious beings have existed for some twenty million years: see what strides machines have made in the last thousand! May not the world last twenty million years longer? If so, what will they not in the end become? (Butler 1921, 236-237)

Butler described machines as though they were autonomous entities that were quickly gaining control over humanity, citing as examples the ever-increasing expansion of those who were fast becoming slaves to machinery, either through dependence upon them or through their increasing obsession with advancing technology (Butler 1921, 248-249). While *Erewhon* was a novel, the writings about machines were based on a previous letter he wrote to the editor of the *Press* in Christchurch, New Zealand, in 1863. Entitled *Darwin Among the Machines*, the article conveyed his thoughts on machine evolution, and clearly stated that machines would one day evolve beyond humanity: "The upshot is simply a question of time, but that the time will come when the machines will hold the real supremacy over the world and its inhabitants is what no person of a truly philosophic mind can for a moment question" (Butler 1914, 184-185).

This idea that technology is an independent agent or force that will one day evolve beyond humanity and take control is a recurring theme among the hard technological determinists. One particular philosophical approach that is a chief proponent of this view is known as technological singularity.

Referencing Butler, Alan Turing expressed the same sentiment as Thornton and Butler. In 1951, Turing advanced the idea that once machines began to think they would one day intellectually surpass humans, and therefore "we should have to expect the machines to take control, in the way that is mentioned in Samuel Butler's *Erewhon*" (Turing 1996, 260). It is this idea of technology eventually evolving beyond human intellectual capabilities that encompasses the core of technological singularity.

Ray Kurzweil and Technological Singularity

The term *singularity* is credited to mathematician John Von Neumann, and first appears in an article about Neumann written by Stanislaw Ulam in 1958. Describing von

Neumann's character, thoughts, and views on technical matters, and in particular a conversation about technology, Ulam writes:

> One conversation centered on the ever accelerating progress of technology and changes in the mode of human life, which gives the appearance of approaching some essential *singularity* in the history of the race beyond which human affairs, as we know them, could not continue [emphasis added]. (Ulam 1958, 5)

The term singularity is not defined by Neumann or Ulam in this article, but it clearly refers to some undefined future state that has come into existence due to the influences of technology on human affairs, a state quite different than the current state during Neumann's time or even the present day.

The concept of singularity was further developed and brought to the forefront by mathematician Vernor Vinge. As a faculty member of the Department of Mathematical Sciences at San Diego University, Vinge presented a paper in 1993 to the VISION-21 Symposium, sponsored by NASA Lewis Research Center, titled "The Coming Technological Singularity: How to Survive in the Post Human Era." In his paper, Vinge made the oft-quoted statement that, "Within thirty years, we will have the technological means to create superhuman intelligence. Shortly after, the human era will be ended" (Vinge 1993, 1). He then creates a definition of singularity that became foundational to the technological singularity movement:

> The acceleration of technological progress has been the central feature of this century. I argue in this paper that we are on the edge of change comparable to the rise of human life on Earth. The precise cause of this change is the imminent creation by technology of entities with greater than human intelligence. There are several means by which science may achieve this breakthrough (and this is another reason for having confidence that the event will occur):
>
> - The development of computers that are "awake" and superhumanly intelligent. (To date, most controversy in the area of AI [artificial intelligence] relates to whether we can create human equivalence in a

> machine. But if the answer is "yes, we can," then there is little doubt that beings more intelligent can be constructed shortly thereafter.)
> - Large computer networks (and their associated users) may "wake up" as a superhumanly intelligent entity.
> - Computer/human interfaces may become so intimate that users may reasonably be considered superhumanly intelligent.
> - Biological science may find ways to improve upon the natural human intellect.
>
> . . . I think it's fair to call this event a singularity ("the Singularity," for the purposes of this paper). It is a point where our models must be discarded and a new reality rules. As we move closer and closer to this point, it will loom vaster and vaster over human affairs till the notion becomes a commonplace. Yet when it finally happens it may still be a great surprise and a greater unknown. (Vinge 1993, 1-2)

Like Neumann, Vinge cannot describe what this future end state will be; he simply states that it is something "unknown." While Vinge was an important catalyst in helping to further define technological singularity, it was futurist and transhumanist Ray Kurzweil who became a champion of the technological singularity movement and popularized the term.[36]

Kurzweil states that biological evolution and human technology show continual acceleration. However, information, particularly artificial intelligence (AI), is evolving at a rate that will surpass human abilities. Expanding beyond the exponential growth set forth in Moore's Law, Kurzweil embraces the idea of the "law of accelerating returns," which he defines as "the inherent acceleration of the rate of evolution, with technological

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[36] According to Humanity+, an international nonprofit membership organization which advocates the ethical use of technology to expand human capacities, Transhumanism is a philosophy about the future "that is based on the premise that the human species in its current form does not represent the end of our development but rather a comparatively early phase" and therefore, by incorporating technological means, will eventually "move beyond what some would think of as 'human'" in a posthuman era. Posthumans are defined as future beings "whose basic capacities so radically exceed those of present humans as to be no longer unambiguously human by our current standards." However, this philosophical system does not imply that humans no longer exist (Humanity+ 2013, Transhumanism FAQ 3.0).

evolution as a continuation of biological evolution" (Kurzweil 2005, 7).[37] This law of accelerating returns is the key idea underlying the impending Singularity, which he defines as:

> . . . a future period during which the pace of technological change will be so rapid, its impact so deep, that human life will be irreversibly transformed. Although neither utopian nor dystopian, this epoch will transform the concepts that we rely on to give meaning to our lives, from our business models to the cycle of human life, including death itself. (Kurzweil 2005, 7)

Kurzweil promotes the idea that this bio-technological evolution toward Singularity proceeds in a pattern, in a very specific order, through six Epochs:

> 1) Physics and Chemistry—information in atomic structures;
> 2) Biology and DNA—information in DNA;
> 3) Brains—information in neural patterns;
> 4) Technology—information in hardware and software designs;
> 5) Merger of Technology and Human Intelligence—the methods of biology (including human intelligence) are integrated into the (exponentially expanding) human technology base; and
> 6) The Universe Wakes Up—Patterns of matter and energy in the universe become saturated with intelligent processes and knowledge. (Kurzweil 2005, 14-17)

Kurzweil believes we are currently in Epoch 5, and that the Singularity will take place in Epoch 6, which will occur in the year 2045 (Kurzweil 2005, 136). He writes that this event *will* happen because humans have no control over the evolutionary process of

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[37] Moore's Law states that the number of transistors on a given chip can be doubled every two years. Gordon E. Moore, cofounder of Intel Corporation, made the following statement in an article published in *Electronic Magazine* in 1965: "The complexity for minimum component costs has increased at a rate of roughly a factor of two per year. Certainly over the short term this rate can be expected to continue, if not to increase. Over the longer term, the rate of increase is a bit more uncertain, although there is no reason to believe it will not remain nearly constant for at least ten years. That means by 1975, the number of components per integrated circuit for minimum cost will be 65,000" (Moore 1965, 114). This has been a "law" of computer science since that time and still holds true. However, the article, "Intel explains rare stumble keeping pace with Moore's Law," published in the December 6, 2013 edition of *The Wall Street Journal*, stated that the company presented a "blemish on its steady two-year pace observing what the industry calls Moore's Law." William Holt, Intel's executive vice president for manufacturing operations, stated that the "hiccup" in Moore's Law was due to "yield problems" and, while rare, was "not unprecedented at the company" (Clark 2013, 1).

technology. Referring to humanity's attempt to slow down or stop the advances of technology through human control, i.e., governmental control, Kurzweil simply states that such controls have had "no measurable effect" on the trends that he has described (Kurzweil 2005, 470). He predicts that after Singularity occurs, the era of the human machine, or nonbiological intelligence, will begin:

> . . . the intelligence that will emerge will continue to represent the human civilization, which is already a human-machine civilization. In other words, future machines will be human, even if they are not biological. This will be the next step in evolution, the next high-level paradigm shift, the next level of indirection. Most of the intelligence of our civilization will ultimately be nonbiological. (Kurzweil 2005, 29-30)

Like Heidegger and Ellul, Kurzweil holds to the idea that the force behind this technological evolution is beyond human control, and that the speed of the evolution is a key factor profoundly affecting the humanity-technology relationship.

Relating this to humanity's relationship with the technologies associated with warfare, the French philosopher Paul Virilio focuses on the relationship between technology, humanity, and speed to further demonstrate the lack of control that humans have in the humanity-technology relationship.

Paul Virilio, Dromology, and Technological Autonomy

In his first book, *Speed and Politics,* philosopher and cultural theorist Paul Virilio focused on the subject of dromology, what he defined as "the study and analysis of the increasing speed of transport and communications on the development of land use" (Virilio 1996, 13). Later, in an interview with John Armitage, principal lecturer in Politics and Media Studies at the University of Northumbria, U.K., he defines dromology simply as the "logic and impact of speed" (Armitage 2000, 3). One area of concern for Virilio is the relationship between space, particularly urban space, and technology as it relates to speed, power, control, and global warfare. He believes it is the speed of the military-industrial complex's technological development that drives humanity, stating that, "history progresses at the speed of its weapons systems" (Virilio 2006, 90). He underscores the idea that today it is technology that mediates wars, fighting "at the speed of light," and enabling the military-industrial complex to achieve victories and attain the ultimate triumph of defeating an enemy without conventional means (Armitage 2000, 4). Virilio calls this war-related technological development of the military establishment "pure war" (Virilio 2008, 68).

Like Heidegger, Virilio highlights the mysteriousness of technology, describing it as a riddle over which humanity has no control, with the products of technology—i.e., the inventions and the creations of science—as expanding with lightning speed, further widening the field of the uncontrollable unknown. "No more illusions about Technology. We do not control what we produce. Knowing how to produce it doesn't mean we know what we are doing" (Virilio 2008, 76).

In agreement with Kurzweil, Virilio wrote that humanity is on the verge of a new epoch in human history, a third industrial revolution called "transplantation," where technology will be anthropomorphized.[38] The revolution of transplantation is possible because of the miniaturization of technology, especially the development of

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[38] According to Virilio, there have been three industrial revolutions. "The first important revolution on the technical plane is that of transportation, which favors an equipping of the territory with railroads, airports, highways, electric lines, cables, etc. It has a geopolitical element. The second revolution, which is almost concomitant, is the transmissions revolution, including Marconi, Edison, radio, television. From this point on, technology is set loose. It becomes immaterial and electromagnetic. The third revolution, which it seems to me we are on the verge of, is the revolution of transplantations" (Der Derian 1995, 4).

nanotechnology, which allows for the introduction of technology into the human body "to achieve what the futurists wished for: to sustain the human body through 'technology' and not just through 'chemistry'" (Der Derian 1995, 4). Like Kurzweil's future, the end result is the creation of a new entity that Virilio defines as a "biomachine":

> In the future, just as the geographic world was colonized by means of transportation or communication, we will have the possibility of a colonization of the human body by technology. That which favors the equipping of territories, of cities, in particular, threatens to apply to the human body, as if we had the city in the body and not the city around the body. The city "at home," in vitro, in vivo. Here there is a sort of anthropomorphism of technology. We see this with supplementary technologies, cardiac stimulators, with the possibility of grafts, of techno-grafts, supplementary memory, as Marvin Minsky proposes. We are on the verge of the biomachine. Personally, I critique this, as the advent of the hyperstimulated man. (Der Derian 1995, 4)

Finally, Virilio believes that technology now defines reality via the virtual world, which allows "the existence of the paradox of being everywhere at the same time while being nowhere at all" (Virilio 2013, 1). Proponents of technological determinism can point to the high-tech virtual systems of today's military as Virilio's paradox coming to fruition: virtual war-games, the creation of the U.S. Cyber Command in 2009, the U.S. President's Comprehensive National Cybersecurity Initiative, satellite systems that allow surveillance of the entire globe, and unmanned systems that permit the military to conduct operations worldwide without ever leaving the continental United States—all seemingly support the idea that technology is driving humanity to an existence in a virtual world.

Other Prominent Contemporary Thinkers

The idea that artificial intelligence has the potential to evolve beyond human control is also held by other contemporary thinkers. In a video interview with the BBC in December 2014, theoretical physicist Stephen Hawking warned that "the development of full artificial intelligence could spell the end of the human race," expressing fears that humanity will one day create an artificial intelligence technology that can "match or surpass humans" (Cellan-Jones 2014, 1-2). He agrees that the type of AI currently in existence has been very useful, but he fears that creating AI that surpasses human intelligence would "take off on its own, and re-design itself at an ever increasing rate," superseding humans "who are limited by slow biological evolution" (Cellan-Jones 2014, 1-2).

The following fall, in October 2014, CEO of Tesla Motors and CEO/cofounder of SpaceX, Elon Musk, told an audience attending the MIT AeroAstro 1914-2014 Centennial Symposium that artificial intelligence and associated research pose a threat to humanity.

> I think we should be very careful about artificial intelligence. If I were to guess at what our biggest existential threat is, it's probably that. So we need to be very careful with the artificial intelligence. I'm increasingly inclined to think that, think there should be some regulatory oversight, maybe at the national and international level, just to make sure we don't do something very foolish. With artificial intelligence, we are summoning the demon. In all those stories where there's the guy with the pentagram and the holy water, it's like yeah, he's sure he can control the demon. It doesn't work out. (Peraire 2014)

He ended the discussion by commenting on a remark by an audience member who assumed, based on his comment, that there would be no HAL 9000, the fictional computer in Arthur C. Clarke's *2001: A Space Odyssey*, on a Space X mission to Mars.

Musk answered that HAL 9000 would be "easy" compared to artificial intelligence, and that AI would "put HAL 9000 to shame" (Peraire 2014).

In January 20015, during a Reddit question and answer session, Microsoft cofounder Bill Gates responded to a question asking how much of an existential threat he thought machine superintelligence will be. He stated:

> I am in the camp that is concerned about super intelligence. First the machines will do a lot of jobs for us and not be super intelligent. That should be positive if we manage it well. A few decades after that, though, the intelligence is strong enough to be a concern. I agree with Elon Musk and some others on this and don't understand why some people are not concerned. (Gates 2015)

The comments about the potential dangers of artificial intelligence by such distinguished individuals as Hawking, Musk, and Gates underscore the reality that there are individuals today who believe in the potential evolution of technology to a point where it will be able to operate outside of human control.[39]

Chapter Summary

This chapter provided background information on the philosophy of technology and the technological determinists' argument that technology is an independent, autonomous force, entity, or agent operating outside of human control. Various philosophical perspectives on technological influence and control were discussed to

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[39] In an ironic turn of events, world-renowned theoretical physicist Hawking, and Tesla's CEO Musk, were identified by the Information Technology and Innovation Foundation (ITIF) as Artificial Intelligence Alarmists, Winning ITIF's Annual Luddite Award on January 19, 2016 (Greene 2016, 1). While ITIF President Robert D. Atkinson acknowledged that both men were "pioneers of science and technology," they were included, Atkinson said, because they were part of "a loose coalition of scientists and luminaries who stirred fear and hysteria in 2015 by raising alarms that artificial intelligence (AI) could spell doom for humanity" (Greene 2016, 1). This event underscores the relevance and importance of this study with regard to the ongoing humanity, technology, and control debate.

demonstrate the diversity of theories that have been developed since the mid-19th century and to provide a foundation for arguments discussed in the following chapters. A short explanation of the difference between social determinism and technological determinism was given to set the context for the different philosophical positions; however, due to the vast number of opinions and theories on the subjects of the philosophy of technology, social determinism, and technological determinism, only a select group of philosophers were addressed.

The technology-humanity-control relationship was examined as it applied to the evolution and the state of being of technology, particularly ideas that viewed technology as an independent entity or agent. The examples of hard and soft determinists provided did not represent the complete range of thought in regard to the subject, but they did achieve the objective of illustrating the diversity of approaches involved with trying to understand the level of technological influence upon society.

In describing the social and technological determinism positions, the distinction between viewing technological autonomy instrumentally and viewing it ontologically was emphasized due to the significant impact these two views have on the arguments related to the control of technology. More emphasis was placed on the ontological arguments associated with the state of being of technology, particularly Martin Heidegger and Jacques Ellul’s positions, as their views provide a strong foundation for the hard technological determinist argument that humanity is not in control of technology. The evolutionary points of view of Richard Thornton, Samuel Butler, Ray Kurzweil, and Paul Virilio were also discussed to demonstrate technological deterministic theories that began prior to the Civil War and are still being adhered to by 21st-century technological determinists, theories that view technology as an evolving entity or force beyond human control that will one day end the human era as we know it.

This chapter set the stage for the following chapters' discussions on the development of unmanned aircraft systems: unmanned flight, remote sensing, and AI systems, and the blending of these technologies onboard autonomous unmanned combat aerial systems. These integrated developments onboard unmanned autonomous systems will then be examined in light of the technological determinism arguments to determine if the theory that humans are losing control of—or never had control of—technology can be substantiated for the UCAS weapon system.

Chapter Four: U.S. Military UAS Development

"We have just won a war with a lot of heroes flying around in planes. The next war may be fought with airplanes with no men in them at all. . . . It will be different from anything the world has ever seen."

— General Henry H. "Hap" Arnold

Chapter Introduction

This chapter provides a historical overview of the development of unmanned flight and aircraft technology prior to World War II, and then moves into an examination of U.S. military unmanned aircraft technological development from the Second World War to the present. In addition to the technology, the human-technology interface and systems integration are examined, with attention paid to the gradual distancing of the human operator from the machine. This examination is foundational to understanding the current development and application of unmanned and semi-autonomous weapon systems in warfare, as well as the research and development activities associated with current efforts to develop more autonomous systems. The use of unmanned aircraft as airborne weapon systems is specifically examined, focusing on the issue of human control over the technology as it advances. This chapter also focuses on the impact that the merger of unmanned flight technologies with weapons has had on the development of the unmanned combat aircraft systems, as well as the relationship between the system operators and the technology. The evolution of unmanned flight sets the stage for examining the integration of remote sensing and artificial intelligence technologies into the unmanned aircraft systems and the corresponding impact these have on creating future autonomous unmanned aircraft systems.

The Evolution of Military Unmanned Flying Craft

"It is apparent to me that the possibilities of the aeroplane, which two or three years ago were thought to hold the solution to the [flying machine] problem, have been exhausted, and that we must turn elsewhere."

— Thomas Edison

Among the many different types of weapon technologies affiliated with the military, the Unmanned Aircraft (UA) has taken a prominent role in recent years. This is primarily because the Unmanned Aircraft System, or UAS, had numerous successes in combat since the Vietnam War.[40] While the separation of the human operator from the flying machine may appear at first glance to be a product of 20th-century technology due to its prevalence in the U.S. military arsenal today, the history of man-made, unmanned flying craft predates the Industrial Revolution by two thousand years. Additionally, the concept of using an unmanned aerial craft to support efforts of warfare is not new, either, for written records show that humans first used unmanned aerial craft technology against their enemies soon after the discovery of human-constructed unmanned flight.

Kites

The exact origin of small, man-made, unmanned flying craft is not known; however, some historians believe that the earliest man-made flying craft can be traced to

[40] An unmanned aircraft system is a "system whose components include the necessary equipment, network, and personnel to control an unmanned aircraft; also called UAS" (U.S. Department of Defense 2010 JP 1-02, 252). The system components include an unmanned aircraft, the personnel responsible for remotely flying the aircraft and operating the on-board sensors, the ground support equipment and associated ground support personnel, and the communications technologies used for relaying signals to and from the aircraft. An unmanned combat air system (UCAS) is a UAS "weaponized to conduct offensive operations," usually carrying air-to-ground missiles but also including weapons for air-to-air combat (U.S. Department of Defense Unmanned Systems 2013, 24). An autonomous UCAS does not require human pilots or sensor operators. This differentiation will be developed further throughout this study.

the Chinese, the originators of paper.[41] It's possible that the Chinese could have created small paper gliders or aircraft similar to what children make and play with today; however, the first recorded flight of a man-made unmanned aerial craft, where an operator on the ground maintained control of the airborne craft, occurred approximately 2,300 years ago in China, on Mt. Lu, when Chinese philosopher Mo Di flew a wooden eagle kite for one day (Ray 2004, 1). Mo Di's kite could also be considered the first UAS, for it was a man-made aerial craft remotely controlled by a human operator, who used a piece of string as the uplink/downlink mechanism to control the altitude of the kite (Wagner 1992, 15). Human control of the kite allowed the Chinese to apply them to a number of different military scenarios as early as 206 B.C. (Archibald 1897, 184). They became the means to measure distances for building tunnels for breaching fortified castle walls—as employed by General Han Hsin in the 3rd-century B.C. (Hart 1982, 25)—and were also used for communicating messages, as used by Emperor Wu of the Liang Dynasty, 464-549 A.D. (Ray 2004, 1-2). Some were even used to carry humans, as documented in the following account of Chinese Emperor Gao Yang in 599 A.D.:

> Gao Yang made Yuan Huangtou [yan Huang-Thou] and other prisoners take off from the tower of the Phoenix attached to paper (kites in the form of) owls. Yuan Huangtou was the only one who succeeded in flying as far as the Purple Way, and there he came to earth. (Needham 1994, 285)[42]

Kites slowly moved westward and found their way to Europe via Marco Polo, where the first recorded military use of kites in Europe occurred during the Battle of Hastings in

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[41] Archeological evidence for paper's origin dates to the second century B.C. in China (Tsien 1985, 38).

[42] According to Needham, the kites were very large, requiring ground crews when aloft. The Purple Way was about 2.5 km away, so Yuan Huangtou flew a considerable distance (Needham 1994, 285).

1066 (Ray 2004, 3; Pardesi 2009, 101).

Throughout the centuries, human control of kites allowed them to be used for a variety of activities, including instruments for the military. Military kites have been used for a variety of different reasons, including carrying humans to conduct observations, aerial photography, and airborne targets. During WWII, a target kite developed by the U.S. Navy was used by both the Navy and Army to train anti-aircraft gunners; it was 5-foot-1-inch in height with a 5-foot wingspan, and it had a rudder mechanism that was controlled by the kite operator “by means of twin flying lines” (Grahame 1945, 2). While no longer used as anti-aircraft targets, kites are still being used for military purposes today. In 2013, the U.S. military deployed Helikites, which are part balloon and part kite, equipped with communications and surveillance systems, to Afghanistan to support small forward operating bases (Defense Systems Staff 2013; Robson 2012, 1).

Balloons

Military hot air balloons have been in existence since at least the 2nd century, when the Chinese Chancellor of Shu Han used Kongming lanterns as a signaling device; however, it wasn’t until humans learned to control the flight of balloons that they became effective weapon systems, and this stage in early UAS evolution didn’t occur until the 18th century.[43]

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[43] According to Chinese author Yinke Deng, historical Chinese writings record that the inventor of the small paper hot-air balloons, called Kongming lanterns, was Zhuge Liang (181-234 A.D.), also known as Zhuge Kongming (Deng 2011, 131). Deng writes that the invention occurred during a military campaign when an oil lamp heated the air under a large paper bag, which floated in the air, frightening the enemy. Later, people named this paper hot-air balloon Kongming’s Light (Deng 2011, 131). Similar hot-air balloons were also recorded being used during military campaigns during the Middle Ages as signaling devices (White 1961, 98).

After experimenting with steam and hydrogen in 1771, Joseph and Jacques Montgolfier were able to achieve sustained unmanned flight by "lighting fires underneath great paper balloons" which ascended to "considerable heights" (Hearne 1909, 28). Soon after, the balloons grew larger, and men began to fly suspended beneath the large tethered balloons in various assortments of containers.[44] While human control over the new balloon flight technology grew, it also remained somewhat limited, and tenuous, in the early years as free flight was initially at the mercy of the winds and weather. In order for balloons to be used for something practical, like sustained observation and reporting of activity on the ground, three things were required: stability, sustained proximity to the area observed, and the ability to quickly and reliably relay messages to the ground. In the early stages, a ground crew was required to control the manned or unmanned balloon to achieve these goals. The ground crew ensured the balloon remained connected to the ground through tethers, using ropes or cables that extended and retracted to maintain control of the balloon's ascent and descent. Human control of the balloon during free flight eventually evolved, first through the use of weights (to adjust ballast) to capture favorable air currents for limited directional control; followed by the added capability of modifying the heat or gas levels (by capturing or venting gasses), thus increasing the ability to adjust to currents; and finally by the addition of propellers, rudders, and stabilizers to better control motion and direction—all technologies that would provide new opportunities for other manned and unmanned applications and achievements, such

[44] The first untethered flight of a balloon with living beings occurred September 19, 1783, when a sheep, a rooster, and a duck flew onboard a Montgolfier balloon; the first free flight of a balloon with human passengers occurred on November 21, 1783, when Jean-Francois Pilatre de Rozier and Francois Laurent flew in a Montgolfier balloon from the Château de la Muette in the Bois de Boulogne in the presence of King Louis XVI and U.S. Envoy Benjamin Franklin (Kotar 2011, 12-17).

as trans-oceanic transportation (Ege 1973, 7).[45] With the obstacle of stability overcome through human control via tethers or onboard control systems, the balloon became a platform for the first use of consistent aerial observation and even aerial photography.[46]

As with kites, it was not long before balloons were used for military purposes. The first recorded military application of a manned balloon in the West occurred during the Battle of Fleurus in 1794, when the balloon *L'Entreprenant* was used by the French Aerostatic Corps to watch the movements of the enemy; however, due to logistical difficulties, the corps was disbanded in 1799 (Hearne 1909, 59). Shortly thereafter, the balloon was considered for its utility as a weapon, its first application as an unmanned aerial weapon system. In 1849 it was reported that the Austrian military attacked the enemy city of Venice, Italy, using unmanned balloons laden with explosives that were ignited by timed fuses or copper wire-triggered electromagnets (More About Balloons 1849, 205). Unfortunately, the lack of human control of the balloon, and the unpredictably of the winds, resulted in the inadvertent bombing of the Austrian lines, making this an unreliable weapon (Naughton 2003, 2). Despite the short-lived service of the early balloon corps, the primary purpose of its mission—aerial observation or reconnaissance—lives on today, and continues as one of the primary applications of the United States military's UAS technology on the modern battlefield.

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[45]The first trans-Atlantic voyage of an airship occurred on July 2, 1919, when Major George Herbert Scott of the British Royal Air Force, and the crew and passengers onboard the R34, flew from East Fortune, Scotland, to Mineola, Long Island, New York, in 108 hours and 12 minutes (*The Transatlantic Voyage of R34*, 1919, 906-907). Scott then returned to Great Britain in the R34 in 75 hours and 3 minutes, becoming the first person to complete a double crossing of the Atlantic (*The Return Voyage of R34*, 1919, 944).

[46] The development of aerial photography and other remote sensing technologies are covered in chapter five.

A little more than 60 years after the disbanding of the French Aerostatic Corps, the U.S. began using balloons for military applications during its Civil War. Both Union and Confederate armies used balloons; however, it was the North that established a more robust program under the leadership of professor Thaddeus S.C. Lowe, chief architect and organizer, who, in the summer of 1861, developed the Union's balloon corps under the authorization of President Abraham Lincoln. The first practical application of Lowe's balloons on the battlefield was for aerial observation to make maps and provide reconnaissance on enemy movements. Lowe, assigned to the Topographical Engineers, used his balloon *Enterprise* to support the commander of the Army of the Potomac, General Irvin McDowell, prior to the First Battle of Bull Run on June 23, 1861, by reporting Confederate troop positions (Crouch 1983, 348-352). On September 24, 1861, Lowe directed artillery from the air, resulting in "the first time in warfare that an accurate barrage was conducted at an enemy that could not be seen by the gunners on the ground" (Evans 2002, 112-113). On the Southern side, Captain John R. "Balloon" Bryan, commander of the Confederate Balloon Service, under the command of General Joseph E. Johnston, conducted aerial reconnaissance against Union troops for the first time on April 13, 1862, near Yorktown (Evans 2002, 195).

While the balloon was the first aerial craft to use photography, there is no record of aerial photography being used during the Civil War (Haydon 2000, 335); however, it was during this war that another technology was introduced to the battlefield that had profound impact on the development of aerial reconnaissance: telegraphic communications. Faster than flags and hand signals, this technology enabled rapid and continuous communication from the airborne observers to the ground via telegraph wires run along the tethers (Evans 2002, 68-69; Hoehling 1958, 104-108).

While manned observation was the primary military application of the balloon corps during the Civil War, unmanned applications were also explored. On February 4, 1863, an inventor from New York City named Charles Perley designed one of the first autonomous unmanned aerial bombers, a balloon; it was registered as patent No. 37,771 and titled "Improvement in Discharging Shells from Balloons" (Report of the Commissioner of Patents 1866, 293). Perley designed a balloon basket laden with a bomb attached to a timing mechanism that would open a hinged basket, releasing bombs.[47] Despite the innovation of the balloon-based weapon release technology, it was never used; the balloon corps ceased operation by the summer of 1863.

The popularity of using human observers beneath balloons grew and remained a viable means for procuring intelligence throughout World War I, in which balloons were used extensively to observe enemy troop movements, direct artillery fire, and locate submarines (Sitz 1930, 28). Eventually, the invention of the manned observer, or reconnaissance aircraft, followed by the armed fighter aircraft superseded the balloon's abilities. The new aircraft were able to fly at higher altitudes, making balloons too vulnerable as a target, and forcing battlefield reconnaissance to be conducted from the faster, more elusive aircraft.

By WWII, balloons used for observation over the battlefield were largely replaced by reconnaissance aircraft; however, manned observation balloons were still used

[47] The timing mechanism consisted of a time match that would trigger an explosive charge in a barrel, driving out the pin that held the hinged basked together (Report of the Commissioner of Patents 1866, 293).

extensively by the U.S. Navy for anti-submarine warfare, patrol, escort, torpedo recovery, and photographic and calibration services (Grossnick 1986, 39).[48] Also, it was during this conflict that the utility of balloons as unmanned systems was tried, put into flight as offensive unmanned weapon systems, as demonstrated by the Japanese "Fu-Go" fire balloons during World War II, albeit with minimal success due to the lack of ability to control the weapon system once set aloft.[49]

With the invention of the radio and remote sensing systems, unmanned moored balloons became capable of providing persistent surveillance for long durations, supporting U.S. military and law enforcement operations such as the U.S. Coast Guard's Mobile Aerostat Program (MAP).[50] The Coast Guard established MAP in the Caribbean from 1984 to the program's decommissioning on March 31, 1992, with the mission to

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[48] WWII was considered the "apex" for U.S. Navy lighter-than-air (LTA) craft. The Navy states: "The story of airship operations and expansion in WWII deals with the largest lighter-than-air fleet and the largest number of LTA operations the world has ever seen. U.S. Navy LTA operations ranged from the Pacific to the Mediterranean and from North Atlantic waters to the South Atlantic" (Grossnick 1986, 38).

[49] Thousands of Japanese "Fu-Go" fire balloon bombs were launched from mainland Japan in WWII, where the easterly winds brought them to Canada and the United States (Christopher 2004, 164). Only a small percentage of the Fu-Go weapons actually made it to their destination, with only six deaths recorded: a Sunday school teacher and five children in the Oregon Cascade Mountains (McPhee 1996). While not very effective, the Fu-Go could be considered the first "successful" unmanned intercontinental weapon system.

[50] Persistent Surveillance is defined by the U.S. Joint Forces Command, Joint Warfighting Center as: "An ISR [intelligence, surveillance, and reconnaissance] strategy to achieve surveillance of a priority target that is constant or of sufficient duration and frequency to provide the joint force commander the information to act in a timely manner" (*Commander's Handbook for Persistent Surveillance, Version 1.0* 2011, I-3). Major David W. Pendall, U.S. Army, provides a helpful definition of persistence in this context: "Persistence means that when global theater or local reconnaissance finds something of intelligence or actionable interest, ISR systems, including processing and analytic systems, maintain constant enduring contact with the target" (Pendall 2005, 41).

conduct shore-based and ship-borne persistent surveillance against illegal narcotics and migrant traffickers (U.S. Department of Homeland Security, 2016).[51]

On May 12, 2012, Graham Bowley, in a *New York Times* article, "Spy Balloons Become Part of the Afghanistan Landscape, Stirring Unease," noted that the U.S. military effectively used unmanned, moored surveillance balloons to carry out reconnaissance missions in the Afghanistan Theater of Operation, and they continue to serve as unmanned persistent surveillance platforms into the 21st century.

Gliders

One of the earliest heavier-than-air craft capable of more controlled flight than a balloon, and the closest to current designs of modern unmanned aircraft, is the glider. The history of flight is filled with stories of humans attempting to master and control flight by strapping on wings and gliding, as attested by the story of Daedalus and Icarus in Greek mythology, the account of the Berber inventor Abbas Ibn Firnas in the 9th century, and the account of Benedictine monk Eilmer of Malmesbury in the 11th century.[52] However, it was Sir George Cayley, sometimes referred to as the father of aviation or aerodynamics, who is credited with designing and experimenting with *working* fixed-wing gliders. Cayley

[51] The Coast Guard Mobile Aerostat Program consisted of two shore-based units located in Key West and Miami, Florida, responsible for unmanned lighter-than-air aircraft mounted with radar and other surveillance equipment. The units were comprised of two teams that alternately deployed aboard Sea Based Aerostat (SBA) Platforms. SBAs normally worked in conjunction with high- and medium-endurance cutters and patrol boat class vessels (U.S. Department of Homeland Security, 2016). On August 16, 2014, Coast Guard Research and Development Center researchers aboard the Coast Guard Cutter *Healy* used an Aerostat to track a simulated spill during an exercise (Eggert 2014).

[52] In his *Journal of Technology and Culture* article, titled "Eilmer of Malmesbury, an Eleventh Century Aviator: A Case Study of Technological Innovation," Lynn White Jr. translates the recordings of the 12th-century historian William of Malmesbury and the 17th-century Moroccan historian al-Maqqari to provide a thorough and concise narrative of the early flights achieved by Ibn Firnas and Eilmer of Malmesbury (White 1961, 97-111).

was instrumental in developing human understanding of the principles of flight, i.e., the forces associated with flight (weight, lift, thrust, and drag); the concept of aircraft "center of gravity"; and camber (the slightly arched surface of airfoils) (L. Day 1998, 136). These were all important elements required for the later development of riggings, apparatuses, procedures, and techniques that would be used to *control* flight, e.g., wings, vertical and horizontal stabilizers, rudders, ailerons, and propellers. Cayley also demonstrated that a glider was capable of sustained flight with a person onboard by sending a young boy aloft in 1849 (Scott 1995, 55). His experiments not only demonstrated that humans could fly in a fixed-wing glider, but also that a fixed-wing craft could carry a payload, which is the primary purpose of the UAS today.[53]

In 1891, German engineer Otto Lilienthal also demonstrated that a glider could carry a payload—himself —for long distances; he conducted more than two thousand glides before his death in a gliding accident in 1896 (L. Day 1998, 436). Lilienthal's achievements of sustained glides, along with American engineer Octave Chanute's early work with gliders, would later influence the Wright Brothers in the development of their manned airplane (Wright 1901, 494).[54] With the Wright Brothers' and others' success in

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[53] A payload is defined as: "1.The sum of the weight of passengers and cargo that an aircraft can carry. See also load. 2. The warhead, its container, and activating devices in a military missile. 3. The satellite or research vehicle of a space probe or research missile. 4. The load (expressed in tons of cargo or equipment, gallons of liquid, or number of passengers) which the vehicle is designed to transport under specified conditions of operation, in addition to its unladen weight" (U.S. Department of Defense JP 1-02 2001, 409).

[54] Referring to Lilienthal, Wilbur Wright declared that "no one did so much to transfer the problem of human flight to the open air where it belonged . . . he was without question the greatest of the precursors, and the world owes to him a great debt" (Wright 1912, 1-2). After Lilienthal's death in 1896, the Wrights began to correspond with Octave Chanute, the leading American authority on flight research, who had exchanged correspondence with Lilienthal for several years. Chanute was an important link between Lilienthal and early aviation pioneers in the United States (Lukasch 2003, 1).

proving that men could fly, unmanned applications of fixed-wing craft were overshadowed, causing unmanned aircraft development to remain in the shadows behind manned aircraft for decades.

As with kites and balloons, unmanned gliders eventually did find their way into the military arsenal; however, unlike kites and unmanned balloons, the military applications for unmanned gliders came a little later to the fight. In the 1920s, unmanned gliders were used in the United States as targets for anti-aircraft crews, and by the 1930s they were being used as targets for fighter aircraft (U.S. Air Force Fact Sheet: G-3, 2007). Like the manned balloons in WWI, it was the military's manned gliders that first took center stage during World War II; they carried troops and equipment during such operations as the invasion of Sicily in 1942 and D-Day in 1944, remaining in service until the helicopter usurped its role.[55] However, unmanned gliders in WWII served in an entirely different capacity than the manned gliders—as lethal weapons. The glide or standoff bomb, an early precursor to the motorized cruise missile, used small wings to improve the weapon's glide performance, allowing pilots of manned aircraft to release the bomb at a safer distance from the target.[56] The progeny of these unmanned glide weapons are the laser-guided bombs and Joint Direct Attack Munitions (JDAMs) currently in use by the military.

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[55] Manned gliders were also used by the German Luftwaffe in the late 1930s and early 1940s to train pilots as the post-World War I restrictions prohibited large-scale production of powered aircraft (U.S. Air Force Fact Sheet: Schneider Schulgleiter SG 38, 2015). The United States followed closely behind by introducing gliders into U.S. Army Air Force's pilot training in 1942 (U.S. Air Force Fact Sheet: Schweizer TG-3A, 2015). The *CG-4A Hadrian* was the most widely used U.S. troop carrier and cargo glider of World War II, with more than 12,000 gliders serving in the European and China-Burma-India theaters (U.S. Air Force Fact Sheet WACO CG-4A Hadrian, 2015).

