



Copy Right for Flight:

Patterns of Technological Adaptation in Military Aviation

by

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APPROVAL

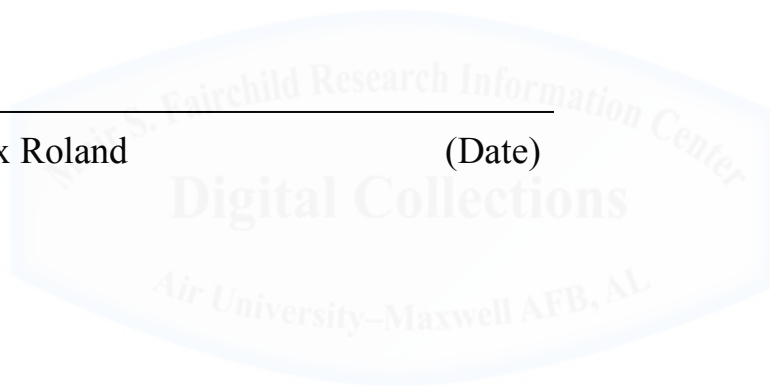
The undersigned certify that this thesis meets master's-level standards of research, argumentation, and expression.

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DISCLAIMER

The conclusions and opinions expressed in this document are those of the author. They do not reflect the official position of the US or French governments, Departments of Defense, Air Forces, or Air University.



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ABSTRACT

Technological adaptation in aviation happens when one organization feel the need to copy and adapt an existing technology for its missions. In a world of competition, where winning is usually the desired goal, technological adaptation is natural and frequent. And since aviation is particularly reliant on technology, this process is even more critical in the third dimension. For both civilian and military air organizations, copying and adapting technology is necessary to remain competitive. In both cases, it can also mean surviving or disappearing.

The aim of this research is to provide a better understanding of technological adaptation in aviation. To do so, the study suggests two theoretical frameworks to grasp the process. A first cognitive approach is based on John Boyd's model for competitive cognition: Observe, Orient, Decide, Act—usually referred to as the OODA loop. Boyd's model not only provides a way to break up and analyze each step of the process, but its chronological motif also provides a reasonable platform for narrative. Then the concept of sustainable development offers a second cognitive apparatus to assess the value and limits of an instance of technological adaptation. These two different approaches represent an attempt to build a theory of technological adaptation that can then be applied to the case studies. But the theory and the case studies are iterative. On one hand, the theory should facilitate understanding and assessing most instances of technological adaptation, and on the other hand, the case studies will validate and reveal the limitations of the theory.

Because the aim is to reveal some common factors in technological adaptation, the case studies are intentionally broad. The first case analyzes how the United States Army Air Forces (USAAF) copied the German concept of military gliders. Although the USAAF achieved some impressive operational results, the study unveils a failure in leadership to understand the value of the glider. The second case revisits the history of the jet age in the airline industry, and how it adapted a military technology—the jet engine—for a civilian purpose. Lastly, the third case examines the current attempts of the French Air Force to develop a drone capability. France looks at the US remote-flying capability with envy and seeks to adapt—unfortunately with great difficulties— this technology for its missions.

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INTRODUCTION

We don't make things, we make things better
- BASF motto

Many innovations in the military do not come from pure inventions, but often from a process of adaptation to existing or emerging technologies. When one military makes a technological breakthrough, the natural tendency for the competing organizations is to make all efforts to acquire the same capability. Military aviation is no exception: the process of technological adaptation is natural since the first objective of any air force is to preserve its superiority against its enemies. Hence, technological adaptation in military aviation essentially happens when one air force, whether enemy or friendly, demonstrates a new capability, forcing all other competing air forces to adapt.

Technological adaptation in aviation has some specific characteristics and therefore requires its own study. More than in most domains, aviation is highly dependent on technology. But more importantly, any minimal technological change in aviation may cause significant effects. These effects may be beneficial or negative and they may also be unstable and disastrous. Heavier-than-air flight is unforgiving, and any slight deviation during technological adaptation may cause death.

As the case studies will reveal, technological adaptation can succeed or fail. The primary objective of this work is to identify some of the recurring factors of success or failure in the process. The second objective is to search for a methodology of technological adaptation that leads to success. The study will finally suggest that the concept of sustainable development can provide an effective theoretical framework for analysis of technological adaptation.

Because technological adaptation is natural and frequent in military aviation, analyzing the process is worthy. However, a US reader may think that her air force is leading in technology, and therefore considerer the topic of technological adaptation useless. Why indeed would a USAF strategist be interested in studying the process of technological adaptation when the USAF is the world technological leader? In fact, there

are two main reasons why technological adaptation is critical, even for a US strategist. First, understanding how your enemy or your allies may copy and adapt your technology can provide a good understanding of their strengths and weaknesses. Second, even if today the United States is leading in military aeronautics, history proves that has not always been the case, and nothing assures that the United States will always hold its technological leading position. For example, the first case study of this research analyzes how the US Army Air Forces copied and adapted the German concept of glider operations. Moreover, many post-World War II breakthroughs in the USAF came from German technology.¹ Even in recent times, the USAF may have found some interest in adapting a concept coming from a foreign air force. A good example is the implementation of the T6 turboprop airplane for basic flight training instead of using a jet airplane, a concept directly borrowed from the British Royal Air Force.

If technological adaptation in military aviation is often an attempt to copy and adapt another air force capability, the recent exponential development of relatively inexpensive civilian technology tends to indicate that the process of technological adaptation in military aviation may take another form: instead of copying and implementing the technological development of a competing military organization, an air force may find some benefit in adapting some civilian technology for its military operations. This is another reason why understanding the process of technological adaptation may help future decision-makers who may have to integrate more civilian technology.

DELIMITING THE FIELD OF STUDY

Technological adaptation can be extremely diverse and complex. Thus, this study does not pretend to give a comprehensive analysis of the process, but offers avenues of reflection to understand the stakes and the mechanisms at play. Even though technological adaptation exists in many (if not all) domains, the study will limit its scope to air power. The case studies will be intentionally broad, because the ultimate aim is to

¹ The swept wing, the jet engine, the rocket...

identify some likely factors of success and failure in the process. Finally, this study did not require the use of classified material, whether French or US, and is therefore accessible to any audience.

METHODOLOGY

The research uses three case studies to hunt for a theory of technological adaptation and to identify factors of success or failure. But preceding the case studies, a first chapter will expose the theoretical framework for a general process of technological adaptation. It will analyze why technological adaptation happens and detail steps in the process. This theoretical approach will help the reader to comprehend the case studies. It will also shape the theoretical framework to determine the factors of success in an instance of technological adaptation. This theoretical chapter will also provide the opportunity to expose the basic concept of sustainable development. Again, familiarization with the ins and outs of sustainable development will reveal while reading the case studies that this concept is a useful tool for analysis in technological adaptation.

Then will follow the three case studies:

- 1) The development of glider operations in the USAAF during World War II
- 2) The integration of the jet engine (a military technological breakthrough) in the airline industry
- 3) The current development of drone operations in the French Air Force.

The three case studies are intentionally broad, and the intent is to demonstrate that even if technological adaptation can take various forms, common denominators exist.

As stated above, the first case study focuses on the US glider operations during World War II. It will explain that the USAAF tried to acquire and adapt a glider force after the Germans first demonstrated the potential of this new air assault capability during the lightning attack on fort Eben Emael. This case will reveal that the US integration of

glider operations was a partial failure because of a lack of analysis from the US leadership. This case study will also reveal that the US implementation of glider operations deviated substantially from the concept of sustainable development.

The second case study is not a military case. It will analyze how the airline industry adapted a military breakthrough—the jet engine—for its business. The choice of a non-military case study is deliberate. Like the concept of sustainable development, this case study will first reveal that some principles of technological adaptation are general and can apply to both the military and the civil sector. All three cases will reveal the importance of the relationship between civil and the military sectors, but examination of how the airline industry adapted a military technology will emphasize the point. This interaction between the civilians and military airmen is indeed critical, since the two sectors have grown more interdependent in recent years. Lastly, from a military perspective, there is always some value in looking at the business world: contrary to the military, successful civilian companies tend to have a common, clearly defined objective, which is to be profitable. Because they constantly live in a strong competitive environment, business companies have to be flexible and reactive, and therefore cannot afford the sort of bureaucratic rigidity that usually characterizes a military organization. Also business companies tend to conform—sometimes even unconsciously—to the principles of sustainable development in order to be durable and profitable. For all these reasons, examining technological adaptation in civilian industry will provide numerous lessons for a military audience.

Finally, the third case study examines how the French Air Force, looking at the USAF development of UAVs, is trying to acquire a drone capability. The drone development in the French Air Force has been a long process which started in 1996 and is still under-way.² Due to budgetary constraints and a lack of urgency resulting from a peace time environment, the French Air Force has had more than fifteen years to mature and reflect on the integration of this new system. This long reflection time may provide some detailed insights into the typical cognitive patterns that accompany technological adaptation.

² French Minister of Defense, "Escadron de Drones 01.033 « Belfort »," no. 01/06/2012 (01/10/2010), <http://www.defense.gouv.fr/air/activites/unites-aeriennes/escadron-de-drones/escadron-de-drones-01.033-belfort> (accessed 23 March 2012).

These three case studies, even though far from comprehensive, will reveal some key characteristics that make an instance of technological adaptation successful or not. The focus will be placed on the cognition of the leaders who direct each case: did the leadership ask the right questions before making a decision, and did they take proper elements into consideration? Finally, the study will evaluate how each case study conforms to the core concept of sustainable development.



CHAPTER 1

THEORITICAL APPROACH OF TECHNOLOGICAL ADAPTATION

A process of technological adaptation follows a typical sequence of events:

- Observation
- Analysis
- Experimentation
- Decision and action

Many aspects of this structure are similar to the OODA loop of John Boyd.¹ The reason is simple: while John Boyd tried to develop a theoretical framework to defeat an enemy in the air, he actually “created a simple, yet elegantly robust description of all human behavior.”² In the case of technological adaptation, the analysis and experimentation steps could be assimilated with the orientation phase of the OODA loop. Similar to the OODA loop, time is a determining factor. In this regard, the case studies will illuminate different examples of time constraints and management: in the US glider case study, General Henry H. Arnold had to act and decide under time constraints because of the pressure of the war. In the case of the French development of drone operations, it almost seems that the French Air Force had no time constraints and therefore extended the analysis phase for decades (about 15 years now), always pushing the difficulty of taking a decision to the future. During the airlines jet race, on the other hand, time and timing reveal themselves as decisive in the outcome of technological adaptation. In all cases, time is nonetheless an abiding factor, and a closer look will reveal how so.

¹ For more details on the OODA loop see:

Frans P. B. Osinga, *Science, Strategy and War : The Strategic Theory of John Boyd* (London ; New York: Routledge, 2007).

² Michael Plehn, *Control Warfare: Inside the Ooda Loop* (School of Advanced Air and Space Studies, Air Univeristy, Maxwell Air Force Base, Alabama, 2000), 15.

The observation phase can be compared to a stimulus. In other words, it is an external event that will influence future courses of action. Observation is always the starting point of a technological adaptation process: for example, air force A observes that competing air force B is demonstrating a new critical capability that may place air force A in a situation of inferiority. Or airline X observes that a new military technology is available and may enhance its business. Or more frequently in modern times, air force Y observes that a new civilian technology is available and thinks that this technology may improve its operational effectiveness.

The observation stage in a process of technological adaptation is critical and represents a vulnerability within the process. The perception may be wrong. In particular during war time, the perception that the enemy has fully developed a new critical capability can easily be false. The enemy may just experiment, or he may operate in a different way because of his specific limitations, or he may even have lost control of operations in a lucky way. These common misperceptions are well explained by Robert Jervis in *Perception and Misperception in International Politics*. More specifically, as Jervis explains, “a common misperception is to see the behavior of others as more centralized, planned, and coordinated than it is.”³ Sometime things indeed happen by accident. Jervis also explains that a perceiver has a tendency to overestimate the capability of any threatening action against him.⁴ The first case study of this research paper, dealing with the US glider employment, will illustrate how the United States overestimated the threat posed by German gliders.

In fact, a victory does not necessary imply superiority, since the fog and frictions of war can always turn the tide in an unexpected way. But the stakes of any war and the fear of losing may encourage a common misperception: any new capability, concept, or idea that the enemy exposes, tends to appear decisive for future battles. This is exactly what Helmuth von Moltke expressed during the Franco-Prussian war: “We are now living through a very interesting time when the question of which is preferable, a trained army or a militia, will be solved in action. If the French succeed in throwing us out of France, all the powers will introduce a militia system, and if we remain the victors, then every

³ Robert Jervis, *Perception and Misperception in International Politics* (Princeton, N.J.: Princeton University Press, 1976), 319.

⁴ *Ibid.*, 349.

State will imitate us with universal service in a standing army.”⁵ And as Jervis reminds us, Moltke was indeed right in his prediction.

Analysis is probably the most critical step of a technological adaptation process, just as orientation is the critical element of the OODA loop.⁶ The same way computer software can straighten a blurred picture, human intelligence should be able to correct the distortion of a perception. But as Jervis maintains, human intelligence is naturally poor at making such corrections.⁷ Hence the importance of studying the sub-routine of analysis with the goal of providing improvements.

Analysis can sometimes compensate for misperceptions and aid in adjustments to context. Intelligence is necessary within the process of technological adaptation in order to make the right decisions on how to implement in one’s own organization a technology that has been developed in a different context and environment. In fact, a successful technological breakthrough or concept in one organization, at a specific time, in one specific environment and context, may be completely useless in other circumstances. Therefore, decision-makers have to raise some questions before involving their organization in the process of integrating a new technology:

- What are the reasons that made the observed technology apparently successful?
- Is it possible that the perceived effectiveness of this technology may be diminished if adapted to my specific organization?
- Is the perceived technology effective just because of its novelty? If the new concept can be easily thwarted with an effective defense, then its value should be minimized.
- Will my organization—considering its own specificity—be able to effectively integrate this technology?
- What will be the cost and the trade off, from economic, social and environmental perspectives, of integrating this new technology? In other words,

⁵ Quoted in *Ibid.*, 230.

⁶ Michael Plehn, *Control Warfare: Inside the Ooda Loop* (School of Advanced Air and Space Studies, Air University, Maxwell Air Force Base, Alabama, 2000), 15.

⁷ Robert Jervis, *Perception and Misperception in International Politics* (Princeton, N.J.: Princeton University Press, 1976), 5.

will attempting to integrate this new technology affect some of my specific critical capabilities?

- Will my organization have time to integrate and employ this new technology before it becomes outdated (or before the war comes to an end)?
- Does this new technology and concept fit my culture and my way of operating? If it does not, the resistance may be too strong to achieve any successful employment of the technology.

These are examples of questions that should be asked during the analysis step of a process of technological adaptation. Depending on the situation, some other questions may be asked: in fact technological adaptation is so complex, that it seems irrelevant to establish a checklist of questions to answer. More important is to understand the critical aspect of human intelligence in the decision process.

Experimentation is usually necessary in a technological process. Experimentation will confirm the validity of integrating a new technology in the organization before unleashing the full investment. This is even more critical when the decision to integrate a new technology may put at stake the survival of the organization. Contrary to common belief, the primary purpose of an experimental process is not to discover a new concept but to confirm an existing one.⁸ Discoveries for their part essentially come through the rupture of a scientific paradigm.⁹ This is why an experimental phase is usually necessary during a process of technological adaptation: The technology already exists, the concept has been invented, but the experimentation phase will confirm its adequacy for one's own organization.

Here again, the time factor determines the ability to conduct extensive experimentation. During war time, as the first case study will show, experimentation may happen in combat due to a lack of time. The airline case study will reveal that one way to experiment is to let another competing—but similar—organization do the

⁸ Roger Raynal, "Les Limites de la Méthode Expérimentale, et de Son Utilisation dans L'enseignement des Sciences " *Revue de l'APBG (Association des Professeurs de Biologie et Géologie)* (2003).

⁹ Thomas S. Kuhn, *The Structure of Scientific Revolutions*, 3rd ed. (Chicago, IL: University of Chicago Press, 1996), 66.

experimentation for you. It is sometimes better to come second instead of being a pioneer: Boeing with the 707 or Douglas with the DC-8 made a lot of money in improving the concept of civilian jet airplanes, when De Havilland, with its pioneer Comet jet airplane, never recovered from the cost of being the first to develop the project.¹⁰ But in every case the experimental phase should include a feedback loop. Depending on the experimental results, the analysis process may pursue some further reflections to make sure that the decision to invest in the technology will be right. This feedback loop may again reveal misperceptions of the results of the experiment. Looking at the experimental process, French mathematician and physicist Henri Poincaré stated: “It is often said that experiments should be made without preconceived ideas. That is impossible. Every man has his own conception of the world, and this he cannot so easily lay aside. We must, for example, use language, and our language is necessarily steeped in preconceived ideas. Only they are unconscious preconceived ideas, which are a thousand times the most dangerous of all.”¹¹ Personal feelings and objectives of the decision-maker may indeed bias the perception of the results of the experiment.

If the process of technological adaptation happens in a time-constrained environment, or if the level of investment is minimal, then the experimental step may be bypassed. In this case, the feedback would come from the first operational employment of the new technology.

The decision to proceed to full-rate production and operationally employ the new technology is the last step of the process of technological adaptation. However, a feedback loop during the first operations—commonly named “lessons learned” in the military—may change the fate of the technology. Even if experiments took place before the first operational use, disappointing results at an early stage of employment may reverse the decision to invest in a technology that seems unsuitable for the mission.

¹⁰ Sam Howe Verhovek, *Jet Age : The Comet, the 707, and the Race to Shrink the World* (New York: Avery), 213-215.

¹¹ Henri Poincaré, W. J. Greenstreet, and Joseph Larmor, *Science and Hypothesis* (London, New York, : Scott, 1905), 74.

Visual representation of a technological adaptation process:

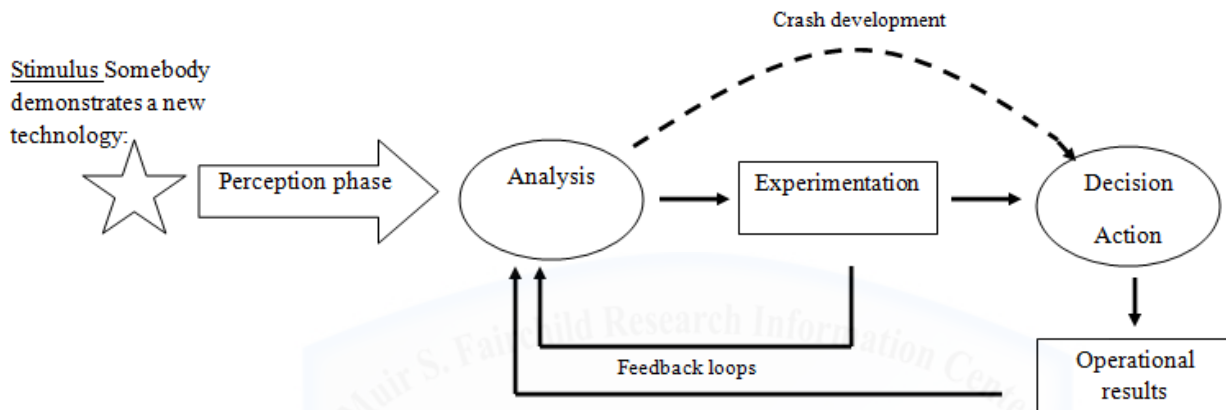


Figure 1: visual representation of a technological adaptation process

Source: Author's creation

UTILITY OF THE CONCEPT OF SUSTAINABLE DEVELOPMENT FOR TECHNOLOGICAL ADAPTATION

The concept of sustainable development is a liberal and idealist answer to the potential limits of growth on earth. Though it is difficult to find the origin of the concept, it became popular after the publication in 1972 of a report from a group of scientists from the MIT—the Club of Rome—titled “Limits to Growth.”¹² With a Malthusian flavor the report explained that the exponential growth of the population is not sustainable since it draws from the earth’s finite natural resources and simultaneously pollutes the environment to dangerous levels. The concept of sustainable development offers a theoretical framework for mitigating the limits to growth.

In the United States, the concept of sustainable development may be denigrated, since it is often associated with environmental agitators. It is, however, a core concept for many European countries, and finds multiple applications among many actors, whether governmental, military, or corporate. Within the framework of this study, the concept of sustainable development may prove a practical tool for assessing the efficacy of an instance of technological adaptation.

A commonly recognized definition of sustainable development comes from a United Nations report in 1987: “Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.”¹³ Sustainable development is based on at least on three essential pillars: economic, social, and environmental.¹⁴ Although these pillars have initially been imagined on the scale of global humanity, they have some universality and therefore apply to many different organizations.

While the economic pillar of sustainable development may appear obvious, the reader may feel confused with the social and the environmental pillars when studying the

¹² Donella H. Meadows and Club of Rome., *The Limits to Growth; a Report for the Club of Rome's Project on the Predicament of Mankind* (New York,: Universe Books, 1972).

¹³ United Nations, "Our Common Future: Report of the World Commission on Environment and Development " <http://www.un-documents.net/ocf-ov.htm#I.3>.

¹⁴ Commission of the European Communities, "Draft Declaration on Guiding Principles for Sustainable Development," (2005), <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2005:0218:FIN:EN:PDF> (accessed).

adaptation of a new technology in a military organization. But as the case studies will reveal, the social aspect of a new technology is often critical, even more critical than the possible utility of the technology itself. The ability to train, to equip, and to organize a workforce dedicated to the new technology can be a challenge. Lastly, the environmental pillar will not take on the usual connotation of protecting the environment. Within the context of this study, the environment takes on a broader sense of meaning and has nothing to do with ecology. The environmental question in military aviation can appear under various forms: for example how to integrate and manage different types of air assets in a crowded airspace, such as the glider during World War II, or the drone in today's operations. As the case studies will reveal, understanding the environmental impact of a new technology and its operational limitations are as critical as the economic or social factors.

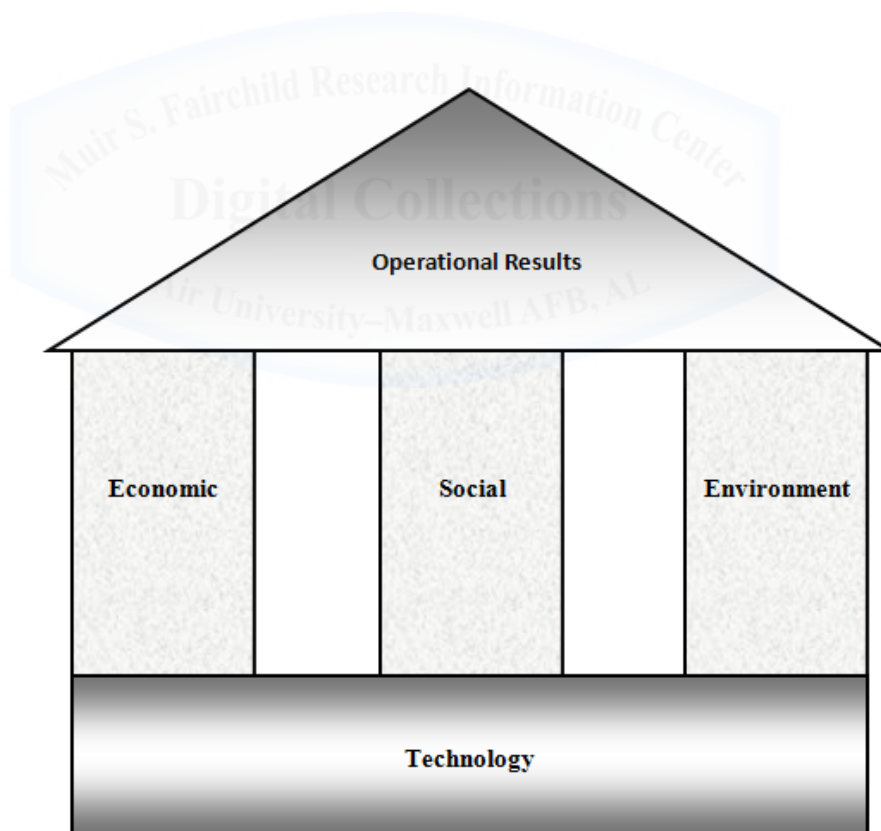


Figure 2: Sustainable development and technological adaptation
Source: Author's creation

CHAPTER 2

CASE STUDY I: THE US AND ITS MILITARY GLIDER OPERATION DURING WORLD WAR II

OVERVIEW

On 10 May 1940, Hitler launched an airborne operation against Belgian Fort Eben Emael and several bridges around Maastricht. In less than an hour, a special force of 10 DFS 230 gliders carrying 77 soldiers was able to paralyze the 800 troops and their artillery of a fort reputed to be impregnable.¹ This spectacular assault resulted in a decisive operation that opened the road for the invasion of France. Since the Germans made their best efforts to keep the glider program secret, the US leadership was completely caught by surprise. The lightning victory of Eben Emael and later some intelligence reports about a large German glider fleet prompted US planners to start the development of a military glider program. But interestingly, the full involvement of the US in its glider program happened at a time when the Germans realized the limitations and the vulnerabilities of large glider operations, in particular during the invasion of Crete in May 1941. Not too surprisingly, the first US glider assault on Sicily in 1943 was a harbinger for more ambitious operations later on in Europe.

The story of the World War II glider is fascinating in itself, but it also sheds light on the subtlety of replicating a foreign technology and its concept. Thus, the case study will not provide all the historical details of the employment of US gliders during World War II, but it will emphasize the key events that explain the process of technological adaptation.

¹ James E. Mrazek, *The Fall of Eben Emael; Prelude to Dunkerque* ([Washington,.: Luce, 1971), 183.

US AND GERMAN GLIDER ADVANCEMENT BEFORE EBEN EMAEL

Historical and cultural reasons led the United States and Germany to follow two completely different paths for the development of a military glider capability.

In Germany, two essential elements fostered the fascination for gliders. First, the Versailles treaty was an initial constraint that forced the interest of the Germans in gliders because they were banned from flying anything else: manufacturing engine parts for aviation had to stop six months after the ratification of the treaty; and all airplanes, seaplanes, and balloons built or in construction also had to be turned over to Allied governments. It is also worth noticing that balloons, zeppelins, and hydrogen production were mentioned several times, but the treaty never talked about gliders.²

The second factor that contributed to the development of gliding as a sport in Germany is cultural. Germany had a long tradition of practicing sports, gymnastics, and outdoor activities; and according to Jean-Paul Massicotte and Claude Lessard, sports and politics in Germany always had a connection.³ Following the Napoleonic wars, sport education had the political objectives of building a strong youth for future wars, and of teaching discipline and cohesion to foster national identity. In a like manner, Hitler, in understanding their potential, increased his political control on all the sport and youth organizations. As a consequence, gliding and model clubs were sponsored by the Third Reich in order to prepare future combat pilots. Still, soaring was a passion, a way to practice an outdoor sport, and it also became a competitive activity. From 1920 to the beginning of the war, competitions at Mount Wasserkuppe stimulated research and development in aerodynamics.⁴ For example, at 23 years old, the famous aircraft designer Willi Messerschmitt aided in the construction of a new light glider with an amazing glide ratio of 16 to 1.⁵ Soaring was a popular activity in Germany, and more than any other sport, it was connected with some political objectives. As John Killen said about Germany after World War I, “it became obvious that the Great War had turned

² "Versailles Treaty," Section III, <http://mjp.univ-perp.fr/traites/1919versailles6.htm>.