[56] More detailed information on the development of unmanned bombs is covered in the WWI section.

Unmanned gliders are still being tested for other military applications today, including a global strike weapon,[57] covert mini systems to gather intelligence,[58] and tactical long-dwell surveillance systems.[59]

Mechanical Flying Machines

As with the earlier flying apparatuses, the discovery and development of powered, unmanned mechanical flying machines predates that of manned powered flight. One of the earliest references to a man-made flying mechanism occurred in the 4th century B.C. and was recorded by first-century Roman author Aulus Gellius. In his work *Attic Nights,* Gellius referred to a "not wholly absurd" story of a mechanical wooden dove created and flown by a student of Pythagoras named Archytas:

> For not only many eminent Greeks, but also the philosopher Favorinus, a most diligent searcher of ancient records, have stated most positively that Archytas made a wooden model of a dove with such mechanical ingenuity and art that it flew; so nicely balanced was it, you see, with weights and moved by a current of air enclosed and hidden within it. (Gellius 1927, 245)

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[57] The Falcon Hypersonic Test Vehicle 2 (HTV-2) Prompt Global Strike experiment, conducted by DARPA, was an unmanned glider that was intended to be an extreme range weapon system that could be released from suborbital space and glide at hypersonic speeds, approximately Mach 20, to its intended target. However, the U.S. military lost contact with the test vehicle shortly after it launched on a test flight on August 12, 2011 (Malik 2011, 1-3).

[58] In 2012, The U.S. Naval Research Laboratory successfully tested tiny unmanned gliders called CICADA (Close-In Covert Autonomous Disposable Aircraft), which can covertly deliver intelligence collection sensors within 15 feet of a target; the CICADAs are delivered by the larger U.S. Navy *Tempest* UAV (Hollister 2012, 1).

[59] The Unites States Naval Postgraduate School is currently developing the hand-launched Tactical Long Endurance Unmanned Aerial System (TALEUAS), an unmanned aircraft that can glide for extended periods of time by using the rising currents of warm air; endurance is limited only by the onboard and sensor system power requirements. The research team is also developing wing-embedded solar cells and a lithium-ion battery that will allow TALEUAS to stay aloft almost indefinitely. In addition, the Woods Hole Oceanographic Institution in Massachusetts is developing the unmanned *Albatross* glider that uses "dynamic soaring," a technique that harnesses wind shear, allowing the aircraft to stay aloft for extended durations (Babbage 2013, 1-2).

While Archytas's mechanical flying dove could certainly be considered among one of the early attempts at creating a mechanical flying machine, the first machine-powered, heavier-than-air unmanned vehicles to achieve flight occurred in Chard, England, in 1848. At an exhibition at Cremorne Gardens in London, John Stringfellow flew a steam-powered monoplane model a few dozen feet (Parramore 2002, 46). This was followed four years later by the first manned flight under machine power, when, on September 24, 1852, Jules Henri Giffard flew his cigar-shaped, gas-filled dirigible 15 miles from Paris to Elancourt, France (Holmes 2013, 174). Giffard was able to control the dirigible's flight using a "lightweight coke-burning, single-cylinder steam engine and boiler" to move the propeller—achieving a top speed of 5 mph—and a "triangular rudder" attached to the rear of the craft to control the direction (L. Day 1998, 285-286). While both Stringfellow and Giffard proved that sustained powered flight was possible, Giffard clearly demonstrated that humans could gain *some control* of a mechanical flying apparatus.

As with the balloon and glider, it was not long before powered mechanical flying machines were considered for military applications. A decade later, on June 3, 1862, Luther C. Crowell of West Dennis, Massachusetts, received a U.S. patent for a piloted aerial machine capable of carrying a bomb load (Crowell 1862, 1).[60] Like Charles Perley's unmanned balloon bomber, Crowell's machine never flew, but it did

[60] Crowell received patent 35,437. The wings of Crowell's flying machine were hollow and designed to be filled with hydrogen or other suitable gas; it was powered by a steam engine located in a car, had wings that pivoted from a horizontal to a vertical position, and two propellers linked by chains or bands that revolved in opposite directions (which were also hinged so that they could function both vertically and horizontally). The craft had a pyramid-shaped rudder and was designed to take off and land vertically, like a helicopter (Crowell 1862, 1).

demonstrate that military applications of steam-powered mechanical flying craft were considered at the genesis of powered flight.

Alphonse Pénaud, a 19th-century French pioneer of aviation design and engineering, also had an early unmanned model aircraft, the *Planophore*. Using twisted rubber as the power source, he successfully demonstrated stable sustained flight with his model airplane in 1871, achieving notoriety as "the first significant powered flight of a heavier-than-air flying machine" (Hallion 2003, 122). However, it was Samuel Pierpont Langley who is credited with the first *sustained* controlled flight by a powered unmanned aircraft large enough to carry a human-sized payload. On May 6, 1896, Langley's steam-powered aircraft, called the *Aerodrome No. 5*, was launched over the Potomac River and obtained sustained flight lasting more than one minute (McDaid 1997, 10). While the flight of Langley's *Aerodrome* was short—only 1,100 yards—it led the way for future developments in both unmanned and manned flight (Johnson 2001, 3). Langley made several attempts to prove that his design could carry a human payload, including two attempts in 1903, one in October and the second on December 8; however, neither flight was successful.[61] Nine days after Langley's second attempt, on December 17, 1903, credit for the first human-piloted, controlled, sustained, and repeatable flight under power was accomplished by the Wright brothers in Kitty Hawk, North Carolina.[62]

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[61] Among the many achievements of Langley was the first flight of a petrol-powered aeroplane. After his successful steam-powered flight he commissioned Stephen Balzer, an automobile engineer, to build a lighter-weight engine. In August 1903, working with Langley's assistant Charles Manly, they successfully powered a model plane with the small petrol-powered engine, producing the first gas-powered aeroplane to fly. The Balzer-Manly engine drove two pusher propellers for Langley's *Aerodrome*; it was an *Aerodrome* with the Balzer-Manly engine that Langley attempted to fly over the Potomac in October and December of 1903 (L. Day 1998, 416).

[62] Other reports of a first, manned, powered aircraft flight are said to have taken place earlier than the historic Wright Brothers flight. On October 9, 1890, it was reported that Clement Ader flew his steam

One of the keys to the Wright brothers' successful flight was overcoming the obstacle of maintaining stability and directional control while in flight—the same issue that challenged all of their predecessors; this understanding was critical to achieving and maintaining unmanned flight. Orville and Wilbur Wright developed a unique technique and system of devices to overcome aircraft instability and maintain control while aloft, for which they received the Aero Club of America, National Chapter, Aero Club Trophy in 1913 (Billings 1997, 67).[63] The technique used by the Wright brothers to overcome the stability and control problem was dubbed "wing warping" by fellow aviation pioneer Octave Chanute, and, according to associate fellow of the American Institute of Aeronautics and Astronautics, Thomas Heppenheimer, the brothers guarded their discovery diligently:

> In presenting the important matter of control, Wilbur showed that he and Orville were well ahead of Chanute. Wilbur took care not to disclose too much, for he was quite aware that other inventors were all too ready to take the Wrights' ideas and run with them to the nearest sand dune. He wrote of twisting the wings, raising and lowering the wingtips on opposite sides of the glider. Chanute coined the term "wing warping," but he did not understand its true significance. He viewed it as a means of turning an aircraft by increasing the drag on one side, an

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engine-powered, bat-winged monoplane, the *Eole*, 50 meters near Paris, France (Parramore 2002, 47). In Germany, another heavier-than-air powered flight is recorded to have taken place in August and September of 1903, when Karl Jatho flew 59 feet in a triplane in August and 196 feet in a biplane in November (Gibbs-Smith 1960, 46). However, neither of these flights were sustained or controlled; thus the history books record the Wright brothers as the first in flight.

[63] The trophy is named after publisher Robert J. Collier, who was an aviator and president of the Aero Club of America, National Chapter (now the National Aeronautic Association). Since 1911, the Collier Trophy has been given as an annual award to a person or group "for the greatest achievement in aeronautics or astronautics in America, with respect to improving the performance, efficiency, and safety of air or space vehicles, the value of which has been thoroughly demonstrated by actual use during the preceding year." Glenn H. Curtis received the first two awards for his hydro-aeroplane and flying boat. Orville Wright received the trophy for the development of the automatic stabilizer in 1913. In 2000, it was jointly awarded to the Northrop Grumman Corporation, Rolls-Royce, the Raytheon Company, L-3 Communications, the United States Air Force, and DARPA for "designing, building, testing, and operating *Global Hawk*, the first fully autonomous, operationally demonstrated, and most capable surveillance and reconnaissance unmanned aerial vehicle in the world." The Collier Trophy is on permanent display at the National Air and Space Museum, Washington, D.C. (National Aeronautic Association 2014).

> approach with which he was already familiar. In fact, wing warping sought to bank a glider by increasing the lift on one side while reducing the lift on the other. By failing to grasp this point, Chanute showed that he no longer was ready to keep up with the latest developments, even when they were presented in a personal letter. (Heppenheimer 2003, 115)

Their wing warping innovation allowed humans to control the flight of a mechanical flying machine, and it sparked a technological explosion in aviation. While unmanned aviation would benefit significantly from the technological breakthroughs made in human-controlled flight by the Wright brothers, along with the subsequent mass development of the airplane, unmanned aircraft achievements would continue to remain largely overshadowed by man's desire to master the skies. This desire quickly led to the application of manned flight for military purposes, which became evident in 1911 when the U.S. Army applied the new technology of aircraft and controlled flight to actual military operations. The Army conducted manned military reconnaissance missions along the U.S.-Mexico border, accurately fired weapons from an airplane, and began the development of the military aircraft and military pilot (Nalty 1997, 18). The race had begun; not only was humanity interested in flying across the skies, there was now a drive to conquer and control flight as well. Due to this desire, the utility and earnest application of unmanned military aircraft would have wait until the latter half of the 20th century.

Radio-Controlled Flight

Once humans began to apply flying machines to various applications, especially military uses, the need for assistance in maintaining control of the aircraft while aloft became extremely important. Various mechanically controlled flight systems, consisting of hinged flaps controlled by wires, cables, and pulleys, were developed to allow the pilot to more easily control aircraft altitude during flight, e.g., the ailerons to control roll, elevators for pitch, and the rudder for yaw, etc. Eventually these control systems became first assisted, and then eventually automated, using pneumatically- or electrically-spun gyroscopes connected to mechanical flight controls via hydraulic lines, allowing pilots to perform other functions while flying, such as navigating, observing movement on the ground, operating cameras, firing weapons, or dropping bombs (U.S. Department of Transportation 2008, 5-2; 5-12). This automation also laid the foundation for unmanned flight, with the remote control of unmanned aircraft, via radio, following shortly thereafter.

In 1836, Samuel F.B. Morse constructed his first telegraph, and by 1895, building upon the work of many scientists and inventors—including Heinrich Rudolf Hertz, Edouard Branly, and Nikola Tesla—Guglielmo Marconi successfully transmitted radio signals the distance of one mile, receiving a British patent for the device in 1897 (Fahie 1899, 296).[64] That same year, Tesla achieved the distinction of actually building the first wireless-controlled vessel, a boat controlled by "Hertzian waves sent out from shore" (Miessner 1916, 84).[65] In 1912, A.J. Roberts of Australia applied the new technology to a dirigible balloon, remotely controlling the propelling and steering motors of the flying craft from a maximum distance of approximately 500 feet (Miessner 1916, 86-87).[66]

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[64] That same year Ernest Wilson was granted a British patent for a wireless system for the shore- or ship-based control of a self-propelled torpedo that could be used as a weapon in naval warfare; but no record exists that he actually constructed or used the wireless-controlled weapon (Miessner 1916, 83).

[65] Tesla received an 1898 U.S. patent for his invention, wherein he mentions the use of "all forms of control energy including electromagnetic induction, electrostatic induction, conduction through earth, water, and the upper atmosphere, and all forms of purely radiant energy" (Miessner 1916, 84).

[66] Roberts controlled his 15-foot-long, 16-pound, gas-filled, pig intestine balloon using "a twelve-inch induction coil transmitter . . . a coherer, tapper, relay, and coherer battery . . . a rotary switch of the

Despite the breakthrough of the new radio control technology, the inventors struggled with the sporadic successes in the operation of their radio systems, the limited effective distances of the radio waves, and the stability of the craft. Regardless of the struggles, the technology was now here, and along with the development and use of the airplane, remote control technology would steadily develop during World War I.

Automated Flight Control Systems

In order for an unmanned aircraft to become an effective weapon, it required the ability to safely lift off and reach effective altitudes, remain stable in flight, and fly on its intended course to meet the mission objectives. This not only required the ability of a ground operator to successfully fly the plane remotely, it also required an onboard automated flight control system, or autopilot, to assist with keeping the aircraft at altitude and on course.

The first technological breakthrough for an operational autopilot is credited to Elmer A. Sperry, inventor of a gyrocompass used by the U.S. Navy, the first of which was installed onboard the U.S. warship *Delaware* in 1911 for stabilization (The Gyroscope 1943, 82).[67] Observing early radio-controlled experiments, Sperry realized that the effectiveness of remote control for aircraft would also depend on automatic

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Tesla type . . . several cells of a storage battery . . . two signal lights . . . and two propelling and steering motors"; the motors were mounted at the ends of "a centrally pivoted, horizontal frame about two feet long," and flight direction was achieved by stopping one of the motors (Miessner 1916, 86-87).

[67] Elmer Sperry is credited with the first *operational* autopilot because the concept was not new. In 1908, Sir Hiram Maxim described a gyroscopic stability augmentation device in his book about aeronautical experiments, *Artificial and Natural Flight* (Kurzhals 1977, I-3). His device, which was "connected to the fore and aft elevators of a large, highly unstable airplane built and tested while tethered," was patented in England in 1891 and is believed to be the first example of an aircraft automated control system (Billings 1997, 67). However, for the next half century, it was Sperry who was associated with aircraft automatic pilots—called "autopilots" (Billings 1997, 67).

stabilization in flight. With support from the Navy, he applied his gyrocompass technology to aircraft, inventing the *gyroscopic stabilizer*, or autopilot, in 1912, to prevent rolling (Pearson n.d, 70).[68] In the summer of 1913, using a U.S. Navy flying boat crewed by pilot Lt. P.N.L. Bellinger and engineer Lawrence Sperry, Elmer's son, he tested the stabilizer (Pearson n.d, 70). The following year, Lawrence Sperry demonstrated the flight stabilizer publicly at a Paris aviation contest by flying the aircraft with his hands away from the flight controls while his assistant, French mechanic Emil Cachin, walked on the wing; the team won the 15,000-gold franc first prize offered by the Aeroclub of France (Scheck 2006, 3). Despite the success, the autopilot was not immediately put into production—it was considered not ready for operational use.

U.S. Military UAS Development: World War I

> *"In the future nations will fight each other thousands of miles apart. No soldier will see his enemy. In fact future wars will not be conducted by men directly but by the forces which if let loose may well destroy civilization completely. If war comes again I look for the extensive use of self-propelled air vehicles carrying enormous charges of explosive which will be sent from any point to another to do their destructive work, with no human being aboard to guide them."*
>
> — Nikola Tesla

While interest in unmanned aircraft never completely ended, as attested by Roberts's remote-controlled balloon, it did stagnate until needs generated by World War I produced the military support and funding necessary to once again generate life into unmanned aircraft research and development.

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[68] Elmer Sperry's autopilot consisted of a gyroscopic heading indicator and attitude indicator that were connected to hydraulically operated elevators and a rudder, permitting the aircraft to fly straight and level on a compass course without a pilot's attention (Now—The Automatic Pilot 1930, 22).

Manned Aircraft Technology in WWI

World War I saw the first large-scale use of the airplane over the battlefield, and while its reputation as a valuable military asset quickly grew in Europe, the U.S. military was slow to catch on, preferring balloons to airplanes (Cooke 1996, 2-5).[69] However, even though the balloon remained the primary platform for aerial observation—it provided the majority of the reconnaissance activity for troop movement and artillery fire direction during the war—the application of aircraft in that particular role steadily grew (Cooke 1996, 25). In addition to aerial reconnaissance, airplanes, like the balloons, were adapted for aerial bombardment;[70] however, unlike balloons, planes could also conduct air-to-air attack missions more efficiently against enemy observation balloons and other aircraft. As the role of these *fighter* aircraft grew, reconnaissance, air-to-air, and air-to-ground combat missions also grew, becoming major functions for military aircraft.

During the period 1914-1918, the technology of aircraft changed rapidly from the days of the *Wright Flyer*. While there were dramatic differences in airframes and performance in aircraft during WWI—from the French *Breguet Bre.4* bomber (1914) to the German *Fokker D. VII* fighter (1918)—the basic physics of flight remained the same as Cayley had first recorded, with weight, lift, thrust, drag, center of gravity, camber, and

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[69] When the U.S. entered the war in April 1917, the Aviation Section of the Signal Corps had a total strength of 65 officers, a little more than 1,000 enlisted men, and approximately 200 training aircraft—though none fit for combat; there was no practical combat experience (Maurer 1978, 51).

[70] Germany conducted aerial bombardments of English cities during the World War. On January 19-20, 1915, two German Zeppelins conducted one of the first aerial bombing raids on a civilian target, dropping high-explosive and incendiary bombs on the English town of Great Yarmouth and surrounding villages, killing four and injuring sixteen (Stephenson 2014a, 14-15). The first recorded use of an airplane as a weapon occurred in 1911 during the Italo-Turkish War, when the Italian Army Air Corps bombed a Turkish target in Ain Zara, Libya (Buckley 1999, 38). The bombs consisted of hand grenades, and they were dropped by Giulio Gavotti on his target during a mission on November 1 (Millbrooke 2006, 1-20). Not long after, airplanes became the primary delivery method for bombs dropped from the air.

power being the central aspects of successful flight. The fundamental structural components required for aircraft flight also remained basically the same, with fuselage, wings, vertical and horizontal stabilizers, rudders, ailerons, and propellers remaining the required components to provide the necessary lift and directional control.[71] Nonetheless, significant changes occurred in the airplanes' engines and control mechanisms, as well as the tactics, techniques, and procedures used for flying them. While the emphasis was on piloted aircraft during these years of rapid development and change, the utility of unmanned aircraft was never completely forgotten, and methods to employ unmanned aircraft during WWI were explored.

Flying Missiles, Bombs, and Torpedoes

In the early years of the war, unmanned aircraft were also considered for military tasks, such as reconnaissance and attack missions (Werrell 1985, 8-12). This was made possible because of the work of a number of inventors, from both sides of the Atlantic, who focused on key areas of control related to unmanned flight, particularly British inventor Archibald Low and American inventors Peter Cooper Hewitt, Elmer A. Sperry, and Charles Kettering.

Archibald Low was a British engineer whose 1914 experiments with the wireless helped develop radio control technology and contributed to the birth of the military UAV. In 1916, the British military looked at Low's remotely controlled airplane as a potential weapon, a solution to "counter German Zeppelin airships and provide rudimentary

[71] The basic physics of general aviation as well the physical components of most modern aircraft remain the same today. Modern technology allows the increase in power and thrust, created by computer-controlled engines, to work alongside computer-controlled flight control systems, to enable aircraft to fly without rear vertical and horizontal stabilizers—such as the *B-2* bomber and *X-47B* UAS.

ground attack capabilities with unmanned aircraft packed with explosives" (Chuter 2010, 1). As an engineer and captain in the Royal Flying Corps, Low assisted the military in its effort to develop these flying missiles.

> He helped research ways to remotely control aircraft, with the idea of turning airplanes into guided missiles. As head of Experimental Works, the military organization in charge of the project, Low supervised a hand-picked team and conducted a test flight of an unmanned craft for military dignitaries on March 21, 1917. The vehicle was launched with compressed air (a first), and although it crashed soon into the test, Low and his team were able to control the plane, albeit briefly. He improved the test vehicle by adding an electrically driven gyroscope (another of his innovations), but the project was soon abandoned by the British military. (Diaz 2014, 1)

While Low's invention never saw combat, it did contribute to a technological foundation that others would build upon to create what would later become human-controlled, weapons-carrying unmanned aerial vehicles.

At about the same time, on the other side of the Atlantic, the U.S. military was also conducting research studies of radio-controlled aircraft. According to military historians James Rife and Rodney Carlisle, the Navy was interested in developing flying bombs—pilotless, explosive-laden aircraft dubbed "aerial torpedoes"—which could be used to attack ships:

> The Navy's flying bomb research program had started in early 1915, when noted technologist Dr. Peter Cooper Hewitt (inventor of the mercury-vapor lamp) consulted with Elmer Sperry, about the feasibility of developing such weapons. . . Sperry gave Hewitt's idea some thought and decided that his company could do the experiments if Hewitt would pay for them. Hewitt agreed and gave Sperry $3,000 to start the work. (Rife 2007, 40)

Unfortunately, the project's funding was quickly depleted and Hewitt and Sperry had to appeal to the military to obtain financial assistance for supporting the research.[72] With funding and Curtis N-9 seaplanes provided from the Navy, Sperry fitted an automatic flight control system onboard and launched the N-9 from a catapult designed by Carl Lukas Norden, who would later invent the Norden bombsight that would be used in WWII. Once airborne, the aircraft left human control and an onboard control system flew the aircraft to a predetermined altitude, leveled off, and flew straight for a predetermined distance—measured by a gear which counted the engine revolutions—at which point it dove to the ground, delivering a 300-pound bomb (Werrell 1985, 8-12). On March 6, 1918, the aircraft, nicknamed the Sperry-Curtiss *Flying Bomb*, flew 1,000 yards near Copiague, Long Island, New York, earning its place in history as the first successful flight of a powered, unmanned aircraft weapon system—the world's first (Newcome 2004, 139). However, despite numerous attempts to get the *Flying Bomb* to an operational status for the war, no system was delivered, and the Navy eventually cancelled the program in 1922 (Werrell 1985, 12). In spite of its nonoperational status, the *Flying Bomb*, like Low's radio-controlled airplane, was another important milestone for the future development of unmanned aerial weapons; it was the first step toward an operational aerial vehicle that operated separately from the human once launched.

During the same time period as Sperry, Mr. Charles F. "Boss" Kettering, an inventor, entrepreneur, and founder of the Dayton Electrical Company (Delco) and Dayton Wright Airplane Company in Ohio, also was experimenting with unmanned

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[72] Hewitt and Sperry were both members of the Aeronautics Committee of the Navy Consulting Board, which was established on October 7, 1915, and were able to make direct appeals to the Board (Rife 2007, 40).

aerial weapons under contract with the U.S. Army, which had the goal to build twenty-five *Liberty Eagle* aerial torpedoes (Newcome 2004, 23-24). The Army was particularly interested in the unmanned aircraft's ability to bomb heavily defended targets while keeping pilots out of harm's way. To address this issue, Kettering built the *Kettering Bug*, a biplane assembled around 180 pounds of high explosives, powered by a four-cylinder engine, launched via a wheeled trolley, and installed with a system to guide the craft to the target area by using gyroscopes, a barometer, and a mechanical computer (Kettering Aerial Torpedo 2014, 1). The *Bug*'s onboard control system—advanced for the day—allowed the aircraft to fly autonomously to the target.

> Most interesting were the Bug's innovations in flight controls, which used a combination of pneumatics, electricity, and gears. Altitude was controlled by an aneroid barometer that could be preset to a given height at which it would trip a switch to turn control over to Sperry's gyroscope to maintain its preset altitude via a link to the elevators. Direction was maintained by the gyroscope, based on its prelaunch alignment, deflecting without touching small pneumatic valves linked to the rudder. The vacuum was produced by a bellows activated by suction produced by the engine crankcase. Distance was measured by a wing-mounted anemometer tied to a pneumatically operated subtracting counter. The counter could be preset to the desired number of clicks, each corresponding to 100 yards, which on reaching zero short-circuited the engine ignition, causing the Bug to dive on its target. (Newcome 2004, 24)

On October 4, 1918, after a number of previous short-term setbacks, the *Bug* flew for an hour at an altitude of approximately 12,000 feet before crashing 100 miles away; the Army, under the recommendation of Colonel Henry Harley "Hap" Arnold, ordered large quantities of the *Bug* during the last months of World War I (Newcome 2004, 28). Regrettably for Kettering, fewer than fifty were built, and, like the Sperry-Hewitt *Flying Bomb*, the war ended before his *Bug* could be fielded. The Army subsequently cancelled the remaining orders, and the lack of additional military funding after the war cancelled further development (Yenne 2004, 15).[73]

With World War I over, the interest in developing unmanned aircraft weapons quickly waned. After the war the Army continued testing the *Bug,* but only twelve were retained; they were used at Calstrom Field, Florida (Jarnot 2012, 5). The U.S. Navy also continued testing, conducting the last aerial torpedo test on April 25, 1921. Shortly thereafter, under mounting economic pressure and the direction of the Navy's Chief of Naval Operations, all further testing subsequently ceased:

> As Rear Admiral Delmer S. Fahrney noted in the Navy's official history of pilotless aircraft and guided missiles, BUORD [the Navy's Bureau of Ordnance] did not necessarily lose interest in flying bombs, but in an era of slashed military budgets in which the Navy needed every cent it could scrape up to maintain a modest fleet, little money existed for experimentation. "If a project was not a complete and howling success on the first trial," he wrote, "it would be dropped." (Rife 2007, 43)

These early UAVs suffered from a number of setbacks that discouraged robust investment and development after the war, including fragility of airframes; limited technology to overcome problems of flight stability, guidance, navigation, and control; accurate and reliable weapon delivery capability; and lack of success during testing. While unmanned aircraft development was no longer a priority after WWI, interest remained, and significant advances in civil aviation technology occurred between the wars, e.g., radial air-cooled engines, retractable landing gear, two-way radio communications, stressed-skin metal monoplanes, and autopilot, to name just a few

[73] The concepts of the Sperry-Hewitt *Flying Bomb* and Kettering's *Bug* would be tried again in the next World War, ultimately seeing operational use by the German Air Force as the jet-powered V-1, predecessor to the modern cruise missile.

(Paulisick 1972, III-11). However, emphasis for using unmanned aircraft as offensive weapon systems would have to wait until World War II.

Even with the decreased emphasis, these early technologies introduced a historic leap in the human-machine relationship. Like the arrow, bullet, cannon ball, and rocket, this technology further contributed to the increased distance between the soldier and the weapon, introducing new challenges for maintaining control of the technology, and in some cases, like the *Flying Bomb* and *Bug*, releasing control of it altogether. With this breakthrough, unmanned aerial systems would divide into two primary areas: those that remain under human control while in flight—the UAS; and those that were given various degrees of autonomy apart from direct human control—the guided munitions and cruise missiles.

U.S. Military UAS Development: 1920 through World War II

> *"In the development of air power, one has to look ahead and not backward and figure out what is going to happen, not too much what has happened."*
>
> — General William "Billy" Mitchell

Despite the drawdown and lack of interest in unmanned aircraft as weapons after the Great War, UAVs continued to be used in training anti-aircraft gunnery crews. During this period, two important advancements in the technology were made that would significantly boost the utility of the UAS for use as weapons systems during WWII: improved radio control and the ability to recover unmanned aircraft.

Radio-Controlled Aircraft

In 1923, electrical engineer Carlos B. Mirick, working with the newly formed Naval Research Laboratory (NRL), began working on a device that would allow a pilot to be physically separated from his aircraft, yet maintain control: the radio-control device. Consisting of a transmitter, receiver, and relay, the device controlled basic functions onboard an unmanned aircraft, resulting in America's first remotely piloted aircraft intended to be used as a weapon (Callahan 2014, 101). Using the gyro-stabilized Curtis N-9 aircraft created by Sperry, Mirick was able to relay a signal to the aircraft capable of actuating an onboard selector switch while it was in flight (Mirick 1946, 947). By the fall of 1924, he successfully flew the *Wild Goose* a number of times with a pilot onboard, and on September 15, 1924, he accomplished his first and last remotely controlled flight with no pilot, subsequently crashing into the Potomac (Callahan 2014, 106). One further attempt was made in another plane that year, but it too crashed, and the NRL received no further funding, thus putting an end to the program for ten years (Callahan 2014, 110). While the setbacks resulted in cancellation of the program, Mirick's efforts paved the way for subsequent, and more successful, radio-controlled unmanned flights.

In 1929, the Army re-examined the idea of radio-controlled unmanned aircraft for anti-aircraft training and purchased a modified Curtis Robin aircraft for a test program, re-designating it the *XC-10* (Bowers 1979, 383-386). The test lasted five years, and the *XC-10* was only flown about 100 hours; however, important experience in flying remotely controlled airplanes was gained (Curtis XC-10 2009, 1). Unfortunately, like their earlier counterparts, the Army program lost funding, primarily due to competing manned-aircraft requirements, and the program was cancelled (Womack 1988, 2-2).

Overseas, the British military also continued to construct a number of unmanned aircraft to be used as anti-aircraft artillery targets and flying bombs, developing technology that would assist U.S. unmanned aircraft development programs. In 1933, one particular model, known as the *Fairley Queen*, successfully demonstrated the ability and usefulness of remote-controlled aircraft by evading naval gunfire for two hours (Werrell 1985, 20). Operational utility of remote-controlled airplanes was slowly recognized, and development in earnest was begun using the British de Havilland *Tiger Moth* biplane to create the *Queen Bee* unmanned aircraft.[74] The *Queen Bee,* a biplane made of spruce and plywood, could fly at 17,000 feet, reach a top speed of more than 100 mph, and travel up to 300 miles—perfect for training anti-aircraft gun crews (Drones: A Photo History 2012, 3). A total of 420 *Queen Bees* were built between 1934 and 1943 (Werrell 1985, 20). It was this aircraft that U.S. Navy personnel observed a few years later while visiting England, resulting in the Navy's renewed interest and effort in unmanned aircraft weapon systems and the subsequent revitalization of the U.S. program (Trimble 1990, 188-190).

Back in the U.S., the military was not the only entity starting to make its own progress with remote-controlled aircraft; the commercial sector was beginning to enter the market as well, providing additional technological developments that would be incorporated by the military.

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[74] One theory in the creation of the term "drone" to refer to unmanned aircraft relates it to the development of the *Queen Bee,* with drone referring to the Queen's male counterpart (Chuter 2010, 3). One of the first written occurrences of the term "drone" occurs in an unmanned aircraft status report written by Lieutenant Commander Delmer Fahrney in December 1936 (Newcome 2004, 4).

In 1934, British-born Hollywood actor Reginald Denny, who had served in the Royal Flying Corps during World War I and developed a fascination with Remote Control (RC) aircraft, started Reginald Denny Industries in Los Angeles, California (evolving, by 1939, into the Radioplane Company), successfully producing and marketing an RC toy plane, the *Radioplane 4* (*RP-4*) (Naughton 2005, 1-3). Denny approached the Army in 1935 about producing a remote-controlled plane for military use, but his initial proposal failed to initially generate interest after an unsuccessful demonstration (Newcome 2004, 57). However, in 1940, the Army subsequently purchased 50 RP-4 model aircraft—later referred to as *OQ-1s*—for use as target drones (Parsch 2003, 1).[75]

Recoverable Unmanned Aircraft

The *Queen Bee* and *OQs* demonstrated another important advancement in the technological development of the unmanned aircraft that was directly related to radio control: unmanned aircraft recovery, primarily a British invention. Before 1935, unmanned aircraft could not return to their original launching point, resulting in their primary use as targets or bombs. With the creation of the British de Havilland (DH) *82B Queen Bee*, unmanned aircraft could return to their points of origin and land, making them the first reusable unmanned aircraft and significantly enhancing their utility (Braithwaite 2012, 52).

[75] Unmanned aircraft were designated by function: OQ denoted a “sub-scale” target drone, “PQ” designated “full-size,” and “A” designated “attack” drones. However, the OQ-1 designation was never officially allocated by the U.S. Army; it was added later after the designation for the RP-5 as the OQ-2 (Parsch 2003, 1).

The *OQ-2* (Denny's *RP-5*) also was an unmanned aircraft system that could be recovered and reused; however, it had a much simpler launch and recovery technology. It was launched by slingshot and recovered by parachute (a recovery method that would be used by UAVs through the Vietnam War) (Hillinger 2005, 11). Despite its simplicity, the radio-controlled and recoverable UAV was effective, and the technology was instrumental in furthering other unmanned aircraft development activities during WWII, enabling significant advancements in offensive unmanned aerial weapon system technology.

Early Unmanned Combat Aircraft Development

A year later, the U.S. Navy initiated PROJECT DOG, a program focused on converting single aircraft into UAVs. On February 17, 1937, using more powerful radios, the U.S. Navy once again pioneered military UAV advancement by successfully flying the *N2C-2* drone—a Curtis *Fledgling* biplane—via remote control. Less than a year later, in September 1938, the project tested the first assault drone with a *N2C-2*, dive-bombing the *USS Utah*. While the test was unsuccessful, it showed the capability of remotely controlling an unmanned aircraft weapon system and provided enough promise for the Navy to continue funding development (McDaid 1997, 11). By August 1939, the Drone Services Group was part of a regular training program for the Navy, training ship-borne gun crews (Callahan 2014, 112-114).

In April 1941, the Navy conducted the first successful live attack with a remotely piloted *Curtiss TG-2*, a single-engine biplane torpedo bomber. The *TG-2*, controlled by an operator from 20 miles away in the "mother" aircraft, released a dummy torpedo and scored a direct hit on a maneuvering destroyer's towed target raft. The Navy subsequently ordered 500 assault drones and 170 "mother" aircraft just before WWII (McDaid 1997, 11). The human-controlled and directed unmanned combat aerial vehicle (UCAV) was officially born.

In 1938, the U.S. Army Artillery Branch grew more interested in drones and asked for a demonstration of one of Denny's models, subsequently purchasing the prototype. By 1940, Denny received a contract to produce the *RP-4*, based on his latest model, which was designated the *OQ-1*. Denny and his team continued to refine their product, and throughout World War II his radio plane company produced and sold to the Army and the Navy more than 15,000 *OQ*s —the Navy designated the drone the Target Drone, Denny (TDD) (Newcome 2004, 58). Like their Navy and British counterparts, these drones were used exclusively as targets for anti-aircraft gunnery training. After WWII the Army adapted the *OQ* to be used for reconnaissance missions, as the consistency of operations clearly demonstrated reliable remote control technology (Blom 2010, 48, 75).

Both the *Queen Bee* and *OQ* aircraft were controlled through a simple rotary telephone dial which used specific numbers to transmit radio signals to onboard pneumatic servos; the servos would then direct the flight controls to influence the aircraft, making it turn left or right, adjust altitude up or down, or increase or decrease speed (Newcome 2004, 57; Braithwaite 2012, 52). Despite their limited use as targets in the 1930s, the remote control aircraft technology would enable more lethal applications during the Second World War.

Unmanned Aircraft Operations in WWII

World War II introduced a number of different applications for unmanned aircraft, including the concept of an unmanned combat aerial weapon system. Unmanned aircraft were used as glide bombs, long-range missiles, and eventually unmanned radio-controlled attack aircraft. While the numbers of these systems were relatively few compared to manned aircraft, military necessity and funding allowed the technology to move steadily forward, setting the stage for more advanced developments after the war. Improvements in radio control and navigation, along with innovations learned from the German V-1, led to the creation of more sophisticated glide bombs and unmanned torpedo planes and bombers. The technologies introduced during this conflict were used to develop new systems that evolved into laser-guided bombs, such as the Paveway series used by the U.S. in the 1960s, unmanned reconnaissance aircraft during the Cold War and Vietnam Conflict, and cruise missiles developed during the 1970s. Each of these systems spawned technologies that enabled development of the offensive UCAVs in operation today, such as the *MQ-9 Reaper*.

Glide Bombs

Only the Germans and Americans successfully used unmanned glide bombs (GBs) in combat during World War II. In 1943, the Germans used the Ruhrstahl *SD 1400 Fritz X* and Henschel *Hs 293* aerial bombs effectively against warships in the Mediterranean Sea, controlling the glide paths of the bombs by radio control (Winter 2000, 1; German "Fritz X" Guided Bomb 2011, 1). The U.S. Army Air Force (USAAF) built GBs similar to those of the Germans and called them the *Aeronca GB-1*—a 2,000-pound bomb with wings, a tail assembly, and a gyroscopic stabilization system. These were released by a *B-17* bombardier and glided straight to the target. The USAAF also developed the *Azon* Vertical Bomb 1 (*VB-1*), a 1,000-pound bomb fitted with a tail assembly containing radio-controlled movable rudders. The *GB-1*s were used in combat during WWII but subsequently abandoned, whereas the *Azon* was the only radio-guided GB to reach operational use during WWII, successfully employed in the European, Mediterranean, and China-Burma theatres of operation (U.S. Air Force Factsheet: VB-1 Azon Guided Bomb, 2015).

These GBs—predecessors of the modern anti-ship missiles—evolved through the course of the war and were fitted with more sophisticated radio-control systems, cathode ray tubes (CRTs) used to guide them in flight, infrared, and eventually computerized radar guidance systems. They were successful, as their existence today testifies; however, they were not true unmanned aircraft, as they were the weapon—not solely the delivery mechanism or system—and were committed to the flight path they were on once launched. Nor were they recoverable or reusable.

The next step in the evolutionary development of unmanned aerial weapon systems during WWII was a bomb that was launched from the ground and flew directly to its target—the flying bomb. Technology from this system would later be used in Vietnam to conduct jet-powered unmanned aerial reconnaissance missions.