³ Jean-Paul Massicotte and Claude Lessard, *Histoire du Sport, de L'antiquité au Xixe Siècle* (Sillery, Québec: Presses de l'Université du Québec, 1984), 129.

⁴ Gerard M. Devlin, *Silent Wings : The Story of the Glider Pilots of World War II* (London: W.H. Allen, 1985), 11.

⁵ *Ibid.*, 12.

Germany into an air minded nation.”⁶ Soaring was one way to lay the foundations of a great air power.

In the United States, the ingredients for developing a military glider fleet were not present as in Germany. Although soaring also became popular, the military never thought about any potential operational development for the glider. Aside from using unmanned gliders as training targets for ground artillery and air gunnery, military officials never found any interest in developing a glider component.⁷ In the United States, the steady development and refinement of the light, internal combustion engine probably overshadowed the potential of the glider as a military asset.

The Versailles treaty, with its ban on the development of motorized aviation, was initially a constraint on German air power, but unexpectedly conferred a definite advantage to the Luftwaffe at the opening of the war. Not only had the Germans developed an original assault capability with the DFS 230 glider, but the intensive practice of soaring created a generation of both skilled airplane designers and combat pilots. A glider is indeed a demanding machine, first to design and then to fly. Contrary to an airplane, bad aerodynamics cannot be compensated with powerful engines. It might even be reasonable to assume that the development of soaring during the interwar period was a breeding ground for future aces. A good example is the story of Adolf Galland: at nineteen he was an expert glider pilot who dreamed of becoming a fighter pilot. He became an ace with more than one hundred kills and was promoted to General of the Fighters in the Luftwaffe.⁸ Quite possibly, the gliding experience gave to the first generation of fighter pilots a slight advantage over their enemies. And this is also probably why many air forces around the world still host gliding schools, as they understand the benefit of soaring for their pilots.⁹

Strong constraints of the Versailles treaty drove the Germans to explore and get the best from the glider, whereas in the United States, complete freedom of action did not

⁶ John Killen, *A History of the Luftwaffe* (Garden City, N.Y.,: Doubleday, 1968), 38.

⁷ Michael Manion, *Gliders of World War II: “the Bastards No One Wanted”* (School of Advanced Air and Space Studies, Air University, Maxwell Air Force Base, Alabama, 2008), 43.

⁸ John Killen, *A History of the Luftwaffe* (Garden City, N.Y.,: Doubleday, 1968), 55.

⁹ For example, both the USAF Academy and the French Air Force Academy have glider programs.

stimulate any deep reflection regarding the glider. In some circumstances, imposing sanctions on an enemy may actually make him stronger.

US GLIDER PROGRAM AFTER EBEN EMAEL

Since the Germans made all the best efforts to keep their glider program secret, the USAAF started to realize the potential military role of the glider only after the German victory at Eben Emael. Intelligence reports later confirmed that the Germans possessed a large fleet of gliders and were therefore able to air-deliver a large force of troops and mechanized equipment.¹⁰ At this point, the United States started to acknowledge the utility of the glider as military asset, and the USAAF started to rush a program for the development of a glider capability. On 25 February 1941, General Henry H. Arnold ordered a study to develop “a glider that could be towed by an aircraft.” The study was required to be complete by 1 April 1941. But in March, air force technical officials were already sending the requirements for a 15-seat glider to a dozen companies, and in May they ordered experimental models of a trainer and the flight test of an 8 and 15-seat transport glider.¹¹

Many engineering difficulties rapidly appeared as almost insuperable. Of the eleven companies, many did not reply favorably to the request of the USAAF, essentially because they were already building other military aircraft—mostly fighters and bombers—and also because the glider program was starting from scratch. No American companies had actually any experience in building transport gliders.¹² When the Waco company of Troy, Ohio, flight-tested its experimental model, the XCG4, in May 1942, the Army Air Forces decided to not wait for any other experimental competitor and directly contracted eleven companies for the production of 640 Waco GC4s. The Army Air Forces perceived an urgent need for a transport glider, and the time constraint forced them to consider that any glider produced under general license could be as good as the Waco. Other conceptual ideas on the employment of the gliders, such as using them as

¹⁰ James E. Mrazek, *The Glider War* (New York: St. Martin's Press, 1975), 53.

¹¹ *Ibid.*

¹² *Ibid.*, 55.

large cargo aircraft, did not go well beyond the experimental phase, essentially because of this time constraint, and the desire to launch the process of mass production.¹³

The eleven companies subcontracted some of the work to another 115 companies, some of them with no credentials in aeronautic construction. Among them were H.J. Heinz Pickle Company, the Steinway Piano company, and a canoe manufacturer named Brunswicke-Balke-Collender.¹⁴ The number and the diversity of the contractors and subcontractors building the GC4 continued to expand with the decision to build hundreds of Wacos “on site” in England, instead of shipping them from the United States. Not surprisingly, the lack of experience of some companies had dramatic consequences. One event captured a lot of attention when a Waco broke one of its wings during an official demonstration in Saint Louis, Missouri, killing all passengers on board, among them the Mayor and military officials.¹⁵ Ironically, one of the subcontractors building the wing was a former manufacturer of caskets. This is probably what started the nickname of “flying coffin” for the Waco. After the accident, an investigation demonstrated the already known issue of quality control in the Waco, but also acknowledged that due to the time constraints of the war, little could be done to improve the process. Nevertheless, the involvement of Ford as the mass producer of the Waco improved the construction quality of more than 2000 gliders, but that was still a small fraction of the more than 10,000 Wacos produced with poor quality.¹⁶

Production of the glider was not, however, the only difficulty for the Army Air Forces. Since most of the new gliders were requisitioned for the European theater, the lack of training gliders put another burden on the program. No glider training started before August 1942, and then the number of dedicated training gliders was not high enough to guarantee effective preparation of both pilots and paratroopers. Training at a division level was also not possible due to a lack of resources. When the production of the gliders finally picked up in 1943, the training program was then plagued by a shortage of tugs, since these were required to ferry all the new gliders across the states. As James

¹³ James A. Huston, *Out of the Blue; U.S. Army Airborne Operations in World War II* (West Lafayette, Ind.,: Purdue University Studies, 1972), 106-109.

¹⁴ James E. Mrazek, *The Glider War* (New York: St. Martin's Press, 1975), 58.

¹⁵ *Ibid.*, 59.

¹⁶ *Ibid.*, 60.

Huston explains, “the inauguration of the glider program presented another example of having immediate plans which were too big for available resources and long range plans which were inadequate for the approved airborne program—and too little coordination for the whole of it.”¹⁷

GERMANS GLIDER OPERATIONS AFTER EBEN EMAEL

After the successful assault of Eben Emael, the Germans had the opportunity to use their gliders twice in the Mediterranean. Noticing the poor experience of Mussolini in the Balkans and in Greece, Hitler felt the need to intervene to restore Axis prestige and to avoid an Italian debacle. A first glider mission was ordered on 25 April 1941 to take control of the bridge over the Corinth Canal, and then on 20 May 1941, for the first time in history, the German launched a large airborne operation over Crete.

The mission for the bridge over the Corinth Canal raised several reflections from the German leadership. Although the glider demonstrated its qualities during the attack of Eben Emael, most commanders considered that the lightning victory happened because of the secrecy of the glider. Thus for the Corinth operation, they initially favored a traditional airdrop of paratroopers, having in mind that the glider could not be as effective as in Belgium. But most of the glider pilots opposed this view and expressed it at the highest level. Indeed, the special-operations characteristic of the mission over Eben Emael created a very short chain of command in the glider community. For example, the team leader of Eben Emael, Captain Walter Koch, reported to General Kurt Student, himself in direct contact with Hitler.¹⁸ Hearing this grass-roots endorsement of the capabilities of the DFS230, the leadership finally agreed to using a glider to take the Corinth Bridge.¹⁹ The mission over the Corinth Canal failed, since the British were able to take the bridge down with a round of shells detonating one of the explosive charges installed on the structure. As James Mrazek recalls, “the Germans had seized the isthmus

¹⁷ James A. Huston, *Out of the Blue; U.S. Army Airborne Operations in World War II* (West Lafayette, Ind.: Purdue University Studies, 1972), 110-111.

¹⁸ James E. Mrazek, *The Fall of Eben Emael; Prelude to Dunkerque* ([Washington,: Luce, 1971), 29-34.

¹⁹ ———, *The Glider War* (New York: St. Martin's Press, 1975), 65.

at 0625. They had lost the bridge by 0635.”²⁰ However, the failure was relative because the destruction of the bridge certainly prevented the Germans from using it, but it also blocked the Commonwealth forces on their escape route. And since the glider did what it was expected to—deliver a force to seize the bridge—it proved again its effectiveness for this specific type of mission, *coup de poing*, where discretion and landing accuracy are necessary.

The battle of Crete presented the opportunity to test in real conditions the concept of massive invasion from the air, using both parachutes and gliders. For the operation, the Germans used 72 gliders. With 5,140 casualties of the 13,000 German troops and around 200 Junkers 52 destroyed, operation Mercury, although victorious, was still a disaster for the Germans. The essential mistake of the Germans was a gross underestimation of the Allied troops.²¹ Glider operations on the island had to face several difficulties. First, the over-water flight to Crete was far from a benign operation. The glider force lost several aircraft which disintegrated or had to be cut loose from their tugs due to heavy turbulences. All of those gliders and their occupants perished in the sea. The remaining gliders encountered tremendous difficulties in making accurate landings, because of navigational errors, confusion, and more than anything else, heavy Allied fire. The Allies were indeed waiting for the invasion and the surprise effect of the glider did not apply. For the overall operation, the gliders achieved 40% of the objective they were assigned, but at the specific place of Akrotiri, they completely failed because of poor landing-zone (LZ) selection and lack of fire support.²²

After the high cost of Crete, the Germans considered that the Allies had learned how to counter a glider attack, and that with the loss of the surprise factor, the glider was no longer an efficacious weapon. After Crete, Hitler and Goering showed no more interest in large glider operations.²³ The Germans, however, continued to use their

²⁰ Ibid., 69.

²¹ Michael Manion, *Gliders of World War II: “the Bastards No One Wanted”* (School of Advanced Air and Space Studies, Air University, Maxwell Air Force Base, Alabama, 2008), 20, 21.

²² James E. Mrazek, *The Glider War* (New York: St. Martin's Press, 1975), 77.

²³ Ibid., 78.

gliders several times in small-scale, special operations. The most famous and spectacular one was the extrication of Mussolini in the Gran Sasso.²⁴

SICILY

Due to the lack of essential training, the first large operation using the Waco took place without an American pilot. The airborne operation for the allied invasion of Sicily in July 1943 employed 133 gliders, all US Waco GC4s with the exception of 8 British Horsas. All the gliders were flown by British pilots, and they carried 1,600 paratroopers from the British I Airborne Division.²⁵ If the overall operation ended up as a victory for the Allies, the airborne part can be considered a disaster. Of the 133 gliders, only 12 landed close to their intended LZ, 47 never made it to the shore and had to ditch, and the rest landed on the island, but far from their target. The reasons for this debacle include a strong headwind that shortened the gliding path, but also a lack of training prior to the operation, as well as a lack of practice for the British pilots on the Waco.²⁶ Although the operation did not go as planned, the contribution of the glider troops was significant, and even the scattered gliders played an unexpected role in confusing the defense.²⁷

After the operation, US military leadership drew some conclusions about its airborne forces, and more specifically about the gliders. General Spaatz, writing to General Arnold, declared that “the missions had demonstrated that parachute and glider operations could be conducted without excessive loss only if surprise were obtained.”²⁸ Spaatz also put some emphasis on the need for a thorough mutual training. In the same

²⁴ After its disaster in Greece and North Africa, Italy’s dictator, Mussolini, was confined in a hotel on top of the Gran Sasso Mountain in central Italy. He was rescued on 12 September 1943 by a team German commandos using 8 DFS 230 gliders. Although one glider crashed in the mountain, the mission was a complete success, without the Germans even firing a single shot. Mussolini was evacuated in a F156 Storch S.T.O.L. aircraft. Reference: William H. McRaven and William H. McRaven, *Spec Ops : Case Studies in Special Operations Warfare : Theory and Practice* (Novato, CA: Presidio, 1995), 163-197.

²⁵ Wesley Frank Craven et al., *The Army Air Forces in World War II, Volume Two Europe: Torch to Pointblank August 1942 to December 1943* (Toronto, Canada: The University of Chicago Press, 1949), 446.

²⁶ *Ibid.*, 447.

²⁷ *Ibid.*, 448.

²⁸ *Ibid.*, 455.

vein, Eisenhower asked for a special study on the operation, and the result served as the basis of training guidance for all Allied forces during the remainder of the war.²⁹ The study concluded in general that “airborne troops should be employed only on missions suited to their role, and then only when the task couldn’t be accomplished by other means more economical or equally well suited to the mission.”³⁰ But one of the major limitations of these conclusions is that they made little distinction between an airdrop and a glider landing, with a tendency to fuse all these missions as “airborne operations.” A second major limitation of the conclusions is the lack of indication on what should be “a mission suited to the role” of a glider. This is a major point that the US military leadership never really raised: what should be the role of a military glider.