Flying Bombs

Germany was the leader in developing flying bombs during WWII. In 1944, German engineer Fieseler Flugzeuhau developed the *Vergeltungswaffe (Revenge*

Weapon) 1, also known as the *V-1*.[76] The 2,000-pound bomb, incorporating newly developed pulse-jet engine technology, was launched by catapult and could reach a top speed of 400 mph, flying along a preprogrammed route for up to 150 miles (Werrell 1985, 42-43).[77] Like Kettering's *Bug*, the *V-1* possessed an autopilot controlled by an internal gyroscope, a magnetic compass, and a barometric device to help it reach its targets, primarily London and Antwerp.[78] As many as 30,000 *V-1s* were built during the war, with one-third of them used against targets in Great Britain (Werrell 1985, 58).[79] As a jet-powered bomb capable of crude navigation by being pointed in a direction and then engaging a countdown mechanism until it reached the target area, the *V-1* became the predecessor of the modern cruise missile. A year later, in 1945, the Germans developed the *V-2*, the first operational ballistic missile.[80]

Upon learning of the German *V-1*, the U.S. Army began developing its own jet bomb, designating it the JB-1; however, difficulties with the homegrown engine ended the program. Instead, the Army developed an indigenous version of the *V-1*, called the

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[76] The buzzing noise created by the pulse-jet engine resulted in the nickname "buzz bomb" or "doodlebug" (named after insects) (Zaloga 2005, 8-9).

[77] A few were also air-launched beneath bomber aircraft (Werrell 1985, 58).

[78] "The Germans used a gyro autopilot, powered by compressed air, to hold a course determined by a magnetic compass and a barometric device to regulate altitude. These devices sent signals to the craft's rudder and elevators on the tail surfaces. A small propeller device armed the warhead after the V-1 flew about 38 miles and then, after a preset number of turns, fired two detonators which locked the elevators and rudder in the neutral position while deploying hinged spoilers on the tail, presumably over the target" (Werrell 1985, 43).

[79] While they were not very accurate—only 2,419 reached London—they were deadly, claiming more than 6,000 lives and seriously injuring about 18,000 people in Great Britain alone (Werrell 1985, 58).

[80] A ballistic missile is "any missile which does not rely upon aerodynamic surfaces to produce lift and consequently follows a ballistic trajectory when thrust is terminated" (U.S. Department of Defense JP 1-02 2010, 23).

JB-2, designed by reverse engineering of a salvaged *V-1* provided by Great Britain (Werrell 1985, 62-63). While there was demand for thousands of the *JB-2s*, the War Department debated the advantages and disadvantages compared to the production of traditional bombs and artillery; the result was a delivery of 1,385 *JB-2s* before production was terminated by the end of the war. However, while plans were made to use the bombs against Japan and Germany, they never saw combat (Werrell 1985, 65).

Unmanned Aircraft as Weapon Systems

In 1941, two technologies were developed that significantly boosted the utility of unmanned aircraft: the television camera—developed by Radio Corporation of America (RCA)—and the radar guidance system, developed by the U.S. Naval Research Laboratory (NRL). Both were used by the Navy in the development of attack drones under the label of Operation Option*,* later designated the Special Air Task Force (SATFOR) (Newcome 2004, 66-68). Through the SATFOR efforts, the Navy became the first service to successfully use unmanned aircraft not as bombs, but as vehicles to deliver weapons in a combat strike mode (Newcome 2004, 139-40).

The Naval Aircraft Factory and the Interstate Aviation and Engineering Corporation developed the attack drones—designated *TDN-1* and *TDR-1* respectively, with the *TDR* version eventually superseding the *TDN*—which were guided to their targets by operators onboard Navy TBF Avenger torpedo bomber aircraft using remote control and television (Newcome 2004, 67). In 1942, the Navy conducted experiments with the armed UAVs. They attached a torpedo, and upon making contact with an enemy ship, the operator would use the small TV monitor to guide the UAV on an attack run and release the torpedo. However, maintenance problems with the UAVs and the success of manned carrier aviation against the Japanese fleet made many naval commanders, including Commander of the Pacific Fleet Admiral Chester W. Nimitz, skeptical of the program. Despite the skepticism, in July 1944 the Navy launched its first operational UCAV missions using four *TDR-1s*. The *TDR-1s* of the Special Task Group One (STAG-1), loaded with 2,000-pound bombs, were launched from the Solomon Islands and scored two direct hits on a Japanese merchant vessel. In a following series of combat tests in September and October of 1944, the Navy tested 46 of the drones; 29 hit their targets. However, the program's critics eventually triumphed, and Chief of Naval Operations Admiral Ernest King cancelled the program (Blom 2010, 47). While these Navy attack drones had limited success, the concept of unmanned attack aircraft clearly had been demonstrated, with no injury or loss of life for the duration of their employment (Newcome 2004, 69).

Meanwhile, in the European Theater, the U.S. military drone efforts did not prove as successful. In 1944, the USAAF and the USN were also engaged in projects to use unmanned aircraft as weapon systems in Europe. The Army effort was code-named Operation Aphrodite, and the USN effort was code-named Project Anvil. The USAAF effort converted old *B-17 Flying Fortress* bombers, designated *BQ-7*s (*Weary Willies*), into unmanned aerial weapons by also blending three technologies: radio control, automatic pilot systems, and TV cameras (Daso 1997, 72).[81] Unfortunately, not one of

[81] The Army used radio-controlled flight controls and two TV cameras, one looking out the nose and the other at the instrument panel. A pilot flew the *BQ-17*—laden with 25,000 pounds of explosives—to a predetermined altitude, and then radio control was transferred to another manned *B-17* (*CQ-17*), the "mother ship." The flight engineer armed the explosives and bailed out with the rest of the crew. The CQ-17 crew then guided the unmanned B-17 to its target (Blom 2010, 48).

the Army's Aphrodite missions was successful, and the Army eventually abandoned the program due to the unreliable radio technology (Blom 2010, 48; Newcome 2004, 69).

Simultaneously, the Navy was working on Project Anvil, which turned *PB4Y-1 Privateer* long-range patrol bombers—a Navy version of the USAAF's *B-24 Liberator*—into unmanned aerial weapon systems (Daso 1997, 72). The Navy program faired only slightly better than the Army's, with only one mission achieving success by damaging German facilities—though not the intended target—in Heligoland, Germany (Werrell, 34).[82] There were no further operations, and the program was eventually abandoned in 1945 (Newcome 2004, 69).

Despite the operational shortcomings of UAV combat missions in both theaters, the technologies developed in World War II were critical for UAV development during the Cold War: jet engine technology, precision radio navigation and guidance systems, very high frequency (VHF) navigational radios, the refinement of TV and radar, and the proven utility of unmanned aircraft, as displayed by the Army and the Navy's mass purchasing of UAVs to serve as targets—all set the stage for continued development of military UAVs (Billings 1997, 75; Blom 2010, 48).

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[82] On August 12, 1944, Lieutenants Wilford J. Wiley and Joseph P. Kennedy (brother of future president John F. Kennedy) were killed when the first Project Anvil aircraft exploded after control was transferred and the bombs were armed (Newcome 2004, 69; Werrell 1985, 34).

U.S. Military UAS Development: Post WWII to Operation Iraqi Freedom

> *"We're at a real time of transition here in terms of future aviation. What's going to be manned? What's going to be unmanned? There are those who see [the Joint Strike Fighter] as the last manned fighter/bomber. And I'm one that's inclined to believe it—whether it's right or not."*
>
> — Admiral Michael Mullen

Following World War II, the U.S. Navy and the Army Air Force (AAF) continued efforts to create unmanned target drones and engaged in efforts to convert old aircraft into unmanned systems—a practice that continues to this day.[83] Over time, the services wanted to reduce the cost of converting aircraft and subsequently placed more emphasis on designing smaller, more maneuverable drones (Wagner 1992, 15). In 1946, the AAF Guided Missile Section was created to oversee this effort, and it quickly developed a 350-mile-per-hour target drone—in conjunction with Reginald Denny's Radioplane company—designated the *Q-1* (Wagner 1992, 15).[84] In 1948, the Pilotless Aircraft Branch of the newly formed U.S. Air Force (USAF) awarded the Ryan Aeronautical Company a contract to develop the *Q-2*, a 600-mile-per-hour drone that made history as the first jet-powered, subsonic UAV (Wagner 1992, 16). Experimental testing of the *XQ-2* was completed by 1951, and 32 drones were soon on the assembly line. The newly created *Firebee* eventually would be converted into an intelligence, surveillance, and

[83] On September 5, 2014, the USAF successfully shot down a *QF-16* unmanned aircraft with an air-to-air missile (Wright 2014, 1). In March 2010, Boeing was awarded the multi-year contract to convert retired *F-16* A and C models into unmanned aircraft for use as aerial targets. The *QF-16* replaces the Vietnam War-era *QF-4*, converted McDonnell Douglas *F-4 Phantoms* (Parsons 2014, 1).

[84] The letter before the number indicates the DOD vehicle type, the number indicates the design number. "Q" designates an Unmanned Aerial Vehicle and 1 designates the first design. Common UAV designators include: "A" for attack; "B" bomber; "R" reconnaissance; "M" for multi-role; "X" experimental; and "Y" prototype. An *RQ-1* would be a Reconnaissance UAV, first design. *MQ-9* would be a multi-role UAV, ninth design (U.S. Air Force Joint Instruction 16-401(I) 2005, 13).

reconnaissance platform, perform different duties, and be used extensively by the military from the Vietnam Conflict to the Iraq Desert Storm Campaign in 1991 (Zaloga 2008, 26).

Early Cold War Development

After WWII a new adversary evolved, the USSR, following the 1946 declaration by Joseph Stalin that war with the West was "inevitable" and the August 29, 1949 detonation of the first Russian nuclear bomb. Increased tensions prompted the U.S. to place high emphasis on intelligence collection over large areas of denied or restricted territory to monitor potential Soviet activities. Prior to the advent of the U.S. Space Program, these missions were conducted by manned low-altitude "SENSINT" reconnaissance missions; high-altitude unmanned photo-reconnaissance balloons under the "Genetrix" program; and the "Project Aquatone" high-altitude *U-2* aircraft, which flew over nations with apparent impunity (Berkowitz 2011, 3-4). It was during this period that a renewed emphasis on UAVs for reconnaissance and decoy missions began. At the same time, post-war technology in computing and radar, radio, long-range, and inertia navigation enabled UAVs to navigate to and from mission areas successfully (Jarnot 2012, 10).

In 1952, Northrop Aircraft Incorporated acquired Denny's Radioplane Company and became a leader in post-World War II UAV development (Northrop 2014, 2). In 1955, breaking from the traditional target drone role, the Northrop Radioplane-71 (*RP-71*) *Falconer*—designated the Surveillance Drone-1 (*SD-1*)—became the Army's first reconnaissance drone. It was launched by two rockets, carried a still film camera, could transmit crude video, and was recovered by parachute. While the *RP-71* never deployed in a combat environment, the Army used them in limited capacity until at least 1970 (Blom 2010, 50).[85]

The Navy not only continued its development of target UAVs post-war, but also continued combat drone experiments. During the Korean War, the Navy used six *F6F-5K Hellcats,* modified as drones, to drop 1,000-pound bombs onto targets in the North. Controlled by radio from Douglas *AD-4N Skyraider* aircraft—from Composite Squadron 35 (VC-35)—they conducted six missions between August 28 and September 2, 1952; however, due to a success rate of less than 50 percent, the program was dropped (Keane 2013, 566). A year later, the Navy worked with the Kaman Company to modify the *HTK-1* two-seat helicopter to be controlled remotely, and after 100 hours of successful flight time, ordered three more of the drones for further testing, in June 1955. Five years later the Navy acquired the *Rotorcycle DSN-1* helicopter from Gyrodyne, successfully landing it onboard a destroyer at sea (Blom 2010, 52-53). Designated the *QH-50 Drone Anti-Submarine Helicopter* (*DASH*), it became the first operational unmanned helicopter designed for a combat role; *DASH* was controlled by multi-channel analog FM radio, used radar and sonar technology, and carried either a Mk-44 homing torpedo, Mark 17 nuclear depth charge, mini-gun, or an assortment of bomblets (Keane 2013, 567). While more than 800 were produced and used for multiple purposes—anti-submarine surveillance, gunfire correction, artillery spotting, smoke screen application, and cargo

[85] This UAV operated similar to the way operations are conducted today in the Ground Control Station of the *Predator* and *Reaper* UAVs. During a mission, the *RP-71* controller sat in a mobile radar tracking control van to guide the UAV to its target. The flight was tracked on a map overlay and the operator monitored the altitude, speed, and distance from the control site using other instruments. Once the drone reached the target, the controller activated the camera. “The use of the radar allowed the RP-71 to function beyond the visual range of the controller, greatly increasing its value” (Blom 2010, 50).

transport—the *DASH* program was canceled in 1970 due to low reliability of the onboard electronics. However, some *DASH*s continued to be used by the Japanese navy, and a few remained in service with the U.S. Army many years later (Zaloga 2008, 18).

In 1959, the Marine Corps also began a seven-year UAV research and development effort, the Bikini program, to explore real-time photo reconnaissance for battalion commanders; however, it too was never fielded as the Corps determined that the technology was inadequate (Keane 2013, 567). Despite the setback, the Bikini concept of real-time photo reconnaissance would be further explored and developed in the 1980s.

In 1960, following the May 1 shoot-down of a *U-2* reconnaissance plane over Russia—the mission piloted by Francis Gary Powers—and the July 1 shoot-down of an *RB-47* "Ferret" reconnaissance mission over the Barents Sea, a Presidential order ended airborne intelligence collection flights over the USSR (Wagner 1982, i., 4-5). A number of options involving UAVs were considered to help fill the gap, but two of the most prominent were Lockheed Martin's *Tagboard* program and Ryan Aeronautical's *Lightning Bug* program.

In 1962, Lockheed Martin Company began development of the *D-21* supersonic photo reconnaissance UAV code-named *Tagboard*. Built in conjunction with the development of the Central Intelligence Agency's (CIA) *A-12* manned reconnaissance aircraft—predecessor to the high-altitude *SR-71 Blackbird*—the *D-21* had a 3,000-mile range, could reach altitudes above 90,000 feet, and flew at speeds greater than Mach 3.3 (Miller 1994, 131). High operational costs and a number of failures doomed the program, however, and it was canceled in 1971.

By far, the Air Force experiments with Ryan Aeronautical's *Firebee* UAV in the early Cold War proved to be the most successful. The military turned toward the development of a jet-powered photo reconnaissance UAV and awarded Ryan a contract to build a reconnaissance version of the *Q-2C Firebee* target drone; however, high development costs soon ended the program—a fate that fell upon many UAV programs during the Cold War, including the Army's SD and the Navy's DASH programs (Blom 2010, 55). Despite the initial setback, the *Firebee* program was picked up two years later under a special program called Big Safari; slowly, it developed into a robust, long-term reconnaissance UAV program that lasted until 1991. The new drone was dubbed the *147A Firefly* and later redesignated the *147B Lightning Bug* (Wagner 1982, 15, 48).

UAV Operations in the Vietnam Conflict

Officially starting in 1964 and ending in 1975, the Vietnam Conflict saw the use of the military UAV come to fruition, primarily in the role of reconnaissance. During this period, 1,016 Ryan 147 *Lightning Bugs* (*AQM-34s*), in various models and configurations, conducted a total of 3,435 operational missions in Southeast Asia under the Strategic Air Command's 100th Strategic Reconnaissance Wing (Wagner 1982, 213). These UAVs flew at both high and low altitudes (below 500 feet to 60,000 feet, and even higher), up to 7.8 hours long, and conducted a variety of missions, including photo reconnaissance, signals intelligence collection, and leaflet and anti-radar chaff delivery (Wagner 1982, 194-197). The *Lightning Bugs* had two launch methods: air-launched from a specially equipped *DC-130* transport craft, or ground-launched aided by rocket boosters (Yenne 2004, 25). Because the technology was not advanced enough to allow the UAV to land on a conventional airfield, it ended its mission by flying over friendly territory and deploying a parachute, a method that resulted in many damaged UAVs and the subsequent development of a new recovery method called the Mid-Air Retrieval System, or MARS (Yenne 2004, 25). Under MARS, the drone would return to friendly airspace over water before deploying its parachute; it was then snagged by a specially equipped helicopter as it floated back to earth. It also could be recovered from the water if the helicopter missed or was delayed.

The *Lightning Bugs* were controlled by a human operator located in a control van or *DC-130* director aircraft. Using the onboard radar set, the operator would send commands that were received and forwarded to the autopilot, with a follow-on pulse sent back to the operator to provide position and altitude for tracking purposes. The *Bug* flew a predetermined flight path overseen by an operator who would also monitor its flight parameters (speed, engine RPMs, etc.) via a telemetry signal and make adjustments as necessary; this was considered a closed-loop guidance system with the human operator closing the loop (Corden 1957, 1). Over time the *Lightning Bug* was controlled by the Radar Altimeter Low Altitude Control System (RALACS), which provided "real-time altitude readouts on the operator's console, making it possible for the operator to control the aircraft precisely and instantaneously" (Wagner 1982, 175).

With the exception of the Ryan 154 *Compass Arrow* high-altitude reconnaissance version of the *Lightning Bug*—which was cancelled due to high cost and other competing Department of Defense (DOD) efforts—the Ryan UAVs achieved great success in reconnaissance and other passive operations of the Vietnam War; however, efforts to deploy an armed version, while close, never came to fruition before the war ended. Two such versions of the *147* were created during the war—the BQM/SSM "FLASH" and the BGM-34A—but these never participated in missions.

The first attempt to convert the *Lightning Bug* UAV into a combat weapon system—the *Firebee* Low Altitude Ship-to-Ship Homing Missile (FLASH)—was started in 1967, with the purpose of creating an interim ship-to-ship missile while the Navy's Harpoon missile was being developed.[86] Despite overcoming four major technical challenges and providing a successful demonstration on September 2, 1971, the Teledyne Ryan Aeronautical (TRA) effort was cancelled, primarily because of funding issues and competition with the Harpoon and other missile programs (Robinson 1973, 16-19).[87, 88]

In December 1971, the TRA program again successfully demonstrated a combat role for UAVs—this time in the dangerous Suppression of Enemy Air Defense (SEAD) mission—making history with the first successful guided missile attack from a remotely piloted UAV. Using the BGM-34A (the 147S *Lightning Bug)*, an AGM-65 Maverick electro-optically-guided air-to-surface missile was launched against a simulated Surface-to-Air Missile (SAM) site, scoring a direct hit. Less than two months later, the BGM-34A delivered a "Stubby Hobo" electro-optical glide bomb, achieving the same success

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[86] While it used the unmanned aircraft platform, this version was *technically* a guided missile—the precursor to the cruise missile—as it was a one-way mission; therefore, the designation BQM/SSM (B: Multiple launch environment; Q: Drone; M/SSM: Guided Missile/Surface-to Surface Missile). Earlier tests in 1964 demonstrated that it could carry up to 1,000 pounds of bombs, and the data gained from this system helped future BGM systems (Wagner 1982, 74). This ability to conduct multiple missions, versus one, is what separates the UAV from cruise missiles.

[87] Teledyne Inc. purchased Ryan Aeronautical in 1969 and became Teledyne Ryan Aeronautical (TRA).

[88] The Navy and Ryan determined that there were four capabilities the *Firebee* target drone needed to display to become a FLASH weapons delivery vehicle: 1) the ability to carry weapons; 2) low-altitude control to the point of contact with the target; 3) the ability to launch from a ship; and 4) real-time guidance to seek and destroy the target (Wagner 1982, 174).

(Wagner 1992, 99). Unfortunately for TRA, the BGM-34A was never used in Vietnam because it did not have the TV technology necessary to perform better than the human pilots in aircraft for spotting the well-camouflaged North Vietnamese SAM sites (Wagner 1982, 185).

Even though it was not deployed, the BGM-34A's success demonstrated a revolutionary capability with significant impact on the human-technology relationship. First, the human-controlled machine could drop weapons from miles away, completely separating the pilot from the battlefield or area of conflict. While not new—intercontinental ballistic missiles and cruise missiles are also weapons separated from the warrior—the implications of a man-machine interface where the machine was separated from the human, yet still directly controlled by a human who was responsible for the offensive combat operations over the battlefield, were yet to be studied. Second, the impact of a pilot participating in a battle remotely, viewing the death and destruction through a TV camera, also was a significant change in the way pilots had engaged the enemy, and noncombatants, to this point in history (bomber pilots previously flew over the conflict areas). Finally, technology had clearly enabled the UAVs to conduct combat reconnaissance missions by following the navigation commands of their onboard computers, and it would not be difficult, as Sperry's and Ketting's UAVs had previously demonstrated, to add commands for these machines to release weapons at predetermined points, with no human involvement at all. But what would be the repercussions or consequences, if any, of this activity? Some of the answers to these questions would have to wait until the first Gulf War, and others have yet to be answered. Regardless, the

UAV advances made during Vietnam were historic, and the military would continue to explore the utility of UAVs for the next war.

Post-Vietnam UAV Development

As the Vietnam War drew down, TRA continued developing improved versions of the BGM-34A: the BGM-34B and C. The all-weather B version was capable of launching a variety of air-to-surface missiles, and the C version was a multi-role UAV capable of strike, reconnaissance, and electronic warfare missions (Wagner 1992, 101, 105). Despite numerous successful test flights of both versions, the familiar post-war UAV scene began to play out: with the end of the war came Defense Department funding cuts, and with those cuts came decisions between continuing UAV development or supporting other defense activities—once again, the UAVs lost out (Wagner 1992, 106-110). Military UAV development would not begin again in earnest until the next major conflict, Operations Desert Shield and Storm in Iraq, more than a decade later.

While the U.S. role as a leader in UAV development and implementation waned after Vietnam, Israel's quickly grew, resulting in the development of tactical UAVs that were eventually acquired by the U.S. military and had positive, lasting effects on the U.S. UAV development program. Building on the knowledge and experience gained from their purchase of twelve Ryan 124I *Firebee* reconnaissance UAVs in 1971—designated *Mabat* (Observation) by the Israeli Defense Force (IDF)—and their use in combat during the 1973 October War, the Israelis quickly developed a robust and effective UAV force (Newcome 2004, 93-94). Included in their arsenal was the Israeli Aircraft Industries' (IAI) tactical UAS based on the USMC's *Bikini,* also called the *Scout,* and the Israeli

Tadiran conglomerate's *Mastiff*, a twin-boom vehicle similar to the *Scout* (Jarnot 2012, 13; Newcome 2004, 94). Built in the mid to late 1970s, the *Scout* and *Mastiff* perfected what the U.S. Marines had envisioned, the ability to provide ground force commanders with near-real-time, close-up imagery of the battlefield—"a first for unmanned aircraft" (Jarnot 2012, 13).[89] The effectiveness of these new systems was successfully proven in the 1983 Lebanon War, and once again, it was the U.S. Navy that would be responsible for bringing this tactical UAV technology back home to the U.S. military.

Following the U.S. Marine Corps barracks bombing in Beirut, Lebanon in 1983, the U.S. military increased its naval surface and air operations against belligerents in Lebanon. During the conflict, two U.S. Naval officers were investigating results of naval operations when they were introduced to the Israeli UAVs. With Secretary of the Navy approval, they initiated procurement of a *Mastiff* system, which was flown by the Marines' first Remotely Piloted Vehicle (RPV) *Platoon*, as a proof of concept for the Navy (Newcome 2004, 96). This led to the joint U.S.-Israeli-developed *RQ-2 Pioneer* UAV used by the Navy, Marine Corps, and Army for over-the-horizon targeting, reconnaissance, and battle damage assessment (Defense Airborne Reconnaissance Office Annual Report, 1995, 5).[90] It was the *Pioneer* that revitalized the U.S. Military's UAV program during the next major conflicts.

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[89] "Near-real-time" refers to data processing that results in an end product slightly slower than real or actual time. Slight delays in seeing or hearing the actual event as it is taking place occur due to the data processing required to convert data from the electromagnetic spectrum into a form that can be transmitted as a signal, along with the transmission time it takes to get the signal from point A to point B.

[90] During the same time, the Marines and Army were contracting with AeroVironment Inc. to produce a hand-launched UAV for real-time video surveillance, the *Pointer*, predecessor to the *Puma* system in operation today (AV Factsheet, 2014). This study, however, focuses on the larger lethal UAV weapon systems.

Military UAV Operations – Operations Desert Storm and Deliberate Force

In 1991, all three branches of the service used the *Pioneer* UAV during Operations Desert Shield—the buildup—and Desert Storm, the execution of military operations to liberate Kuwait from the invading Iraqi army. The *Pioneer* was used to conduct ISR missions in support of military efforts. Two Navy, three Marine, and one Army *Pioneer* were deployed to Southwest Asia during Desert Storm, providing support to naval bombardment and tactical battlefield operations, target designation, damage assessment, and reconnaissance (U.S. House of Representatives 1997, 902).

An unexpected by-product of the UAVs in Iraq was the psychological effect of these operations, i.e., the impact of the presence of UAVs on the battlefield. A highly publicized example of this was the Iraqi soldiers who surrendered to *Pioneer* UAVs controlled by service members onboard the battleship *USS Missouri*, an event humorously referred to as "the first electronic capture in history" (Shelsby 1991, 1). Another psychological effect was the association with UAVs and airstrikes. As UAVs were used to find and identify targets for aircraft and artillery, their presence put fear in soldiers who waited for the arrival of bombs and missiles, creating another negative effect on the combatants (Singer 2009b, 306).

During the war, U.S. forces flew approximately 500 UAV sorties, which included *Pointer* and *Pioneer* missions, and while these were human-controlled UAVS, the technology during this war was available to allow fully autonomous flights (Jarnot 2012, 14). The decision to keep pilots in the loop was made primarily because of the requirement for the UAVs to loiter over areas of interest and quickly react to unplanned situations; as the global positioning satellite (GPS) and computer technology were not integrated enough to allow the machines to make changes on short notice, pilots remained in direct control (Jarnot 2012, 14). However, this technical shortfall would not last long, and the DOD would see the first autonomous flight operations of a UAV in the very near future.

The DOD final report on the war documented that UAVs provided excellent, immediately responsive, and highly valuable near-real-time reconnaissance, surveillance, target acquisition, and battle damage assessment throughout the conflict (U.S. House of Representatives 1997, 832, 902). While the U.S. had been working since the early 1980s on UAV development projects, under organizations such as the Defense Advanced Research Projects Agency (DARPA), UAS success in Iraq prompted the revitalization of UAV efforts, leading to the development of a new generation of UAVs, including long-dwell systems like the medium-altitude *Predator* and high-altitude *Global Hawk* (McDaid 1997, 60.)

While the DOD was developing the *Pioneer* and other systems, the CIA was also developing a system of its own (U.S. General Accounting Office 1999, 3). In 1993, in partnership with General Atomics Aeronautical Systems, Inc., the CIA successfully deployed the *Gnat-750*—a low-cost, long-loiter (40 hours) UAV that could, via satellite, relay electro-optical and infrared video in near-real-time—to monitor the conflict in Bosnia (Newcome 2004, 107).[91]

[91] The *Gnat-750* was designed and built by Abraham Karem, owner of Leading Systems, Inc. and a former Israeli Air Force engineering officer. He received funding under a DARPA/Navy program, called Amber, to design a "low-cost, medium altitude long-endurance UAV capable of being used either as a weapon or for long-term surveillance" (Newcome 2004, 104). His signature V-tail UAV (seen on the *Predator*) was successfully tested from 1986 to 1989, but the project ended in 1990. He built a commercial version of Amber, the *Gnat-750*, and sold the company to General Atomics (Newcome 2004, 107).

In 1993, the Defense Airborne Reconnaissance Office (DARO) was created to consolidate UAS development within the DOD; that same year, a new process for military acquisitions also was started—the Advanced Concept Technology Demonstration (ACTD).[92] On January 7, 1994, General Atomics was awarded a contract with the Navy to produce a Tier II (Theater [operational] endurance) UAV capable of loitering for 24 hours, with a 500-mile range, and carrying a 400-to-500-pound payload, that could produce 1-foot resolution imagery; their larger design of the *Gnat-750*, the *Predator*, was subsequently built and tested in July of that year (Newcome 2004, 109). While still in the ACTD phase, *Predators* were successfully deployed to Albania during Operation Deny Flight—the enforcement of a United Nations (UN) no-fly zone over Bosnia and Herzegovina—and in Deliberate Force, the 1995-1996 NATO air campaign in Bosnia. These demonstrated all the required capabilities required to satisfy the military's ISR and target acquisition requirements (U.S. General Accounting Office 1999, 4). While deployed, the *RQ-1 Predators* conducted 128 missions, and in 1996, they transitioned from ACTD to the formal acquisition process and were subsequently used as an ISR collection platform in Kosovo, Iraq, and Afghanistan (McDaid 1997, 60; Newcome 2004, 109).[93]

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[92] The intent of the Advanced Concept Technology Demonstration process is to permit the early and inexpensive evaluation of mature advanced technologies—like the *Gnat-750*—by warfighters in the field to determine military utility before making a commitment to the formal acquisition process (Defense Acquisition University 2010, ACTD website).

[93] In 1995, a DARPA project to develop a high-altitude, long-endurance aircraft for *U-2*-type ISR missions was created. Out of this the Northrop Grumman RQ-4 *Global Hawk* was developed. *Global Hawk* can fly more than 32 hours and loiter at altitudes up to 65,000 feet, with a multi-role ISR sensor suite. It transitioned to production in 2001 and flew missions in Iraq and Afghanistan. By March 2005, the new system had flown more than 4,000 hours of combat operations. The first operational model was deployed to Central Command in 2006 (Blom 2010, 106). The *Global Hawk* will be discussed further in chapter five.

Armed UAV Operations – Operations Enduring Freedom and Iraqi Freedom

On October 7, 2001, less than one month after the September 11 terrorist attacks against the U.S. homeland, Operation Enduring Freedom (OEF) began in Afghanistan. With an emphasis on Special Forces and precision aerial strikes to defeat the Taliban harboring Al-Qaeda leadership, *Predator* and other UAVs played a major role in this war and were used extensively for ISR, target acquisition, force protection, and killer-scout missions.[94]

> Despite flying an average of only 200 sorties a day, Air Force crews engaged as many targets each day as it had when flying 3,000 daily missions during DESERT STORM. Among the factors that led to this increased efficiency, was the use of UAVs for target acquisition. Special Forces troops worked in conjunction with UAVs to monitor Taliban and al-Qaeda forces and decrease the sensor-to-shooter loop. Such integration of air and ground-based intelligence sources had a long history, going back to World War II when battle commanders regularly went aloft in liaison planes assigned to their units to confirm or verify intelligence reports. The live-video feeds of the *Predator* and *Global Hawk* gave the same capability to unit commanders without having to leave the ground. . . . The Predator's ability to rapidly locate and identify targets made it possible to hit targets that previously would have escaped because of the delay in sensor-to-shooter. (Blom 2010, 114-115)

Earlier in 2001, U.S. Air Force efforts to arm the *Predator* that began after the Kosovo War in 1999 proved successful at Indian Springs Air Force Auxiliary Airfield near Nellis Air Force Base, Nevada. On February 21, 2001, an armed *Predator* successfully launched a "live" Hellfire-C laser-guided missile that hit an Army tank target on the ground (Baker 2001, 1). In 2002, after successfully demonstrating the ability to carry and employ Hellfire air-to-ground missiles, the *Predator* was re-

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[94] In a force protection mission, the UAVs patrolled ahead of advancing forces, providing near-real-time information about the enemy's position and movement. In the killer-scout role, the *Predator* did not fire weapons, but served as an airborne forward air controller (FAC), providing target identification, verification, and tracking and location information for attack aircraft or field artillery (Blom 2010, 114).

designated from *RQ-1* (reconnaissance) to *MQ-1* (multi-role) and given an armed reconnaissance role (U.S. Department of Defense Unmanned Aerial Vehicle Roadmap 2002-2027, 6).

Before this designation, armed versions were already conducting missions in Afghanistan. On October 7, 2001, the CIA used armed *Predators* in Afghanistan on missions against the Taliban and Al Qaeda (Written Statement for the Record 2004, 16). On November 3, 2002, the U.S. conducted its first strike in the War on Terrorism outside Afghanistan, in Yemen, when a Hellfire missile destroyed a car carrying Qaed Salim Sinan al-Harethi, an al-Qaeda leader thought to be responsible for the *USS Cole* bombing in October 2000 (Priest 2002, 3). Armed *Predators* also supported operations in Iraq as part of 2003 Iraq War during Operation Iraqi Freedom (Blom 2010, 116).

In 2007, the General Atomics Aeronautical Systems *Predator B*, designated the MQ-9 *Reaper* by the military, became operational (U.S. Air Force Fact Sheet: MQ-9 Reaper Unmanned Aircraft System 2015). The multi-mission *Reaper* has a 3,850-pound payload capacity, which can include the Paveway II Guided Bomb Unit (GBU)-12, GBU-38 Joint Direct Attack Munition, or laser-guided AMG-114 Hellfire Air-to-Ground Missiles (General Atomics 2015b, 1).[95] The *Reaper* was deployed to Afghanistan in September 2007 and flew operational missions in Iraq starting in July 2008 (Shanker 2008, 2; USAF News Service 2007).

The wars in Afghanistan and Iraq resulted in extensive development of a number of UAV systems, too numerous to cover in this study, as well as other air, ground,

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[95] HELLFIRE is an acronym that initially stood for the Helicopter Launched, Fire and Forget Missile (Boeing, 2014).

surface, and subsurface unmanned systems. These systems are now an integral part of the U.S. military arsenal and, unlike the pattern of the past, it does not appear UAVs will be mothballed anytime soon. Civilian applications—from police surveillance and firefighting to agricultural monitoring and package delivery—have resulted in the formation of unmanned system organizations, university programs, and numerous businesses that are exploring new ways to use these systems. Meanwhile, the military is moving forward with the next generation of UAVs, including semi- and fully autonomous systems, such as the Navy's *X-47B* Unmanned Combat Air System (UCAS) Carrier Demonstration program, all in seeking to leverage the newest technology for future "dull, dangerous, or dirty" military applications that are best suited for machines.

Chapter Summary

This chapter provided a historical overview of the development of unmanned flight from the time humankind began to control kites with string to the present. Throughout history, all of the UAV systems that have been developed have had this in common: the technology enabled the aircraft to become more autonomous as time progressed. The human-technology interface and systems integration has gradually distanced the human operator from the machine to the point that pilots sitting in a van in Nevada can conduct missions over Afghanistan and Iraq. With every advance in the development of unmanned and semi-autonomous weapon systems, we increase the level of the machine autonomy, and the use of such systems as weapons only underscores the importance of remaining focused on the issue of the human-machine interface. To date, the relationship between system operators and the technology has been very symbiotic, yet humans have clearly remained in control of the technology. However, the advent of remote sensing technologies that surpass human sensing abilities, and powerful lightweight micro-computers with AI that exceed human computational abilities, are revolutionizing the capabilities of unmanned aircraft systems. These capabilities will be examined in the next chapter to better understand the contributions they make to the development of autonomous unmanned combat aircraft systems, and to evaluate the ability of humans to control the technology.

Chapter Five: Remote Sensing, UCAV Autonomy, and Human Control

"A bird is an instrument working according to mathematical law, which instrument it is within the capacity of man to reproduce with all its movements."

— Leonardo da Vinci

Chapter Introduction

Building on the foundation of unmanned aircraft development previously discussed, this chapter focuses on the integration of the additional technologies that enabled the transition of the unmanned aircraft into an Unmanned Combat Air System (UCAS). Specifically, remote sensing, autonomous flight, and Artificial Intelligence (AI) will be examined to determine the impact they are having on the issue of human control. The emphasis is placed on understanding the influence of these technologies on the evolution of the UCAS, from today's state-of-the-art existing technology of remotely piloted aircraft, under human control, to the art-of-the-possible, where completely autonomous weapon systems using technologies that surpass human sensing and computational abilities may conduct lethal combat missions in the future.

The chapter starts with a brief examination of the development of early telescopic and photographic technologies and then moves into the aerial optical remote sensing technologies developed prior to the First World War. The World Wars provide a foundation for understanding the development of military aerial remote sensing and their associated intelligence disciplines. A survey of the post-WWII period demonstrates the departure from predominately using traditional, literal imagery (visual) technologies—photography—to the more advanced nonliteral geospatial technologies, e.g., infrared

(IR), thermal infrared (TIR), and radar images. This advancement culminated in the use of these technologies as an extension of human senses on unmanned aircraft systems used during the Vietnam War. The post-Vietnam era is briefly examined to show further advancement in remote sensing technologies, including synthetic aperture radar (SAR) and multi- and hyperspectral (Spectral) imagery, and their use and development in modern unmanned aerial warfare operations.

The study then focuses on the development and evolution of advanced computer technologies that are used to develop autonomous flight capabilities in 21st-century UCASs like the *X-47B*. The integration of the remote sensing technologies with the autonomous unmanned aerial vehicle technology is studied to see how these technologies replicate the sensory and thinking abilities of humans, and how this technology influences autonomous UCAS development activities in such areas as automatic target recognition (ATR).

The last section explores the role of AI in UCAS development, including some of the challenges associated with replication of human intelligence that need to be overcome before a UCAS would be allowed to deliver a weapon in combat without human oversight.

This chapter provides the final component required to determine if there is a widening control gap between the technology and humanity in the UCAS arena, and whether this gap is actually impacting the ability of humans to maintain control of the technology.

Military Remote Sensing System Development – Pre-WWI

"The aerial photograph is itself harmless and valueless. It enters into the category of 'instrument of war' when it has disclosed the information written on the surface of the print."