NORMANDY AND OTHER LARGE US GLIDER OPERATIONS

While Crete put an end to large-scale German glider operations, limited success in Sicily and Operation Mercury did not cool the Allies on their intent to use gliders. The three long years of planning for Overlord as well as the energy already invested in the glider program did not leave much latitude after Sicily for reconsidering the utility of the glider. During the Normandy invasion, the gliders were tasked with the crucial role of establishing an inland foothold in order to seize critical nodes of communications and disrupt German reinforcement of the beaches. Operation Neptune started with a first wave of six gliders, which successfully carried out the essential mission of marking the landing zones and drop zones (DZs) for the coming waves. For the main body of gliders, several difficulties plagued the operation. If good weather and visibility presented a problem by enabling German fire, then fog, darkness and poor visibility were even bigger dangers, since Allied gliders had to land on small LZs with many natural and artificial obstacles. Some of these artificial obstacles were named “Rommel asparagus,” strong wood poles set by the Germans to prevent any glider landings. But there were also many common natural obstacles in this part of France, such as massive hedgerows, trees, or

²⁹ Ibid.

³⁰ Ibid.

even large marshes. Despite all these difficulties, the US and British glider missions were mostly successful. Of the 517 gliders that took part in the operation, less than 10% of aircraft and personnel were lost, compared to the 75 to 80% that was predicted during planning. Moreover, during the first six days after the beginning of the airborne operation, 90% of the pilots were repatriated or identified in a safe place, and almost ready to fly a new mission.³¹ However, the picture is grimmer from a material standpoint: most of the gliders suffered too much damage after their landing to be recovered for another mission, and even those still serviceable were not brought back in time to England before being damaged or vandalized on the battle field. And so, Mrazek explains that 97% of the Allied gliders were “left to rot in the narrow pastures in which they landed.”³²

Since the airborne operation in Normandy was considered in many aspects a success, Allied leadership envisaged a much more ambitious operation in the Netherlands for Operation Market Garden. During the first days of the airborne operation, no less than 1545 paratroop planes and 451 gliders with their corresponding number of tugs flew over Holland.³³ This unsuccessful operation came with the cost of killing and wounding 7,212 of the 10,095 paratroopers. Of the 1700 glider pilots, 147 were killed and 469 wounded or captured.³⁴ The main reason for this extremely high number of pilot lost lay in the fact that none of the US glider pilots had any infantry training. The already-emerging issue in Normandy of managing the glider pilots after their landing took on utmost importance in the Netherlands. This was also a battle of interest between organizations in which airmen considered that pilots should focus on their primary mission, namely flying, and Army commanders wanted to reinforce their control on the pilots and make them, first and foremost, infantrymen. This is illustrated in the words of General James Gavin: “I feel very keenly that the glider pilot problem at the moment is one of our greatest unsolved problems. I believe now that they should be assigned to

³¹ James A. Huston, *Out of the Blue: U.S. Army Airborne Operations in World War II* (West Lafayette, Ind.,: Purdue University Studies, 1972), 186.

³² James E. Mrazek, *The Glider War* (New York: St. Martin's Press, 1975), 160.

³³ Gerard M. Devlin, *Silent Wings : The Story of the Glider Pilots of World War II* (London: W.H. Allen, 1985), 247.

³⁴ *Ibid.*, 277.

airborne units, take training with the units and have a certain number of hours allocated periodically for flight training.”³⁵

Operation Bastogne revealed the utility of the glider for specific missions. When German Panzers encircled the city of Bastogne and overran the 101st hospital, gliders were able to supply the troops with 106,291 pounds of cargo, mostly medical supplies, accompanied with medical personnel.³⁶ The discretion of their silent approach let most gliders land before being detected by the Germans. The glider was the perfect machine for this mission and it was also an excellent back-up plan, considering the shortage of parachutes for the airdrop of bundles.³⁷

The question of the glider pilots on the ground was finally solved during operation Varsity in March 1945 for the crossing of the Rhine River. After landing, the pilots of the 789 gliders regrouped in a designated area, reported to their chain of command, and were evacuated shortly after.³⁸

In order to improve the process of recovering the airworthy gliders after their landing, the AAF developed an ingenious “snatch technique”. A C-47 equipped with a special brake winch would fly over the GC4, and grasp a rope between two poles in order to snatch the glider into the air. This was a quicker and more efficient way to recover the glider than sending a team to dismantle and crate the craft. Also it is worth noting that the AAF used the snatching technique in order to medevac wounded soldiers during the battle of the Ludendorff Bridge in March 1945. This snatching technique was also extensively used in Burma.³⁹ It provided a new evacuation capability unmatched until the helicopter appeared a few years later.

³⁵ Quoted in James E. Mrazek, *The Glider War* (New York: St. Martin's Press, 1975), 219.

³⁶ *Ibid.*, 228.

³⁷ Michael Manion, *Gliders of World War II: “the Bastards No One Wanted”* (School of Advanced Air and Space Studies, Air University, Maxwell Air Force Base, Alabama, 2008), 61.

³⁸ Alan Wood, *History of the World's Glider Forces* (Wellingborough: Stephens, 1990), 260.

³⁹ John L. Lowden, *Silent Wings at War : Combat Gliders in World War II* (Washington: Smithsonian Institution Press, 1992), 16, 17.

COMMENTS ON THE US AND GERMAN GLIDER PROGRAM

While the existing literature usually considers the glider operations as heroic and essential to the Allies' victory, this study has taken a more critical position. The development of the US glider program can indeed appear as a tremendous achievement especially when considering the time constraint. But in reality, the USAAF failed to understand the reasons for the German success in Eben Emael, and therefore led the United States down the path of costly and sometimes inefficient large glider operations. The US glider program is therefore a fascinating case of technological adaptation.

While the Germans were naturally tempted to develop such a capability, for both cultural and historical reasons, the Americans found some interest in the glider only after the Germans demonstrated the capability. Lacking the tremendous experience the Germans had in building and operating gliders, the US program suffered some setbacks early, but finally achieved impressive results late in the European theater. Interestingly, while the United States copied from Germany the idea of using gliders for military operations, each country followed a different path in its glider employment. In Germany, the costly invasion of Crete led German leadership not to consider use of the glider for any large airborne operations. They, however, continued to use it on a small scale for special operations, such as the rescue of Mussolini. That decision from the Germans was probably taken a little too hastily since the main reasons for the high number of casualties was more related to an intelligence problem about the number of enemy troops, than to the overall concept of large airborne operations. Although the Germans came up with the judicious concept of the attack glider, their quick dismissal of large airborne operations reveals an overall lack of analysis at the top of their hierarchy.

In the United States, initiating the program took time and faced numerous difficulties. Engineering and investing in a completely new product when most industries were already focusing on the construction of motorized aircraft presented real challenges. The time constraints of the war added an extra pressure to the development of the glider. To overcome this difficulty, the AAF adopted the strategy of rapidly choosing one prototype of glider and mass-producing it. The GC4 glider was not the best glider, but it was rugged and possessed enough quality for the completion of most of its missions. The

Waco GC4 had a glide ratio of 8:1, while its German counterpart, the DFS230, had one around 16:1.⁴⁰ On the other hand, the Waco was a larger glider, with a higher payload, and was used both as a transport and an attack glider. In Sicily, the poor glide ratio probably doomed many Wacos to sea landing, but for most operations, such as in Normandy, gliding performance was not a decisive factor since the gliders were released over their LZs. The choice to mass-produce the first available prototype had its limitations, but it fit the US culture. Due to the time constraints, it was probably the only available option to the AAF.

On the social or human aspects of the glider program, all indications tend to demonstrate that the AAF completely underestimated the training requirements. With Sicily being the best example, the Allies clearly failed to understand that glider operational effectiveness relied heavily on training and mission preparation. However this issue was progressively resolved, and during 1944 the Allies' preparation and training for their glider operations matched the Germans.

It is also possible to criticize the US glider program for being shaped with some form of technological determinism. Following Eben Emael and the clear indication that the Germans had a large glider force, the AAF launched its program without challenging the concept of glider operations. The AAF had a longstanding doctrine for airborne operations which would paralyze the enemy by seizing key nodes of communication behind enemy lines: Field Manual 31-30 officially stated that parachute troops were considered "the spearhead of a vertical envelopment of the advance and guard element of air landing troops or other forces."⁴¹ But at no point did the discovery of the glider change or bring anything new to the concept. Gliders were used like parachutes, with only the additional ability to deliver heavier loads. But at a cost of about \$20,000 a-piece, and for most of the time with the ability to conduct only one mission, the Waco was a much more costly alternative to the parachute.⁴²

⁴⁰ Tim Lynch, *Silent Skies : The Glider War, 1939-1945* (Barnsley: Pen & Sword Military, 2008), 204, 207.

⁴¹ John L. Lowden, *Silent Wings at War : Combat Gliders in World War II* (Washington: Smithsonian Institution Press, 1992), 49.

⁴² Interestingly enough, the Russians were pioneers in the development of glider operations because they considered the glider to be a cheaper option than the expensive silk of the parachute. The Germans benefited from this Russian expertise during the interwar period through the treaty of Rapallo.

Contrary to the Germans, the AAF never really understood the specificity of the glider, and the situations in which it would provide a clear operational benefit. Compared to the parachute, the glider can proceed for a long silent approach and deliver quickly a gathered team of force, at a specific point, with a high level of accuracy. The paratroopers and their noisy cargo aircraft do not exhibit the same discretion, and airdrops tend to scatter forces over a zone. While “paradrops” are impossible above certain wind conditions, gliders can safely land in high wind, providing that the release point is moved in accordance with the wind. With a higher approach speed, gliders are less vulnerable to enemy small-arms fire than a non steerable parachute floating in the air with a slow rate of descent. On the other hand, glider operations required much more aircrew training than airdrop, because the skill of the pilot was a determining factor.

With all these considerations, the huge investment of the AAF in a glider capability appears a waste of resources and energy. Most of the European missions did not use the discreet characteristics of the glider, or its ability to concentrate forces. But on the other hand the same missions suffered from numerous constraints related to glider employment. The logistics of the glider—construction, shipping, assembly, training—were much more complex than the simple use of parachutes. Moreover, the glider was also responsible for many casualties due to the complexity of landings in a difficult environment. The Waco also provided the unique capability to deliver heavy cargo, an obvious contribution to the success of many European operations. However, if this was the unique contribution of the glider to airborne operations, a better option was then probably to develop an equipment airdrop capability from an airplane, a program probably no more complex than building a glider from scratch.

Aside from a few specific operations, such as the seizure of bridges, or the evacuation of wounded soldiers, the US glider program did not provide any really new capability over conventional airdrops. The program was complex and costly and probably diverted some resources that could have been used more efficiently.

With the advent of the helicopter, the glider disappeared as a military weapon. But interestingly enough, there are no equivalent capabilities today that can deliver both with discretion and accuracy, a small team of force able to seize a fort or a bridge. To perform this type of mission today, the only option would be to use a high altitude air

drop of modern ram-air parachutes, which imply the ability to fly high close to the zone, contrary to a glider which can be dropped far from enemy lines. Hence, no military equipment today combines the payload, discretion, accuracy, and penetration capability of a World War II glider.

The story of the US glider program can be summarized in the words of a post-war article: "Like many other new weapon, the glider was first overlooked, then over-dramatized, later over disparaged."⁴³

WORLD WAR II GLIDERS AND SUSTAINABLE DEVELOPMENT

In many ways, the concept of sustainable development helps clarify the difficulties of the US glider program. Although the gliders carried out their missions during the time of the war, the program was not sustainable over a longer period. Analysis of economic, social, and environmental factors will demonstrate some deficient thinking by the Americans.

First, as already mentioned, the program was not economically viable. In 1944, a C-47 carrying 28 paratroopers cost \$85,000 and could be used for many years.⁴⁴ On the other hand, a Waco GC4 carrying 13 paratroopers had an average price tag of \$20,000 and was usually scrapped after its first mission. When airdropping was an option, delivering troops with a glider was clearly nonsense from an economic standpoint.

Second, the social aspect of developing a glider program was largely underestimated. The key success of a glider mission relied more in the proficiency of its pilots than in the characteristics of the glider. The AAF did not realize the constraints and cost of the training requirements. Contrary to a C-47, whose pilots would return to base shortly after the airdrop, the management of the glider pilots was a complex problem that the AAF solved only at the end of the war during the last airborne operations. The overall social consideration of the glider pilot was also a problem not sustainable in the

⁴³ Quoted in Tim Lynch, *Silent Skies : The Glider War, 1939-1945* (Barnsley: Pen & Sword Military, 2008), 74.

⁴⁴ Budget and Fiscal Office Air Technical Service Command, " Average Unit Cost of Airplanes Authorized, by Principal Model: Fiscal Years 1939 to 1945," <http://www.usaaf.net/digest/t82.htm>.

long term. While the glider crews had the understandable reputation of taking great risks in their “flying coffin,” they were still considered low-class pilots. For example, the paratroopers flying in gliders earned a special hazardous pay that the glider pilots did not even receive until mid 1944.⁴⁵ The glider program did not raise insurmountable social difficulties, but they added an additional burden to the program. Unfortunately, the US leadership was slow to react and deal with social issues, some of which were indeed still not solved at the end of the war.

Third and lastly, the glider raised some serious questions about its footprint on the operational environment. Shipping the gliders from the US to the theater of operations was at first a complex issue, partially resolved by outsourcing some of the construction in England. Nevertheless, the glider is a fragile aircraft that requires complex and costly logistics to be moved from one place to another, and its recovery from the field can pose additional problems. In the air, the glider also added significant complexity to the problem of air traffic deconfliction. Whether towed or in free flight, it was one more asset in the air, with a slow airspeed, and poor maneuverability. Finally on the ground, the requirement for sufficiently large landing zones that were free of water hazards and obstacles was another environmental constraint for glider operations. During large airborne operations these LZs tended to be rapidly congested with troops, equipment, and the gliders them self. In that sense, gliders were ‘self polluting’ and posed an extreme hazard to subsequent waves.

Lewis Mumford once quipped that the battlefield was the ultimate consumer.⁴⁶ US glider operations in World War II lend credence to his contention. Fortunately, the abundance of American resources at the time could withstand such profligacy and waste, but perhaps no more. Thus copying technology in air warfare begs a rigorous analysis of alternatives and consequences.

⁴⁵ Michael Manion, *Gliders of World War II: “the Bastards No One Wanted”* (School of Advanced Air and Space Studies, Air University, Maxwell Air Force Base, Alabama, 2008), 49-50.

⁴⁶ Lewis Mumford, *Technics and Civilization* (New York, : Harcourt, 1934), 93.

CHAPTER 3

CASE STUDY II: THE AIRLINES AND THE JET AGE

OVERVIEW

Commercial aviation, with its evolution from piston to turbine engines, is a fascinating case of technological adaptation. During World War II, the Allies, and more effectively the Germans, developed the jet engine to produce faster and superior fighters. After World War II, the desire to build fast, long-range bombers provided the airline industry with jet engines powerful enough for large passenger planes.¹ De Havilland was the first to enter the jet race for commercial aviation: its Comet flew its maiden flight on 17 July 1949.² But the Comet was a false start: it was too innovative too early and its main flaw—a faulty fuselage design—resulted from a time constraint and a lack of experimentation. After several crashes, the Comet was finally grounded for years of enquiries and modifications. Nevertheless, the race to shrink the world was opened, and Boeing with the 707 and McDonnell Douglas with the DC-8 started to compete for the market of large jet airline passengers.

DEVELOPMENT OF THE JET ENGINE

With the great improvements in aerodynamics and airframe structures during the 1920s, research on the jet engine came from the need to overcome the limits of piston engines on fast airplanes. In 1931, an airplane registered a speed of 407 mph for the

¹ Ronald E. Miller and David Sawers, *The Technical Development of Modern Aviation* (London: Routledge & K. Paul, 1968), 161.

² Paolo Matricardi, *The Concise History of Aviation : With over 1,000 Scaled Profiles of Aircraft from 1903 to the Present* (New York: Crescent Books : Distributed by Crown Publishers, 1985), 153,154.

Schneider record, and that was nearly twice the speed record of 1921 at 205mph. In 1934, in order to achieve a new record of 440mph, Italian test pilot Francesco Agello had to fly an airplane powered by a combination of two engines of twelve cylinders set back-to-back. The piston engine was clearly becoming the limiting factor for speed.³ In addition to the quest of speed, the desire to build jet engines was also the result of interests in high altitude flight.⁴

Both the Germans and the British pursued independent researches on the jet engine to address the need for a more powerful propulsion system. British Air Force Cadet Frank Whittle and German physicist Hans von Ohain are indeed co-inventors of jet propulsion. They worked independently and apparently did not even know of the existence of each other.⁵ But the development of the jet engine became more effective in Germany than in the UK, essentially because of the prospect for war and the interest of the Air Ministry in this promising propulsion.⁶ Thus, the first jet airplane to fly was the Heinkel He-178 on 27 August 1939.⁷ Then, with great difficulties and limited results, the Germans flew the first operational jet fighter in April 1944: the Me 262. With the Me 262 The Germans were definitely ahead of the Allies in jet propulsion, but with its poor maneuverability, its limited endurance, and the lack of good pilots, the Me 262 did not have decisive impact.⁸ At this time, the fate of Germany was already sealed, and technology alone could not compensate the level of destruction that the Allies were inflicting upon the Third Reich. Nevertheless, the Me 262 was still a great step for aviation. As with many current modern jet planes, the Me 262 had radial compressors and its engines were set in pods. The swept wings, and the overall conception, were particularly innovative and prefigured the design of modern commercial airplanes. In

³ T. A. Heppenheimer, *A Brief History of Flight : From Balloons to Mach 3 and Beyond* (New York: Wiley, 2001), 238.

⁴ Ronald E. Miller and David Sawers, *The Technical Development of Modern Aviation* (London,: Routledge & K. Paul, 1968), 157.

⁵ Mary Bellis, "Jet Engines - Hans Von Ohain and Sir Frank Whittle," <http://inventors.about.com/library/inventors/bljetengine.htm> (accessed 18 February 2012).

⁶ Ronald E. Miller and David Sawers, *The Technical Development of Modern Aviation* (London,: Routledge & K. Paul, 1968), 159.

⁷ T. A. Heppenheimer, *A Brief History of Flight : From Balloons to Mach 3 and Beyond* (New York: Wiley, 2001), 243.

⁸ Sam Howe Verhovek, *Jet Age : The Comet, the 707, and the Race to Shrink the World* (New York: Avery), 76-78.

many ways, the features of the Me 262 helped the Allies develop their military jet aircraft as well as their commercial airplanes.⁹

If the Allies came late to the jet engine, they were able to catch up rapidly. Contrary to the Germans, they did not have to suffer from constant bombardments of their factories and from critical shortages of raw materials.¹⁰ In the United States, the desire to produce long-range jet bombers provided engines powerful enough to drive large commercial airplanes.¹¹ The Pratt and Whitney J-57, which equipped the first version of the Boeing 707, was essentially developed under government funding in order to power the B-52.¹² Similar patterns happened with the Rolls Royce Ghost engine, which powered the Comet, although it was originally designed for the De Havilland Vampire and the Gloster Meteor.¹³ With the lack of Allied investment in jet propulsion during the war, developing jet engines revealed itself to be extremely costly and was therefore possible only with government financial support.¹⁴ With powerful engines for bombers available, aircraft manufacturers found a unique opportunity to develop large commercial airplanes at minimized costs.

COMET: THE PRIDE OF A NATION

With the fall of Germany, Britain became the leading nation in jet-engine development and sought to benefit from this advantage. Building the first commercial jet was a way to restore British prestige and also an attempt to get an early advantage in the

⁹ Ronald E. Miller and David Sawers, *The Technical Development of Modern Aviation* (London,: Routledge & K. Paul, 1968), 165.

¹⁰ T. A. Heppenheimer, *A Brief History of Flight : From Balloons to Mach 3 and Beyond* (New York: Wiley, 2001), 252.

¹¹ Ronald E. Miller and David Sawers, *The Technical Development of Modern Aviation* (London,: Routledge & K. Paul, 1968), 161.

¹² T. A. Heppenheimer, *A Brief History of Flight : From Balloons to Mach 3 and Beyond* (New York: Wiley, 2001), 346.

¹³ Royal Air Force Museum, "Comet Engines - Jet Powered Passenger Flight," <http://www.rafmuseum.org.uk/online-exhibitions/comet/comet3.cfm> (accessed 18 February 2012).

¹⁴ Ronald E. Miller and David Sawers, *The Technical Development of Modern Aviation* (London,: Routledge & K. Paul, 1968), 161.

jet airline market. The mindset of De Havilland at this time is clearly illustrated in the words of one of its top representatives: "Timing is a vital factor in producing a new aircraft and it is often better to produce a slightly inferior aircraft at the right time than a perfect one at the wrong time."¹⁵ Thus, the British government supported De Havilland for the production of the first jet airliner with the hope to fill the gap in aeronautical development with the US. The British commercial aviation industry almost came to a stop during the war, and producing the Comet was a quick way to restore British prestige and place an economic bet on the future market of airline transportation.¹⁶ At the end of the war, saving the British Empire may have been a struggle, but the Comet gave hope for a new empire in the air.¹⁷

The Comet made its first commercial flight on 2 May 1952.¹⁸ It flew at a speed of 480mph at an altitude of 40,000 feet, compared to the DC-3, the most common commercial airplane at this time, which flew non-pressurized below 25,000 feet at 180 mph. The design of the Comet was derived from piston-engine airplane practice, and this was done intentionally in order to save time.¹⁹ The four Rolls Royce ghost engines with their centrifugal compressors were buried within the wings and close to the fuselage. This unique design favored better aerodynamics, minimized the probability of bird ingestion in the engines, and reduced the size of the rudder because of the limited potential for asymmetric thrust.²⁰ In many aspects, the Comet was a very advanced airplane: not only it was the first commercial jet, but it was also the first airliner to use full hydraulically actuated controls, to have glued-skin panels and a highly pressurized cabin (8.25 psi), and also the first to use high-pressure refueling.²¹ The Comet was as

¹⁵ Sam Howe Verhovek, *Jet Age : The Comet, the 707, and the Race to Shrink the World* (New York: Avery), 99.

¹⁶ Ronald E. Miller and David Sawers, *The Technical Development of Modern Aviation* (London,: Routledge & K. Paul, 1968), 179.

¹⁷ Sam Howe Verhovek, *Jet Age : The Comet, the 707, and the Race to Shrink the World* (New York: Avery), 4.

¹⁸ Royal Air Force Museum, "Comet Engines - Jet Powered Passenger Flight," <http://www.rafmuseum.org.uk/online-exhibitions/comet/comet3.cfm> (accessed 18 February 2012).

¹⁹ Ronald E. Miller and David Sawers, *The Technical Development of Modern Aviation* (London,: Routledge & K. Paul, 1968), 179.

²⁰ Francis Decon, "I Saw This Jet Liner Fly 500 M.P.H.," *Popular Science* n156 102.

²¹ Royal Air Force Museum, "Comet Engines - Jet Powered Passenger Flight," <http://www.rafmuseum.org.uk/online-exhibitions/comet/comet3.cfm> (accessed 18 February 2012).

beautiful as it was innovative. It was a revolution in commercial aviation, but unfortunately it was not completely airworthy.

On 10 January 1954, a Comet flying out of Rome exploded at high altitude over the island of Elba.²² This disastrous accident was actually not the first problem for De Havilland with the Comet. A Comet had already broken apart a few minutes after taking off from Calcutta in May 1953, and several incidents, sometimes fatal, had already happened during the take-off rotation in several locations.²³ With so much faith and pride of the British people in the Comet, it took a second explosion in the air on April 1954 for Prime Minister Winston Churchill to ground the airplane and call for an inquiry to determine the reason for the frequent accidents.²⁴ Autopsy of the remains and analysis of the wrecks suggested that the passengers died from abrupt and explosive decompression. Since there was also no sign of engine fire or bomb explosion, the investigation team opted for the possibility of structural failure. To validate this hypothesis, an ingenious, highly constrained system was then constructed to test the structure of one of the grounded Comets. The plane was placed in a gigantic water tank which was repeatedly filled-up and drained to simulate a high number of pressurization cycles, and at the same time, hydraulic actuators shook the wings to put the structure under constant stress. After about 2000 cycles, and an equivalent flight time of 9000 hours, a small fissure appeared at the corner of a one of the squared windows. This fissure was the result of metal fatigue, and it was enough to tear apart the structure of the airplane when in flight and pressurized.²⁵ This was a devastating result for De Havilland and the British government. It took four years to redesign the Comet IV, which was then an obsolete plane compared to the new airliners developed in the United States. And even if the Comet was the first commercial jet to fly over the Atlantic, the plane did not sell well in a market that was soon to be dominated by Boeing and Douglas.

²² T. A. Heppenheimer, *A Brief History of Flight : From Balloons to Mach 3 and Beyond* (New York: Wiley, 2001), 349.

²³ Sam Howe Verhovek, *Jet Age : The Comet, the 707, and the Race to Shrink the World* (New York: Avery), 15.

²⁴ T. A. Heppenheimer, *A Brief History of Flight : From Balloons to Mach 3 and Beyond* (New York: Wiley, 2001), 349.

²⁵ Sam Howe Verhovek, *Jet Age : The Comet, the 707, and the Race to Shrink the World* (New York: Avery), 172-174.

Although the Comet flew until 1997, it did not become a commercial success: only 114 Comets were built—to include the prototypes—compared to a thousand of the ubiquitous Boeing 707.²⁶ Nevertheless this first British experience in jet airliners contributed tremendously to the safety of the next generation of airplanes. Squared windows disappeared and were advantageously replaced with oval windows. Aircraft builders also paid more attention to the concept of failsafe structure, which permits the rupture of some parts without compromising the entire aircraft. Furthermore, the next generation of jet airliners corrected the poor flying qualities of the Comet at low speed which had been the cause of several incidents during rotation at take-off. Lastly, all the British efforts to solve the Comet mystery allowed the development of investigation techniques that became useful in later accident cases.²⁷

BOEING: BUILDING THE DASH-80 AND THE 707

While the British immediately jumped into the turbine race for commercial passengers, US manufacturers were much more cautious. It was the beginning of the Cold War, and the aircraft industry was already making large profits in selling military planes. American aircraft builders had no reason to risk bankrupting their company in developing commercial jet airplanes.²⁸ It actually took the will of a few dreamers as well as a combination of some unexpected elements to build the 707. At this time, William Allen was Boeing's president.²⁹ Allen was a dreamer and an innovator, but he was also economically a realist, and his main objective was for Boeing to make money, diversify, and minimize risk. The main restraint on Boeing in the development of a large commercial jet was economic, since the level of investment required for the jet could

²⁶ Timothy May Walker and Scott Henderson, *The First Jet Airliner: The Story of the De Havilland Comet* (Ponteland: Scoval, 2000), 169.