— Edward Steichen

Remote sensing, defined in chapter one, is employed when an object of interest or a target is beyond the ability of human contact or observation because it is in a remote, denied, or inaccessible area, or because it is beyond the capability of the human senses to detect and observe, e.g., in the form of ultra-low radio frequency or gamma rays. This object of interest can be a person, place (lake, forest, airfield), event (missile launch or explosion), or activity (moving column of tanks, aircraft taking off, conversation). Remote sensing technology replicates the human senses by collecting waves, particles, and other forms of energy through interaction with the electromagnetic (EM) spectrum—just as human eyes and ears do—enabling collection of different forms of energy in the EM spectrum well beyond human capabilities and far removed from the object being observed.[96]

A variety of different passive and active sensor systems are used to detect, collect, and measure waves, particles, and other EM radiation emitted or reflected by the object or other objects near it.[97] The energy collected comes in different wavelengths across the

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[96] The EM spectrum is how electromagnetic waves are described. Waves are produced by photons moving at light speed, and their energy determines the frequency, or wave length, of the light associated with it. The greater the photon energy, the greater the frequency of light; less energy, less frequency. The entire range of waves comprises the EM spectrum. They are called electromagnetic because they consist of combined electric and magnetic waves that result when a charged particle (electron) accelerates. The spectrum is divided into sections and given descriptive names: high frequency, short wavelengths, are gamma and X-rays; low frequency, long wavelengths are radio waves (Graham 1999, 2-3).

[97] Passive sensors only collect emitted, transmitted, or reflected energy by or from an object (heat, radiation). Active sensors collect reflected energy originating from the human-made sensor source, e.g., radar energy which a sensor system sends out is reflected off an object and then collected by, usually, the

EM spectrum, each containing or producing different types of data and information, from extremely low frequency radio waves to extremely high frequency gamma rays (gamma radiation). A discussion of all waves and particles across the entire spectrum is not possible within the scope of this research; therefore, this study will only focus on small portions of the radio frequency, visible, and invisible light spectrums most commonly associated with unmanned combat air vehicle operations.[98] These include the radiative, reflective, and absorptive energy in the spectrum that sensors capture to produce electro-optical, infrared, thermal infrared, multi- and hyperspectral, radio- and radar-generated products (reports, studies, analysis, film, photographs, videos, graphics, depictions, recordings, other images, etc.).[99] As mentioned in chapter one, imagery products can be categorized as either literal—i.e., visible imagery (like black and white, color, or infrared images that provide an actual depiction of the object or scene)—and nonliteral, i.e., data and information that cannot be interpreted literally by the human eye and cognitive systems (such as hyperspectral and radar-phased history data derived from the non-visible portion of the electromagnetic spectrum) and is not recognizable as a literal

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same sensor system. A few of the different sensor types include: radio-frequency, radar, sonar, acoustic, seismic, magnetic, plasma, optical, electro-optical, infrared, thermal infrared, multi- and hyper-spectral, and particle.

[98] In the intelligence community remote sensing usually refers to the technology of acquiring information about the earth's surface (land and ocean) and atmosphere using sensors onboard airborne (aircraft, balloons) or space-borne (satellites, space shuttles) platforms.

[99] Unless it has a temperature of absolute zero (-273°C), an object reflects (called convection), absorbs (conduction), and emits (radiation) energy in unique ways at all times (Jensen 2007, 37-38). Warm air rising from the earth's surface that has been heated by the sun is an example of convection. A metal pan heated by fire is an example of conduction, and electromagnetic (EM) waves emitted by the sun and stars are examples of radiation. The higher the temperature of an object, the faster its electrons vibrate, resulting in shorter wavelengths; the lower the temperature of an object, the slower the electrons vibrate, resulting in longer wavelengths.

depiction of the object or scene without being processed and turned into an image or other identifiable data first.

Department of Defense (DOD) unmanned aircraft systems are constantly being upgraded with the latest remote sensing technologies to detect, locate, identify, track, monitor, and display targets—literally or nonliterally—whether they are natural (humans, animals, vegetation, or elements) or man-made (equipment, tools, weapons, vessels, or buildings). These systems work by capturing the different types of energy associated with the target. The capabilities of these remote sensing systems onboard UCAVs are proven, and are utilized by the military on a daily basis to support passive intelligence, surveillance, and reconnaissance (ISR), as well as active targeting and strike missions. Like the UAS, these remote sensing technologies also were applied to military operations soon after their discovery and development.

The First Remote Sensing Device – The Telescope

The very first documented remote sensing technology, the telescope, was invented in the Netherlands in October 1608 (Van Helden 1977, 20-25).[100] This instrument extended human vision by allowing the user to see "faraway things as though nearby" (Van Helden 1977, 5). The instrument was improved upon and made famous by Galileo, who soon after its discovery created his own version, publishing his observations of the Moon, planets, and stars in his work *Sidereus Nuncius* in March 1610 (Van Helden 1977,

[100] There is disagreement on who actually made the discovery, and the following three Dutch men are identified as possible founders: Hans Lipperhey and Sacharias Janssen of Middelburg, and Jacob Metius of Alkmaar. These men requested patents for the telescope around the same time, making it impossible to ascertain who actually invented the device (Van Helden 1977, 20). Additionally, there are other nondocumented references to telescope-like devices in the 16th century.

5). The same year the telescope was invented, the Dutch created an instrument that allowed both eyes to be used—binoculars—and soon after, Galileo created a binocular form of his telescope. These new instruments were quickly copied and spread throughout Europe, and like the invention of the kite, balloon, and airplane, were soon adapted for military purposes.

Observing the new technology, soldiers in The Hague were quick to recognize the military application, as had Galileo, who also saw the potential of its application as a military tool early in its development (Dunn 2009, 23-25). Over time, a number of spinoffs from this new technology had important applications for the military: telescopes were quickly acquired by soldiers and sailors and used for terrestrial or celestial observation and navigation; lenses and mirrors were modified to change magnification levels or invert images, important discoveries for the development of photography; and following Isaac Newton's 1672 published paper on light and colors and the discovery of the theory of light, reflective lenses were created, allowing for the future development of multispectral viewing and imagery (Van Helden 1995, 2-6). As magnifying lenses continued to develop and were refined, they were applied to cameras, which could capture events observed for later recall, study, and analysis—replicating human memory—in the hopes of revealing additional information about the place or object photographed, and allowing for picture archiving for future reference purposes. It was from the developments of the telescope and binoculars that military remote sensing instruments and systems replicating the human senses evolved, becoming indispensable tools in warfare, particularly important for airborne surveillance and reconnaissance missions (Dunn 2009, 132).

The Birth of Aerial Remote Sensing – Optical Imagery

The first recorded permanent photographic image, which captured buildings and vegetation, was taken by Joseph Nicephore Niepce, around 1826, in Saint Loup de Varnne, France, with technology consisting of an optical camera obscura and a metal plate coated with bitumen (Gernsheim 1952, 118-121).[101] A little more than 30 years later the first aerial photograph occurred, taken by Gaspard Felix Tournachon (he was also known as “Nadar”) from a tethered balloon 80 meters above the village of Petit-Becetre, France, in 1858 (Mattison 2008, 12). Two years after that event, the first aerial photographs over U.S. soil were taken by photographer James Wallace Black and balloonist professor Sam King over Boston, Massachusetts, on October 13, 1860 (Tennant 1903, 154); thus was born the technology enabling aerial photo reconnaissance.

The early aerial photography pioneers also experimented with unmanned photography from balloons, maintaining control over the balloons via tethers and using remotely controlled switches from the ground or through an onboard timing mechanism to control the cameras, thus setting the stage for further technological developments that would eventually evolve into what is known today as unmanned aerial remote sensing systems (Mattison 2008, 12).

Kites soon followed as aerial photography platforms, with credit for the first recorded uses of kites given to two pioneer photographers: Douglas Archibald and Arthur Batut (Tennant 1903, 168). In 1887, Archibald, a British meteorologist, added additional

[101] A dark chamber, or camera obscura, was a lens mounted on a box that focused images onto a mirror and then reflected on a plate of glass, usually for tracing (Jensen 2007, 62). Niepce used bitumen, parts of which hardened with exposure to light, to create the lasting photograph (Gernsheim 1952, 118-121).

technology to the traditional operator-wire-kite system used on balloons by attaching a camera to a kite wire and controlling the shutter "by explosion" (Archibald 1897, 185). Around the same time, Batut, of Labruguiere, France, also was credited with being the first to take a photograph from a kite. He published a book on kite aerial photography, *La Photographie Aerienne Par Cerf-Volant* (1890), in which he described its many uses, including reconnoitering for the military (Batut 1890, 63).

U.S. Military Aerial Remote Sensing

One year after Nadar took his historic photograph above France, the new optical technology was tested in 1859, above the Solferino battlefield in the second War of Italian Independence, after Napoleon III ordered aerial photographs of Austrian positions (Brodine 1918, 342). However, despite its use at Solferino, and Black and King's aerial photography of Boston a year later, America would not immediately use the airborne camera for military purposes. While some have written that aerial photographs were taken during the American Civil War, there are no surviving Civil War-era aerial photographs or documents to substantiate the claim (Colwell 1997, 5-6; Haydon 1941, 334-335).[102] Even though cameras were not used by the U.S. military for aerial observations during the Civil War, telescopes, binoculars, and ground photography were widely used.[103] The Union Army Signal Corps, founded by Maj. Albert J. Myer in 1860,

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[102] Some books and articles mention Civil War aerial photography, e.g., the *Manual of Photogrammetry, 2nd Ed.*, 1952. However, according to Frederick Stansbury Haydon, Civil War aviation expert, there is no documented supporting evidence for the claim (Haydon 1941, 334-335).

[103] The Library of Congress contains approximately 7,000 Civil War-era glass negatives and related prints showing different views and portraits taken from 1861 to 1865 (U.S. Library of Congress 2014).

used a combination of flags to transmit messages from battlefield commanders—or scouts conducting reconnaissance—using telescopes to read them from long distances (Raines 1996, 6-9). Additional methods of communication used by the Corps during the war included hand signals, burning torches, rockets, and the telegraph, with the latter providing the foundation required to create another intelligence discipline—signals intelligence (SIGINT)—that would become an important mission of future aerial reconnaissance systems.[104]

The telegraph was a technology that replicated human communication, and shortly after Samuel Morse's version was developed, the device was put to use by the military in the Mexican War (1846-1848); however, its use was limited due to its unreliability at the time (Raines 1996, 4). By the time the Civil War started, the telegraph—which had been improved and was used to send messages coast to coast—was incorporated, along with the other forms of communication, into the military communication system (Raines 1996, 16-17). Professor Thaddeus Lowe introduced the use of the telegraph from a balloon on June 17, 1861. Using a battery-powered telegraph key connected to a wire that ran along one of the tethers anchoring the balloon, he successfully demonstrated to President Lincoln the capability to transmit messages from air to ground (Evans 2002, 68-69). Accompanied onboard by U.S. military Signal Officers, Lowe combined observation and communication technologies, using double telescopes with 80x magnifications to observe troop movements—ranging from six to 30

[104] Communications technology impacted the future development of UAV data transmission systems as engineers developed software, hardware, and procedures to collect data and protect information once stored on the aircraft, e.g., UAV command and control data used to direct the UAV activities and the intelligence data collected as it was uploaded, stored, and downloaded to and from the UAV (Maslowski 1995, 39).

miles away—and using either flags or the telegraph to report the activity to ground personnel (Haydon 1941, 319, 360-363; War 1972, 266-316).[105] The telegraph eventually became a significant means of communication from the balloon, and this technology, along with photo-telegraphy and eventually the wireless, would become vitally important for the development of future manned and unmanned military aerial reconnaissance missions (Hoehling 1958, 104-108). While sparsely used during the Civil War, U.S. military airborne remote sensing systems and reconnaissance were born, and they would continue to develop and grow in importance in every subsequent war involving the U.S.

In addition to balloons, kites were also adapted by the military, becoming the earliest *unmanned* aerial photoreconnaissance system. In 1895, William A. Eddy, of Bayonne, N. J., took the first photographs from a kite in the Western Hemisphere, providing data "of inestimable value to the United States Weather Bureau and the War Department" (Tennant 1903, 169). Three years later, Eddy's kites were sent to Puerto Rico by General Adolphus Greely to augment balloon photography; they were used for military purposes during the Spanish-American War (Tennant 1903, 169). During this assignment, Eddy took the first U.S. wartime photographs from a kite using a shutter release attached to a string; his remotely controlled photography of enemy positions can be considered the first documented use of an unmanned aerial system's surveillance of the battlefield (Krock 2002, 2).

[105] While the Union Army did use balloons for reconnaissance roles during the Civil War, they were never under the Signal Corps' control; instead, civilians like Lowe were employed. The Balloon Corps started under the Bureau of Topographical Engineers, moved to the Quartermaster Department in March 1862, the Corps of Engineers in April 1863, and was subsequently disbanded (Raines 1996, 16, note 48).

Other unmanned systems that saw experimentation before the First World War included rockets. Alfred Nobel (of Nobel Prize fame), Alfred Maul, and others filed patents and experimented with rocket-mounted cameras; however, due to the growing popularity of using planes for aerial photographs, and the early difficulties associated with getting a good photograph from a rocket, the military application of a rocket camera would be postponed, not coming to fruition until the Cold War in the 1950s (Macinnis 2003, 121).

Photography from the Air

The first pictures taken from airplanes occurred five years after the Wright Brothers' historic powered flight in 1903, when L.P. Bonvillian took moving pictures over Camp d'Auvours, Le Mans, France, in a Wright Flyer piloted by Wilbur Wright (Jensen 2007, 73).[106] One year later the airplane was once again a platform for aerial photography, as described by RAF Flight Officer Constance Babington-Smith:

> On April 24, 1909, Wilbur Wright himself, accompanied by a photographer whose name is unrecorded, took off from Centocelle near Rome, and succeeded in obtaining a series of cinematograph pictures. At about the same time French photographers started experimenting on similar lines, and the first effective stills were those taken by M. Meurisse in December of 1909. During the next five years the work of the pioneers continued apace, and the way was soon open for the successes of the First World War. (Babington-Smith 1957, 3)

Not long after, the first official aerial reconnaissance flight from an airplane occurred during the Italian-Turkish War when an Italian pilot, Captain Carlo Piazza, reconnoitered Turkish positions on October 23, 1911 (Boyne 2005, 37). Piazza was also the first to take reconnaissance photographs using a camera mounted on his Bleriot

[106] Only a still from the original moving picture, published in a French magazine in 1908, survives (Newhall 1969, 144).

aircraft. However, it would be another eight years, during World War I, before cameras were routinely mounted to planes (Stephenson 2014b, 108).

Aerial Remote Sensing During the World Wars

> *"It is true that more is heard of combat between planes than of the routine task of collecting information, and the public eye is more apt to be impressed by the fighting and bombing aspects of aerial warfare. Nevertheless, the fact remains that the chief use of the airplane in warfare is reconnaissance. The airplane is 'the eye of the army.'"*
>
> — Major Herbert E. Ives

The U.S. military eventually added the airplane to its balloon arsenal as a means of conducting airborne reconnaissance missions, and by 1916 the Army Signal Corps Aviation Section created the 1st Aero Squadron, commanded by Major Benjamin Foulois (Hamm 1995, 141). The first operational use of U.S. aircraft for such missions occurred during the 1916-1917 Mexican Campaign when General John Pershing used the 1st Aero Squadron, based in San Antonio, Texas, to patrol the Mexican border. The purpose of the missions was communication, surveillance, reconnaissance, and initial experiments with aerial photography in support of Pershing's expedition to pursue Pancho Villa (Campbell 2008, 78). Despite these early military aerial reconnaissance missions, when the U.S. entered into the First World War, reconnaissance was still conducted primarily by cavalry, and the Army aviation wing was almost three years behind the other nations (White 2008, 66). It was during WWI, however, when U.S. military aerial reconnaissance came of age, and remote sensing systems were developed; in just a few short years the camera, photographer, airplane, and pilot were integrated to form an effective intelligence discipline still used today—airborne imagery (Campbell 2008, 77).

U.S. Aerial Photoreconnaissance in WWI

During World War I, balloon companies were routinely used to observe activities over and around the battlefield. Observers aboard tethered balloons, usually consisting of junior officers suspended in an observation basket in contact with the ground via telephone or telegraph—later a wireless set—conducted the same type of missions as their early Civil War counterparts: locate and count enemy forces, adjust friendly artillery fire, and locate enemy artillery for counter-battery fire (Campbell 2008, 78). Although some vintage photographs of these balloon companies show them equipped with aerial cameras, military documentation underscores that airborne photoreconnaissance actually developed along with the utility of the airplane (Campbell 2008, 78).

Once aircraft were used operationally in the war, aerial observers—solo pilots or a team consisting of a pilot and an observer flying in a two-seater airplane—conducted reconnaissance just as their counterparts in balloons were doing, by drawing what they observed, making notes, and verbally reporting their observations once on the ground (Baumann 2008, 8). Over time the aircrews started to bring cameras onboard to acquire battlefield photographs, but this quickly revealed that normal camera technology, while useful, was not conducive for use in open cockpits; cameras had to be handheld, required manual changing of the large photographic plates (one at time while in flight), and did not provide systematic coverage (Campbell 2008, 79).[107] This resulted in the development of cameras specifically designed for aerial photography: mounted on the side or bottom of the aircraft with semi- or fully automatic controls.

[107] Initial reaction to aerial photographs taken by pilots on their own initiative was not favorable; they were rejected as "a most disgraceful thing to have attempted" (Newhall 1969, 144).

The first practical hands-free aerial camera was invented and designed by Captain John Moore-Brabazon and manufactured by the British company Thornton-Pickard Ltd. (Rendell 1992, 27–34). It was a tapered wooden box inserted into the floor of the aircraft that was manually triggered by the pilot at intervals; it was first used operationally in the war by the Royal Flying Corps in March 1915, over Fauquissant, France, and significantly enhanced the operational efficiency of aerial photography (Rendell 1992, 27–34). The advantage of the fuselage-mounted camera was that the pilot alone could conduct reconnaissance missions, without reliance on an additional observer, removing the need for two humans to control the technology (Gorrell, n.d., Roll 34, 351). After its introduction, aerial camera technology evolved rapidly during the war, moving from the manually operated, through the semi-automatic, to the fully automatic camera in a few short years (Campbell 2008, 83). The manually operated cameras were manipulated directly by the pilot or crewmember and required each plate to be changed by hand when a new exposure was required; semiautomatic aerial camera shutters were still triggered by the pilot, but the plates were changed by a mechanical device powered by timers, electrical mechanisms, or air-driven propellers (Campbell 2008, 84). The fully automatic aerial cameras required no human involvement, taking pictures automatically at preset intervals; however, the technology at that time was often unreliable and crewmembers preferred to use the semiautomatic override (Ives 1920, 125).

While the German, French, and British forces had conducted aerial photoreconnaissance from aircraft early in the war, the American Expeditionary Force (AEF) did not do so until later in the conflict. However, it did not take long for aerial recon to quickly become the second-most common mission of the U.S. Army Air Service

Section (Finnegan 2006, 221-225).[108] Once again, it was the 1st Aero Squadron that conducted the first U.S. photo recon mission of WWI; on April 15, 1918, a plane photographed territory over an enemy-held section of France (Hamm 1995, 141).

During the war, aerial photography came in two forms: oblique—a horizontal line-of-sight image taken by balloon or airplane while flying over friendly airspace—and mosaic, taken by airplane directly above the enemy target. Mosaics were used extensively for mapmaking, revealing enemy positions and activities, and strategic planning; analysts used stereoscopes to hunt for visual clues about enemy gun emplacements and ammunition storage areas on photos that were stitched together to form mosaic maps (Gettinger 2014, 4).[109] With improvements in the quality of cameras and increased frequency of flights, aerial reconnaissance eventually upstaged the horse and cavalry as the dominant method for military reconnaissance, e.g., during the Battle of the Somme in 1916, the Royal Flying Corps took more than 19,000 aerial photographs and collected 430,000 prints during the five-month campaign (Gettinger 2014, 5). Two years later, the French were printing up to 10,000 aerial photographs a day, and during the September to November Meuse-Argonne Offensive, 56,000 aerial prints were delivered to American Expeditionary Forces in just four days (Jensen 2007, 75). Aerial photographic technology had proven itself, becoming the extended eyesight of military commanders, enabling them to see a snapshot of the battlefield and allowing them to

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[108] The number one mission for the U.S. Army Air Service was visual observation of the battlefield conducted by balloon companies (U.S. Army 1917, 22-25).

[109] Stereoscope: a binocular device used for viewing two separate images, depicting left and right-eye views of the same scene as a single three-dimensional image, creating the illusion of depth. A mosaic is a series of overlapping photos aligned together to create a single comprehensive view of an area (Gettinger 2014, 5).

conduct better strategic planning for the placement of military forces. The new airborne photographic technology would be used and improved upon by the military for every successive conflict, as evidenced by the primary roles that aerial imagery and full-motion video play in military airborne intelligence, surveillance, and reconnaissance missions today.[110]

Along with aerial photography came advancements in counter technologies developed to deny aerial observers the ability to conduct successful photo reconnaissance missions. These technologies included fighter aircraft—planes with manual or semi-automatic mounted machine guns—used to shoot down observation balloons and aircraft, or enemy fighter aircraft threatening to do the same to that side's aerial reconnaissance craft. On the ground, military forces developed different types of camouflage to hide personnel and equipment from aircraft, and different denial and deception (D&D) technologies and techniques were employed to mislead or confuse photo interpreters. To counter these technologies and efforts, new remote sensing technologies were applied that enabled military intelligence analysts to "see" aspects of the battlefield that were no longer visible in normal optical photography, i.e., to see through the denial and deception efforts. One of the first included the development of infrared (IR) photography.[111]

Prior to the early 1900s, IR photography was not possible because the silver halide emulsion used to develop film was not sensitive to the longer infrared

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[110] As of 2015, the *U-2* manned high-altitude reconnaissance aircraft Optical Bar Camera—a camera developed in the 1960s—was still producing traditional film, high-resolution, broad-area synoptic imagery, and was being prepared to be tested onboard the *Global Hawk* high-altitude UAV (Malenic 2015, 1).

[111] Infrared imagery is produced by sensing electromagnetic radiations emitted or reflected from a given target surface in the infrared portion of the electromagnetic spectrum, approximately 0.72 to 1,000 microns (U.S. Department of Defense Joint Publication 1-02 2015, 113).

wavelengths, but in 1903 professor Robert Wood of Johns Hopkins University successfully conducted experiments using filters and dyes that allowed for ultraviolet photography (Williams 2002, 2). In 1904, further experimentation resulted in the development of IR-sensitive photographic film, and by 1910, Wood published the first infrared photographs in the February edition of *The Century Magazine* (Kornfeld 1938, 201-202; Wood 1910, 565). During the war, experiments were conducted in the U.S. with various photographic plates to capture different portions of the light spectrum, including those beyond human capabilities—ordinary (sensitive to violet and blue), orthochromatic (blue, green, and yellow), and panchromatic (all colors)—as well as the chemical interaction with plates to capture the red and infrared spectrum for spectrographic analysis (Stratton 1919, 114-16).[112] By 1917, the Bureau of Standards and the War Department were conducting joint experiments with cameras, filters, and dyes to improve landscape photography, and by 1918 the bureau had proven the value of IR photography in penetrating haze and smoke and detecting camouflage (Stratton 1919, 117). The war ended before extensive wartime application could be made, but the value of IR photography was not lost. The new imaging technology enabled commanders to see in poor visibility and, because IR images made clear distinctions between animate and inanimate objects—trees versus equipment—they could better identify camouflaged enemy positions.

[112] Spectrographic analysis, a.k.a., spectrometry or spectroscopy, uses an optical device (spectrometer, spectrophotometer, spectrograph, or spectroscope) for observing and recording multiple bands of light or radiation from a material or source. Each band is characterized by "bandpass (or band), cutoffs, center frequency, and peak transmissions," with multispectral imaging collecting images in two or more bands, hyperspectral in hundreds of bands, and ultraspectral in thousands of bands (Evans 2014, 153, 294).

Another remote sensing technology further developed during WWI was signals intelligence collection, the use of which had important political and military effects on the war, setting the stage for airborne SIGINT remote sensing collection in World War II. An important spin off the SIGINT technology that impacted aviation navigation was the development of direction finding. A result of new radio technology, this was the use of radio-receiving equipment to pinpoint the location of a radio transmitter on the ground or onboard a ship, initially used to enable war fighters to track the movements of the enemy. These SIGINT remote sensing activities would come fully of age during the Second World War, including airborne intercept operations, but it would still be two more decades, during the Vietnam War, before the capability would be placed onboard unmanned aircraft.

After WWI, additional experimentation with other remote sensing technologies continued, including multispectral imagery and radio detection and ranging (radar). These technologies required humans to rely on additional technologies, such as computers, to help collect, process, and interpret the data produced from these remote sensing systems. As with the early stages of UAV development, the human operator was beginning to be distanced from the remote sensing technology. Instead of looking through a lens, or developing film by hand, automation was beginning to take over these functions. While humans remained in control of the remote sensing processes, they were becoming more reliant on the machinery and computer technology to assist operating the systems onboard the aircraft, moving into more of a supervisory position—as they did with the growing automation required to fly aircraft remotely.

Remote Sensing Development between the World Wars

Toward the end of World War I, Sherman M. Fairchild developed a camera with an internal, between-the-lens shutter that significantly reduced distortion, a new technology that allowed for more accurate aerial mapping (Woodring 2007, 7). By 1920, the war was over, and as with the unmanned vehicle programs being developed during the war, the military did not see the need to purchase more than a couple of aerial photography cameras for training. Fairchild turned his attention to the commercial market, further developing aerial surveillance technologies, including specialized aerial cameras, high-wing aircraft—that removed visual obstructions and provided better visibility—and mapping and surveying techniques that would be used by seven U.S. federal agencies (Baumann 2008, 13).[113]

Other important technological achievements made after WWI that significantly impacted military remote sensing in the next World War included the development of multilayer color film by Leopold Damrosch Mannes and Leopold Godowsky, Jr. in 1924, Kodachrome color film by Eastman Kodak in 1935, the use of color film for aerial photography in 1937, and the developmental work conducted on radar by the U.S. Navy and Army (Baumann 2008, 9; Lindsay 2000, 1).[114]

In 1930, Lawrence A. Hyland, Albert H. Taylor, and Leo C. Young—researchers at the U.S. Naval Research Laboratory (NRL) in Washington, D.C.—proposed a patent

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[113] The agencies supported included: Soil Conservation Service, Agricultural Adjustment Administration, U.S. Forest Service, U.S. Geological Survey, Tennessee Valley Authority, Coast and Geodetic Survey, and, eventually, the U.S. Army Air Corps (Baumann 2008, 13).

[114] Aerial color film was limited until after World War II because of technical deficiencies, including slow film speeds, immature lenses, atmospheric issues, and processing inconsistencies (Baumann 2008, 12).

for using radio equipment to detect ships and aircraft (Hyland 1934). Four years later, Taylor, Young, and Robert Morris Page successfully tested the first U.S. pulsed radar system, conducting sea trials on the *USS Leary* in 1937 and placing the first operational radar onboard the U.S. Navy battleship *New York* in 1939 (Page 1962, 128, 133).[115]

The U.S. Army Signal Corps laboratories were also developing radar technology, conducting their first experiments in 1933, with the first Army-specific radar development starting in 1936, service tests beginning in 1938, and successful completion and standardized production beginning in 1940 (Coulton 1945, 742-743, 747). During the Second World War, the new radar technology would be integrated onboard aircraft, opening the door for yet another airborne remote sensing capability: radar imagery.

Military Remote Sensing Technologies in World War II

Throughout WWII photography remained the primary airborne remote sensing capability, but the war brought even more sophisticated techniques and the fine-tuning of aerial photo interpretation, with Germany pioneering and leading many of the applications of photo reconnaissance early in the war (Baumann 2008, 13). When the U.S. entered the War in 1941, it had minimal experience in military remote sensing; however, by the end of the War, technological advancements paved the way for the U.S. to become a world leader in aerial reconnaissance and photo interpretation (Baumann 2008, 13).

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[115] There are two types of radars using waveforms: continuous wave (CW) and pulsed. The CW radar continuously emits electromagnetic energy and uses separate antennas for transmitting and receiving. Pulsed radars use a line or train of pulsed electromagnetic waves and are identified by the frequency of pulse repetitions—low, medium, or high Pulse Repetition Frequency (PRF) (Mahafza 2013, 8-9).

While photography remained center stage in terms of intelligence and reconnaissance missions, other remote sensing developments continued to be developed. Lessons learned about infrared during WWI led to more use of infrared analysis to detect targets in bad weather or to assist with countering camouflage and denial and deception techniques. Military applications for radar also were quickly proven, as the Axis and Allied powers both used this remote sensing technology to focus on guiding and detecting ships and aircraft from the ground, sea, and air, thus birthing the disciplines of electronic intelligence and electronic warfare (Finley 1995, 163). Other applications of radar technology demonstrated by the Navy and Army research laboratories before the war also proved their effectiveness, including directing searchlights and anti-aircraft and naval guns; assisting naval vessels with navigation, target detection, tracking, and targeting; and working as proximity fuses for ground and anti-aircraft artillery. With the development of the cavity magnetron, radar technology became small enough to be placed aboard military aircraft.[116] The new airborne radar technology provided Allied and Axis air crews assistance with nighttime flying, poor weather navigation, target detection of airborne and ground targets, targeting capabilities for aerial bombardment, and ground mapping. This latter application of radar would evolve into side-looking airborne radar, ground moving target indicator radar, and synthetic aperture radar, intelligence collection technologies regularly used onboard UAVs today.

Counter radar technology was developed in turn, with radar-intercept receivers placed onboard aircraft to remotely detect, locate, and characterize enemy radio

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[116] The British had the first operational airborne radar, an Airborne Interception Mk. III radar onboard the *Bristol Blenheim* light bomber as early as November 1939 (Gunston 1976, 176).

navigation beacons and radars; this became a new intelligence collection activity that would evolve into the discipline of electronic intelligence, or ELINT.[117] Like the aerial photograph, radar became an extension of human sight, with the advantage of operating in electromagnetic bands well beyond the human visual range.

Remote radio signal intelligence collection also expanded during WWII, and was mainly conducted by radio operators at ground sites or onboard ships intercepting enemy Morse code, Teletype, and voice transmissions. Operators onboard aircraft were slowly utilized to purposefully intercept enemy communications—as opposed to inadvertently picking up enemy transmissions while operating their equipment—and toward the end of the war, the U.S. Army Air Forces placed German linguists onboard heavy bombers conducting raids against Germany, while Japanese linguists served onboard *RB-24* and *B-29* aircraft conducting raids against the Japanese mainland and targets in the China-Burma-India Theater. These flights allowed limited voice intercept reconnaissance operations (Tart 2012, 1660, 1710-1713). Even though initially limited, this application of remote SIGINT intercept—an extension of human hearing—would remain and grow as a critical component of the military's airborne reconnaissance mission in future conflicts and wars, and along with equipment automation, it would become a key mission area for UAVs.

As mentioned in chapter four, television technology was used with glide bombs and UAVs to help direct them to their targets, and radar was integrated into munitions in

[117] The British used the H2S airborne ground-scanning radar for the first time in 1943 Lancaster bombing raids against Germany, with Germany developing the Lichtenstein SN2 Airborne Intercept radar to find the bombers at night (Farquhar 2004, 11). By 1943, the U.S. started conducting electronic reconnaissance with specially modified electronic reconnaissance aircraft called "Ferrets" (Farquhar 2004, 12).

the form of proximity fuses, but imagery and radar technology were not used on UAV systems during WWII for remote sensing and intelligence collection missions; these applications would not be developed until the Vietnam War. During World Wars I and II, the primary remote sensing technology was imagery, including photography, film—gun cameras—cathode ray tubes, and TV. While partially automated, the technologies remained firmly within the control of the human operators, who determined when, how, where, and how long they would be utilized. As the technology moved outside of the familiar natural visual and auditory realms into new areas—frequencies—of the electromagnetic spectrum, new ways of utilizing and controlling the technology were developed. The speeds at which aircraft could fly, and which the remote sensing systems could obtain and process the different forms of electromagnetic data, were quickly evolving beyond manual human capabilities; therefore, the operators and analysts were becoming more reliant on technology to assist with operating the collection systems and processing the collected data, i.e., transferring radio waves to voices, radar energy to a blip on a scope, etc. While the technological developments were moving relatively quickly, the merging of the remote sensing technologies with UAVs progressed at a relatively slow pace—it took almost half a century to come to fruition in a combat environment—primarily because of the preference for humans to fly intelligence, surveillance, and reconnaissance missions.

Remote Sensing Advances – Korea to the Second Gulf War

"Drones ply the liminal space between the physical and the digital—pilots fly them, but aren't in them. They are versatile and fascinating objects—the things they can do range from the mundane (aerial photography) to the spectacular—killing people, for example."
— John Battelle

The Cold War followed closely on the heels of WWII, a product of many factors, not the least of which was the Soviet Union's first atomic weapon detonation in 1949 and its development of long-range missile technology, the lack of knowledge of the post-World War II Soviet military, and the large "denied" (inaccessible) area that constituted the USSR. These factors made collecting information on the USSR a national security requirement; therefore, the U.S. Navy and newly created U.S. Air Force began airborne remote sensing collection flights in both the European and Pacific regions in response (Center 2009, 1).[118] Prior to the mid-1960s, film imagery and signals intercept were still the primary remote sensing technologies, but by the time of the Vietnam War, the imagery technology began to be supplemented with other nonliteral imaging technologies: infrared, thermal infrared, multispectral, and radar.

During the Korean War, manned aerial photography, along with ground, naval, and limited airborne SIGINT remote sensing systems, were widely used for intelligence, surveillance, and reconnaissance (ISR) collection missions.[119] Unmanned aerial vehicles were used by the U.S. Navy during that conflict, but only as offensive weapons

[118] In the postwar period, the services dedicated aircraft for SIGINT missions, such as *B-29*s, and over time other aircraft were specially configured as well and were designated with an "R" in front of the nomenclature, e.g. RC-130, to identify their primary purpose as reconnaissance (Center 2009, 1).

[119] During the Korean War, the military did use limited airborne collection that also was useful for testing intercept equipment and general concepts of operations for airborne operations (Hatch 2009, 10).

systems—precursors to cruise missiles—not as ISR platforms (Newcome 2004, 70).[120] It wasn't until two years after the 1953 Armistice that a camera was mounted on a UAV for the first time.[121] The camera-carrying RP-71 Surveillance Drone (SD)-1 *Observer*—a relative of Reginald Denny's RP-1 RC model—has the distinction of being the first UAV to conduct operational, remote sensing reconnaissance missions, and was used by the U.S. Army from 1955 to 1966 (Newcome 2004, 72).[122] Additional developments in military remote sensing technology also occurred during this time, including the application of color and color-infrared film as well as new intelligence applications for radar.

In 1954, Westinghouse, under sponsorship from the U.S. Air Force, developed the first side-looking airborne radar (SLAR) system, a technology that used radar energy to create "images" of objects.[123] While a crude technology in the early years, its usefulness would steadily be improved, allowing the military to conduct reconnaissance missions at night and in cloudy or low visibility weather, environments not conducive to regular photography. By 1958, experiments were being conducted to mount these new

[120] Commander Delmer Fahrney, head of the Navy's guided missile efforts during the 1950s, was instrumental in developing the unmanned aircraft during the Korean War. His work resulted in WWII-era Grumman *Hellcat* fighter aircraft being used as unmanned bombs. The radio-controlled *Hellcats* were loaded with 2,000-pound bombs and flown against bridges in North Korea (Newcome 2004, 70).

[121] An unmanned aircraft designed to be launched, conduct a reconnaissance mission, and return to base, not unmanned glide bombs or explosive-laden aircraft used as weapons, as previously mentioned.

[122] The SD-1 carried two cameras types: KA-20A for daytime and KA-39A for nighttime; the cameras collected 95 frames and 10 frames, respectively, in a 30-minute flight (Newcome 2004, 72).

[123]The U.S. Geological Survey defines SLAR as "an image-producing system that derives its name from the fact that the radar beam is transmitted from the side of the aircraft during data acquisition" (U.S. Geological Survey 2015). It is an active sensor system providing its own source of target illumination using microwave energy, obtaining imagery day or night. Since microwave energy penetrates most clouds, it also can be used to prepare image maps of cloud-covered areas (U.S. Geological Survey 2015).

technologies onboard UAVs. The Aerojet General *SD-2 Overseer* program tested film cameras—including 70mm film that was developed, scanned onboard, and subsequently transmitted to the ground by a data link—infrared sensors, and the SLAR; however, difficulties with navigation and other technical problems resulted in the Overseer program's cancellation in 1966 (Newcome 2004, 74). Even with these setbacks, development on combining remote sensing technology with UAVs—to create a reusable, operationally responsive intelligence collection system—continued and came to full fruition during the Vietnam War.

While difficulties existed with integrating internal navigation systems onboard the UAVs, the 1950s saw significant technological development with onboard navigation that would eventually enable remote sensor systems to be carried aboard UAVs. The advances made included the inertial navigation system (INS), star trackers, the hyperbolic radio navigation system—the principles of which were used in the long-range navigation (LORAN) system developed by the Navy during WWII and adopted for the early satellite global positioning systems (GPS) developed in 1960—and terrain matching systems.[124] The INS, developed in 1953 by Dr. Charles Stark Draper and his team at the Massachusetts Institute of Technology, used advanced theories from Draper's gyroscope stabilization systems that eventually resulted in the Space Inertial Reference Equipment (SPIRE) used onboard intercontinental ballistic missiles (ICBMs) and *Apollo* spacecraft;

[124] Hyperbolic radio navigation measures the time delays between signals from two geographically separated broadcast stations, revealing the difference in distance from the receiver to the two stations. A navigator plots lines of position by making hyperbolas (arcs) that intersect to give a precise location. WWII pilots used the system to navigate portions of the Atlantic and Pacific oceans (Hyperbolic Systems 2013).

it was this system that would help enable future unmanned systems to navigate without external human input during flight (Newcome 2004, 78-80).