²⁷ T. A. Heppenheimer, *A Brief History of Flight : From Balloons to Mach 3 and Beyond* (New York: Wiley, 2001), 160.

²⁸ Ronald E. Miller and David Sawers, *The Technical Development of Modern Aviation* (London,: Routledge & K. Paul, 1968), 179.

²⁹ Boeing official website, "William M. Allen ", <http://www.boeing.com/history/boeing/allen.html> (accessed 20 February 2012).

quickly bankrupt the whole company if plane was not selling. But in 1951 Allen found a unique opportunity to make the dream possible. With the Korean War, Congress put an “excess profit tax” on aircraft builders who were making additional profit due to the war demand. With this regulation, Boeing, which was essentially a military aircraft manufacturer, expected its 1951 profits to be taxed at 82%.³⁰ One way to circumvent this regulation was to invest a large amount of money in the development of a commercial jet aircraft. Any dollar invested in this project would in reality cost Boeing 18 cents, the other 82 cents being equivalent to tax evasion.³¹

Another factor that also reinforced Allen’s intention to develop a large commercial jet airliner was the possibility to build one airplane for two different programs. The prototype of the 707—the Dash80—could be the platform for a commercial jet, as well as a refueling tanker that the Air Force was seeking.³² With the tanker program, the Pentagon actually paid for the tooling and production equipment that ended-up also building the 707.³³ This was the real genius of Allen, the ability to minimize the cost and the risk of developing the plane, first by capitalizing on a tax break and second in building a multi-role platform, or in other words, making a dual-use of technology.

For the development of the Dash 80, Allen invested in a huge wind tunnel capable of subsonic aerodynamic testing.³⁴ After hours of experimentations in the tunnel, Boeing engineers explored with great accuracy the German concept of swept wings. In fact, the Germans had already studied swept wings but they tried them on the Me 262 almost by accident: the Me 262 had a center of gravity too far aft, and slightly sweeping the wings aft was the easiest fix.³⁵ But Boeing engineers knew that the design of the swept wings

³⁰ Sam Howe Verhovek, *Jet Age : The Comet, the 707, and the Race to Shrink the World* (New York: Avery), 107.

³¹ *Ibid.*, 107, 108.

³² *Ibid.*, 109.

³³ T. A. Heppenheimer, *A Brief History of Flight : From Balloons to Mach 3 and Beyond* (New York: Wiley, 2001), 348.

³⁴ Sam Howe Verhovek, *Jet Age : The Comet, the 707, and the Race to Shrink the World* (New York: Avery), 89.

³⁵ T. A. Heppenheimer, *A Brief History of Flight : From Balloons to Mach 3 and Beyond* (New York: Wiley, 2001), 142.

Heppenheimer explains how a similar center of gravity issue happened on the DC3, which resulted in adopting swept back wings for a plane that was flying below 200mph.

was critical in order to safely achieve high subsonic speed, but also to ensure maneuverability at slow speed during takeoff and landing. After testing 68 different types of wings during more than 27,000 hours, Boeing engineers found out that a 35° angle was the best formula for the wings of the Dash 80. With the wind tunnel, designers also found out another innovation for the Dash 80. Instead of having the engines buried in the wings as with the Comet, they would place them in pods under the wings, with an optimal location slightly ahead of the leading edge.³⁶ This design did not affect the cruising performance of the airplane, but it increased the maneuverability at low airspeed, a critical weakness of the Comet. It also reduced the potential risk of having an engine fire spreading across the wings, and it made easier the maintenance of the engines. Lastly, it solved the problem of wing flutter and therefore reduced the weight of the airframe structure at the wing roots.

Even if in the history of commercial aviation the 707 was a jump in modernity, Allen had no guarantee that he could sell the airplane. Among the American public, the jet was more a matter of military than commercial aviation.³⁷ And since airline executives were already making decent benefits using propeller-driven airplanes, they too saw no reason to risk their business with costly jets. Compared to the \$1.5 million of a DC-7, a jet such as the 707 would cost not less than \$4 million. The feeling at this time about jet commercial aviation was clearly illustrated in the words of Ralph Damon, president of TWA: “the only thing wrong with the jet planes of today is that they won’t make money.”³⁸

DOUGLAS ENTERS THE JET RACE

Not only was the market of commercial jets not clearly defined, but Boeing had also to reckon with a new competitor in Douglas. Even if Douglas was years behind in

³⁶ Ibid., 343.

³⁷ Sam Howe Verhovek, *Jet Age : The Comet, the 707, and the Race to Shrink the World* (New York: Avery), 93.

³⁸ Quoted in T. A. Heppenheimer, *A Brief History of Flight : From Balloons to Mach 3 and Beyond* (New York: Wiley, 2001), 347.

the development of a large commercial jet, the company founder's objective was clear: "In our business, the race is not always to the swiftest or the first to start. There may be some distinction in being the first to build a jet transport. It is our intention at Douglas to build the best and the most successful."³⁹

Douglas had the handicap of being behind Boeing in the development of jet airliners with the DC-8, and moreover it had no prototype. But on the other hand, Douglas was able to offer the perspective of building an aircraft with a larger cabin, and above all, with better performances than the 707. The superior range of the DC-8 would allow nonstop transatlantic flights, and this was possible with the new generation of more fuel-efficient jet engines in the J-75, also developed for military use. With such prospects on the DC-8, Pan American—the largest US and European airline—placed some purchase options on the DC-8 and the 707, but with an official preference for the Douglas DC-8. For Boeing, the fear was then to reiterate with the 707 the experience of the Stratocruiser.⁴⁰ The Stratocruiser (Boeing 377) was a civilian version of the C-97 Stratofreighter, itself derived from the B-29 bomber. Relying on World War II technology, the plane quickly became outdated and Boeing sold only 56 of them.⁴¹ For Boeing, the 707 could not suffer the same fate: the plane had to sell and therefore had to be the best on the market.

Since Douglas and its DC-8 was emerging as a potential leader in the new market of jet aviation, Boeing made the difficult but logical decision to modify the 707. This was both costly and risky. The new 707 would use the J-75 engine and also be capable of non-stop transatlantic flights. But this upgrade necessitated costly modifications on the wing structure, and also required new and lengthy flight tests. Boeing was again taking great risks, but this move happened to be the right decision as these figures reveal: in 1955, Douglas sold 100 DC-8s when Boeing had only 72 orders for the 707, but in 1956 the trend reversed, and in 1957 the DC-8 sales became almost marginal. Douglas, in fact, started to face the drawbacks of its strategy: coming late to the market, Douglas did not

³⁹ Sam Howe Verhovek, *Jet Age : The Comet, the 707, and the Race to Shrink the World* (New York: Avery), 182.

⁴⁰ T. A. Heppenheimer, *A Brief History of Flight : From Balloons to Mach 3 and Beyond* (New York: Wiley, 2001), 352.

⁴¹ Boeing official website, "Model 377 Stratocruiser Commercial Transport," <http://www.boeing.com/history/boeing/m377.html> (accessed 8 May 2012).

build a prototype, and as a consequence, the first DC-8s revealed their imperfections. To fix them, Douglas had to modify the entire chain of production, and this was economically a bottomless pit compared to Boeing's use of a prototype.

The 707 became a tremendous commercial success, and Boeing sold more than a 1000 of them. Most of the technical solutions adopted on the 707 prefigured at least half a century of airliner design. Even today, an Airbus A340 or even an A380 is not very far from the design of the 707. For its part, the DC-8 was also a good airplane and sold more than 500 copies. But Douglas had not made the best jet airplane, and after merging with McDonnell in 1967, the company ended-up absorbed by Boeing in 1997.⁴² On the British side, the Comet IV became the first commercial jet to fly a transatlantic route, but it was not enough of an achievement to make the public forget about the tragic beginning of the aircraft. Less than 114 Comets were built, and in 1963 De Havilland disappeared as a company and became a division of Hawker Siddeley Aviation Ltd.⁴³ Although the failure of the Comet was probably not the only factor that played in the disappearance of De Havilland, it certainly played a major role in the company's decline.

THE TECHNOLOGICAL ADAPTATION PROCESS OF THE JET RACE

The aeronautical industry as well as the airlines took a considerable time to understand the value of the jet engine for commercial aviation. The initial perception that the jet engine was not for the civilian market proved wrong. Jet engines were considered complex, fragile, dangerous and expensive for commercial use. None of this turned out to be true, and the public craze for jet airplanes started immediately when they became commercially available. As Michael Smith explains, the post-World-War-II era was a time when technological determinism was shaping the public identity. The belief was that "social progress is driven by technological innovation, which in turn follows an

⁴² _____, "The Boeing Logbook," <http://www.boeing.com/history/chronology/index.html> (accessed 22 February 2012).

⁴³ Royal Air Force Museum, "De Havilland - Post War," http://www.rafmuseum.org.uk/online-exhibitions/dehavilland/post_war.cfm (accessed 18 February 2012).

‘inevitable’ course.”⁴⁴ Even after the Comet had blown-up in the air, its airline (British Overseas Airways Corporation) was frequently selling out all the available seats on its jet flights, perhaps because they represented social progress. With all its imperfections, the Comet proved that the jet engine had its place in commercial aviation, whether or not most aircraft designers were fully persuaded.

Experimentation was an essential factor in building a successful jet liner. De Havilland and the British government made every effort to be first in the jet race. As the first commercial jet plane, the Comet was also an experiment itself. And as previously mentioned, it proved the validity of developing jets for the airlines, but it also brought to light some critical aspects of jet operations. In many ways, the Comet experience contributed to the success of its competitors. For example, the square windows of the Comet, which were responsible for the mid-air explosions, were advantageously replaced by oval windows on the next generations of jet liners. The new jets improved their maneuverability at low speed, and they provided means of transportation for the masses instead of for the elite. For Douglas, the time factor did not favor experimentation, and the DC-8 never had a prototype like the Dash-80 for the Boeing 707. Extensive experimentation with the Dash-80 is one of the reasons why the 707 became such a commercial success. If there is one thing that the jet race teaches, it is the sensitivity of the time factor: the time of experimentation directly influenced the design of an airplane. The design of the Comet was flawed because it was the first airplane of its own type, and therefore did not incorporate lessons learned from past experiment. The Comet was too innovative too quickly, the DC-8 came slightly too late in the fray and lost some attraction even though it was a good airplane, and Boeing with the 707 was about right in its time management. In aeronautics, launching a new technology a few months too quickly or too late can ruin a company.

Feedback considerations also played a critical role. De Havilland and the British government had a tendency to deny the Comet’s problems because they put too much hope and confidence in the program. In many ways, the management of the Comet was similar to the development of a desperate military program to achieve victory. No one

⁴⁴ Merritt Roe Smith and Leo Marx, *Does Technology Drive History? : The Dilemma of Technological Determinism* (Cambridge, Mass.: MIT Press, 1994), 38.

would put the project into question until failure became grossly obvious. On the other hand, Boeing stayed continually alert for any feedback information and made the right decision to modify the 707 in order to keep the airplane competitive against the DC-8.

SUSTAINABLE DEVELOPMENT AND THE JET RACE

Looking at the development of jet commercial aviation through the concept of sustainable development can yield important insights. Switching from propeller to jet conformed—sometimes unexpectedly—with the three essential pillars of sustainable development: economic, social and environmental. The jet airplanes revealed themselves to be money-makers, they had great social appeal, and the governments found answers to the initial environmental issues.

The real unexpected benefit of jet airplanes was their ability to increase the airlines' profits. The fear that the jet engine would not be profitable was initially a genuine restraint for the airlines. But with the exception of short flights, where the extra fuel that jet engines burn during take-off is not compensated by a long-enough high-altitude cruise, jet airliners revealed themselves to be more cost-effective than propeller airplanes. First, the simplicity of the design made the jet engine more reliable than its propeller counterpart, and this of course reduced maintenance costs: jet engines have neither the complex gearbox, nor the fragile pitch-control system necessitated by the propeller. Second, the overconsumption of fuel by jet engines was effectively compensated by the increased airplane speed, as well as the augmentation in airplane capacity. Having four jet engines on a 40-seat plane such as the Comet was not economically sustainable. But the size of the Boeing 707 and its seating capacity of between 150 and 200 passengers changed the whole economic logic of jet engines. As Miller and Sawers explain in *The Technical Development of Modern Aviation*, airplanes such as the Boeing 707 or the Douglas DC-8 cost 33% less to operate and flew 40% faster than the last generation of propeller planes.⁴⁵ This higher speed reduced the flight

⁴⁵ Ronald E. Miller and David Sawers, *The Technical Development of Modern Aviation* (London, : Routledge & K. Paul, 1968), 3.

time, lowered the level of maintenance per miles, increased the tempo between each flight, and therefore raised the overall profitability of the airplane.