By the mid-1950s the *U-2* high-altitude reconnaissance aircraft was built for the Central Intelligence Agency (CIA) under the code name AQUATONE. On September 2, 1958, a Soviet *MiG-17* shot down a U.S. Air Force *RC-130* reconnaissance aircraft over Soviet Armenia, killing 17 crewmembers (Center 2009, 2). On May 1, 1960, during an Operation OVERFLIGHT mission—covert *U-2* photoreconnaissance missions over the Soviet Union to observe ICBM testing sites and air bases—a *U-2* was shot down near Sverdlovsk, USSR, and the pilot, Francis Gary Powers, was captured and sent to prison in the Soviet Union (Lowenthal 2012, 22). On July 1 of that year, a Boeing *RB-47* reconnaissance aircraft flying an electronic intelligence mission near the Soviet Union also was shot down.[125] These events became the catalyst for expediting a number of military remote sensing programs, including the U.S. satellite reconnaissance program, a high-altitude, high-speed reconnaissance aircraft—the Lockheed A-12 Oxcart (CIA) and SR-71 Blackbird (Air Force) programs—and unmanned, jet-powered reconnaissance aircraft, i.e., the new Ryan Model 136 *Red Wagon* and *Lucy Lee* drones. However, both drone programs were unexpectedly canceled (Robarge 2012, 6).[126]

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[125] The total number of military members lost during that period is unknown due to the classified nature of the missions. The U.S. National Security Agency reports the first documented case of an attempted shoot-down of a U.S. reconnaissance aircraft occurred in October 1949, when Soviet fighters attempted to down a *B-29* over the Sea of Japan. More than 50 aircraft were shot down from 1945 to 1977 (Center 2009, 2).

[126]The GRAB Electronic Intelligence satellite, launched by the U.S. Navy, became the first operational U.S. reconnaissance satellite, and the CORONA imagery satellite, launched in August 1960, was the first successful space-borne imagery collection program (U.S. National Reconnaissance Office 2015). In September 1961, the National Reconnaissance Office (NRO) was formed to oversee and execute the national satellite reconnaissance program (Sweetman 2007, 267).

With the downing of a second *U-2* aircraft over Cuba during the October 1962 Cuban Missile Crisis, efforts to create unmanned systems were revived. The Air Force contracted with Ryan Aeronautical to modify the existing *Firebee* target drone and turn it into an unmanned reconnaissance platform, the Model 147 *Fire Fly*. The drone—equipped with a timer-programmer, gyrocompass, altimeter, and U-2 camera tucked into the nose—flew a preprogrammed direction, altitude, and time period, returning the way it came, with no guidance from the ground (Wagner 1982, 26-27). The follow-on variant ordered by the Air Force, the Ryan 147 *Lightning Bug*, flew its first operational photoreconnaissance mission against China in 1964—replacing the *U-2* in 1965 for missions over hostile Vietnamese airspace—and was subsequently used throughout the Vietnam War (Wagner 1982, 55, 82, 213).[127] As with Korea, the primary missions remained imagery collection, with *Lightning Bugs* conducting their photoreconnaissance and post-strike battle damage missions (both low and high altitude) against Vietnamese surface-to-air missile (SAM) sites, enemy airfields, and other important targets. Over time, additional remote sensing system capabilities were added to the UAV, including live video, infrared, and Color Infrared (CIR) imagery, ELINT, and SIGINT collection systems (Wagner 1982, 142, 168, 176).[128] Developments in the infrared portion of the spectrum spun off a number of other important military applications, including forward-

[127] The U.S. Navy flew its first operational photo reconnaissance flight of a Navy *Lightning Bug* in November 1969—the *Belfrey Express*—with the last mission occurring in May 1970; the Lightning Bug missions were subsequently discontinued (Wagner 1982, 160-163).

[128] WWII-era color infrared, or camouflage detection film, was further developed and refined by Robert Colwell in the 1950s, and was significant in developing the field of remote sensing (Campbell 2011, 12).

looking infrared (FLIR) systems, infrared Search and Track systems, and infrared missile-seeker heads (Chen 2013, 7-1.1).[129]

Multispectral and Other Technologies

In 1666, Sir Isaac Newton discovered that a prism could be used to disperse light into a spectrum—red, orange, yellow, green, blue, indigo, and violet—and that a second prism could recombine the colors into white light, thus opening the door for the future development of multispectral imagery (MSI) collection, where images of a target are obtained by separating the EM spectrum, which are then observed and studied to derive information about its features (Campbell 2011, 20). Development of MSI technology started in the 1950s, growing out of color infrared imagery, which was used successfully by the military in the 1960s (Lee 2003, 12-1).[130] As the technology progressed, the imaging devices looked at the visible to shortwave infrared (SWIR), the thermal infrared (TIR), mid-wave infrared (MWIR), and long-wave infrared (LWIR) portions of the electromagnetic spectrum—culminating in the hyper- and ultraspectral collection systems used today.[131] MSI airborne remote sensing technology was not used during Vietnam, but a four-band (red, blue, green, and near-IR) multispectral scanner (MSS) was used

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[129] Forward-Looking Infrared (FLIR): an electro-optical (EO) thermal imager that detects far-infrared energy, measuring the difference in temperature between objects and surroundings. (U.S. Department of Defense JP 1-02 2010, 94).

[130] MSI collects in two or more spectral bands. Classical MSI involves spectral bands in the visible to the shortwave infrared (SWIR) portion of the EM spectrum. Active airborne MSI collection programs date back to the 1950s, leading to the launch of the first NASA Landsat satellite in 1972 (Lee 2003, 12-2).

[131] Collection in each of the bands has specific applications for military missions; e.g., IR detects hardware hidden in vegetation, TIR assists with identifying an actual vehicle versus a decoy (or detecting surface, ocean, or air temperatures), and hyperspectral assists with identifying particular chemicals.

aboard the first NASA Landsat satellite, launched in 1972 (Lee 2003, 12-2; U.S. Geological Survey 2013, 1).[132]

Over time the *Lightning Bug* drone was equipped with a radar sensor—a radar warning receiver (RWR)—that detected an aircraft or surface-to-air missile radar signal. Once RWR detected a radar signal, it sent a command to the drone's guidance system, causing it to make evasive maneuvers (Wagner 1992, 88). Electronic countermeasures were also added to jam radars, as well as a multiple altitude control system to allow it to randomly change altitudes (to confuse radars) and improved guidance systems that used Doppler navigation radars and received updated position data from the LORAN radio location network—all of this enabled the drone to more accurately fly preprogrammed routes (Wagner 1982, 42, 137, 166, 194).[133] The different variations and payloads demonstrated the UAV's versatility in conducting ISR missions, and its success would ensure the use of these systems in future wars, but not without significant pause in the UAV development process.

The last operational *Lightning Bug* UAV mission occurred in June 1975, with a few test variants flying until 1979.[134] The Vietnam War-era *Lightning Bugs* successfully laid a solid foundation for future UAVs and UCAVs, having effectively made the transition from serving only as targets to fully operational remote sensing platforms

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[132] Landsat 1 was instrumental in developing technologies that would be important to future UAV programs. The first was the collection and exploitation of multispectral data, previously acquired only in specialized research laboratories, and the second was the use of digital images, also only found in specialized labs. Both became a standard for imagery collection and analysis (Campbell 2011, 15).

[133] Additional *Lightning Bugs* had the capability to dispense chaff to confuse radars and to drop propaganda leaflets (Wagner 1982, 154, 197).

[134] The final total of *Lightning Bug* missions flown against Communist China, North Vietnam, and North Korea was 3,435 (Wagner 1982, 213).

(Shaw 2014, 7).[135] Nevertheless, with the post-Vietnam drawdown, there was little financial support for UAVs due to competing requirements with other military programs, and with the exception of one U.S. Navy and Marine Corps program—the *Pioneer* UAV—the Department of Defense UAV efforts were subsequently terminated without being completed (Rodrigues 1999, 3).[136] The non-Department of Defense Central Intelligence Agency picked up the mantle from the DOD and was the only government agency that continued developing remote sensing UAV systems, working on the *GNAT-750* in early 1990s; this craft was a remotely piloted, long-endurance UAV equipped with near real-time imagery sensors (Strickland 2013, 2). While the *GNAT* was under development, the DOD was procuring operational *Pioneer* UAVs from one of its allies: Israel.

Sensor Applications in Iraq and Bosnia

The 1990-1991 military operations Desert Shield and Desert Storm saw the resurrection of the UAV for military remote sensing missions, and they soon evolved into a “must have” capability (Clark 2000, 34). The Navy used the *Pioneer* UAVs—launched

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[135] During the Vietnam War, the U.S. Army did not deploy its *SD-1* drones in Southeast Asia, but the U.S. Navy, as part of the Drone Anti-Submarine Helicopter (DASH) program, modified some turbine-powered *DSN-3* helicopter drones to provide live video to ships to assist with directing naval gunfire. However, the DASH program ended in 1969 (Blom 2010, 55, 58).

[136] From 1979-1987 the Army spent more than $1 billion on the *Aquila* UAV, a small, remotely controlled, propeller-driven UAV with autopilot, sensors, laser designator, and video system; however, payload size and avionic and the communications link problems canceled the program (Rodrigues 1997, 2). DARPA also conducted research in the 1980s, contracting with Abraham “Abe” Karem—an Israeli emigrant and UAV pioneer who built video-laden UAVs for the Israel during the 1973 War—to build a long-endurance model (Strickland 2013, 2). His Amber program was cancelled, and he sold his business to General Atomics, which used Karem’s UAV, called the *GNAT-750*, to conduct testing and build the *Predator* UAV (Strickland 2013, 2-3, 5). The Navy and Marine Corps’ *Pioneer* UAV was not developed by the U.S. government nor acquired through the formal DOD channels, but was “procured directly from a joint venture of Israeli and U.S. firms” in 1986 (Rodrigues 1997, 3). While successfully used by Israel, *Pioneer* was plagued with problems (Ward 1990, 8-10).

from battleships—to provide electro-optical and IR imagery support for shore bombardment operations, and the Army used the *Pioneer* for target designation, damage assessment, and reconnaissance (Bone 2003, 25-26; U.S. House of Representatives 1997, 902).[137] The Gulf War successes of the UAS remote sensing missions led to further testing and operational involvement in the 1992-1995 Bosnian War.[138]

In February 1994, under the code name Lofty View, the CIA secretly conducted reconnaissance missions using its *GNAT-750* to support UN peacekeeping forces in the former Yugoslavia, feeding motion imagery (video) back to CIA headquarters in Langley, Virginia (Strickland 2013, 6).[139] The concept was proven, and later that year a DOD UAS Advanced Concept Technology Demonstration (ACTD), based on a CIA program, was started with the General Atomic Company's UAV, now called the *Predator,* to conduct remote sensing military operations. The DOD's *Predators* were first flown in June 1994 and subsequently deployed to the Balkan Bosnian conflict from 1995-1996, in support of Operations Nomad Vigil and Deliberate Force (the NATO air campaign against Bosnian Serb forces) (Rodrigues 1999, 4). The *Predator* used satellite communications (SATCOM) to send control data to the UAV while simultaneously transmitting remote sensing data to the ground station, successfully demonstrating "long-range (500 nautical miles), long endurance (more than 20 hours), remote sensing

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[137] The Army used *Pointer* micro-UAVs, but poor weather made them less effective (McDaid 1997, 60).

[138] This war also saw the first use of satellite multispectral imagery by the military for mapping and terrain databases; although the technology was not yet carried aboard UAVs, the value to tactical battlefield commanders was being introduced (Lee 2003, 12-10–12-11).

[139] This activity was significant as it made historic advances in transmitting and receiving data—commands to the UAV and data from the sensors—across thousands of miles to conduct effective persistent surveillance of the target areas (Strickland 2013, 3-5).

capabilities to satisfy intelligence, reconnaissance, surveillance, and target acquisition requirements" (Rodrigues 1999, 4). This extended range also removed the requirement for UAV operators to be in or near the areas where drones were being flown; they could now operate the UAV overseas and receive the sensed data while remaining in the U.S. The ACTD subsequently transitioned to the Air Force in 1997 after successfully flying missions over Bosnia (Bone 2003, 22).

The *Predator* would subsequently be outfitted with an array of remote sensing systems still in use today, including electro-optical (EO) and infrared (IR) cameras, a MultiSpectral Targeting System (MTS) sensor ball, a laser designator that allows EO/IR tracking of moving targets, and an all-weather synthetic aperture radar (SAR) enabling imaging through inclement weather (Gertler 2012, 34).

However, despite the long history of UAV development, the technological advancements in navigation, communications, remote sensing, and computer technologies that make today's unmanned combat aerial system (UCAS) missions possible have occurred only in the last 15 to 20 years, demonstrating that the UAS is still in "a period of innovation, both in their design and how they are operated" (Gertler 2012, 6).[140] These advances and innovations in UAV and remote sensing technologies were made possible through the development of computer technology, particularly semiconductor devices and digital computers. Computers, and follow-on advancements toward AI technologies, not only enabled the disparate systems onboard the UAV to

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[140] The number of systems acquired does not correspond to the number of unique platforms. With different sensors, a common airframe can serve the requirements of multiple services. General Atomics' *I-GNAT* developed into the Air Force *Predator*/*Reaper*, which served as the basis for the Army's *Gray Eagle* and DHS's *Predator* used for marine environments; Northrop Grumman's Air Force *Global Hawk* became, with different equipment, the Navy's Broad Area Maritime Surveillance (BAMS) system (Gertler 2012, 6).

interact—e.g., flight controls, communications, navigation, sensors, weapons, etc.—but also enabled various degrees of system autonomy, lessening the need for direct human control and opening the door for technological determinists to point to these systems as examples in which humans may not retain the ability to maintain control.

Autonomous UAV Development

> *"My contention is that machines can be constructed which will simulate the behaviour of the human mind very closely. They will make mistakes at times, and at times they may make new and very interesting statements, and on the whole the output of them will be worth attention to the same sort of extent as the output of a human mind."*
>
> — Alan Turing

Up to the Vietnam War, UAV technology consisted mainly of onboard mechanical systems, such as a gyroscope to maintain level flight or a mechanical counter to measure the number of rotations made by the propeller before shutting off the engine. Some onboard mechanical systems, such as automatic pilots, allowed aircraft to maintain a specific course and altitude for a specific period of time—like the Kettering *Bug*—without input from an operator on the ground. Even during the early years of the Vietnam War, the *Lightning Bugs* often flew preprogrammed routes, conducting remote sensing missions and returning to a recovery site where they parachuted to earth (Ehrhard 2010, 24). With the development of computer technology, UAVs were guided by both remote control and onboard computerized automation, which eventually acquired many of the lower-level human operator command, control, and navigation functions, such as maintaining course, altitude, and speed; turning at predesignated waypoints; activating sensors; and conducting evasive maneuvers—all activities that provided the UAV a very basic type of autonomy. Unlike the development of the aircraft or sensor systems, the computerized elements of the UAV have a much shorter history, but the impact has been monumental, thrusting into the limelight such human-technology-related issues as safety, security, privacy, morality and ethics, laws of armed conflict, and human control.

Computers, Algorithms, and Programs on UAVs

Building on the computational efforts of Wilhelm Schickard, Blaise Pascal, Gottfried Leibniz, Joseph Marie Jacquard, Charles Babbage, Ada Lovelace, Vannevar Bush, and others, English mathematician Alan Turing was instrumental in constructing the first operational computer during World War II (Kurzweil 1992, 167). In 1940, while applying his cryptologic expertise on cracking the German Enigma Code, he laid the foundation for the modern electronic computer and artificial intelligence (Menzel and D'Aluisio 2000, 23; Kurzweil 1999, 67).

Most dictionaries define *computer* with similar descriptors: a machine or electronic device that can do calculations, store, organize, and find data or information. However, Ray Kurzweil's definition highlights elements that are important for understanding the difference between the earlier computational calculating machines and today's computers, differences responsible for the change in relationship between the human and the machine:

> I would define a computer as a machine capable of automatically performing (that is, without human intervention) sequences of calculations, and of choosing between alternate sequences of calculations based on the results of earlier calculations. The description of the sequence of calculations to be performed, which includes all alternate paths and the criteria for choosing among them, is called a program. A programmable or general purpose computer is one in which we can change the program. A special purpose computer is one in which the program is built in and unchangeable. (Kurzweil 1992, 169)

It is the programming—specifically, the algorithms—and "choosing" aspects of the modern computer that separates it from a pure calculating device or an automatic mechanical apparatus of the past, and it is these aspects that provide the foundation on which UAV autonomous operation and artificial intelligence is built.[141]

Modern computer programs onboard UAVs enable them to automatically perform specific sequences of calculations and choose between alternate sequences of calculations based on the results of earlier calculations; e.g., a computer program onboard may be written to solve the problem of drifting off course. Using the data received from an inertial navigation system or GPS, an algorithm can be written to detect course deviations, and once detected, send an electronic signal—an electric current—that activates the mechanical rudder on an aircraft to correct it to the original course setting, maintaining that course until the program changes the course at a predetermined time. Alternatively, another program can be written for an onboard sensor—such as a radar-warning receiver—to detect a specific radar signal from a guided missile and then instruct it to send another signal to the UAV's flight control system to immediately and radically change course, following another preprogrammed maneuver, to avoid being hit. These were the types of programs used on the Vietnam-era *Lightning Bugs*. As the programs and algorithms onboard became more sophisticated and prolific, the machines appeared to be "thinking" and able to make decisions as a human would; however, what

[141] Programs are specific ways to describe and implement a "finite, deterministic, and effective method to solve a problem" (Sedgewick 2011, 4). This consists of a finite set of logical step-by-step instructions or rules followed in order to solve a math problem, or complete a math process, i.e., an algorithm. There are different ways of notating algorithms, making up the different types of programming "languages," e.g., Ada, Perl, C, C++, Java, SQL, etc. The organization of computational data is called data structuring, and together with algorithms, forms the central components of computer programming (Sedgewick 2011, 4).

is actually occurring is the machine following its mathematically derived steps of instructions.

Computer Technology Onboard Aircraft – WWII to Vietnam

As discussed in chapter four, Sperry's 1912 control system, consisting of three gyroscopes connected to the aircraft control systems, was the first autopilot. It was this mechanical autopilot system, combined with mechanical calculating and timing systems, which enabled the development of the unmanned Sperry-Curtiss *Flying Bomb* and *Kettering Bug,* and it was this same mechanical-based system that remained the primary means for unmanned flight control and navigation prior to Draper's inertial navigation system (INS) developed in 1949. The drawbacks to the mechanical systems were twofold: First, they were too unreliable to allow autonomous navigation due to weather and turbulence, both of which adversely affected the mechanical mechanisms; second, they required a remote radio input to make course adjustments or corrections (Newcome 2004, 78-79). It was Draper's INS, combined with onboard computers, which provided the technology required for unmanned aircraft to fly and conduct missions without human intervention. However, these mechanical and electrical aircraft control systems were not replaced by onboard computers until the 1950s.

The early computers developed during WWII—such as the Navy's electromechanical Torpedo Data Computer (TDC), the Army's Electronic Numerical Integrator Computer (ENIAC), or the British Heath Robinson, Bombe, and electronic Colossus code-breaking computers—were very large machines impractical for use onboard aircraft. [142] It wasn't until after the war, in 1947, when Bell Laboratories engineers William Bradford Shockley, Walter Brattain, and John Bardeen developed the transistor—a semiconductor device used to amplify and switch electronic signals and electrical power—which ushered in the micro-electronics revolution and enabled the creation of electronic computers small enough to be practically carried onboard aircraft and subsequently UAVs (McClellan 2006, 406; Springer 2013, 122).[143]

Q2 Firebee UAVs and Semi-Autonomous Flight

Prior to the development of the computerized flight control systems after World War II, the unmanned vehicles used as targets—the early model Ryan *Q2 Firebees*—were given simple commands via radio control from a remote operator: fly straight, turn right/left, climb/dive, increase/decrease speed. With the development of the *Q2C Firebee* in 1958, the computerized microprocessor flight control system (MFCS)—designated the AlA37G-3—allowed operators to make the jet-powered UAVs perform more sophisticated maneuvers, thus making better, more realistic targets for training (Woolley 1978, 208).[144] With the creation of integrated circuits in the early 1960s, a new version of the flight control system, the AlA37G-8, was used onboard the Model 147 *Fire Fly*

[142]Computers may be analog, electromechanical, or electronic. Analog represent data by measurable, numerical quantities, such as the rotation of gears, the angle of rotation of a shaft, or a difference in electrical potential. Electromechanical consists of small, electrically driven mechanical switches called relays. Electronic computers have no moving parts, only electrons, that originally moved through vacuum tubes—the valves—and can operate extremely fast (Copeland 2000, 2-4).

[143] Semiconductor: material that has the electrical conductivity between metal and an insulator (like glass), with the most common semiconductor used in integrated circuitry being silicon (Neamen 2003, 1).

[144] Microprocessor: a computer processor that incorporates the functions of a computer's central processing unit (CPU)—where the program instructions are executed—on a single integrated circuit or microchip. The first microprocessor was the Intel 4004, introduced in 1971 (Kent 1987, 140-141, 158).

and subsequently the *Lightning Bug* reconnaissance drones—the modified *Firebee* target drones—enabling the UAVs to fly and navigate either remotely by an operator or on a preprogrammed route autonomously (Woolley 1978, 209). [145] This semi-autonomous system was the peak of computerized capability for the *Lightning Bug* flight control systems during the Vietnam War. Today, the DOD defines *autonomous* as not under remote control; i.e., when the aircraft is under remote control (a remotely piloted vehicle) it is not autonomous, but when it is operating solely under the guidance of a computer's programming it is not being remotely controlled (U.S. Department of Defense Unmanned Systems 2013, 15). The *Lightning Bug* was a semi-autonomous system because, even though it could fly a preprogrammed route, it could not take off, fly its route, conduct its mission, and land without human involvement.

Condor: The First Fully Autonomous UAV Flight

Although the reconnaissance UAVs were significantly scaled back after the Vietnam War, more sophisticated flight control system capabilities continued to be developed. Two U.S. Air Force competitive programs, one called Compass Dwell and the other Compass Cope, were started in 1968 and 1971, respectively, to develop a high-altitude long-endurance (HALE) unmanned aircraft, i.e., a UAV that could fly above 50,000 feet for more than 24 hours (Newcome 2004, 101). While the E-Systems company's *XQM-93* UAV and Martin Marietta's *845A* proved the HALE capabilities—both operated above 50,000 feet and broke endurance records—the Compass Dwell

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[145] The integrated circuit developed by Jack Kilby of Texas Instruments, in 1958, received a U.S. patent in 1964, and was defined by Kilby as a body "where all components of an electronic circuit are formed in or near one surface of a relatively thin semiconductor wafer . . ." (Kilby 1959, Section 2, line 20).

program ended in July 1972, with neither company receiving a production award (Newcome 2004, 102).[146] In the follow-on Compass Cope program the Boeing and Teledyne-Ryan companies competed against each other, producing HALE demonstrators and flying them in 1974. However, it was the Ryan UAV—the YQM-98 *Tern,* aka *Compass Cope R*—that not only demonstrated the HALE capabilities but also the capability to take off and land on conventional runways while operating autonomously under the control and guidance of an onboard computer (Woolley 1978, 209).[147] Unfortunately for both companies, this program was cancelled in 1977, and neither company's demonstrators were produced operationally.

Additional research on HALE and medium-altitude long-endurance (MALE) UAVs continued during the 1980s under the direction of the Defense Advanced Research Projects Agency (DARPA), and it explored different power sources and control capabilities. Within this period of events, in 1986, the Boeing *Condor* HALE UAV became the first to make a fully autonomous flight; using preprogrammed data in the onboard computer, it took off, landed, and flew with no human intervention, carrying an automated failure management system onboard to address in-flight emergencies (Newcome 2004, 105). Between 1986 and 1988, the *Condor* also set the piston-powered altitude world record—67,028 feet—and the world UAV endurance record, remaining

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[146] The *XQM-93* set the world's first endurance record of 22 hours in January 1972, and the *845A* broke that record, flying 27 hours and 54 minutes in July 1972, as the program ended (Newcome 2004, 102).

[147] The capability demonstrated by the *Condor* illustrates autonomy Level 4, Fully Autonomous, where: "The system receives goals from humans and translates them into tasks to be performed without human interaction. A human could still enter the loop in an emergency or change the goals, although in practice there may be significant time delays before human intervention occurs." (See complete definition in chapter one.)

aloft, unrefueled, for 51 hours (Newcome 2004, 105). These were significant achievements, and *Condor*'s missions were technically considered autonomous flights in accordance with the DOD's Level 4 autonomy definition of Fully Autonomous—as discussed in chapter one—because the *Condor* system received its goals (flight plan) from humans (in the form of a computer program) and then translated them into actual tasks to be performed—taxi, takeoff, fly, land—without any human interaction. A human could still enter the loop at any time to address an in-flight emergency or change the goals, but the *Condor* was able to achieve a high level of Human Independence (HI), albeit in a very restricted environment.[148] While the Navy showed some interest in the *Condor*, this program ended without approval for production, ending further testing.

Despite the cancellation of these programs, the capabilities demonstrated during the 1970s and 1980s laid the foundation for autonomous UAV operations that would occur a decade later.

Pioneer to Global Hawk: Normalizing Autonomous UAV Operations

When the military UAV programs began to be rebuilt starting in the 1980s, computer-controlled semi-autonomous operation—DOD Autonomy Levels 2 and 3: Human Delegated or Human Supervised—was built into systems such as the RQ-2A *Pioneer* (1986), *GNAT-750* (early 1990s), R-Q1 *Predator* (1994), and RQ-7 *Shadow*

[148] While an amazing achievement, this is not autonomy where the UAV is able to define its own path according to an independently chosen goal, or to choose the goal that is dictating its path; the goals and path are completely human generated and created as mathematical algorithms and programs which direct the UAV's actions. The DOD's Unmanned Systems Integrated Roadmap provides the clarification regarding the definition of autonomy as used by the military (see chapter one).

(2000).[149] The computerized onboard flight control systems integrated into the *Pioneer*, *Predator,* and *Shadow* systems provided the ability for preprogrammed autonomous flight, like the *Lightning Bugs* during the Vietnam era; however, these systems remained predominately human-controlled (DOD Autonomy Level 1), with the onboard systems being controlled by a human operator via line-of-site (LOS) or satellite communication links (Pioneer 2015, 3; Springer 2013, 189, 192, 203).[150] The onboard computers also provided the option for an autopilot hold mode, or in some systems—like the *Predator*—a "lost link" operation, where the communication, command, and control link between the ground control station and the UAV is broken or disrupted. In this situation, the *Predator*'s computerized onboard flight control system would detect the lost link, and in accordance with its programming, default to a preprogrammed route consisting of waypoints—longitude and latitude coordinates—forming a looping holding pattern until either the link was reestablished or the UAV ran out of fuel and crashed (Van Cleave 2011, 1-2; Carrigan 2008, 5).[151] Aside from the autopilot hold or lost link modes, autonomous flight was not used in these systems; however, by 1995, a DARPA ACTD

[149] The Army's version of the *Predator*, the *Gray Eagle*, has an automatic takeoff and landing system that allows it to be launched and recovered without any human interaction (General Atomics 2015a, 1).

[150] The current *Predator B* can be remotely piloted or operate in a fully autonomous mode (General Atomics 2015b, 1); however, as previously mentioned, the decision for human involvement was due to the requirement for the UAVs to quickly react to unplanned situations, and once UAVs were armed, to abide by current rules of engagement that mandate human decisions employ the onboard weapons system.

[151] During normal operations, the *Predator B* received both a line-of-site (LOS) signal from the ground station and an Iridium® satellite signal. Should the LOS signal be lost, the Iridium® satellite provides limited control through preprogrammed autopilot hold modes. In this mode, direct human control was not possible. The LOS signal takes precedence when it is available, but if the aircraft loses power the Iridium® communications equipment is automatically deactivated to conserve battery power (Carrigan 2008, 5).

program produced the RQ-4 *Global Hawk*, an operational HALE UAV that could fly its missions at DOD Autonomy Level 3: Human Supervised.[152]

The *Global Hawk*, like its *Condor* predecessor, has the capability to fly an entire mission autonomously. Once the mission parameters are preprogrammed into the UAV, it can taxi, take off, fly, remain on its predesignated orbit capturing imagery at preprogrammed locations, return, and land, with human pilot involvement required only for monitoring the UAV's health and status, to change its navigation or ISR sensor plans during flight, or to take control in an emergency (Loochkart 2008, 1). Typically, *Global Hawk* missions are flown by pilots in a Launch and Recovery Element (LRE) and a Mission Control Element (MCE). The LRE pilot is located at the RQ-4 air base and is responsible for UAV launch, flight to and from the designated target area, and recovery back to base (U.S. Air Force Fact Sheet: RQ-4 Global Hawk 2014, 1). The MCE pilot controls the *Global Hawk* during the ISR mission, while the sensor operator controls the onboard remote sensing systems. Command and control of the UAV is enabled via data links and cockpit displays in the LRE and MCE that provide pilots the ability to monitor aircraft and sensor health and status, the means to alter the navigational track, or to take complete control of the aircraft if required (U.S. Air Force Fact Sheet: RQ-4 Global Hawk 2014, 1). While the ability of the RQ-4 to fly completely autonomously has been proven, information is not readily available to determine what type of autonomous modes

[152] A DARPA program concurrent to *Global Hawk* was the joint Lockheed Martin/Boeing-produced *DarkStar* stealth UAV, which made its first flight in March 1996 but crashed during its second flight in April. A second prototype conducted an autonomous takeoff, flight plan, and landing in 1998, but was cancelled after its fifth flight in January 1999 (Lockheed Martin/Boeing RQ-3A DarkStar 2015).

exist on the current RQ-4 Block 40 UAVs or to what degree the UAV actually uses the autonomous flight capability.[153]

In addition to autonomous intelligence collection missions, the Department of Defense has been actively involved in developing autonomous UAVs that have the capability to deliver weapons, as demonstrated by the *X-45A* and *X-47B* Unmanned Combat Air Systems (UCAS), both of which have made significant breakthroughs for future autonomous combat operations.[154]

Artificial Intelligence and Autonomous UCAVs

> *"This is the future of aviation. Our children will not believe that people used to drive cars and drive airplanes. We are the weak link in the chain."*
>
> — Chris Anderson

Under a DARPA program, the Boeing *X-45* made its maiden voyage on May 22, 2002, and the following year the Department of Defense consolidated the Boeing X-45 program with the Northrop Grumman X-47A project creating the DARPA/U.S. Air Force/U.S. Navy Joint Unmanned Combat Air Systems (J-UCAS) program, an effort focused on weaponizing unmanned air vehicles for combat operations deep within denied

[153] *Global Hawk* began supporting overseas contingency operations only two months after the September 11, 2001 attacks while still a developmental system. Since then, it has surpassed 125,000 flight hours and as of 2014 had 100,000 operational hours. Also in 2014, an RQ-4 Block 40 flew a 34.3-hour flight, setting the endurance record for longest unrefueled flight by a U.S. Air Force aircraft (Global Hawk 2014, 1).

[154] The MQ-8 *Fire Scout* helicopter can fly autonomously (no pilot in the loop), taking off and landing on any aviation-capable ship or from prepared and unprepared landing zones. The *Fire Scout* is monitored by an operator using the control system, which provides a variety of override commands and enables the operator to upload new missions in real-time and perform override control (Northrop Grumman 2010).

enemy territory (DARPA 2004, 1).[155] The J-UCAS program employed a common computer operating system that integrated the UCAVs' flight, sensor, communication, and weapon components (U.S. Air Force Fact Sheet: Boeing X-45A J-UCAS 2015, 1). The X-45A program concluded on August 10, 2005 after completing more than 60 flights and demonstrating many autonomous capabilities, including dropping munitions on a target (Boeing 2015, 2; DARPA 2015a, 1). Two months later, on October 20, 2005, the Northrop *X-47B* was awarded continued funding (DARPA 2015b, 1). This program subsequently transitioned to the military services' leadership by November 1, 2005, and the *X-47B* became part of the United States Navy's Unmanned Combat Air System Demonstration (UCAS-D) program established in 2007 (DARPA 2015c, 1; Ehrhard 2007, 3).

The computer-controlled *X-47B* completed its autonomous flight test in February 2011; the at-sea deck handling trials aboard the *USS Harry S Truman* (CVN 75) took place in December 2012; the first carrier-based launch and touch-and-go landings by an autonomous UAV were performed aboard the *USS George H.W. Bush* (CVN 77) in May 2014; and the first ever autonomous aerial refueling (AAR) of an unmanned aircraft took place on an *Omega K-707* tanker on April 22, 2015—completing the final test objectives under the Navy's UCAS-D program (Northrop Grumman 20015, 1). The accomplishments of the *X-47B* are extraordinary because it does not need a pilot; just like the Navy's manned F/A-18E/F *Super Hornet*, it has the capability to taxi and launch from

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[155] Another UAV produced around the same time that can probably operate autonomously is the USAF *RQ-170 Sentinel* (U.S. Air Force Fact Sheet: RQ-170 Sentinel 2009, 1). The Air Force has published little on the *RQ-170*, known as the Beast of Kandahar, but since acknowledging its existence in 2009 numerous press agencies and defense publications have made speculations based on sightings. It has been featured in numerous press articles since an *RQ-170* was lost in Iran in December 2011 (Jaffe 2011, 1).

an aircraft carrier, refuel in mid-air, complete a mission—potentially reconnaissance (like the *Global Hawk*) or strike (as demonstrated by the *X-45A*)—and return to a carrier deck—all with no human input.

While many specific details of the *Global Hawk* and *X-47B*'s programming and autonomous capabilities are not available to the general public, their accomplishments are groundbreaking in terms of autonomous operations and the change in human-machine interaction, where the human operators now primarily monitor systems as the aircraft's onboard computers perform their various functions as programmed. As demonstrated by both systems, not only do the onboard computers and sensors assist with the UAVs' situational awareness of the environment in which they fly, the combination of remote sensing capabilities with autonomous flight enables the platform to search, find, identify, and track a target automatically, a process labeled automatic target recognition (ATR) by the Department of Defense.

Automatic Target Recognition and Autonomous Weapons Delivery

ATR uses onboard remote sensing systems and computer processing to automatically detect and recognize signature data produced from electro-optical, infrared, radar, laser, and non-imaging sensors (Dudgeon 1993, 3). The importance of ATR for autonomous unmanned combat aircraft systems is that it not only provides the capability to find and track a target, but also to apply a weapon against that target without human intervention. This was demonstrated on April 18, 2004, by the *X-45A* in the DARPA UCAS test program. The goal of the program was to demonstrate the capability of using unmanned combat air vehicles to conduct suppression of enemy air defenses (SEAD) missions—the destruction of radars and anti-aircraft guns and missiles—using the *X-45A* to release an inert 250-pound precision-guided weapon from its internal weapons bay to successfully hit a ground target (U.S. Air Force Fact Sheet: Boeing X-45A J-UCAS 2015, 1; Boeing 2015, 2). In August 2005, during the final demonstration, the capabilities of two autonomous *X-45A*s demonstrated the success of the integrated flight, sensor, communication, and weapon operating systems, and the systems' ability to find, target, and destroy a ground target. The activities of the two *X-45A*s included:

1. Flying a preplanned SEAD mission against simulated ground-based radars and associated surface-to-air missile launchers;
2. using their onboard, decision-making computer software to avoid a new, unplanned threat;
3. independently determining which of the *X-45A*s would attack the new target based on their position, weapons, and fuel;
4. attacking the target;
5. returning to base (U.S. Air Force Fact Sheet: Boeing X-45A J-UCAS 2015, 1).[156]

The *X-45A* detected an active radar signal to identify its target, but today's sensor systems onboard the *Predator*, *Reaper*, *Global Hawk*, and other UAV platforms can also detect passive targets (buildings, vehicles, equipment, etc.) using EO, SAR, IR, or hyperspectral remote sensing technology as described earlier. Currently, however, such fully autonomous ATR and weapon delivery operations are not yet in operational use for a number of reasons, including U.S. Defense Department policy and limitations associated with ATR technology.

A primary reason an autonomous ATR and weapon systems-equipped UAV is not operating is because current U.S. DOD policy restricts UAVs from being allowed to

[156] The *X-45A* pilot-operator at Edwards Air Force Base checked and approved the plans created by the UCAVs' software; the autonomous *X-45A*s successfully attacked and returned to base (U.S. Air Force Fact Sheet: Boeing X-45A J-UCAS 2015, 1).

independently launch any kind of weapon without human oversight and approval. According to U.S. DOD Directive 3000.09, autonomous and semi-autonomous weapon systems must be designed with specific limitations and allow humans to exercise their judgment over the use of force:

> (1) Semi-autonomous weapon systems (including manned or unmanned platforms, munitions, or sub-munitions that function as semi-autonomous weapon systems or as subcomponents of semi-autonomous weapon systems) may be used to apply lethal or non-lethal, kinetic or non-kinetic force. Semi-autonomous weapon systems that are onboard or integrated with unmanned platforms must be designed such that, in the event of degraded or lost communications, the system does not autonomously select and engage individual targets or specific target groups that have not been previously selected by an authorized human operator.
> (2) Human-supervised autonomous weapon systems may be used to select and engage targets, with the exception of selecting humans as targets, for local defense to intercept attempted time-critical or saturation attacks for:
> (a) Static defense of manned installations.
> (b) Onboard defense of manned platforms.
> (3) Autonomous weapon systems may be used to apply non-lethal, non-kinetic force, such as some forms of electronic attack, against materiel targets in accordance with DOD Directive 3000.3 (Reference (d)).[157] (U.S Department of Defense Directive 3000.09 2012, 3).

Other limiting factors for autonomous UCAV weapons delivery are associated with ATR and are caused by environmental *clutter*, i.e., unwanted returns or echoes from radar, imaging, and other sensors that are detected along with or instead of the intended target; and *noise*, i.e., the unwanted, unknown, or spurious electronic changes to an electronic signal caused by the sensor equipment itself or during the transmission, reception, and/or processing of the signals (Dudgeon 1993, 3). In addition, there is the challenge of the ATR systems' ability to process extremely large amounts of data from the remote sensors in a timely manner, especially with systems like hyperspectral

[157] DOD Directive 3000.3, DOD Executive Agent for Non-Lethal Weapons (NLW), and NLW Policy, reference (d), refers to Joint Publication 3-13.1, "Electronic Warfare," January 25, 2007.

imagery, which require extremely comprehensive algorithms to sort through the data (Dudgeon 1993, 4). Once processed, the collected data must then be matched against an existing database of target signatures, but due to a high degree of variability caused by clutter, noise, and possible changes in the target's physical makeup due to camouflage, modifications, or even temperature of the target, timely exact matches are difficult (Dudgeon 1993, 4). These factors associated with ATR operations often make it difficult to clearly distinguish a target, a limitation that has a significant impact on unmanned combat air system operations because it conflicts with the Law of Armed Conflict (LOAC), specifically the principle of discrimination or distinction. This principle requires the combatting parties of a nation to distinguish between civilians and combatants—as well as between civilian objects and military objectives—with the stipulation that the combat operations will be directed only against military objectives (United Nations 1996, 97). Until ATR can repeatedly and accurately distinguish targets, it will require human oversight and approval, a significant contributing factor in DOD's policy to restrict weapons delivery by autonomous UAVs.

To overcome these limitations, the DOD is working on a number of different technologies to address the difficulties associated with ATR, including research in detection theory (using statistical testing to separate target signatures from clutter), pattern recognition (using feature vectors, or templates, to distinguish between target clusters and clutter), and artificial neural networks (the attempt to build a system that technologically replicates human vision in order to differentiate between target signatures and clutter) (Dudgeon 1993, 4-6). Another area of research is called model-based target recognition; this approach uses AI to assist with overcoming the ATR deficiencies by forming "an initial set of hypotheses based on sensor data (the *indexing* problem), then use the hypotheses to predict features and their relationships, and finally compare the predictions to features extracted from the data" (Dudgeon 1993, 7). This latter approach, using AI, introduces the technology and processes that the hard technological determinists believe will be the catalyst for enabling weapon systems to act autonomously in the sense of self-governance, eventually evolving to the point where they operate independently from human control.

Artificial Intelligence and UCAS Operations

According to the Office of the Secretary of Defense for Research and Engineering, autonomy for military unmanned combat air systems relies on three multidisciplinary technical fields, all represented in the unmanned combat aircraft system: *perception* (sensors which provide data and the associated algorithms used to turn the data into contextual understanding), *action* (a mechanical system operating without a human control), and *cognition* (artificial intelligence) (U.S. Department of Defense Office of Technical Intelligence 2015, iii-2). It further defines the cognition aspect as the ability of the machine to make decisions, ranging from simple—e.g., a vending machine's decision tree—to very complex, e.g., the *X-47B*, relying on computational hardware and AI algorithms (U.S. Department of Defense Office of Technical Intelligence 2015, 2). The DOD understands that there are multiple definitions of autonomy, but regardless of how it is defined, it recognizes that future autonomous UCAV systems need to move "beyond autonomous mission execution"—i.e., simply executing a preprogrammed plan—to "autonomous mission performance," where the

UCAV operates in a diverse mission environment, where circumstances and outcomes can vary, and where it is required to deviate from its preprogrammed tasks (U.S. Department of Defense Unmanned Systems 2013, 66). This requires the UCAV to execute AI as defined in chapter one—computer programming that goes beyond operating remote sensing and aircraft systems to making decisions—to execute a mission by incorporating laws, strategies, and algorithmic reasoning to allow the UCAS to operate itself, enabling it to integrate the human functions of "sensing, perceiving, analyzing, communicating, planning, decision-making, and executing" to adapt to the environment and achieve mission goals (U.S. Department of Defense Unmanned Systems 2013, 67). In other words, the DOD recognizes that for an autonomous UCAV like the *X-45A* or *X-47B* to successfully deliver weapons in a combat environment, it must have the intelligence to continually monitor, observe, orient, sense, anticipate, update, decide, and act—in a similar manner as a human being. This requires the human-created computer algorithms to act in the same manner as the human brain, function in constantly changing environments, adapt to change, and predict what will happen next. But despite the successes of the *Global Hawk*, *X-45A, X-47B*, and other UAV programs, after 50 years of AI research and development, a human-level of automated conceptualization remains elusive, and the technology that would replicate a human-level of autonomy has not yet been identified (Rogers 2015; U.S. Department of Defense Unmanned Systems 2013, 67). There are numerous reasons this has not happened yet, but a primary one is that computer automation and AI are only as good as the human algorithm, code, and software writers and developers, who must correctly observe, understand, capture, and replicate patterns of human life, the surrounding environment, brain function, and other unexplained human phenomenon, like self-awareness, consciousness, emotion, and "gut feeling"—all important components to AI development. All are needed to ensure accuracy and correctness of a decision-making process within the AI software of an unmanned combat air system (Rogers 2003, 31-33; Rogers 2015; U.S. Department of Defense Unmanned Systems 2013, 68).[158]

Despite its elusiveness, autonomy and AI research and development remain a priority for the U.S. military, as demonstrated by the *Technical Assessment on Autonomy* published in February 2015 by the DOD's Office of Technical Intelligence. This assessment underscores the military's understanding of the importance of autonomous weapon systems, because they have "the potential to enable U.S. forces to break out of current limitations by allowing systems to understand the environment, to make decisions, and to act more effectively and with greater independence from humans. In doing so, autonomy can augment or replace humans to enhance performance, to reduce risk to warfighters, and to decrease costs" (U.S. Department of Defense Office of Technical Intelligence 2015, iii). The military also understands that as these systems are developed there will be continual changes in the human-machine relationship, and therefore the military will need to further study the technical-operational and ethical-legal implications of the development and use of autonomous systems to "inform both what is

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[158] There is interesting computational research work being conducted at the Air Force Institute of Technology and the Air Force Research Laboratory that demonstrates the complexity of representing and replicating the factors enabling human situational awareness, e.g., the many elements derived from the human senses, memory, experiences, intuition, etc. The researchers express these as *qualia*, or the "internal perception of the basis set we use to represent the variety of stimuli we encounter" (Lacey 2008, 2; Rogers 2003, 31). The difficulty of programming a computer to computationally use qualia begins with the ability to define how these human qualia can be represented as "the infinite varieties of stimuli observed in the physical world are represented as qualia" (Lacey 2008, 2).

possible and what is appropriate" (U.S. Department of Defense Office of Technical Intelligence 2015, 18).

Chapter Summary

This chapter provided a historical background of the development of remote sensing, autonomous flight, and AI technologies in relation to the evolution of autonomous unmanned aerial vehicles. The integration, or blending, of these technologies was examined to determine their influence on the development of the unmanned combat aircraft system (UCAS). It was shown how the remote sensing technology not only replicated, but extended, the human senses, enabling intelligence collection platforms to "see" and "hear" in the electromagnetic spectrum well beyond human capabilities. With the development of computer technology, the flight systems, navigation, and communication onboard aircraft, along with the sensor systems, could be automated to the point that a human is no longer required to operate them; however, it was shown that current policy still dictates that humans maintain a significant role. With the integration of remote sensing and computerized flight technologies, UAVs can not only conduct autonomous missions, they can also follow their onboard programming to take off and land from an aircraft carrier, conduct aerial refueling, and even deliver weapons without human intervention. This technological integration also enabled the development of automatic target recognition (ATR) technology, which provides the potential for a UCAV to find, identify, target, and employ a weapon against a target. It was also shown that with the research and development activity being conducted on artificial intelligence, today's state-of-the-art (SOA), remotely piloted (*Predator/Reaper*), and autonomous (*X-47B*) technology—albeit with some very significant obstacles yet to be overcome—is pointing UCAVs to the art-of-the-possible (AOP), where completely autonomous weapon systems, using technologies that surpass human sensing and computational abilities, may conduct lethal combat missions in the future. In the final chapter, the impact of these technologies will be critically examined in light of the technological determinists' arguments (introduced in chapter three) to determine the impact the technology has on human control over these systems, and whether humanity is losing that control.

Chapter Six: Findings and Conclusion

"Technology is just a tool."

— Bill Gates

Chapter Introduction

This chapter begins with some positive and negative societal and cultural implications of autonomous unmanned combat aircraft system (UCAS) technology. This is followed by a critical examination of the technological determinists' arguments discussed in chapter three in light of the historical background of the evolution of the distinct technologies of the UCAS (unmanned aircraft, remote sensors, and onboard computers), the integration of these technologies, and the introduction of artificial intelligence (AI) into the equation, as discussed in chapters four and five. A summary of the findings, which include technological, legal, political-military, and moral-ethical challenges for autonomous UCAS technology, are then offered to answer the research question: *Does the presence and influence of the integrated technologies of unmanned aircraft systems, remote sensing systems, and artificial intelligence, found in the development of the autonomous UCAS, support the technological deterministic view that humanity's ability to maintain control is threatened or transcended?* This is followed by some recommendations, areas for further research, and a conclusion that addresses what it means to be human in the age of technology and 21st-century warfare.

UCAS Technology and Humanity

> *"Unmanned systems, particularly autonomous ones, have to be the new normal in ever-increasing areas. For example, as good as it is, and as much as we need it and look forward to having it in the fleet for many years, the F-35 should be, and almost certainly will be, the last manned strike fighter aircraft the Department of the Navy will ever buy or fly."*
>
> — Ray Mabus

When contemplating the impact that military autonomous UCAS technology has on society, it becomes apparent that there are a number of positive and negative implications. The ones cited here are by no means exhaustive, but are provided to demonstrate that UCAS technology, like every other form of technology that has preceded it, has lasting positive and negative effects upon humanity as a whole.

Positive Social Implications of UCAS Technology

First, the military recognizes that unmanned systems have "proven they can enhance situational awareness, reduce human workload, improve mission performance, and minimize overall risk to both civilian and military personnel, and all at a reduced cost" (U.S. Department of Defense Unmanned Systems 2013, 20). UCAVs are valuable for replacing humans in what are referred to as the "dull, dirty, or dangerous" missions (U.S. Department of Defense Unmanned Systems 2013, 20). They are free from the restrictions of human physiology and are not affected by many of the strains and constraints associated with combat-related activities. As an example, the dull, repetitive, long-duration missions required for effective aerial surveillance are often hampered by the physiological limits of the military member, i.e., the need to eat, rest, exercise, and find relief limits the length of time a human can physically stay strapped into the cockpit of an aircraft. The UCAV removes this limiting factor, allowing missions to continue for as long as the UAV can stay aloft, which can be a considerable period of time, as demonstrated by the *Global Hawk* or other UAV platforms that are used in overlapping sequences to provide persistent surveillance (Haddal 2010, 3).

UCAVs can also conduct the "dirty missions," those that must take place in environments that are extremely hazardous or lethal to humans, such as chemically, biologically, or radiologically contaminated areas (U.S. Department of Defense Unmanned Systems 2013, 20). While protective suits and equipment do exist to allow humans to operate in such environments, UAVs can operate for extended periods of time without consideration of the physiological or psychological impact to their systems, or without interruptions or delays caused by human needs or the limitations of their human-centric equipment, e.g., breathing apparatus, air filtration systems, protective suits, the time limit restrictions for exposure to chemical or radiation hazards, etc.

The same holds true for dangerous missions. Flying is inherently dangerous for humans, and flying in combat behind enemy lines even more so. With the elimination of man-rating requirements for unmanned aircraft—i.e., the human support systems and other pilot interfaces required to support the human pilot or crew—a UCAS can operate with greater speed and maneuverability due to less weight, resulting in capabilities that are well beyond what the human body can endure (DARPA 2004; Department of Defense 2011, 3). Additionally, free from the human, future UCAVs are anticipated to be able to react even quicker to various situations because the sensing systems and computers will be able to process data and make local decisions faster than human pilots (Grabowski 2015, 27). Without the humans, UCAVs can now conduct missions in hostile combat zones, allowing military members to observe and participate remotely, far from harm's way. If the unmanned vehicle is destroyed, the loss is only material and financial, not human.

A second positive aspect of using unmanned systems is the enhanced surveillance capabilities provided by the remote sensing equipment onboard, capabilities that extend and enhance human perception, action, speed, and persistence while reducing fatigue (Murphy 2012, 4). As demonstrated earlier, the near-real-time intelligence data provided by the onboard aerial intelligence, surveillance, and reconnaissance (ISR) sensors can detect target activity that would be impossible to track with human senses alone. A UCAV's signals or geospatial intelligence pods can intercept or detect signals in the electromagnetic spectrum well beyond the range of human capabilities, for longer periods of time, thousands of miles away, with the added advantage of being quickly redirected to new targets. Automatic Target Recognition (ATR) technology on board the UCAS can detect a target through clouds and bad weather, at night, or when camouflaged, enabling weapons carrying UCAVs to process, identify, track, and fire on that target. At the same time, threat detection sensors can detect radar, missile, aircraft, or other hostile threats, while other specialized sensors can be placed onboard to detect nuclear, chemical, or biological agents in the battlefield. All this can be accomplished with no threat to a human pilot or crew; should the systems fail or the UCAV be destroyed by hostile fire, there is, again, no loss of human life.

A third positive impact is the considerable cost savings the UCAV technology provides the U.S. government and taxpayer. According to the DOD's Unmanned Systems Roadmap, FY2013-2038, unmanned systems have proven they can conduct their missions at reduced costs compared to manned missions (U.S. Department of Defense

Unmanned Systems 2013, 15). The Roadmap underscores that, by far, personnel are the greatest single cost in the DOD, and unmanned and autonomous weapon systems reduce the number of personnel needed (U.S. Department of Defense 2013, 25). UCAVs can also be deployed overseas or in remote locations with minimal personnel on-site, allowing the remainder of the UCAV personnel, including pilots and sensor operators, to conduct their missions from the continental U.S. or other locations away from the battlefield, decreasing the human presence forward and the cost to support and sustain them. The ability to operate from a fixed ground site also limits the wear and tear on equipment that must be unpacked, assembled, disassembled, and repacked for contingencies and remote operations (Bolkcom 2004, 3-4).

A final positive impact is the political benefits gleaned from using UCAVs. Veteran USAF pilot Lt. Col. James “Opie” Dawkins Jr., highlights some of these political advantages:

> UCAVs give politicians a feeling of control that they do not otherwise experience with other aerial assets. This control comes in many forms. First, the politician can conduct operations without having to secure forward basing permissions, thereby controlling the timing and tempo of operations absent interference from host nations. Second, the politician does not have to worry about incurring casualties during an operation, in effect allowing him a large degree of control over the debate in Congress and with the public over decisions requiring the use of force. If he knows that an action is risk-free, then he is unlikely to feel compelled to vet an issue through Congress or use other means of dealing with the situation. Finally, the politician may believe that he can precisely control operations all the way down to the tactical level. From takeoff to landing, they may be tempted to get involved in the details of target and weapons selection, go/no-go criteria, and weapons release authorization in a way only depicted in Tom Clancy novels. Having control over these three areas may lead the politician[s] to believe that they can precisely control the outcome of an operation, more closely tying together diplomacy and force, allowing them to ratchet up or down coercive pressure as needed. (Dawkins 2005, 2)

Dawkins's comment that politicians may believe that they can precisely control operations reigns true, as U.S. policy makers have made it clear that they are indeed in control of UCAV activity—"all the way down to the tactical level." In a 2013 speech on U.S. drone and counterterror policy presented at the National Defense University, President Barack Obama emphasized his personal involvement in tactical UCAV activity to prevent the public from being shielded from U.S. government actions:

> For this reason, I've insisted on strong oversight of all lethal action. After I took office, my administration began briefing all strikes outside of Iraq and Afghanistan to the appropriate committees of Congress. Let me repeat that—not only did Congress authorize the use of force, it is briefed on every strike that America takes. That includes the one instance when we targeted an American citizen: Anwar Awlaki, the chief of external operations for AQAP [al-Qaida in the Arabian Peninsula] . . . Going forward, I've asked my administration to review proposals to extend oversight of lethal actions outside of warzones that go beyond our reporting to Congress. (The White House 2013)

As emphasized by President Obama, past Presidents, and other leaders, U.S. military UCAV technology has contributed significantly to the successes in the Gulf Wars, Global War on Terrorism, and overseas contingency operations. At the time of this writing, DOD unmanned air systems are deployed throughout Iraq, Afghanistan, and Syria to find, identify, track, assess, target, and engage terrorists, and the Department of Homeland Security's (DHS) unmanned aircraft fleet is deployed along the U.S. borders and coastlands to assist in the effort to prevent illegal aliens, drug traffickers, and terrorists from infiltrating the United States. However, despite the successes, the cost savings, and the removal of humans from dull, dirty, and dangerous missions, not all of the impacts on humanity are positive.

Negative Social Implications of UCAS Technology

UCAS remote sensing technology provides the capability to track targets quietly, from high altitudes, over long distances, for extended periods of time, during all hours of the day in all weather conditions, making it apparent that there are a number of negative aspects in the UCAS-humanity relationship. Because human activity can be monitored by these systems unknowingly, and persistently, the technology provides for the potential infringement upon the civil liberties and rights of U.S. citizens, particularly in violation of the U.S. Constitution's Fourth Amendment, which states: "The right of the people to be secure in their persons, houses, papers, and effects, against unreasonable searches and seizures, shall not be violated, and no warrants shall issue, but upon probable cause, supported by oath or affirmation, and particularly describing the place to be searched, and the persons or things to be seized."

This amendment is particularly pertinent for those living along U.S. borders, as the purpose of ISR missions conducted there are to fulfill intelligence requirements—gaps in knowledge or understanding—which are by nature "searches" for data or information on natural, man-made, or human targets (U.S. Department of Defense JP 1-02 2010, 118-120). As it is extremely difficult to narrow down and control the amount of data collected by many remote sensors during ISR operations—e.g., broad-area sensors like wide-area motion imagery (WAMI), especially when the collection is automated—these technologies could easily infringe on the privacy rights of U.S. citizens. The subtle danger is that the average U.S. citizen may never know they are being monitored, and therefore would not have the recourse to counter the activity as it is occurring.

While it is true that the potential abuse and misuse of ISR assets has always existed, autonomous UAVs allow for this abuse and misuse on a new level because of the advanced technology of the sensor systems, the long-term persistent surveillance capability, and the massive amounts of collected data. It is also true that this capability exists with satellite systems; however, the cost and ease of producing and employing UASs, compared to that of various satellite systems, increases the ease with which this technology can be proliferated and inadvertently, or purposefully, abused. Additionally, by making the U.S. DHS the executive agency for the larger class—i.e. *Predator,* remotely piloted aircraft operations related to U.S. border and immigration enforcement—Congress removed the potential violations of the 1878 Posse Comitatus Act, allowing a department with law enforcement responsibilities to utilize the UAVs to conduct surveillance activities within the U.S.[159] This has also expanded beyond the DOD and DHS for, as of November 3, 2015, the Federal Aviation Administration granted 74 governmental organizations—including local police departments and other federal departments and agencies—certificates of waiver or authorizations (COAs) allowing public operation of UAVs for specific unmanned activities (U.S. Department of Transportation 2015b, 1-3).

While a UAS surveillance operation inside U.S. borders—conducted by DHS and other law enforcement agencies—may be a legal and correct action to take, it still does not guarantee that the data collection mission using unmanned aerial remote sensing systems will not inadvertently, or purposefully, violate the privacy rights of U.S. citizens.

[159] According to *Black's Law Dictionary*, the Posse Comitatus Act is a federal law prohibiting the U.S. military, with a limited number of exceptions, from "directly participating in civilian law-enforcement operations, as by making arrests, conducting searches, or seizing evidence" (Garner 2004, 1201).

The reality of this potential violation is underscored by the ongoing security vs. privacy rights debates in political and judicial circles, and is yet to be resolved (Williams 20015, 1-4).[160] Related to this issue, but beyond the scope of this study, is the possible use and subsequent impact of lethal UAVs in a law enforcement role.

A second negative effect UCAS technology has on society and culture is a contribution toward the dehumanizing aspects of warfare on a number of new and different levels. First, the ongoing terrorism-related conflicts in the Middle East, like all wars in the past, perpetuate stereotyping through an "us versus them" mentality (Stahelski 2005, 5).[161] With the insertion of autonomous UCAV technology into the battlefield, this stereotyping is further compounded due to application of the remote sensing, remote piloting, and autonomous computer technologies that remove the combatants further and further from the conflict and each other.

According to Dr. Anthony Stahelski, psychology professor at Washington State University, the sociology and social psychology fields describe a conditioning process that is used to distance people from each other and transition them into individuals who can kill others, a process that consists of the following phases: depluralization, deindividuation, dehumanization, and demonization (Stahelski 2005, 3). The first phase,

[160] Some of the important court cases establishing precedents in regards to privacy, surveillance, and UAVs that are worth reading for further exploration in these issues include: Katz v. United States (1967); Smith vs. Maryland; Oliver vs. United States; Florida vs. Riley; Dow Chemical Company vs. United States; United States v. Torres; California vs. Ciraolo; and Kyllo v. United States. Also, Bennett Wells's *Civilian Drones, Privacy, and the Federal-State Balance* provides a useful summary as well.

[161] This sentiment was expressed by President George W. Bush during his post-9/11 address to a joint session of Congress, September 20, 2001. "Every nation, in every region, now has a decision to make. Either you are with us, or you are with the terrorists. [Applause.] From this day forward, any nation that continues to harbor or support terrorism will be regarded by the United States as a hostile regime" (The White House 2001). This false dilemma is still prevalent at the time of this writing.

depluralization, deals with removing an individual's identity with all other groups, a process that can be seen used by military organizations, and to greater and more negative extent by cults, gangs, and terrorists groups (Stahelski 2005, 3). The second phase, deindividuation, consists of two types; the first is termed *self-deindividuation* and consists of the removal of a person's individual identity; the second is termed *other-deindividuation,* and refers to the removal of the personal identity of a foe or enemy (Stahelski 2005, 3). The third phase, dehumanization, conditions a person to consider an enemy as sub- or nonhuman, preparing them for the final phase, demonization, in which the enemy is considered evil (Stahelski 2005, 3).

Stereotyping is an important element in the *other-deindividuation* stage because it helps to distance combatants from each other, creating barriers that prepare a person to demonize the other, subsequently providing the justification to kill them. It is at the *other-deindividuation* stage that UCAV technology, particularly the remote sensing capabilities, can most clearly be seen entering into the dehumanization process. Because of the ability to see targets across the electromagnetic spectrum, remote sensing capabilities reduce human activity to pictures, symbols, pixels, or even spots of energy on a computer screen. The less human in appearance an enemy appears, the easier it is to suppress the reality that they are indeed human, potentially resulting in an experience of war that seems more like a video game than actual conflict.

It is true that this phenomenon of distancing combatants from each other has occurred throughout the history of warfare and its associated technological development, for humanity has indeed progressively moved through various states that have increased the distance between combatants, from striking an enemy with a hand or object, to throwing a rock, to using man-made instruments, such as a sling, spear, bow and arrow, gun, mortar, cannon, rocket, aerial bomb, or missile. In 2016, just as it was in WWI, there is a greater distance between aircrew members and the combatants on the ground, or in other machines in the air; however, the majority of aircrew onboard tactical aircraft—i.e., fighters, fighter-bombers, manned tactical reconnaissance platforms, helicopters, and tactical transports—still have some direct link or connection with the human aspects of warfare and the battlefield. At a minimum, crewmembers of manned tactical aircraft can still see, firsthand, the aftermath of destructive military force above the battle. They can also experience the sights, sounds, smells, and feel of the horrors of battle directly via personal psychological trauma, injury, or death; by observing these aspects occurring to fellow crewmembers, or by operating in or near the combat zone and seeing the effects on friendly, enemy, and noncombatants alike. Even strategic bomber crewmembers have an experience in the battlefield, as they must fly deep inside enemy territory to deliver their weapons—with the potential to be harmed by an adversary's anti-aircraft weaponry or fighter aircraft—despite the fact the targets they hit may only be seen on a radar screen or another remote sensing device. With the development of UCAV technology, these visceral elements of warfare have been even further removed from the operators involved in air-to-ground combat. UCAV operators are no longer physically engaged in or over the battlefield at all, and may not even be in the same country or region, operating a weapon system that is more similar to a guided bomb or cruise missile, so that some of the crucial human elements of warfare—physical contact or proximity, involvement of the senses, etc.—also have been removed further from the crewmembers, even more than what manned aircraft technology alone accomplished.[162]

A third negative aspect of UCAVs are the new and different technology-induced stresses experienced by crewmembers. Even while operating at great distances from the battle, unmanned aircraft and remote sensing technology, particularly high resolution full-motion video (FMV), has allowed pilots and sensor operators to physically and psychologically remain in touch with the real stresses of warfare, albeit in a much different manner than that of the manned aircraft (Otto 2013, 3). While crewmembers are not physically flying over the battlefield, technology has ensured stress levels remain high due to fewer number of UAV crewmembers, a high operations tempo (lots of overlapping flight sorties), extremely long-duration and monotonously repetitive missions (enabled by UAV aerodynamics), lack of a clear separation between military and family life (going home to family after striking a target), long periods of social separation (operating inside control vans), lengthy sedentary periods, and extended periods in front of computer screens (Otto 2013, 3). In addition, engaging in combat operations and experiencing the immediate post-engagement battle trauma—even though physically removed and without the tactile, auditory, taste, and olfactory elements—still creates real psychological stress as the carnage can be graphically displayed on video screens, and can be repeatedly reviewed (Otto 2013, 3). All of these stressors combine in

[162] It is acknowledged that Air Force and Navy ballistic missile and ballistic missile submarine crewmembers, as well as Navy, Air Force, and Army crewmembers who launch cruise and surface-to-surface missiles, also can operate weapon systems that are greatly removed from the battlefield, also experiencing degrees of separation between combatants, and thus be affected by an increased level of dehumanization caused by technology. However, the purpose of this study is to focus on the impact of the UCAS and its impact on the human-technology relationship associated with combat and warfare.

the mind and body of the UCAV crewmembers, resulting in technology-induced cases of post-traumatic stress disorder (PTSD) in levels that are equal to manned aircraft crewmembers (Otto 2013, 3). According to a 2013 report by the Armed Forces Health Surveillance Center that compared all UAV pilots to all manned aircraft pilots deployed to Iraq/Afghanistan from October 1, 2003 to December 31, 2011, "There was no significant difference in the rates of MH [mental health] diagnoses, including post-traumatic stress disorder, depressive disorders, and anxiety disorders between RPA [remotely piloted aircraft] and MA [manned aircraft] pilots" (Otto 2013, 3).[163]

While the UCAS crewmember stressors are real, there are still significant differences between UCAV and manned combat. If a UCAV wingman is lost in battle, the operator only sees his wingman's video screen go black; the wingman himself gets up and moves to another console to fly another UCAV—this is not the same as a real person dying in an explosion, parachuting, or crashing to the ground. The immediate carnage, while real, is not seen in the same way as a pilot flying over the hazardous battlefield, but is rather viewed more like a store surveillance camera, news broadcast, war movie, or video game—i.e., there are no sensual, visceral experiences, nor is there the possibility of one becoming harmed by the repercussions of the ongoing attack, e.g., secondary explosions, chemicals being released into the atmosphere, or an unexpected counterattack

[163] The researchers acknowledge four study limitations: 1) mental health (MH) outcomes may be incomplete as findings only reflect clinically detected outcomes; 2) analyses were limited to active USAF members only, not National Guard, Reserve, or other services; 3) deployment and demographic records were used to determine exposure time to remote or traditional combat, and multivariate analysis was used for deployment duration, as opposed to incorporating hours exposed; and 4) the findings were based on incident, dichotomous MH outcomes only; no recurrent outcomes were assessed. Findings suggested that RPA pilots have a similar MH risk profile to manned aircraft pilots (Otto 2013, 7).

by the enemy.[164] In 2005, Lt. Col. Dawkins commented on these "modern video warriors," observing that they:

> do not fit neatly within the traditional warrior culture. The operating environment of the UCAV operator is much different than that of the traditional ground or air combatant. Their workspace is an air-conditioned operations trailer. Additionally, operators can take breaks when necessary, handing off their responsibilities to other operators when they get tired or hungry, something that the battlefield or battlespace combatant cannot do. Furthermore, in performing their duties they encounter little if any risk from direct combat. UCAV operations, therefore, are relatively benign and risk free when compared to the battlefield combatant. *Predator* operator Lt. Col. Kurt Scheible describes it this way: "When I'm back in Nellis [Air Force Base, located in Las Vegas] I can fly a mission over Iraq with the *Predator*, and then go home and take my children to a ball game." (Dawkins 2005, 44)

Ten years of unmanned aerial vehicle combat has elapsed since that statement was made, and thousands of hours of *Reaper* missions have been flown, generating a generation of UCAV pilots. While the evolution of weaponry has continually distanced the combatants, the visceral aspects have always been part of the human experience of war where the missile-laden *Reaper* UCAVs currently fly. And with the possibility of completely autonomous combat operations looming, humanity may take another step back, further widening the gap between the technology of weaponry and the direct effect on humanity.[165]

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[164] Admittedly, there is a possibility of the ground crews operating in danger outside of the actual war zone through sabotage or terrorist attack, but the probability of physical harm from this is much lower than a manned aircraft flying over a hostile battlefield.

[165] Some may argue that nuclear bombs and missiles have already distanced humans engaged in warfare to the same degree as the UCAVs. However, it is important to remember that only two atomic bombs have ever been dropped, and no nuclear missiles have been launched. While the concept of erasing an entire city with one bomb may not have immediately registered with the crew—as it was the first time in history that this occurred—the surviving aircrew members of the *Enola Gay*, the B-29 bomber that dropped the first atomic bomb on Hiroshima, distinctly remembered what they saw, even later in life. The navigator, Theodore J. (Dutch) van Kirk, remembered the following: "We turned to where we could look out and see the cloud, where the city of Hiroshima had been. . . . The entire city was covered with smoke and dust and dirt. . . . I describe it looking like a pot of black, boiling tar. You could see some fires burning on the edge

This separation from the trauma and suffering of war is the very antithesis to the idea of finding resolution to conflicts by encouraging human solidarity. According to political philosopher Richard Rorty, the notion of solidarity includes empathizing with the pain and suffering of others; the quality of empathy becomes a key component for bringing people together. Rorty explains that human solidarity is a goal that we should strive to achieve.

> It is to be achieved not by inquiry but by imagination, the imaginative ability to see strange people as fellow sufferers. Solidarity is not discovered by reflection but created. It is created by increasing our sensitivity to the particular details of the pain and humiliation of other, unfamiliar sorts of people. Such increased sensitivity makes it more difficult to marginalize people different from ourselves by thinking, "They do not feel it as we would," or "There must always be suffering, so why not let them suffer?" This process of coming to see other human beings as "one of us" rather than as "them" is a matter of detailed description of what unfamiliar people are like and of redescription of what we ourselves are like. (Rorty 1989, xvi)

In previous wars, the experience of pain and suffering was shared by combatants and noncombatants alike, and these negative experiences reminded them of the inhumanity and cruelty of war. As improvements in autonomous weapon technology and machine warfare continue, modern warriors move further from the actual battle, these experiences diminish, and the killing and destruction become more mechanical and less real. No longer do UCAV operators have to see their victims as suffering humans; instead, it is now possible for them to mercilessly inflict pain, suffering, and death upon

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of the city" (Niebuhr 1995). The pilot/commanding officer, Paul W. Tibbets, recalled it this way: "Have you ever seen newsreels of tornados? Well, that is what it was like. Tumbling, all this stuff was trying to climb up. . . . It imprinted itself on my mind that there's a tremendous energy in it" (Niebuhr 1995). Similar descriptions were given by the crewmembers of the B-29 *Boxcar*, the plane that dropped the second atomic bomb, on Nagasaki (Atomic Heritage Foundation 2015). This provides some evidence that the crewmembers' missions in the combat zone and their participation in the events did indeed "imprint" a lasting memory of the devastating effects against humanity caused by weapons of warfare.

their enemies, or innocent noncombatants, without being present on the battlefield. The modern enemy now becomes just an image or character on the video screen that simply disappears when destroyed. If an autonomous weapon system can achieve this with no human intervention at all, then whole societies and cultures could be adversely affected with no thought given to human solidarity or suffering.

A final negative implication of autonomous UCAS technology is the increased separation of the warriors from the instrument of war itself—on a completely different level than the separation that exists between the human and cruise or ballistic missiles (the fire-and-forget technology), which can be seen as throwing a very sophisticated rock. With the development of the autonomous UCAS, the separation is caused by technology that allows the unmanned aircraft system to observe the surrounding environment using its onboard sensing systems, make decisions using its onboard programing and algorithms, and conduct operations using its onboard automatic target recognition, targeting, and weapons release systems—all with less of a requirement for human involvement. It is this further advancement of UCAV technology that has caused the hard technological determinists—like Ray Kurzweil with his idea of singularity, and Stephen Hawking with his belief that the development of full AI could spell the end of the human race—to voice the concern that this technology is quickly evolving beyond human control (Cellan-Jones 2014, 2).

Hard Technological Determinism and Autonomous UCAS Control

As discussed in chapter three, hard technological determinists view technology as an autonomous force, independent of social constraints, that moves and shapes all elements of society in such a way as to determine its course or direction. Starting with Henry Brooks Adams in the Civil War era and continuing today in the writings of such notable personalities as Kurzweil and Hawking, the belief is that technology will one day move beyond the ability of humanity to control. A key element of this understanding—that humanity is not in, or may not be able to remain in, control—is the reification of technology, the ontological perspective that technology is an actual entity or force with its own independent existence. In order for something to be autonomous it must act independently and be self-governing and, in order to make a case for the inevitability of a completely autonomous UCAS capable of operating outside of human control, the transfer from technology as a tool, or an abstract idea, to technology as its own essence or being is important. Martin Heidegger and Jacques Ellul's philosophical views of technology seemingly support the position that modern technology already is beyond human control, as it is not of human making, because the essence or sociological phenomenon of technology is not technological or the technology itself, but rather a pre-existent, mysterious, transcending, autonomous, and determinative reality that interacts with humanity.

According to this hard determinist perspective, the Heidegger and Ellul arguments are seen as coming to fruition in the technology of the modern battlefield, particularly the technology involved with autonomous unmanned combat air systems. Such technology is seen as a result of the extraction of the resources in the reserves of the natural elements—which could include the reserves of the electromagnetic spectrum—to create remote sensing technology and the hardware, data, information, and knowledge that constitute computer technology. These resources are then ordered to create computerized control systems that enable machines to replicate birds in flight, sensors that replicate human sensory functions, and artificial intelligence that replicates human intellect; all are areas where this presumed essence of technology is showing forth, and which will continue to be revealed, regardless of the human attempt to control it. Once the argument that this essence, or force of technology, has revealed itself to be a self-existing entity tending toward closure and self-determination is embraced—i.e., an end in itself and not under human control—a case can be built for the evolution of a "mechanical consciousness," as cited in Samuel Butler's novel *Erewhon* and referenced by Alan Turing. Over time, this technological autonomy will continue to evolve until it reaches a point of singularity that surpasses human intellect, resulting in Kurzweil's Epoch 6 Singularity and the follow-on nonbiological intelligence. Along with Paul Virilio, Kurzweil believes that the speed and force of this technological evolution is simply beyond human control, with the result potentially being, as Hawking stated, "the end of the human race" (Cellan-Jones 2014, 2).

As it is impossible to prove the existence of an invisible essence, technique, or force that is determining the evolution of UCAS technology, and subsequently the impact on human control, only the challenges to the idea that the UCAS technology itself is evolving beyond human control will be offered here. The conclusions made will stay within the current technologies previously discussed and within the limits of reproducible scientific experiment. If there exist insurmountable challenges and limitations to UCAS technological development that would prevent or limit human-like autonomy, then the technology can be controlled, and if technology can be controlled, then that would challenge the hard technological determinists' view that humanity is losing control—or in fact never had control—of UCAS technology.

Technical Challenges to the Hard Determinist View of Autonomous UCASs

"An algorithm is only a set of instructions, and even the most sophisticated machine executing the most elaborate instructions is still an unconscious automaton."
— Mark Anderson

Prominent technological challenges to the development of completely autonomous UCAS weapon systems are the computer and AI technologies themselves, the components that actually control the onboard systems. These particular technologies are at the very heart of the argument that humanity will lose control as technology continues to evolve. But despite successes of the unmanned "autonomous" capabilities of *Global Hawk*, *X-45A*, *X-47B*, and other unmanned programs, after more than half a century of computer and AI research and development, a level of automated conceptualization and thinking that even approaches the human level remains elusive, and the technology that would replicate the human thought processes and enable greater levels of autonomy has not yet been identified (Rogers 2015; U.S. Department of Defense Unmanned Systems 2013, 67). The problems stem from the limitations inherent in human-developed algorithms and programming, the human-levied constraints and limitations associated with software and hardware development, and the lack of understanding of human cognition.

Human Limitations in Algorithm Development and Programming

There are a number of reasons a human level of AI and autonomy has remained elusive—some of which are understood and some that still need to be discovered—but a primary reason is the human limitations in algorithm development and computer programming. Computers, automation, and AI are only as good as the human-generated algorithms, codes, and software that are created by the teams of designers, developers, and coders. Software deficiencies and errors are caused by design faults that occur when a designer or programmer either misunderstands, misinterprets, or doesn't understand a design specification, or they simply make a mistake (Inacio 1999, 3).