If economically the jet engine was a surprise, the social appeal it created was also unexpected. In the airline industry, the initial perception was that the engine had too much of a military connotation, and therefore passengers would be reluctant to use jet airliners. In reality, jet airplanes quickly attracted passengers for many reasons.⁴⁶ Not only were jet airplanes about twice as fast as propeller-driven airplanes, but they also flew more smoothly at high-altitude, where there is less turbulence, and with less vibration. Also, the gain in power with jet engines gave the opportunity to build larger airplanes such as the 707 or the DC-8, with roomier cabins and greatly improved overall comfort. Lastly, due to their simplicity, jet engines quickly became more reliable than piston and turbine-driven propellers, and the fear of seeing a motionless propeller while in flight completely disappeared. Even if a jet engine were down, the passengers would hardly notice.⁴⁷

Jet airplanes raised some environmental questions. First they needed longer runways: while the last generation of propeller airplanes such as the DC-7 required a 7000 feet runway, a jet like the 707 needed about 11,500 feet.⁴⁸ Also, with both the increased capacity of the airplanes, and the faster tempo of jet service due to the fact that jet planes spent less time in the air, airports had to be modernized. Lastly, the noise of jet engines during take-off required new airports to be farther away from city center and also called for aircraft builders to invest in noise suppression: Boeing, for example, spent \$10 million on the development of this technology in the 1950s.⁴⁹ All of this called for large public investment in airport infrastructure, as well as a modernization of ground navigation equipment to cope with increasing and faster traffic.⁵⁰ Investing in airport infrastructure was usually a good bet for cities: for example, Atlanta in Georgia economically flourished in becoming a major hub while its closest competing city,

⁴⁶ Ibid., 177.

⁴⁷ T. A. Heppenheimer, *A Brief History of Flight : From Balloons to Mach 3 and Beyond* (New York: Wiley, 2001), 360.

⁴⁸ ———, *Turbulent Skies : The History of Commercial Aviation*, Sloan Technology Series (New York: J. Wiley & Sons, 1995), 185.

⁴⁹ Ibid., 186.

⁵⁰ Ibid., 171-174.

Birmingham, AL, stagnated with its old and small airport. While the airports may not be the only reason for the discrepant growth of these two cities, they probably played a significant role.

CLOSING REMARKS ON THE JET AGE

In many aspects, strategy in the business world—in this case in the aviation industry—seems to resemble military strategy. In particular, some similarities between the first case study—WWII gliders—and the jet race in commercial aviation are striking. In both cases, the initial perception was wrong: the USAF overestimated the potential of the glider, while the airline industry had a tendency to underestimate the value of the jet engine for commercial aircraft. Also, in both cases experimentation and timing revealed themselves as critical. The race to win a war seems not very different from the race to win a new market, and whether civilian or military, the late starter usually pays the price of not having enough time to experiment, but gains the advantage of learning from a competitor's error. Lastly, military-civilian cooperation appears beneficial, whether from a military or a civilian standpoint. The German military glider program was initially successful, essentially because gliding was very popular as a sport among the German youth. In a similar manner, Boeing found a tremendous advantage in developing the Dash-80, a platform that could serve the development of both commercial and military airplanes.

CHAPTER 4 :
CASE STUDY III :
N'ER DE VOL SANS HOMME :
THE FRENCH AIR FORCE AND DRONES

OVERVIEW

Although French industry has extensive experience and expertise in manufacturing drones, the last decade revealed a French Air Force without any modern drone capability. Companies such as Nord Aviation or Aérospatiale have built remote-controlled flying targets for more than thirty years, and the French Army has continually showed some interest in drones.¹ But for the French Air Force (FAF), even today, drone capability is extremely limited and its future remains uncertain.² In 2010, the French Air Force stood up its first operational drone squadrons, the 01.033 Belfort. But the squadron operates only four Harfangs, a modified version of the Israeli drone “Heron” built by the European Aeronautic Defense and Space Company (EADS).³ Even more restrictive is the single ground station available for the squadron. With only four airframes and one ground station, the French Air Force is able to deploy two drones in Afghanistan at the cost of being unable to conduct any training at home, since the lone ground station is also deployed. This poor capability does not, however, reflect a lack of interest in drones. Quite the opposite, the advent of the drone in Israel during Operation Peace in Galilee in 1982 as well as the exponential rise in the use of drones by the United States has aroused interests among the French establishment and stimulated many debates. In a typical case of technological envy, France covets the US drone capability, but also fails to

¹ Nord aviation built the CT20 target for fighter planes training air ground to air missile, and Aérospatiale built the drone target C22.

Pierre Pascallon, *Quel Avenir pour les Drones : Avions Sans Pilote* (Paris: L'Harmattan, 1998), 43.

² Marc Grozel and Geneviève Moulard, *Drones, Mystérieux Robots Volants : les Yeux et le Feu du Xxie Siècle* (Panazol: Lavauzelle, 2008), 222.

³ Jean Guisnel, "Dans le Secret des Drones de L'armée de L'air " *Le Point* (2009), <http://www.lepoint.fr/actualites-monde/2009-04-18/dans-le-secret-des-drones-de-l-armee-de-l-air/1648/0/336071> (accessed 20 march 2012).

acknowledge it may have neither the need nor the economic power for such a capability. Trapped into some belief of technological determinism, the French Air Force envisions the drone to be an “inevitable” technology regardless of cost. The organization has also ignored its true needs and seems confused, at best. Typical of technological innovation that displaces proprietary subcultures, the French Air Force drone program drags out into long debates in which organizational interests tend to supersede operational and political needs. While the drones are of proven benefit, and while France has an industry capable of the producing innovative drones, the French Air Force has been unable to set up a coherent force of unmanned aerial vehicles (UAV), and this situation will likely endure for a while.

HISTORICAL REVIEW OF THE DRONES IN FRANCE

The first experimentations with drones in the French military occurred in the 1950s. The French Air Force at this time was trying to make remote-controlled flying targets using its decommissioned aircraft. The first unmanned flight occurred in the experimental center of Bretigny with the remotely controlled flight of a Vampire.⁴ Since the mission of this makeshift drone was to test and improve the effectiveness of interception missiles, the experimental team decided to load cameras onboard the flying target in order to study with more accuracy the trajectory of the missiles when they were approaching the target.⁵ This accidental birth of the observation drone encouraged the French Air Force to pursue some experimentation in this domain, however with great difficulties: the target planes were antique, and the remote technology was still in its infancy. Numerous accidents occurred, essentially due to pilot error or radio interference. For these reasons, most of the experimentations took place in the Algerian

⁴ Océane Zubeldia, "L'armée Française et L'utilisation des Drones dans les Missions de Reconnaissance, de 1960 au Conflit du Kosovo," *Revue historique des armées* (2010), <http://rha.revues.org/index7104.html> (accessed 20 March 2012).

⁵ Claude Petit et Patrick-Xavier Henry, "Les Entrepôts de L'armée de L'air, le CEV et les Cibles Téléguidées," *Revue Trait d'Union* (1980): 115. Quoted in Océane Zubeldia, "L'armée Française et L'utilisation des Drones dans les Missions de Reconnaissance, de 1960 au Conflit du Kosovo," *Revue historique des armées* (2010), <http://rha.revues.org/index7104.html> (accessed 20 March 2012).

desert.⁶ Despite this interest in the drone, the French Air Force did not develop any operational capability, simply because unmanned flight was at this time not a priority.⁷

While the French Air Force did not invest in a real operational development of the drone, the Army in 1960 saw potential in owning unmanned observation assets. Thus, Nord Aviation, a corporation that was already building remote-controlled targets, developed an observation drone, the R20, a modification of the already existing CT20 flying target.⁸ But the CT20 was plagued with technical issues; in particular its remote-control system was unreliable.⁹ France then decided to join a Canadian-British drone program in 1978 and bought the Canadair CL-89 and later the CL-289.¹⁰ Since the Army showed great interest in acquiring a drone able to transmit real-time imagery, the French Directorate General of Armament (DGA) developed two main drone programs: project Scorpion in 1979 for recognition and target identification, and, in 1990, the Brevel drone.¹¹ Interestingly, the Army need for the drone was and remains not far different from the one at the eve of World War I: to possess an aerial platform able to see behind the first ridgeline in order to adjust artillery fire.¹²

The French participation in the first Gulf War (1990-1991) was a turning point that revealed the full potential of the drone. For its intelligence needs the Army used different platforms, including the Horus system, a Moving Target Indicator (MTI) radar in a Puma helicopter that transmitted real-time information to a ground station. But the helicopter had some limitations and in particular was vulnerable to enemy fire.¹³ Thus

⁶ Océane Zubeldia, "L'armée Française et L'utilisation des Drones dans les Missions de Reconnaissance, de 1960 au Conflit du Kosovo," *Revue historique des armées* (2010), <http://rha.revues.org/index7104.html> (accessed 20 March 2012).

⁷ Ibid.

⁸ Jean-Dominique Merchet, "La Préhistoire des Drones Français " *Secret défense* (2010), http://www.marianne2.fr/blogsecretdefense/La-prehistoire-des-drones-francais_a61.html (accessed 20 March 2012).

⁹ Pierre Pascallon, *Quel Avenir pour les Drones : Avions Sans Pilote* (Paris: L'Harmattan, 1998), 46.

¹⁰ Océane Zubeldia, "L'armée Française et L'utilisation des Drones dans les Missions de Reconnaissance, de 1960 au Conflit du Kosovo," *Revue historique des armées* (2010), <http://rha.revues.org/index7104.html> (accessed 20 March 2012).

¹¹ Ibid.

¹² Ibid.

¹³ Maurice Faivre, "Le Renseignement Militaire Dans La Guerre Du Golfe," *Institut de Stratégie Comparée, Commission Française d'Histoire Militaire, Institut d'Histoire des Conflits Contemporains*, http://www.stratisc.org/strat_5152_Faivre.html (accessed 21 March 2012).

the division Daguet in Iraq decided to deploy an experimental drone program, the MART, a small remote-control airplane that technically was not far from a large RC model airplane. The MART weighed around 200 pounds, had a speed range between 50 and 120 knots, and was visually piloted by its ground operator after being launched. After a first portion of visually guided flight, it had the capability to fly autonomously using GPS positioning.¹⁴ The MART carried out only a small number of missions, but it nevertheless revealed value for the Army and minimized the risk of losing a helicopter and its crew. One of the MARTs indeed was shot down by enemy fire in the First Gulf War on 19 February 1991.¹⁵ Even though the drones were used sparingly, the enthusiasm of the Daguet division for the MART confirmed that the drone would become an essential player in modern warfare. This feeling was also reinforced by the observation of the new American way of war during Desert Storm. While the reasons for Allied success during the first Gulf War are both manifold and debatable, many observers believed that Desert Storm announced a Revolution in Military Affairs (RMA). Warfare was to become network-centric and superiority would derive from the possession of an “information advantage.”¹⁶ In this complex network—also called a system of systems—the drone would play a critical role and constantly feed the network with real-time information.¹⁷ During a debate at the French National Assembly in 2004, Pierre Pascallon, a politician and academic specialized in military issues, explained how Net-Centric-Warfare (NCW) “relies essentially on a CROP (Common Relevant Operative Picture), which is fed by drones, satellites, and reconnaissance airplanes.”¹⁸ While the French—as the Americans—later understood that the effects of the RMA were probably overestimated, the drone still attracted a lot of attention because it fit well with the new

¹⁴ MART stands for Mini Avion de Reconnaissance Téléguidé. Pierre Pascallon, *Quel Avenir pour les Drones : Avions Sans Pilote* (Paris: L'Harmattan, 1998), 44.

¹⁵ Général Jean-François Durand, "Guerre Du Golfe – Operation Daguet – 15 Ans Apres (Souvenirs)." <http://amicale.daguet.pagesperso-orange.fr/Temoignages/colonel%20Durand.htm> (accessed 21 March 2012).

¹⁶ P. W. Singer, *Wired for War : The Robotics Revolution and Conflict in the Twenty-First Century* (New York: Penguin Press, 2009), 184.

¹⁷ *Ibid.*, 185.

¹⁸ Pierre Pascallon, *Satellites et Grands Drones dans le Cadre de la Politique Spatiale Militaire Française et Européenne* (Paris: Harmattan, 2005), 24.

concepts of 'war without death' (*guerre zéro mort*) and helped the political leaders manage the increased media coverage of modern conflicts (CNN effect).¹⁹

After Desert Storm, the French Army deployed drones again in Bosnia and Herzegovina. The 7th artillery regiment (7^{ème} RA) used the CL-289 and completed more than thirty missions between 15 February and 30 May 1995, contributing to the enforcement of the Dayton agreement by identifying and counting the military assets on the ground.²⁰ At the same time, the French Air Force finally started to commit with more resolve to the development of a drone capability and opted for the acquisition of an Israeli platform, the Hunter, which arrived in 1996 at the flight test center of Bretigny and then in Mont de Marsan.²¹ But in 2001, although the drone was still in the experimentation process, the French Air Force deployed the Hunter in Kosovo and flew more than twenty-five missions. As Anne Musquere explained, "with Kosovo, the drone became a key player for any modern military, and it is now one of the essential elements of the digitalized combat network."²²

With the Hunter scheduled for retirement in 2004, the French Directorate of Armament (DGA) decided to accept an EADS proposition for a so-called SIDM (Système Intérimaire de Drone MALE) drone, the Harfang.²³ The SIDM is a Medium Altitude Long Endurance (MALE) drone, its concept based on an Eagle 1 platform built by Israel Aerospace Industries (IAI).²⁴ While the SIDM was supposed to enter service in 2003 in order to smoothly replace the retiring Hunter, the program experienced five years

¹⁹ Grégory Bouterin and Emmanuel Goffi, "Les UAV Armés Sous le Feu des Débats," *Revue de Défense Nationale* n°735 (2010).

²⁰ Océane Zubeldia, "L'armée Française et L'utilisation des Drones dans les Missions de Reconnaissance, de 1960 au Conflit du Kosovo," *Revue historique des armées* (2010), <http://rha.revues.org/index7104.html> (accessed 20 March 2012).