As discussed in chapter one, a common misperception when referring to UCAS autonomy is that the computer systems onboard provide machines independent thought and action, when in fact they only provide a self-governing capability that is strictly bounded by imperfect algorithms and programs consisting of, and governed by, very specific man-made capabilities, not some mysterious "black box" that replicates the human brain (Murphy 2012, 5). Because humans do not possess infinite knowledge, they have only an incomplete understanding and comprehension of the key elements required to develop true artificial human intelligence. These key elements include a complete understanding of the physiological and psychological operations and processes of the human brain, including thought, memory, and learning processes, as well as human feelings, emotions, and behavior. Neither do humans possess a complete understanding of their surrounding environments (visible or invisible), the interactions between humans and environments, or the interactions between humans; each is a critical element that collectively comprises the components for human patterns of life.[166] As mentioned in the previous chapter, AI developers and coders must correctly understand and replicate these cognitive, emotional, social, and environmental elements to create algorithms within AI software, in this particular case the software that will be used onboard a UCAS to assess patterns of life and make potentially lethal decisions for combat missions. The Department of Defense states the problem as follows:

> In these algorithms, the "patterns of life" are critical to automation and must be observed and captured properly to ensure accuracy and correctness of a decision-making process within the software. Ensuring accuracy and correctness requires a continual process in which the observe–orient–decide–act (OODA) loops in the software are continually updated via manual analysis, training, and operator understanding of algorithm inputs and outputs. The human brain can function in dynamic environments and adapt to changes as well as predict what will happen next. In simplistic terms, the algorithms must act as the human brain does. (U.S. Department of Defense Unmanned Systems 2013, 67-68)

Computationally modeling pattern-of-life elements is extremely complex due to the multiple levels of interaction between individual human behaviors, including complex cognitive processes, as well as the collective social patterns of humanity as a whole (Folsom-Kovarika 2013, 1582). This presents significant technological challenges for creating an AI that can not only be replicated, but, as the hard determinists fear, one day supersede human thinking and understanding.

This complexity may be illustrated in the performance of the revolutionary question-answering (QA) super computer Watson, named after IBM founder Thomas J. Watson (Ferrucci et al 2010, 78). Part of IBM's AI DeepQA project, Watson defeated the human reigning champions on the TV quiz show *Jeopardy!* in 2011. This system was

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[166] Patterns of life are the typical observable properties—where the whole is greater than the sum of its parts—of a complex sociocultural system (Schatz 2012, 4).

developed not to model all of the pattern-of-life elements previously mentioned, but only the open-domain QA problem, considered one of the most challenging problems for AI because of the requirement to synthesize a number of disparate elements, including information, data retrieval, natural language processing, knowledge representation, reasoning, machine learning, and computer-human interfaces (Ferrucci et al 2010, 60; IBM 2015b, 3). Watson addresses this problem by analyzing unstructured data using natural language processing in order to understand grammar and context; it then processes the data to understand complex questions, evaluates all possible meanings, determines a question being asked, and then provides answers and possible solutions based on supporting evidence and the quality of information found (IBM 2015a, 3-5).[167] *New York Times Magazine* journalist Clive Thompson, while reporting on Watson, provided a layman's explanation of how the super computer works:

> The great shift in artificial intelligence began in the last 10 years, when computer scientists began using statistics to analyze huge piles of documents, like books and news stories. They wrote algorithms that could take any subject and automatically learn what types of words are, statistically speaking, most (and least) associated with it. Using this method, you could put hundreds of articles and books and movie reviews discussing Sherlock Holmes into the computer, and it would calculate that the words "deerstalker hat" and "Professor Moriarty" and "opium" are frequently correlated with one another, but not with, say, the Super Bowl. So at that point you could present the computer with a question that didn't mention Sherlock Holmes by name, but if the machine detected certain associated words, it could conclude that Holmes was the probable subject—and it could also identify hundreds of other concepts and words that weren't present but that were likely to be related to Holmes, like "Baker Street" and "chemistry." . . . In theory, this sort of statistical computation has been possible for decades, but it was impractical. Computers weren't fast enough, memory wasn't expansive enough and in any case there was no easy way to put millions of documents into a computer. All that changed in the early '00s. . . . Ferrucci's main breakthrough was not the design of any single, brilliant new technique for analyzing language.

[167] According to IBM, 80 percent of all data today is unstructured—naturally encoded knowledge, raw natural language—and includes news articles, research reports, social media posts, and enterprise system data (IBM 2015a, 3-5; IBM 2015b, 3).

> Indeed, many of the statistical techniques Watson employs were already well known by computer scientists. One important thing that makes Watson so different is its enormous speed and memory. Taking advantage of I.B.M.'s supercomputing heft, Ferrucci's team input millions of documents into Watson to build up its knowledge base. (Thompson 2010, 6-7)

The super computer was built in about three years by a core algorithmic development team consisting of "20 researchers and software engineers with a range of backgrounds in natural language processing, information retrieval, machine learning, computational linguistics, and knowledge representation and reasoning" (Ferrucci et al 2010, 75). In 2011, Watson used 3,000 processors, a database consisting of 200 million pages of information stored on 4 terabytes of disk space and approximately 16 terabytes of memory, 2,500 processor cores, 6 million logic rules—requiring 10 server racks each with 10 IBM Power 750 servers—and two large refrigeration units contained in a separate room on IBM's Yorktown Heights campus (Ferrucci et al 2010, 75; Paul 2011, 3).[168] These numbers are not only exceptionally large, but are important for a couple of reasons. First, they illustrate the size and complexity of the system required to process unstructured data, and the difficulties associated with providing this capability onboard an autonomous unmanned combat aircraft. Second, they illustrate the complexity of the human brain and cognitive system, and the technical difficulties and amount of software, hardware, and physical infrastructure required to replicate only a small portion of human thinking and cognitive functions.

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[168] Watson requires a significant amount of human interaction. Literature for new subject areas—e.g., Word documents, PDFs and web pages—must be collected by humans, analyzed for relevance, validity, and currency, and then loaded into the computer so it can start to "learn" before it can begin to answer questions. Humans then must upload questions and answer pairs on the subject matter to "train" Watson on the subject matter (called machine learning). Watson's human-developed programming then searches "millions of documents to find thousands of possible answers," uses statistical modeling algorithms to weigh evidence, and then uses a scoring algorithm to rate the quality of the evidence, ranking all possible answers based on the score of its supporting evidence (IBM 2015a, 5).

Watson did defeat the reigning human champions while making errors, just as the human competitors did, underscoring that the super computer could perform only as well as the human-entered data, algorithms, and programming.[169] While this did unquestionably demonstrate a significant jump in Big Data processing and analytics, *it did not demonstrate a capability of independent, human-style thinking capable of autonomous, creative thought*.[170] It is also important to note that special concessions were made to accommodate the limitations of Watson's AI capabilities during this contest, particularly the lack of sensory abilities. First, Watson received each question in electronic text form, not verbally (in Watson's case, through voice-recognition software) like the human challengers (Thompson 2010, 2; Jackson 2011, 2). Second, audiovisual questions—where an audio or video segment is played or a picture is displayed—and "Special Instruction" questions, i.e., those that are not "self-explanatory" but rather require a verbal explanation be given to a contestant to describe how the question should be interpreted and solved, were not included per an agreement between IBM and

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[169] Watson initially had difficulty answering questions on a variety of subjects, including matching the names of actors and directors to movie titles, politics, and knowledge about newspaper sections (Paul 2011, 1-2). It tied champion Brad Rutter on the first night; however, after three days of play using its immense body of knowledge and betting algorithms, the super computer ultimately won with $77,147, with Ken Jennings finishing with $24,000, and Rutter with $21,600 (Jackson 2011, 1-3).

[170] There is no agreed upon definition of Big Data in the cyber and information technology communities; however, an attempt to consolidate some of the mainstream academic, commercial, and government definitions—from companies such as Oracle, Intel, Microsoft, Google, and others—was made by Jonathan Stuart Ward and Adam Barker of the University of St Andrews in Scotland. Their consolidation defined Big Data as "a term describing the storage and analysis of large and or complex data sets using a series of techniques including, but not limited to: NoSQL [non-relational], MapReduce [software framework for processing large data sets in parallel] and machine learning" (Ward 2013, 12). The U.S. Department of Commerce's National Institutes of Standards and Technology Special Publication 1500-1 is a 32-page publication dedicated to providing multiple definitions of Big Data, starting with the following statement: "Big Data refers to the inability of traditional data architectures to efficiently handle the new datasets" and includes "volume, variety, velocity, and variability" (U.S. Department of Commerce 2015, 5).

Jeopardy Productions, Inc. (Ferrucci et al 2010, 62-63).[171] These questions were excluded from the contest because Watson did not have the sensory ability to incorporate audio, image, and video capabilities, with the IBM development team conceding that these were "very interesting challenges from an AI perspective" (IBM 2015b, 2; Ferrucci et al 2010, 63).[172]

After the *Jeopardy!* match, IBM announced its intent to use Watson in the field of health care, and the question arose as to whether computer algorithms could be used to diagnose patients. Dr. Iltifat Husain, Wake Forest University School of Medicine, offered the following reasons why an algorithm could not replace the human physician:

> When physicians are asking patients their symptoms, we're analyzing a complex amount of information that is not tangible and cannot be spoken or inputted into an algorithm: Eye contact; Subtle physical movements; How they respond to questions—does their tone change when describing a particular symptom, leading me to believe I'll uncover more information if I ask more about this; How they smell; How they are sitting; The reaction of family members when the patient responds to a particular question; What they are wearing; Any signs of underlying trauma; and much more.
>
> There are so many more things being analyzed that are not included in the above list—and it all occurs within seconds. And depending on each of the above and more, my questions for the History and Physical (H&P) will change, as will my treatment plan. It's why we're taught in medical school that the H&P is the most important part of the exam. . . . At the end of the day, algorithms are only a guide, and you have to use your own clinical judgment, because each patient is unique in their own way. (Husain 2011, 2-3)

[171] An example of a Special Instruction question: "Category: Decode the Postal Codes. Verbal instruction from host: We're going to give you a word comprising two postal abbreviations; you have to identify the states. Clue: Vain. Answer: Virginia and Indiana" (Ferrucci et al 2010, 63).

[172] On August 6, 2015 IBM announced a planned merger with Merge Healthcare Incorporated that would eventually allow Watson to "see" by incorporating into the super computer data and images obtained from Merge's medical imaging management platform (IBM 2015c, 1).

The Watson example is pertinent to this study because the Department of Defense is also focusing on Big Data analytics to swiftly and accurately process massive amounts of data, and considering ways to integrate Watson and other related technologies, e.g., Lockheed Martin's Wisdom software, to enhance geospatial—which would include sensor data—and open-source data analysis within the defense and intelligence communities (Feuss 2015, 1). As discussed in the previous chapter, timely and accurate data is imperative for UCAS automatic target recognition, identification, and targeting. However, the room-sized supercomputers presently required for Big Data processing are not feasible for use onboard autonomous UCAVs, and even if Moore's Law provides the ability to place Watson-type capability onboard a UCAS in the next couple of decades, the same "patterns of life" and human-machine limitations in the medical field highlighted by Dr. Husain above will be major obstacles to overcome before any UCAS weapon system would be allowed to fire against targets completely outside of human monitoring.[173]

The Watson example illustrates that despite the incredible processing power and capabilities of AI supercomputers, there is still a significant requirement for human interaction in the form of algorithm development, software coding, and data preparation. This is because human cognition consists of complicated interactions between the physiological, psychological, and social—including areas that are unknown or not

[173] Moore's Law, based on a statement made by Gordon Moore in a 1965 article in *Electronics* magazine, addresses the exponential growth of data generated and stored. Moore estimated that the density of transistors on an integrated circuit board would double every two years, and this "law" was subsequently applied to all aspects of computing (Moore 1965, 114-117). Since that statement, the rate has both accelerated, e.g., the growth rates of data volumes more than doubling every eighteen months, and slowed, as stated by Moore in 2015 when he mentioned Stephen Hawking's explanation of the finite velocity of light and the nature of atomic materials as reasons for limiting integrated circuit technology (Courtland 2015).

understood—and human knowledge and understanding is incomplete and flawed, thereby severely inhibiting the development and ultimate achievement of an artificial intelligence—built with human algorithms and programming—that is superior to that of the human. These human limitations affect all of the approaches currently being used to develop AI, including agent-based and biologically inspired reasoning, machine learning systems, naturalistic interfaces, and hybrid modeling approaches (U.S. Air Force Autonomous Horizons, 2015, 4).[174]

Flawed programming and algorithm development replicating *known* processes have resulted in catastrophic failures, as exemplified by the infamous Patriot Missile System failure in 1991; the Mars Climate Orbiter (MCO) and Mars Polar Lander (MPL) mission losses in 1999; and NASA's Demonstration of Autonomous Rendezvous Technology (DART) mishap in 2005.[175] In order to create an autonomous UCAS capable of making decisions in a highly unpredictable combat environment better than humans, the machine's AI programming would have to surpass the human intelligence

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[174] Agent-based: rule-based expert systems, Bayesian belief networks, particle filtering, case-based reasoning, and fuzzy logic. Biologically inspired: neural networking and genetic algorithms. Machine learning: data mining systems, supervised and unsupervised classifiers, and "deep" neural networks, along with naturalistic interfaces, e.g., natural language processing, semantic analysis, and speech/gesture recognition. Hybrid modeling: combines one or more (U.S. Air Force Autonomous Horizons 2015, 4).

[175] In February 1991, a Patriot missile defense system in Saudi Arabia failed to intercept a missile, resulting in the deaths of 28 Americans; the cause was a software problem in the weapons control computer creating inaccurate tracking calculations that became worse over time (U.S. General Accounting Office 1992, 1, 6). MCO was part of NASA's Mars Surveyor Program; in September 1999 it was lost when it crashed after entering the Martian atmosphere; the investigation determined human failure "to use metric units in the coding of a software file" (Stephenson 1999, 7-9). NASA lost contact with the MPL just prior to its scheduled atmospheric entry in 1999, and communications were never regained; the review found software was not properly implemented, resulting in a premature shutdown of the engines (Casani 2000, 20-26). On April 15, 2005, the NASA DART spacecraft experienced pre-mature propellant depletion and retirement, and a subsequent collision with a communications satellite; findings showed the underlying cause to be software conducting a cycle of "resets" throughout the mission, triggering excessive thruster firings resulting in rapid fuel depletion (National Aeronautics and Space Administration 2006, 4).

that created it in terms of cognition and learning ability, and it would have to take into account all of the human attributes previously mentioned.

In addition to the human limitations in AI development, design and engineering constraints and limitations also provide overwhelming obstacles for creating the human type of AI feared by the hard determinists.

Design and Engineering Constraints and Limitations

The advantages provided by computer-controlled weapon systems such as a UCAV are clear: consistency, reliability, and predictability, as demonstrated by the successful algorithms and programming used in human-controlled or monitored *Predator*, *Global Hawk*, and *X-47B* operations (U.S. Air Force Autonomous Horizons, 2015, 5). The successes with the *X-47B* to date have been so extraordinary that on April 15, 2015, the Secretary of the Navy, Ray Mabus, made the statement that he believed that the F-35 Joint Strike Fighter (JSF) "almost certainly will be the last manned strike fighter aircraft the Department of the Navy will ever buy or fly" (LaGrone 2015, 1). However, six months later, in an interview with Military.com, the Air Force Chief Scientist, Mica Ensley, underscored that despite the rapid evolution of computer algorithms and processing speed, there were still difficulties with developing a machine that had the human qualities of responding instantly to other moving objects or changing circumstances (Osborn 2015, 1). Ensley further stated that the significant obstacle is creating a UCAV with the same perceptual capabilities as humans, and more importantly, the ability to understand the context in which its target is operating, e.g., a machine may be programmed with an automatic target recognition system but lack the ability to properly interpret the surrounding context and potential civilian casualties.

These difficulties are in a large part due to the constraints and limitations (C&L) inherent in the development and engineering of the algorithms, codes, and associated software and hardware affiliated with creating a human-independent artificial intelligence. The C&L on the designs and engineering tolerances for machine learning and autonomous technology software and algorithm development must take into consideration the purpose for the programming, business (organizational) rules it must abide by, probability of error, and the numerous assumptions that occur in everyday human thinking and action, often taken for granted, that must be designed and programmed in a step-by-step manner for the software to function according to the customers' and designers' intent. Software engineers must also "take into account the constraints and limitations of the physical components that will execute the program, and they must follow any stylistic conventions that the final program is required to obey" (Weigert 1998, 317). These constraints provide significant obstacles to AI, as explained by the Air Force Office of the Chief Scientist,

> The challenge has been that the suitability of those actions [consistency, reliability, and predictability] is often limited to a constrained set of situations—ones that the designer has envisioned and the software developers have programmed for—and a constrained set of measurements available from a limited sensor suite that is limited in its ability to sense and understand the environment it is operating in. Creating systems that can accurately not only sense [sic] but also understand (recognize and categorize) objects detected, and their relationship to each other and broader system goals, has proven to be significantly challenging for automation, especially when unexpected (i.e., not designed for) objects, events, or situations are encountered. This capability is required for intelligent decision-making. Unfortunately, most automation to date has suffered from brittleness, that is, operating well for the range of situations it is designed and programmed to address, but needing human intervention to handle all the cases

> and situations it is not designed/programmed to handle. (U.S. Air Force Autonomous Horizons, 2015, 5)

The major limitation described by the Office of the Chief Scientist is technology's inability to handle unexpected or unplanned situations not covered in the programming, i.e., a lack of a human-level of conceptualization to respond to uncertain or changing environments, as mentioned in the previous chapter. For AI to function on the level of a human and control its own actions, it requires a human understanding of the surrounding environment, along with the associated contexts and meanings. In a combat environment, military operations are constrained by the law of armed conflict (LOAC), rules of engagement (ROEs), and tactics, techniques, and procedures (TTPs), many components of which can be, and have been, captured in algorithms and software code, as illustrated in the *X-45A* delivery of munitions on target and the *X-47B* aircraft carrier and aerial refueling operations. [176] But during combat missions, events and circumstances often occur that are not within the ROEs or TTP mission parameters, requiring humans to make rapid decisions, adaptations, or alterations to deal with a changing environment consisting of incomplete, changed, or missing information. This changing, ambiguous environment of war was described by the 19th-century Prussian military analyst Carl von Clausewitz as "the realm of uncertainty; three quarters of the factors on which action in war is based are wrapped in a fog of greater or lesser

[176] The U.S. DOD defines Rules of Engagement (ROEs), Law of War, and TTPs as follows: ROEs are the "directives issued by competent military authority that delineate the circumstances and limitations under which United States forces will initiate and/or continue combat engagement with other forces encountered." The Law of War is "that part of international law that regulates the conduct of armed hostilities"; it is also called the law of armed conflict. Tactics are the "employment and ordered arrangement of forces in relation to each other"; Techniques are "non-prescriptive ways or methods used to perform missions, functions, or tasks"; and Procedures are the "standard, detailed steps that prescribe how to perform specific tasks" (U.S. Department of Defense JP 1-02 2010, 195-243).

uncertainty"—a description soon after referred to as "the fog of war" by military commanders (Clausewitz 1976, 101). UCAS platforms are constrained and limited to following the specific algorithms and programs loaded onto their systems, and they cannot deviate beyond their programs. To develop algorithms and programs that can sense the surrounding environment, conceptualize the unexpected, and then respond, in a variety of different wartime scenarios, contrary to their programmed instructions, is a significant obstacle and a capability that only exits in nature (Rogers 2015, 23).

Associated with the constraints and limitations inherent in algorithm and software development is the issue of getting designers and developers to accept system risk. No software developer or engineer will guarantee that source code, software, algorithms, and hardware will work together with 100 percent accuracy and reliability; instead, the developers and engineers design and develop to specific tolerances and accuracies that the customer specifies in the requirements, i.e., how much risk the customer is willing to accept to receive the desired outcome. Even before algorithms and source code are developed, there is no guarantee that the system requirements for which they are being developed are free from human error (Schubert 2006, 345). As the software code is developed, human errors can and often do occur, and because of this, software developers use tools to help detect errors; yet, even these detection tools cannot be guaranteed to be 100 percent free from bugs and errors (Schubert 2006, 346). In addition, deficiencies, flaws, and mistakes also can be introduced into existing software with additions or changes to existing programs, with an error of even a few lines creating severe issues in a program running millions of lines of code (Bernstein 2008, 1).

Another complicating factor is the development team itself. Because such large programs are written by teams of algorithm developers and coders, not all team members know or completely understand the entire program for such complex systems as a UCAS; therefore, no programmer can know or predict the effect of any specific command in relation to another with 100 percent certainty, since portions of programs consisting of millions of lines of code may interact in unexpected ways (Lin 2008, 8). It is for these reasons that developers provide complex software products with less than a 100 percent guarantee that the algorithms and codes will operate as designed (Everett 2007, 107).[177]

In order for a machine to operate and make decision like a human beyond the constraints and limitations of its programming, it would require algorithms and software that model the human cognitive processes, and in order to model those processes the processes themselves would have to be understood. It is the lack of understanding of the human brain that offers the most significant challenges to the development of a UCAS AI capability that could wrest control away from the human creators and operators.

Science and Technology Limitations

The worlds of neuroscience and neuropsychology and their relationship to the development of artificial intelligence are well beyond the scope of this study, but a few

[177] It is acknowledged that humans are also not perfect, prone to mistakes and bad decisions, and therefore it is an unrealistic expectation to be able to create perfect machines and AI capabilities. The purse of this argument is to demonstrate that algorithms and programs are not spontaneous creations constructed by some autonomous technological entity or force operating outside of human control, but that their creation is a human-generated product.

issues need to be discussed regarding these areas to better understand the difficulties in producing a human-like artificial intelligence.[178]

The most important point is that despite significant progress in the field of brain mapping, almost nothing is known about how the brain produces awareness.[179] Despite massive amounts of research, the extremely complex and intricate system and associated interactions of the brain's regions, neurons, connections, cells, and chemicals have left many questions related to brain function, structure, operation, memory, recall, sensory processing, learning, experiences, emotions, and more, unanswered (Lau 2011, 3). In the words of neuroscientist Dr. David Eagleman, "We know a lot about the mechanics of neurons and networks and brain regions—but we don't know why all those signals coursing around in there mean anything to us. How can the matter of our brains cause us to care about anything? The meaning problem is not yet solved" (Eagleman 2015, 33).

Relating this reality to current deep machine learning (like Watson), the development of AI, and the future evolution of a singularity that could usher in malevolent computers that will threaten human existence, Dr. Rodney Brooks, Founding Director of MIT's Computer Science and Artificial Intelligence Laboratory, offers the following insight:

> I think it is a mistake to be worrying about us developing malevolent AI anytime in the next few hundred years. I think the worry stems from a fundamental error in

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[178] Neuroscience is the scientific discipline concerned with the development, structure, function, chemistry, pharmacology, clinical assessments, and pathology of the nervous system (*Medical Dictionary for the Health Professions and Nursing*. S.v. "neuroscience"). Neuropsychology is the discipline combining neurology and psychology to study the relationship between the functioning of the brain and cognitive processes or behavior (*Dorland's Medical Dictionary for Health Consumers*. S.v. "neuropsychology").

[179] The Defense Advanced Research Project Agency Neuro Function, Activity, Structure, and Technology (Neuro-FAST) program is using research in genetics, optical recordings, and brain-computer interfaces, in conjunction with Stanford University's CLARITY whole-organ imaging process, to make major breakthroughs in the new era of whole-organ imaging of the brain (Sanchez 2015).

> not distinguishing the difference between the very real recent advances in a particular aspect of AI, and the enormity and complexity of building sentient volitional intelligence. Recent advances in deep machine learning let us teach our machines things like how to distinguish classes of inputs and to fit curves to time data. This lets our machines "know" whether an image is that of a cat or not, or to "know" what is about to fail as the temperature increases in a particular sensor inside a jet engine. But this is only part of being intelligent, and Moore's Law applied to this very real technical advance will not by itself bring about human level or super human level intelligence. While deep learning may come up with a category of things appearing in videos that correlates with cats, it doesn't help very much at all in "knowing" what catness is, as distinct from dogness, nor that those concepts are much more similar to each other than to salamanderness. And deep learning does not help in giving a machine "intent," or any overarching goals or "wants." And it doesn't help a machine explain how it is that it "knows" something, or what the implications of the knowledge are, or when that knowledge might be applicable, or counterfactually what would be the consequences of that knowledge being false. Malevolent AI would need all these capabilities, and then some. Both an intent to do something and an understanding of human goals, motivations, and behaviors would be keys to being evil toward humans.[180] (Brooks 2014)

Brooks underscores the monumental technical challenges for developing a functional AI modeled on the human brain and cognition, particularly one that can produce a human-like autonomous UCAS able to operate as a free agent, make its own decisions, and operate beyond human control. These challenges, together with the constraints and limitations associated with algorithms and software, and the impact of human limitations in their development, are the reasons that despite the numerous predications made since the 1950s, the time scale for reaching a "human-level" of AI remains open and completely uncertain, if possible at all (Armstrong 2012, 28).

The technical challenges presented currently hamper any capability for a UCAS to spontaneously develop human-like autonomy that could willingly operate outside of

[180] Rodney Brooks is a mathematician, roboticist, and cofounder of iRobot, the company that makes commercial robotic vacuums and cleaners as well as the unmanned observation, Bomb Disposal/Explosive Ordnance Disposal robots for the Department of Defense and other agencies (see http://www.irobot.com/About-iRobot.aspx for more information).

human control. In addition to these technical obstacles, there is the direct human involvement that creates legal and political challenges that serve to provide additional controls and further restrict spontaneous autonomous UCAS development.

Political-Legal Challenges to the Hard Determinist View of Autonomous UCAS Control

> *"Nonetheless, if this technology is to be deployed, then restricted, careful and graded introduction into the battlefield of lethal autonomous systems must be standard policy as opposed to haphazard deployments, which I believe is consistent with existing International Humanitarian Law (IHL)."*
>
> — Ronald Arkin

When it comes to the application of autonomous unmanned weapons technology and the potential use of lethal force against humans, existing U.S. Department of Defense policies require that a human always be in the decision loop, regardless of the level of autonomy of the weapon system (U.S. Department of Defense Directive 3000.09 2012, 2). These DOD policies were created by politicians and lawmakers in accordance with international and domestic laws associated with the development of new autonomous technologies, international humanitarian law, the U.S. military's rules of engagement, and civil and international aviation laws.[181]

Laws Associated with the Development of Autonomous Weapon Technology

When a new weapon technology is developed or an existing one modified—such as the *X-47B* or the *MQ-9 Reaper*—international law and best practices, as developed by

[181] Again, it is acknowledged that laws and policies are created by flawed humans, and that they can be easily changed to become more restrictive or liberating depending upon the power brokers and decision makers responsible for creating them. This human-centric argument is given to demonstrate that in addition to the technical challenges, humanity itself is the controlling force, providing oversight and additional obstacles to UCAS technology spontaneously developing autonomous capabilities.

the leaders of the international community, dictate that the technology should be evaluated to ensure compliance with the provisions of international humanitarian law, also called the laws of war.[182] Article 36 of the 1977 Protocol Additional to the Geneva Conventions of August 12, 1949 (Protocol I), which entered into force December 7, 1978, states:

> In the study, development, acquisition or adoption of a new weapon, means or method of war, a High Contracting Party is under an obligation to determine whether its employment would, in some or all circumstances, be prohibited by this Protocol or by any other rule of international law applicable to the High Contracting Party.[183] (International Committee of the Red Cross 1977, 258)

This particular protocol brings international attention and scrutiny to nations that develop new military technology, and it is the policy of the civilian leadership of the United States government to oversee defense development and acquisition activities to ensure international armaments treaty and law cooperation to the maximum extent feasible (Department of Defense Directive 5000.1 2003, E.1.1.1). Included in this civilian oversight is the activity of ensuring that agreements for international armaments cooperation programs complete an interagency consultation process, and that Congressional notification requirements are met in accordance with U.S. law, e.g., 10 U.S. Code § 2350a (Cooperative Research and Development Agreements: NATO Organizations; Allied and Friendly Foreign Countries); § 2751 (Need for International

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[182] International humanitarian law, also known as the law of war, is based on “a large number of treaties, in particular the Geneva Conventions of 1949 and their Additional Protocols, and a series of other conventions and protocols covering specific aspects of the law of armed conflict,” as well as a “substantial body of customary law that is binding on all States and parties to a conflict” (International Committee of the Red Cross 2010, 1).

[183] A High Contracting Party refers to the representatives of nations who have signed or ratified a treaty. As of 2013, Protocol I had been ratified by 174 states but not by the United States; however, the U.S. was one of the original signers of the Protocol on December 12, 1977, along with Iran and Pakistan, an action signifying the intent to work toward ratification (International Committee of the Red Cross 1977).

Defense Cooperation and Military Export Controls; Presidential Waiver; Report to Congress); § 2531 (Defense Memoranda of Understanding and Related Agreements); and 22 U.S. Code (Foreign Relations and Intercourse) (Department of Defense Directive 5000.1 2003, E.1.1.1). The civilian and military leadership of the DOD also ensures that weapons acquisition and procurement activities remain consistent with applicable domestic laws, treaties, international agreements, customary international law, and the law of armed conflict, together known as the “laws and customs of war” (Department of Defense Directive 5000.1 2003, E.1.1.15). In addition, it is DOD policy that all DOD activities be fully compliant with arms control agreements of the U.S. Government (Department of Defense Directive Number 2060.1 2001, 2).

Specific to autonomous weapon system development and use, the DOD created Directive 3000.9, *Autonomy in Weapon Systems*, in 2012. This directive established policy and responsibilities—which include the civilian and military leadership—for the development and use of autonomous weapon systems (AWSs) and provides guidelines to minimize the probability and consequences of AWS failures, especially those that could lead to unintended engagements with other nations (U.S. Department of Defense Directive 3000.09 2012, 1). This policy mandates (1) clear procedures for humans to be able to activate and deactivate AWSs; (2) that AWSs be operated in accordance with the law of war, applicable treaties, weapon system safety rules, and applicable rules of engagement; and (3) that human-supervised autonomous weapon systems may not be used to select and engage human targets (U.S. Department of Defense Directive 3000.09 2012, 3).

On the international level, the political representatives at the United Nations established the Convention on Certain Conventional Weapons (CCW), also known as the Inhumane Weapons Convention, for the purpose of political oversight to ban or restrict the use of specific types of weapons that are considered to cause unnecessary or unjustifiable suffering to combatants or to affect civilians indiscriminately (United Nations Office at Geneva 2001, 1). It is "the indiscriminate affect to civilians" portion of this convention that the nation's leaders applied to autonomous weapon systems, subsequently resulting in a CCW High Contracting Parties agreement on establishing a new mandate on lethal autonomous weapon systems, also known as LAWS.[184] In accordance with the LAWS mandate, the CCW convened an informal meeting of experts in April 2015 to discuss questions related to emerging technologies in the area of LAWS (United Nations Office at Geneva 2015, 1). Because LAWS, which includes UCAS weapon systems, is still in the infancy stage in terms of developing protocols for the control of future use, nothing definitive and no agreed-upon protocols or definitions—including the definition of meaningful control—resulted from this meeting; however, more than 100 nations participated, demonstrating the importance that the nations' leaders place on the issue of control with regard to LAWS. The U.S., a state party to the CCW on all five protocols—but not yet a signatory—fully supported the informal LAWS meeting, emphasizing its ongoing efforts in controlling LAWS with DOD Directive

[184] Article 48 of the 1977 Additional Protocol I, Basic rule, states: "In order to ensure respect for and protection of the civilian population and civilian objects, the Parties to the conflict shall at all times distinguish between the civilian population and combatants and between civilian objects and military objectives and accordingly shall direct their operations only against military objectives." An agenda item in the CCW LAWS 2015 informal meeting was the possible challenges to international humanitarian law, and the ability of LAWS to discriminate between combatants and noncombatants was a point of discussion (United Nations Office at Geneva 2015, 1). This will be discussed in more detail in the next section.

3000.09, the requirement for additional effort to establish a common understanding of LAWS, and its neutral position on the potential future development of LAWS (Meier 2015, 1-2).[185] At the end of the meeting, the U.S. delegation's closing comments underscored the U.S. leadership's desire to be diligent in distinguishing legal prohibitions from moral and ethical arguments, which, it acknowledged, present the States with another set of technical challenges in regard to developing LAWS (U.S. Delegation 2015, 1).

While not as restrictive to fully autonomous weapon system operations as the science and technical challenges—primarily because laws can be circumvented or even ignored—the political and legal oversight provided by the U.N. CCW, the LAWS meetings, and international and domestic laws specific to autonomous weapon system development are important factors in preventing technology from autonomously evolving beyond human control. The domestic and international political organizations and their laws—and the processes used to create them—add additional levels of restrictions and safeguards, keeping humanity closely connected to, and in a position of control over, the development of autonomous weapon system technology.

As just described, the existing international political system, the laws, and the current discussions specific to the development of autonomous weapon technology center on another set of international laws and rules that also help regulate the human-technology relationship in the area of autonomous weapon system control: International

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[185] The five CCW Protocols include: Protocol I on Non-Detectable Fragments; Protocol II on Prohibitions or Restrictions on the Use of Mines, Booby Traps, and Other Devices; Protocol III on Prohibitions or Restrictions on the Use of Incendiary Weapons; Protocol IV on Blinding Laser Weapons; and Protocol V on Explosive Remnants of War (United Nations Office at Geneva 2001, 1).

Humanitarian Law (IHL), also known as the Law of Armed Conflict (LOAC) or the Law of War (International Committee of the Red Cross 2004, 1).

The Law of War

As with the discussion on neuroscience, a comprehensive examination of all the legal aspects of the Law of War is well beyond the scope of this study; however, a few pertinent examples will suffice to demonstrate that the additional restrictions and limitations provided by these human-generated laws and rules also help to prohibit the possibility of autonomous weapon technology evolving beyond human control.

The U.S. DOD Directive on Autonomy in Weapon Systems mandates the joint political-military involvement of the Under Secretary of Defense for Policy; the Under Secretary of Defense for Acquisition, Technology and Logistics; and the Chairman of the Joint Chiefs of Staff before fielding an autonomous weapon system. These officials must ensure that autonomous system capabilities and human-machine interfaces have "demonstrated the capability to allow commanders and operators to exercise appropriate levels of human judgment in the use of force and to employ systems with appropriate care and in accordance with the Law of War" (U.S. Department of Defense Directive 3000.09 2012, 7). This directive also mandates that persons using, directing the use of, or operating autonomous weapon systems do so in accordance with the Law of War (U.S. Department of Defense Directive 3000.09 2012, 7). In addition, DOD Directive 2311.01E, *DOD Law of War Program*, states that it is DOD policy for all DOD members to comply with the Law of War during all armed conflicts (DOD Directive 2311.01E, 2006, 2).

Both of these directives emphasize adherence to the Law of War, which is defined as a part of international law, i.e., law of nations, which seeks to limit the effects of armed conflict by restricting the means and methods of warfare, particularly on persons who "are not or are no longer participating in the hostilities" (International Committee of the Red Cross 2004, 1). Article 38 of the Statute of the International Court of Justice (ICJ) lists the following primary sources of international law: international conventions (legal, signed treaties), international custom (customary international law or the "unwritten" rules States are bound by), general principles of law recognized by civilized nations (judicial opinions of domestic courts), and judicial decisions and teachings of "the most highly qualified publicists of the various nations" (United Nations International Court of Justice 1945, Chapter II, Article 38).[186] Among these and many other sources that comprise the Law of War, two play a major part: the four Geneva Conventions of 1949 (considered customary international law, which nearly every nation in the world has agreed to be bound by), and the two Additional Protocols of 1977 relating to the protection of victims of armed conflicts (International Committee of the Red Cross 2004, 1; Musselman 2011, 17-18).[187] Some of the key Law of War principles considered

[186] These legal sources also deal with three time frames associated with warfare: laws dealing with how States initiate armed conflict (*Jus ad Bellum*), laws governing the conduct of States during the conflicts (*Jus in Bello*), and laws governing the end of the conflict and re-establishment of peace (*Jus post Bellum*) (Musselman 2011, 10). (See the U.S. Army Judge Advocate General *Operational Law Handbook 20015* or *Law of War Deskbook* for more detailed definitions and explanations.)

[187] The U.S. ratified all four Geneva Conventions, but did not ratify—only signed—the Additional Protocols (AP) of 1977 due to opposition to certain provisions in AP II, specifically the provisions to treat any war of liberation as an international conflict and the granting of combatant status to irregular forces that do not distinguish themselves from civilians or abide by the law of war (U.S. Congress 1987, III-IV). Despite this fact, the U.S. Army Judge Advocate General School teaches that "the protocols remain important to the DOD for at least two reasons: (1) Certain provisions of AP I and AP II are considered customary international law, and therefore binding on the U.S.; and (2) many U.S. coalition partners have ratified AP I and II and therefore may have different legal obligations than the U.S. during a combined operation" (Musselman 2011, 44).

during military planning and operations include Military Necessity (Protocol 1, Art. 52(2)); Unnecessary Suffering (Protocol 1, Art. 35); Distinction (Protocol 1, Arts. 48 and 51(4) and (5)); and Proportionality (Protocol 1, 51(4) and (5b)).

Relative to the development of technology and the application of the Law of War, the ICJ, addressing the "Legality of the Threat or Use of Nuclear Weapons" in 1996, recognized as "cardinal" two principals of international humanitarian law—Distinction and Unnecessary Suffering (United Nations 1996, 97). The court stated:

> After sketching the historical development of the body of rules which originally were called "laws and customs of war" and later came to be termed "international humanitarian law," the Court observes that the cardinal principles contained in the texts constituting the fabric of humanitarian law are the following. The first is aimed at the protection of the civilian population and civilian objects and establishes the distinction between combatants and non-combatants; States must never make civilians the object of attack and must consequently never use weapons that are incapable of distinguishing between civilian and military targets. According to the second principle, it is prohibited to cause unnecessary suffering to combatants: it is accordingly prohibited to use weapons causing them such harm or uselessly aggravating their suffering. In application of that second principle, States do not have unlimited freedom of choice of means in the weapons they use. (United Nations 1996, 97)

Therefore, when the international community discusses the legality of an autonomous weapon, such as at the U.N. CCW LAWS 2015 meetings, the two principals of distinction and humanity are foundational, i.e., the weapon system cannot be indiscriminate by nature, and it cannot be "of a nature" to cause "un-necessary suffering or superfluous injury" (Anderson 2014, 399). In addition, per the ICJ ruling, the development of LAWS is also under scrutiny in the context that "States do not have unlimited freedom of choice of means in the weapons they use." A specific example of these principles related to autonomous UCAV development includes the potential application of an onboard automatic target recognition (ATR) system. The principle of distinction would require an autonomously operating UCAV to distinguish between combatants, civilians, military targets, and civilian objects, a capability that, as previously discussed, has yet to be developed. Additionally, the principal of humanity would restrict an autonomous UCAV from employing weapons that could cause excessive collateral damage or unnecessary suffering to combatants or civilians. Both of these principals were discussed during the LAWS meetings.

An additional Law of War principle related to distinction and autonomous weapons is control. Protocol I, Article 51 (4)(c) states that indiscriminate attacks include "those which employ a method or means of combat the effects of *which cannot be limited* as required by this Protocol; and consequently, in each such case, are of a nature to strike military objectives and civilians or civilian objects without distinction" [emphasis added]. Therefore, an autonomous weapon system can be deemed illegal if the harmful effects of the weapon are not capable of being limited or "controlled" (Anderson 2014, 400). This too was a discussion topic of the LAWS meeting.

The political leadership responsible for the DOD recognizes its responsibilities and emphasizes the obligations to the Law of War, mandating that all members of the DOD comply with the Law of War during all armed conflicts. A key U.S. law providing oversight of DOD's adherence to this law is Title 10, United States Code (USC), Section 140, which establishes the office, duties, and responsibilities of the General Counsel (GC) of the Department of Defense. The GC is a civilian, appointed by the President with the advice and consent of the U.S. Senate, that serves as the chief legal officer of DOD, "performing such functions as the Secretary of Defense may prescribe" (10 USC § 140 (a)). The DOD GC provides legal advice to the Secretary and Deputy Secretary of

Defense on all legal matters and services performed within, or involving, DOD, including significant international law issues raised by major military operations, the DOD Law of War Program, or legality of weapons reviews (U.S. Department of Defense Joint Publication 1-04 2011, I-1).

Because autonomous UCAS operations will have to conform to the Law of War, particularly principles of discrimination, humanity, and control, the system will be scrutinized by a number of domestic and international political and legal institutions and organizations to ensure accountability with the laws. Those involved include the civilian and military elements of the U.S. government as well as civilian and military elements of the international community, i.e., the U.N., NATO, and other politico-military institutions. Prior to any completely autonomous UCAS deployments in combat, numerous discussions and debates will take place alongside extensive testing to prove to the international community the safety, reliability, and accountability of the UCAS systems. As with the laws associated with the development of autonomous weapons technology, the Law of War, while not as restrictive as the technical challenges, provide another layer of human intervention that helps to prohibit the possibility of technology evolving past the point of human control.

The actual application of international protocols and humanitarian laws by the U.S. military occurs in the form of the rules of engagement and the use of force under which all military personnel and systems operate and are held accountable.

Military Rules of Engagement and the Use of Force

Rules of Engagement (ROE) are additional human-generated legal elements related to the Law of War that are available to control autonomous weapons systems. They are defined by the DOD as directives that are “issued by competent military authority that delineate the circumstances and limitations under which United States forces will initiate and/or continue combat engagement with other forces encountered (U.S. Department of Defense JP 1-02 2010, 211). Rules for the Use of Force (RUF) apply to DOD personnel performing civil support missions, land-based homeland defense missions within U.S. territory, and law enforcement functions at all DOD installations worldwide, governing how and when military forces may use nonlethal and lethal force (Chairman of the Joint Chiefs 2005, L-1).

The ROE/RUF provide guidance from the President and Secretary of Defense (SECDEF), as well as subordinate commanders, to deployed units on the use of force. Their purpose is to ensure national policies and objectives are reflected in the actions of commanders and personnel in the field, e.g., they may restrict the types of targets that may be engaged, the type of weapons systems that may be used, or the amount of force that may be applied (Lee 2015, 81).

The U.S. Secretary of Defense approves ROE/RUF requests, the DOD General Counsel ensures all ROE/RUF lists are reviewed for compliance with applicable laws and policies as required by the DOD Law of War Program, the DOD Legal Counsel for the Office of the Chairman of the Joint Chiefs of Staff reviews and advises the staff on ROE/RUF, and the military components incorporate legal considerations and instructions for developing ROE/RUF in the combatant commander's planning guidance (U.S. Department of Defense JP 1-04 2011, II-7).

Currently, DOD Directive 3000.9, *Autonomy in Weapon Systems*, dictates that persons who authorize the use of, direct, operate, or are responsible for development and pre-deployment of autonomous weapon systems must do so in accordance with applicable rules of engagement (U.S. Department of Defense Directive 3000.09 2012, 3,7). However, once autonomous UCASs become operational, they will be required to operate in accordance with ROE, just like pilots. Pilots conducting combat missions are required meet a specific ROE before employing weapons against a target, including positively identifying military targets, making judgments in regard to proportionality, and minimizing collateral damage (Lazarski 2002, 81).

To operate in a combat environment, a completely autonomous UCAS must be reliable enough to do the same as a manned combat aircraft, and it is the ROE, as the operational portion of the Law of War, which serves as another safeguard for autonomous weapon system development, providing human access into the fielding and operational use of the UCAS.

One final area of law that needs to be discussed, because of the in-depth involvement of the human element, is civil and international aviation.

Federal and International Aviation Laws

The laws and rules that govern flight operations in national and international airspace (NAS/IAS) have a significant impact on autonomous UCAS development because they deal with the operating procedures and command and control requirements required for safe unmanned flight in national and international airspace.[188] UAS operations are not completely foreign to the U.S. and international civil aviation communities, as evidenced by the transnational flights of the *Global Hawk* and other military UAVs and the operation of Department of Homeland Security UAS missions; however, both communities are preparing for an increase in unmanned activity as the civil market expands it unmanned capabilities. Up to this point, the vast majority of UAS operations have been military, and have occurred over war or combat zones where the military had air superiority and there was limited air traffic, especially civilian air traffic. The change to UAS flight in civilian airspace is requiring significant involvement of the U.S. Federal Aviation Administration (FAA) and the International Civil Aviation Organization (ICAO).

The FAA has been responsible for the safety of U.S. civil aviation since 1958, and the administration fulfills this responsibility by developing air traffic rules and regulations, assigning the use of airspace, controlling air traffic, developing and operating air traffic control and navigation systems for civil and military aircraft, encouraging and developing new aviation technology, exchanging aeronautical information with foreign authorities, and negotiating bilateral airworthiness agreements with other countries (U.S. Department of Transportation 2005, 1-2). Likewise, the ICAO is a specialized agency of the United Nations, established by States in 1944, with the responsibility of managing the administration and governance of the Convention on International Civil Aviation and

[188] FAA regulations that govern aircraft in the U.S. are found in Title 14 of the Code of Federal Regulations. Title 49 of the United States Code §§ 40102 (a)(41) and 40125 govern public, including military, aircraft operations; however, military aircraft are still required to comply with the regulations applicable to all aircraft operating in the U.S. national airspace (NAS) (U.S. Department of Transportation 2014, 3).

working with the Convention's 191 Member States and industry groups to reach consensus on international civil aviation Standards and Recommended Practices (SARPs) and policies supporting a safe, efficient, secure, economically sustainable, and environmentally responsible civil aviation sector (United Nations 2014, 1). Detailed coordination with and involvement by the FAA and the ICAO is required for any aircraft conducting flight operations, and the same will hold true for autonomous UCAS flight operations.

The FAA is currently dealing with the development of rules, regulations, and procedures for the growing remotely piloted unmanned fleet of military and civilian aircraft. Since 1990, it has authorized a limited number of important missions in the public interest, e.g., firefighting, disaster relief, search and rescue, law enforcement, border patrol, military training, and testing and evaluation, and has also given limited authorization to commercial firms, under certain circumstances, for wildlife conservation flights, aerial surveying, and oil/gas pipeline patrols (U.S. Department of Transportation 2015a, 1-3). The FAA currently restricts U.S. UAV flight operations, completely prohibiting unmanned flight in the airspace over major urban areas and containing the highest density of manned aircraft, only allowing flights with Certificates of Waiver or Authorization (COAs) to operate in special-use airspace (U.S. Department of Transportation 2015a, 2). Similarly, the ICAO issued Cir 328, *Unmanned Aircraft Systems (UAS),* which prohibits unmanned aircraft flights over the territory of a contracting State without special authorization by that State, mandates that UAVs with permission to fly in regions open to civil aircraft are to be controlled to avoid danger to civil aircraft, and expressly states that fully autonomous aircraft operations are not being considered at this time (United Nations 2011, 3 and 11).

In the *Integration of Civil Unmanned Aircraft Systems (UAS) in the National Airspace System (NAS) Roadmap,* the FAA lists a number of significant challenges that must be overcome to allow remotely piloted UAS operations in U.S. civil airspace. Some of the most important challenges include: policy, guidance, and regulatory changes to specifically address UAS integration into the NAS; development of minimum standards for Sense and Avoid (SAA) capabilities, changes related to UAS Control and Communications (C2) and separation assurance procedures; Air Traffic Control clearances and instruction procedures; establishment of safe, secure, and reliable voice and data communications exchange capabilities; and determination of wake vortex and turbulence avoidance criteria (U.S. Department of Transportation 2013, 14-17). ICAO Cir 328 addresses many of the same issues for the international community.

These challenges require intensive hands-on participation by numerous members of both the FAA and ICAO communities, and once these issues are addressed, new laws and procedures will need to be created, developed, and put into effect for automated unmanned systems. As discussed previously, a UCAS is unlike manned or remotely piloted aircraft, and requires onboard computers to be programmed with precise algorithms and software instructions in order to fly. The significant challenge for automated systems operating in the NAS/IAS is reacting to a very diverse, high-traffic environment with multiple unknown or unexpected events, e.g., unexpected weather, other aircraft being operated illegally or out of parameters, newly created or altered unmapped structures, or a combination of these events. In addition, a weapons-carrying

UCAS operating in such an environment will require significant human oversight in the programming as well as during flight operations to prevent injury or loss of life or property caused by a malfunction with no human pilot onboard or at the controls.

As safety is a primary mission for both the FAA and ICAO, each organization has the responsibility to ensure autonomous UCAS capabilities are in place to minimize danger to other aircraft as well as personnel and property on the ground; therefore, in addition to the requirements to meet compliance laws associated with the development of autonomous weapons technology, the Law of War, and ROEs, autonomous UCASs will undergo additional in-depth scrutiny for airspace compliance issues by the FAA and ICAO.

Together with the scientific and technological limitations in algorithm development and programming, the domestic and international political and legal systems provide a seemingly insurmountable impediment for unmanned combat air systems to spontaneously develop the human-equivalent AI capability required to break away from human control. However, it is not only the national and international laws, conventions, and protocols that provide significant obstacles to the evolution of a truly autonomous UCAS, more importantly, it is the human motivation behind the creation of those laws. The desire to reach a peaceful resolution of a conflict before it reaches the battlefield, or failing that, to limit the type, amount, use, and duration of violence by setting limits to what is or is not permissible in the conduct of war, is the very inspiration for creating the laws. These laws are only a reflection of the moral and spiritual element of humanity, and this human element is another factor that keeps UCAS technology from becoming uncontrollable.

Moral-Ethical Challenges to the Hard Determinist View of Autonomous UCAS Control

> *"The possibility of constructing a personal AI raises many ethical and religious questions that have been dealt with seriously only by imaginative works of fiction; they have largely been ignored by technical experts and by philosophical and theological ethicists."*
>
> — Michael R. LaChat

All laws are based on some moral framework of right and wrong. Whether the source of this framework is a by-product of the natural mysteries of biological evolution, survival of the fittest, and the establishment of rules for the common good and survival of the group; or through the result of a mysterious reception and subsequent following of divine commands given to individuals created in the image of God is well beyond the scope of this study. So is a discussion of all of the moral and spiritual dimensions of the various worldviews, ethical philosophies, and approaches to warfare. However, it can be said that every nation, group, or person has a worldview in regard to moral and ethical standards of behavior, whether it is universal law or moral absolutism of right and wrong, such as Kant's Categorical Imperative, or the social-cultural creation of standards of right or wrong as advocated by ethical relativism. These worldviews result in different moral stances in terms of warfare, from total pacifism (it is never right to wage war), through Just War theory (Law of War), to the extreme of Total War theory ("war is hell" and there are no rules in the "just" cause to defeat an enemy) (Lin 2008, 47, 51). The origins of these moral frameworks will not be discussed as doing so would not be pertinent to the point of demonstrating the limitations associated with programming some type of moral standard and ethical behavior into a UCAV.

The Law of War and the military ROE and RUF mentioned in the previous section are all based on moral principles regulating the activities and conduct of combatants in time of war, primarily to protect noncombatants and limit the amount of violence and destruction. Even the laws of the FAA and ICAO exist to ensure order and the safest possible transit through national and international airways, underscoring the idea that it is wrong to cause willful or negligent harm to others through inappropriate, unsafe, or illegal activities in the air. Subsequently, the U.S. government and military services base their laws, regulations, and instructions upon moral and ethical principles, as evidenced by the existence of general counsels and ethics offices in the Federal Government and each branch of service. Therefore, the same moral and ethical behavior required of military members in warfare must also be transferred into any lethal autonomous weapon system, as articulated in a U.S. Navy, Office of Naval Research-sponsored study: "When robots with even limited autonomy must choose from among different courses of action, the concern for safety is transmuted into the need for the systems to have a capacity for making moral judgments (Lin 2008, 26)." However, like artificial intelligence, there are severe limitations with programming human-like morals and ethics into a machine.

Both American roboticist and roboethicist Ronald Arkin and British artificial intelligence and robotics expert Noel Sharkey, while disagreeing on whether autonomous weapon systems should be used in warfare, or can even be programmed with an artificial morality, agree on the monumental difficulties of such programming. In *Governing Lethal Behavior in Autonomous Robots*, Arkin lists the following five "daunting problems":

> 1. The transformation of International Protocols and battlefield ethics into machine-usable representations and real-time reasoning capabilities for bounded morality using modal logics.[189]
> 2. Mechanisms to ensure that the design of intelligence behaviors only provide responses within rigorously defined ethical boundaries.
> 3. The development of effective perceptual algorithms capable of superior target discrimination capabilities, especially with regard to combatant-noncombatant status.
> 4. The creation of techniques to permit the adaptation of an ethical constraint set and underlying behavior control parameters that will ensure performance should those norms be violated in any way, involving reflective and affective processing.
> 5. A means to make responsibility assignment clear and explicit for all concerned parties regarding the deployment of a machine with a lethal potential on its mission. (Arkin 2009c, 211-212)

Sharkey also lists the following ethics-related obstacles in the article "The Evitability of Autonomous Robot Warfare":

> 1. A major IHL [international humanitarian law] issue is that autonomous armed robot systems cannot discriminate between combatants and noncombatants or other immune actors such as service workers, retirees, and combatants that are wounded, have surrendered, or are mentally ill in a way that would satisfy the principle of distinction.
> 2. A second IHL issue is that robots do not have the situational awareness or agency to make proportionality decisions . . . making the decision about whether to apply lethal or kinetic force in a particular context . . .
> 3. A third issue is accountability. A robot does not have agency, moral or otherwise, and consequently cannot be held accountable for its actions. (Sharkey 2012, 788-790)

Sharkey also emphasizes that Arkin's work is "merely a suggestion for a computer software system for the ethical governance of robot 'behaviour,'" and states:

> This is what is known as a 'back-end system.' Its operation relies entirely on information from systems yet 'to be developed' by others sometime in the future. It has no direct access to the real world through sensors or a vision system and it has no means to discriminate between combatant and noncombatant, between a baby and a wounded soldier, or a granny in a wheelchair and a tank. It has no inference engine and certainly cannot negotiate the types of common sense

[189] Modal logics is based on deontic (Kantian rule-based) ethics and is distinguished from standard formal logics in that it provides a framework for distinguishing between what is permitted and what is required (Arkin 2009a, 99; Moor 2006, 18-21).

> reasoning and battlefield awareness necessary for discrimination or proportionality decisions. There is neither a method for interpreting how the precepts of the laws of war apply in particular contexts nor is there any method for resolving the ambiguities of conflicting laws in novel situations. (Sharkey 2012, 790)

With these ethical limitations added to the legal and AI technical limitations, it becomes extremely difficult to make a realistic argument that autonomous weapons will one day unilaterally develop the capabilities to break free from human control.

One last area that needs to be briefly mentioned is that of the spiritual, or metaphysical, sphere. In chapter three, Martin Heidegger's concept of the essence or being of technology was shown to be fundamentally important to the hard determinists because it is required for defining technological autonomy as an agent of change through the evolution and influence of computer technology and artificial intelligence. In order for something to be truly autonomous it must act independently and be self-governing and, in order to make a case for the autonomy of technology, the transfer from technology as an instrument or tool to technology as an essence, or being, is important. Once the argument is made that technology has revealed itself to be a self-existing entity not under human control, proponents can begin to build a case for the reality of technological autonomy. Heidegger wrote that an important part of revealing is the realization or truth that the essence of technology actually exists, and once the concept of revealing is understood, then technology is no longer seen solely as an instrument or means, but as a way of revealing, a way of discovering truth. He proposed the idea that modern technology is not a human endeavor, a critical component of the technological determinists' argument that technology is not a passive instrument, but an active agent that determines the actions and course of events through the ordering of humanity.

Likewise it was shown that Jacques Ellul identified Technique as artificial, yet autonomous, self-determining, and independent of human intervention, a non-neutral force that does not bend to the will of the human, but operates independently of human intentions and objectives. He unequivocally stated that Technique is truly autonomous, can do what it wills, and is neither good nor bad, admitting that this claim is an unrecognized "outrageous" truth. Ray Kurzweil, following suit, also promoted the idea of bio-technological evolution culminating in patterns of matter and energy in the universe becoming saturated with intelligent processes and knowledge. Further, Paul Virilio highlights technology as a riddle over which humanity has no control, and Stephen Hawking and Elon Musk warned that humans, limited by their slow biological evolution, would be superseded by AI, which is "our greatest existential" threat (Sainato 2015, 1).

One thing that all of these positions have in common is the philosophical speculation into the ontology of technology and the future, i.e., a worldview that embraces technology as an autonomous entity with being that is evolving past human control. This is a belief system, something that cannot be proven with facts but must be embraced with faith. There is insufficient information available to prove or disprove the philosophical arguments for an ontological view of technology, to prove that there exists an independent element or essence of technology that operates completely beyond human control. This position falls within the same realm as religious beliefs, and it is equally valid to believe that there is a God who created all of humanity, and that each human is created in the image of this God, complete with godlike qualities like volition, intelligence, creativity, emotion, morality, and ethics. Perhaps the reason technology cannot completely replicate the human brain, emotions, or morality is because these are divine qualities that separate humanity from the rest of creation, and are what enable humans to create technology, overcome it, and have dominion and control over it—like gravity or the atom. Perhaps this is what caused the revealing, realization, and way to discover the truth that Heidegger proposed, and that it is the human that is determining the actions and course of events through the ordering of humanity by their choices. Perhaps the intelligent processes and knowledge saturating Kurzweil's patterns of matter and energy in the universe is the presence of humanity. It may also be the unrecognized "outrageous" truth of Ellul and the riddle of Virilio—that these are divine qualities in the autonomous human so endowed by God. If so, then AI could not supersede human intelligence and become our greatest existential threat.

However, this position of a divinely endowed humanity is also a belief embraced by faith. What is known, and what has been shown in this study, is that there are moral and ethical factors included in the conduct of warfare that must be built into autonomous systems; and yet, unlike the human brain, science and technology does not have the capability to program these into a UCAS, providing still another limitation factor for the UCAS to spontaneously evolve beyond human control.

Summary of Findings

"Technology gives us power, but it does not and cannot tell us how to use that power."

— Jonathan Sacks

The research conducted in this examination revealed that the integration of unmanned aircraft, remote sensing, and computer technologies has indeed played a critical role in enabling the development of the UAS, for without their integration UAS capabilities could not exist. With the additional integration of integrated circuits and microcomputer processing, and preliminary "artificial intelligence" computer technology, the UAS and remote sensing technologies also played a critical role in the development of the airborne lethal autonomous weapon system, designated the unmanned combat air system (UCAS). This brought into question how this technology should be deployed, and more importantly, monitored and controlled. The symbiotic relationship between the technologies allows UCAS platforms to operate without direct human control, seemingly an integral step toward complete autonomy. However, the AI utilized in the UCAS, while replicating certain human capabilities and characteristics, falls far short of an artificial intelligence equal to human cognitive abilities, intelligence, emotion, and morality.

Humans Remain Fully in Control of UCAS Technology

Based on these findings, the following conclusions may be made in regard to the integration of these technologies on UCAV development and the impact on human control.

First, the integration of advanced nonliteral remote sensing technologies with automated navigation systems, precision-guided weapon systems, automated control systems, and onboard AI capabilities do allow for autonomous UCAS systems that can launch, navigate to the operations area, conduct surveillance operations, and conduct aerial refueling. These systems can also search, find, identify, track, assess, target, and destroy a target, recovering to base with no human interaction after the initial commands are uploaded into the system. However, because the AI utilized by the UCAS is not human intelligence, the autonomy that is exercised by the system is severely limited, and not the same as the autonomy experienced by humans, i.e., autonomy that is independent, self-governing, self-determining, self-aware of its environment and existence, and self-directed toward a goal. Instead, the machines exercise self-direction toward a goal apart from external outside control because their behavior, albeit sophisticated and technically complex, is governed and directed by laws and strategies encoded in mathematical algorithms and software programs created by teams of human operators and software developers. The machines can only do what they are programmed to do—even machine learning is a product of algorithms and software processes—and cannot operate beyond the constraints and limitations of their flawed, imperfect human programming.

Second, there is a technology-humanity gap created by UCAS technology; however, it is not in the realm of weapon system control, but rather in the realm of human-technology interaction. The necessity of direct human interaction with the weapons technology as it operates within the bounds of its programming has been diminished significantly. While it is true that less human interaction is required to directly control the UCAS systems, this is not equivalent to a UCAS being an autonomous agent that can decide, of its own volition, to change its goals, in direct opposition to its programmers, and operate contrary to or different from its programming.

Third, there is also a humanity-humanity gap created by the remote sensing technology, especially nonliteral technologies like synthetic aperture radar and spectral imagery. This technology has significantly increased the UCAS capability for awareness of its environment, enabling the system to employ automatic recognition and precise targeting capabilities. However, this nonliteral capability on the UCAS also contributes to the widening of the physical, emotional, and psychological gap between the human combatants. They are not only separated by great physical distances due to the operating range of the unmanned systems, but the nonliteral sensing technology also renders human combatants unrecognizable as humans, resulting in a dehumanizing effect that contributes to violating the humanity principle of the Law of War. These dehumanizing effects serve as an important reminder to remain cognizant of the further development of autonomous weapons technology, especially lethal autonomous weapons systems (LAWS). This study showed that UCAV evolution has continued increasing the separation between human combatants, as other weapons advancements have done throughout history, but that the distance from the actual battlefield, increased by remote sensing technology, has significantly restricted the human actors from fully participating in the visceral elements of armed conflict and warfare.

Fourth, while autonomous UCAV development may appear to support the hard technological deterministic theory of the loss of human control, the current state of UCAS technology and the significant scientific and technical limitations associated with it present severe obstacles that run counter to the technological determinist claim. Science cannot fully understand, nor technology fully replicate, the human brain, cognitive thinking, and decision-making processes, especially in the realms of anticipating, predicting, and incorporating the emotional, moral, and psychological element of decision-making. This provides severe limitations for the evolution of a true machine autonomy for the UCAS, particularly to the point in which humanity would lose control of the technology.

Fifth, human political and legal involvement at the national and international levels, while not perfect, places additional limitations on autonomous UCAS evolution through a comprehensive check and balance process that occurs in the development and employment phases of lethal autonomous weapon capabilities like the UCAS. While not as severe a limitation as the technical, the political and legal processes do help keep humanity involved with the programming, processes, and procedures of such systems by providing avenues for discourse, oversight, restriction, and control.

Sixth, insufficient information is available to prove or disprove the philosophical argument that there exists an independent element or *essence* of technology that allows such technology to operate completely beyond human control. Such a philosophical argument falls within the same realm as religious beliefs and faith. However, the influencing effect that technology has on humanity cannot be denied, nor can the influence of unexpected technological capabilities that arise as a by-product of new technologies such as the UCAS. What can be seen in the evolution of the UCAS is best expressed by Don Ihde, that the technology is not deterministic, but rather transformative, and the transformations brought about by the "mediating position" of the UCAS impact humanity by causing humans to "experience an environment or world in a new or technological way" (Ihde 1993, 112).

The integration of the technologies did indeed play a critical role in the development of current UCASs, and will continue to play an important role in future developments. However, until human cognition, emotion, morality, and volition can be fully understood, technological and human-generated limitations will ensure that control of UCAS technology remains firmly in the hands of the human creators. *Therefore, while* *the integration of UAS, remote sensing, and AI technologies do play a critical role in creating the environment needed to produce a completely autonomous UCAS, the mere existence and application of these technologies do not necessarily support, and currently run counter to, the technological deterministic view that humanity's ability to maintain control of this specific technology is threatened or transcended.*

Potential Critiques and Objections

Because this study employed an interdisciplinary, qualitative analysis of historical and contemporary literature, following the U.S. military's development of unmanned combat aerial system technologies from World War I to 2015, experts in any one of the particular fields covered could make the complaint that the subject matter was not dealt with in enough detail, particularly in the area of artificial intelligence. Some philosophers may argue that too much time was spent on Martin Heidegger's thinking and not enough on the other technological determinists' views, and that there was not enough material provided to show a stronger position for humanity's inability to maintain control. Historians may view the case study of unmanned aerial systems as too narrow, and that other lethal autonomous weapon systems, such as ground, surface, and subsurface, should have been examined to provide a more comprehensive argument. Computer scientists may point to the unprecedented advancements in computer technology since WWII, as well as the growing fields of nano- and bio-computer technology, as evidence that such technologies are likely to usher in the AI capabilities addressed in this study. In response to these criticisms, the following is offered:

Heidegger's work was discussed in greater detail than others because his writings on technological ontology pioneered the field and addressed technological control in the context of an autonomous influence behind technology, an element that needed to be considered when addressing the possibility of an artificial intelligence having the capability to evolve beyond human control. The other viewpoints of the hard technological determinists build upon this foundational work and bring in other elements to sufficiently demonstrate the adherents' stances, as discussed in chapter three. The social influences of the soft determinists were also addressed to demonstrate the human interaction in the development and advancement of technological influences, but as societal influences require human decision-making and involvement, these were not covered in depth as the evolution of technology as an autonomous agent, outside of human involvement, was the focus of this study. Philosophers embracing hard technological determinism may use the current existence of lethal autonomous weapons technology as proof that technology proceeds outside of human control. However, the in-depth look, in chapter five, at the evolution of computer and AI technology, along with the limitations of this particular technology discussed in this chapter, offers a counterpoint to the view that this technology is evolving on its own and reaching levels beyond human control. UCAS technology clearly responds to the commands of the programmers, and the inherent flaws and checks and balances of the development demonstrates that the process is controlled.

The study focused solely on the UCAS because of the additional difficulties that are associated with a flying weapon system, as opposed to an autonomous vehicle, ship, or submersible. While each of these other areas have significant challenges for weapon systems, the technology required to lift a body into the air, maintain flight while working against gravity, navigate, orient and find targets, and safely return to base or ground provided the ideal case study. Many of the achievements associated with the UCAS have been implemented into the autonomous ground, surface, surface and subsurface systems, and similar limitations apply.

The additional arguments that could be brought to bear regarding the growing fields of nano-, bio-, and other computer technologies still suffer from the same limitations as all computer technologies previously addressed in this study: the lack of understanding of human cognition and the difficulties in developing algorithms and software to accurately mimic human thinking in the limited areas that are currently understood. Introducing the "possibilities" of such technologies would only build the back-end system described earlier by Ronald Arkin, making assumptions entirely on information from newly developing technologies that are yet to be fully developed by others sometime in the future.

Finally, the nature of an interdisciplinary, qualitative analysis using historical data, an accepted method of research, provides a reliable conclusion for this subject matter. This study examined three specific technologies in a case study involving the development of unmanned combat air systems, focusing on the interaction and integrations of these systems throughout history to create the current weapon system. The aspects, pros, cons, and limitations in relation to the problem of control were examined, providing an assessment and conclusion based upon the limits of current technological developments.

Areas for Further Research

A topic for further humanity-technology research related to this study would be a comparison of the current accountability and governance systems used for nuclear and other weapons of mass destruction and the applicability of these systems to effectively govern lethal autonomous weapons. As more decision abilities are coded into the machines, and more autonomy exercised, would a different system be required, and if so, what would that system look like? How would such a system be implemented and enforced in the international community?

A second appropriate topic area would be an examination of the application of current military UCAS systems to domestic law enforcement roles. Multiple discussion could be generated from this topic, including the need for such systems, rules of engagement, limitations of use, authority and control over such systems, and legal responsibilities and repercussions for using such systems in the domestic environment.

Recommendations: A Roadmap for Maintaining Control

It is the responsibility of the citizens of a liberal democracy to conscientiously monitor and ensure controls are in place for the development and deployment of any lethal autonomous weapon system technology. It is also the responsibility of the citizens to discover how to implement such technology in a way that is most beneficial for the people, while ensuring citizens are protected from those who would strive to do them harm with the technology. These activities must be done without devaluing the lives of the human participants and without forfeiting civil liberties and freedoms. These responsibilities are embraced by the U.S. and the international community, as evidenced by the political and legal activities previously mentioned, and in order to ensure continued control over military technology human involvement must continue.

As John Rawls stated, the only way to maintain balance in a free and open society like the U.S. is by involvement in, and focusing on, the basic structure of society. This structure, based on the concepts of justice, an overlapping consensus of reasonable comprehensive doctrines, and public discussion, will ensure majority rule and that the basic rights of citizens are upheld (Rawls 2005, 44). As shown in this work, UCAS technology will not likely evolve past a point of human control on its own; however, this is not the real issue that threatens humanity. The real issue will be lack of human involvement in the development and operation of this technology, a lackluster commitment by humanity to stay engaged in the oversite and control of the UCAS. As Merritt Roe Smith said in commenting on Langdon Winner: “Human ‘somnambulism (sleepwalking),’ rather than any inherent technological imperative, has allowed large technological systems to legislate the conditions of human existence” (Smith 1994, 2). The critical point is this: *If humanity loses control of technology, it is most likely because humans choose to allow it to happen by handing over control to machines.* To counter this, citizens—especially elected leaders and the military leadership those elected members appoint—must stay cognizant of the human-technology relationship through involvement with the total lifecycle of the UCAS systems—from initial concept design, through development and fielding, to system retirement—by constantly monitoring and deciding the limits of the systems.

The first step toward involvement is education, staying abreast of the science, research, and development activities, while also understanding history—the where, how, and why these systems were and are now being developed—as well as the sociology, the human behavior, development, organizations, networks, institutions, and belief systems associated with the use of such systems. The next step is applying the knowledge gained by staying engaged with political activities, legal rulings, and moral and ethical decisions associated with UCAS technology while it is being developed. Through active participation, humanity ensures through its involvement that genuine human engagement with technology is taking place. All these steps are required to avoid the potential trap of "human somnambulism." Only through education, involvement, and decisive decision-making can humanity effectively continue to maintain control over any technology. This can be seen as illustrated by the small thriving Amish communities that make decisive choices in regard to the amount of technology they allow into their societies; through large governments, such as the United States, that create laws to limit lethal autonomous weapon systems; and to global organizations like the United Nations, which create Laws of War.

Conclusion

> *"Technology is a gift of God. After the gift of life it is perhaps the greatest of God's gifts. It is the mother of civilizations, of arts and of sciences."*
>
> — Freeman Dyson

The findings of this study provide a better understanding of the extent to which UAS, remote sensing, and AI technologies have contributed to the creation of the autonomous UCAS, the extent of autonomy the UCAS can actually achieve, and the actual level of control humans have over the technology. As related to the technological determinism debate associated with technological autonomy and human control, the findings contribute to a better understanding of what it means to be human in the age of 21st-century technology. As control is a key component in understanding the human-technology relationship, examining the issue in the context of humanity, technology, and warfare was critical to enhance understanding. The study revealed that these specific UCAS technologies do not currently support, and run counter to, the hard technological deterministic view that humanity's ability to maintain control over UCAS technology is threatened or transcended.

These findings may be applied to current discussions addressing future military use of autonomous unmanned weapon systems, contributing to the political and social discourse on the implications of their use. The findings not only apply to current moral questions being raised by philosophers, academics, and industrialists concerning the control of autonomous military technology, but also apply to U.S. policy questions concerning the use of such systems in the future. These findings also may be used by those directly involved with developing autonomous military technologies, providing them information that can encourage them to keep the humanity-technology relationship in consideration in order "to work for a world that is harmonious, just, and merciful."

Appendix A

Law of War Principles

Department of Defense Joint Publication 1-04

Legal Support to Military Operations

August 17, 2011

Military Necessity. The principle of military necessity justifies those measures not forbidden by international law that are indispensable for securing the complete submission of the enemy as soon as possible.

Unnecessary Suffering. The principle of unnecessary suffering forbids the employment of means and methods of warfare calculated to cause unnecessary suffering. This principle acknowledges that combatants' necessary suffering, which may include severe injury and loss of life, is lawful. This principle largely applies to the legality of weapons and ammunition.

Distinction. This principle requires parties to a conflict to distinguish between combatants and noncombatants and to distinguish between military objectives and protected property and places. Parties to a conflict must direct their operations only against military objectives.

Proportionality. The principle of proportionality prohibits attacks that may be expected to cause incidental loss of civilian life, injury to civilians, damage to civilian objects, or a combination thereof, which would be excessive in relation to the concrete and direct military advantage expected to be gained. As such, this principle is only applicable when an attack may possibly affect civilians or civilian objects, and thereby may cause collateral damage.

Source: *U.S. Department of Defense Joint Publication 1-04*, August 17, 2011: viii-ix.

Acronym Glossary

AFIT	Air Force Institute of Technology
AFRL	Air Force Research Laboratory
AI	Artificial Intelligence
ALFUS	Autonomy Levels for Unmanned Systems
ARIAA	Autonomous Reconnaissance Intelligence Integration Analyst: supercomputer in D.J. Caruso's 2008 film *Eagle Eye*
AWS	Autonomous Weapon System
COMINT	Communications Intelligence
CR-UAV	Close-Range Unmanned Aerial Vehicle
DARPA	Defense Advanced Research Projects Agency
DHS	Department of Homeland Security
DOD	Department of Defense
EDI	Extreme Deep Invader: UCAV in Rob Cohen's 2005 film *Stealth*
ELINT	Electronic Intelligence
EM	Electromagnetic
EO	Electro-optical
E-UAV	Endurance Unmanned Aerial Vehicle
FMV	Full-Motion Video
FY	Fiscal Year
GCS	Ground Control Stations
GEOINT	Geospatial Intelligence
Gov't	Government
GPS	Global Positioning System
HAL 9000	Heuristically programmed algorithmic computer in the Stanley Kubrick's 1968 film *2001: A Space Odyssey*
HALE	High Altitude Long Endurance UAV
HI	Human Independence (associated with levels of autonomy)
HMI	Human-Machine Interface
HQ	Headquarters
HRI	Human-Robot Interface
HSI	Hyperspectral Imagery
IA	Intelligence Amplification
INS	Inertial Navigation System
IR	Infrared
ISR	Intelligence, Surveillance, & Reconnaissance
LAW	Law of Armed Conflict
LAWS	Lethal Autonomous Weapon System
LiDAR	Light Detection and Ranging/Light and Radar
LoA	Levels of Autonomy
MALE	Medium Altitude Long Endurance UAV
MASINT	Measurement and Signature Intelligence
MSI	Multispectral Imagery
NASA	National Aeronautics and Space Administration
NGA	National Geospatial-Intelligence Agency

NIH	National Institutes of Health
NIST	National Institutes of Standards and Technology
NSA	National Security Agency
ONR	Office of Naval Research
OSD	Office of the Secretary of Defense
RADAR	Radio Detection and Ranging
RF	Radio Frequency
RPA	Remotely Piloted Aircraft
RPS	Remotely Piloted System
RPV	Remotely Piloted Vehicle
RSS	Remote Sensing System
SAR	Synthetic Aperture Radar
SIGINT	Signals Intelligence
Skynet	Intelligent computer network in James Cameron's 1984 film *The Terminator*
SOAR	A cognitive architecture created by John Laird, Allen Newell, and Paul Rosenbloom at Carnegie Mellon University
SPECTRAL	Multi-, Hyper-, and Ultraspectral
SR-UAV	Short-Range Unmanned Aerial Vehicle
TIR	Thermal Infrared
UA	Unmanned Aircraft
UAS	Unmanned Aircraft System
UAV	Unmanned Aerial Vehicle
UAVR	Unmanned Aerial Vehicle Roadmap
UCAS	Unmanned Combat Air System
UCAS-D	Unmanned Combat Air System–Carrier Demonstration
UCAV	Unmanned Combat Air Vehicle
UMS	Unmanned System
USI	Ultraspectral Imagery
USIR	Unmanned Systems Integrated Roadmap
UWS	Unmanned Weapons System
VTOL-UAV	Vertical Takeoff and Landing–Unmanned Aerial Vehicle

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