²¹ The French flight test center is called (CEV: Centre Experimental en Vol). Official history of the first French Air Force Squadron is available on the official presentation brochure: <http://www.defense.gouv.fr/content/download/87174/799241/file/Plaque%20escadron%20de%20drones.pdf> (accessed 22 March 2012)

²² Anne Musquere, "Les Drones Montent en Puissance," *Air & Cosmos*, 11 June 2004 (2004): 24.

²³ SIDM is a bilingual acronym of acronyms: Système Intérimaire de Drone MALE, where MALE stands for Medium Altitude Long Elongation. The word "intérimaire" means temporary, which suggest that the Harfang was supposed to be a temporary solution. The Harfang is the actual name of the French SIDM drone.

²⁴ Yves Vandewalle and Jean Claude Viollet, "Rapport D'information Déposé en Application de L'article 145 du Règlement Par La Commission De La Défense Nationale Et Des Forces Armées sur les Drones," (2009), <http://www.assemblee-nationale.fr/13/pdf/rap-info/i2127.pdf> (accessed 23 March 2012).

of delay. It finally arrived in the French Air Force in 2008, the year in which it was originally supposed to be retired!²⁵

Since the Harfang was then extended to proposed retirement in 2013, the question of its successor arose almost at the same time it entered service. The new French and British cooperative agreement signed in London by Nicolas Sarkozy and David Cameron in November 2010 should offer a solution to the third generation of MALE drone but not earlier than 2020. Thus, the French Air Force needs again a temporary solution to make ends meet between 2013 and 2020. One of the options was to buy seven US Reapers with two ground stations from General Atomics at a cost of €209 million. The second option came from Dassault with also an offer for seven drones and two ground stations. The acquisition process appears to be similar to what happened with the Harfang: Dassault would build an agreement with IAI and buy the Heron-TP for the airframe. Dassault would then modify it for French Air Force needs at a total cost of €318 million.²⁶ While Dassault offered a “30% more expensive and 20% less effective asset,” the French government made the decision in November 2011 to reject the American (Reaper) proposal and opted for the Dassault-IAI offer.²⁷ This decision was disapproved by the Senate, and began what the newspaper *Le Point* called “the war of the drones,” an open confrontation between the government, the National Assembly, and industrial lobbyists on one side and the Senate on the other.²⁸ The government argued that buying the US drone would place the independence of the French decision process at risk.²⁹ The fear of the Dassault-IAI proponents is that the US may curtail supply parts or take control of some critical communication means within the system if France chose to use the asset in a manner contrary to US policy. The other concern is that buying the Reaper would

²⁵ Ibid., (accessed.

²⁶ Xavier Pintat and Daniel Reiner, "Avis Présenté au Nom de la Commission des Affaires Étrangères, de la Défense et des Forces Armées sur le Projet de Loi de Finances pour 2012, Adopté Par L'assemblée Nationale, Tome Vi Défense : Équipement Des Forces," (2011), <http://www.senat.fr/rap/a11-108-6/a11-108-61.pdf> (accessed 23 March 2012).

²⁷ Ibid., (accessed.

²⁸ Jean Guisnel, "Sénat Contre Dassault : la Guerre des Drones Aura Bien Lieu," *Le Point* (2011), http://www.lepoint.fr/chroniqueurs-du-point/jean-guisnel/senat-contre-dassault-la-guerre-des-drones-aura-bien-lieu-12-12-2011-1406564_53.php (accessed 23 March 2012).

²⁹ France has historically been extremely sensitive to maintaining its political independence. This was one of the major obsessions of General de Gaulle that led France build own independent nuclear forces.

preclude French industry from developing the required technology for the next generation of drones, thus condemning future French options to buying only US drone equipment.³⁰ The government also added that the Dassault-IAI option would provide a better return on investment, since it would create jobs in France and give Dassault the opportunity to position itself in the promising medium-altitude, long-endurance (MALE) drone market. On the other hand, the Senate criticized the government for succumbing to the pressure of Dassault and wasting tax-payer money on the most expensive and least effective drone offer. The Senate also recalled that the cooperation between the French industry and IAI had already provided limited satisfaction, first with the Hunter, and then with the Harfang. Also, the proprietary arrangement with IAI never provided the French industry enough skills to develop its own MALE program.³¹ From initially being a question of operational capability for the Air Force, the MALE drone became a matter of domestic politics closely connected to industrial and economic issues.

FRENCH DRONES ANALYZED THROUGH THE PROCESS OF TECHNOLOGICAL ADAPTATION

The observation phase of the process of technological adaptation for drones in the French military started with two essential events. First, the massive use of drones by the Israelis during the first Lebanon War in 1982 aroused French interest.³² In the Bekaa Valley, judicious Israeli employment of drones yielded impressive results against the Syrian defense, without any loss of Israeli airplanes. As P.W. Singer explains, the Israelis used their drones in a very effective way: first the drones collected the signature of the Syrian radars and then “a swarm of UAVs flew over the area, sending out fake

³⁰ Journal Officiel de la République Française session ordinaire de 2011-2012 Sénat, "Compte Rendu Intégral, Séance du Lundi 28 Novembre 2011," 114.

³¹ Jean Guisnel, "Sénat Contre Dassault : la Guerre des Drones Aura Bien Lieu," *Le Point* (2011), http://www.lepoint.fr/chroniqueurs-du-point/jean-guisnel/senat-contre-dassault-la-guerre-des-drones-aura-bien-lieu-12-12-2011-1406564_53.php (accessed 23 March 2012).

³² Océane Zubeldia, "L'armée Française et L'utilisation des Drones dans les Missions de Reconnaissance, de 1960 au Conflit du Kosovo," *Revue historique des armées* (2010), <http://rha.revues.org/index7104.html> (accessed 20 March 2012).

signals. The Syrians thinking it was a real attack, fired off their missiles. While they reloaded, a second wave of Israeli jets flew in and took out the entire defense system, using missiles that homed in on the radars that the drones had unmasked.”³³ With what was at the time the most advanced, real-time, centralized command, control, communications, and information (C3I) system, the Israeli Air Force put out of service nineteen SAM batteries in less than two hours. The Israelis canceled sixty planned aircraft sorties since the mission was accomplished more quickly than expected.³⁴ With the historically close—although not always smooth—relationship that the French had with the Israelis, the French could not stay impervious to the stunning operational effectiveness of the drones in 1982.³⁵

The second main event that created a stimulus among the French military was Desert Storm. As Grégory Bouterin and Emmanuel Goffi explained in an article published in 2010 in *la Revue de Défense Nationale*, the very small number of casualties and the fast pace of operations was considered to be the new model of warfare. In this model, the extensive use of drones in conjunction with precision weapons and cruise missiles was an essential ingredient for success.³⁶ The main idea was to distance combatants from the hot zones of the theater.³⁷

These observations happened at a time when the French military had already experimented with drones. As previously explained, the development of the surveillance drone in France happened almost by accident after some experimentations on remote-controlled flying targets. Even though the French industry was far from being able to build a fully operational modern drone, the military had experimented in this domain, and France was therefore not starting a program from scratch.

³³ P. W. Singer, *Wired for War : The Robotics Revolution and Conflict in the Twenty-First Century* (New York: Penguin Press, 2009), 56.

³⁴ John Andreas Olsen, *A History of Air Warfare*, 1st ed. (Washington, D.C.: Potomac Books), 150.

³⁵ The French military had traditionally close relations with the Israelis. The Suez crises in 1956 and the raid on Entebbe in 1976 are good examples of that connection. The French military industry also provided the IAF with much equipment such as the Mirage F1. The Israelis later made a copy of the Mirage F1 under the name Kfir, as a result of the embargo that General de Gaulle put on them in 1968 after the 6 days war...

³⁶ Grégory Bouterin and Emmanuel Goffi, "Les UAV Armées Sous le Feu des Débats," *Revue Défense Nationale*, December 2010.

³⁷ Ibid.

After observation came analysis. In that regard, it would be unfair to criticize the French for a lack of reflection. The amount of thinking is visible through the high number of articles and public debates published in many governmental reviews and specialized journal. The reflection has animated all strata of the hierarchy, from the operational user, to the highest political level at the National Assembly and the Senate. While the French clearly understood the potential value of drones, they also rapidly identified its limits, and the danger of overreliance on remotely piloted technology. The main recurring topics of reflection follow:

- Limitations and utopian ideals of the RMA: the French clearly see a danger and a moral issue in the no-death-war concept that derives from a feeling of technological superiority.³⁸ Network-centric warfare and the intensive use of drones is clearly a force multiplier, but it will probably not be the ultimate solution to win all wars.³⁹
- The French rapidly understood the limitations of the drones, in particular for long range UAVs. These are large, carry a lot of transmission equipment, and are therefore visible and vulnerable when flying in enemy airspace. Also, contrary to satellites, drones have to comply with international border restrictions. The French therefore consider that large observational drones are at best a supplementary asset to extant satellites and manned platforms.⁴⁰
- Last, the French see a clear ethical issue in the recent evolution of the drone as a weaponized platform. Some French academics consider the armed drone to be a first step toward full automation of the process of target designation and killing.⁴¹ This evolution raises the ethical

³⁸ Pierre Pascallon, *Satellites et Grands Drones dans le Cadre de la Politique Spatiale Militaire Française et Européenne* (Paris: Harmattan, 2005), 27.

³⁹ This resonates with Benjamin Lambeth's argument that "high technology was a significant but not single-handedly determining factor in the coalition's success in Desert Storm." Benjamin S. Lambeth, *The Transformation of American Air Power*, Cornell Studies in Security Affairs (Ithaca, N.Y.: Cornell University Press, 2000), 152.

⁴⁰ Henri Schlienger, "La Connaissance du Théâtre D'opérations, Rôles de L'avion de L'uav et du Satellite," *Bulletin de documentation du centre d'enseignement supérieur aérien* (2002).

⁴¹ Eric Germain, "2010: Année Zéro des Guerres Robotisées," *Revue de Défense Nationale n°740* (2011).

question of using robots for the purpose of killing humans.⁴² With the CIA use of drones in Pakistan and in Yemen, the French see the danger of employing non-legitimate military violence (since there is no declaration of war) by simply moving a joystick at home.⁴³

Since the beginning of its involvement in drones, the French Air Force has been mired in a permanent state of experimentation, without producing any real capability. This is illustrated by the fact that each new drone that enters the French Air Force is indeed a palliative measure waiting for the next ideal platform. The best hope today lies with the French-British agreement to build the third generation of MALE drone. But this project still remains hypothetical, and, even if everything happens as planned, will not come into being before 2020. Despite France's extensive experimentation with drones, the feedback loop seems to be non-existent at the strategic level (political and industrial). While at the tactical and operational level, the French Air Force amasses experience and knowledge, the political level of decision seems to be intransigent. The choice of an IAI-Dassault solution based on the Heron TP platform illustrates this point: the recent operations in Afghanistan and in Libya demonstrated the need for a drone able to fly fast and at a minimum altitude of 25,000 feet. The Heron will not meet these requirements. Also, the Héron TP will lack the high-resolution detection technology that is critical today in Afghanistan to detect furtive and moving targets.⁴⁴ Finally, the IAI-Dassault solution to replace the Harfang is similar to the two preceding drone acquisitions for the French Air Force. IAI tends not to meet the deadlines and its after-sales service has not lived up to French expectations. It is therefore highly probable that the same problems that were encountered with the Hunter and then with the Harfang will happen again.⁴⁵

⁴² This question is not recent: In 1950, Isaac Asimov wrote a fiction book "Robot" where he was already advocating for what he called the first law of robotics: "A robot may not injure a human being or, through inaction, allow a human being to come to harm".

⁴³ Eric Germain, "2010: Année Zéro des Guerres Robotisées," *Revue de Défense Nationale* n°740 (2011).

⁴⁴ Xavier Pintat and Daniel Reiner, "Avis Présenté au Nom de la Commission des Affaires Étrangères, de la Défense et des Forces Armées sur le Projet de Loi de Finances pour 2012, Adopté Par L'assemblée Nationale, Tome Vi Défense : Équipement Des Forces," (2011), <http://www.senat.fr/rap/a11-108-6/a11-108-61.pdf> (accessed 23 March 2012).

⁴⁵ Ibid.

While the choice of the Reaper also carried some critical problems, such as possible US restrictions on its use, the French government is likely setting up the French Air Force for failure with the choice of the Heron-TP as a replacement for the Harfang. This tends to reveal a lack of appreciation for past experiences. Not enough time has passed to make an objective assessment of this recent decision from the French government. Nevertheless, it is probable that rationality alone cannot fully explain the choice to invest “30% more in order to get 20% less effectiveness than the Reaper.”⁴⁶ As Alison and Zelikow explained in their book *Essence of Decision*, rationality is not the only factor involved in a political decision: organizational behavior and governmental politics can also influence a decision process.⁴⁷ The actions of the Senate strongly suggest that the drone program in the French Air Force is under some influence from organizational interests and above all, government politics. Unfortunately, the operational need of the French Air Force remains behind these interests.

THE FRENCH DRONES AND SUSTAINABLE DEVELOPMENT

The economic factor represents one of the essential arguments for the development of a drone capability. In France, the high cost of social security contribution makes manpower prohibitively expensive. With recent decades of growing deficits, presidents Chirac and Sarkozy—and their respective governments—chose to reduce the number of state employees.⁴⁸ The drone fits into this fiscally constrained environment since it gives the impression that technology will replace costly pilots. In addition to the saving in manpower, there is also the expectation that a drone such as the Harfang should have a much lower cost per hour than any other conventional platform, such as a fighter airplane or an AWACS. The small 115HP engine of the Harfang should

⁴⁶ Jean-Louis Carrère et al., "Drones : le Mauvais Choix du Gouvernement Français," *Le Monde*, http://www.lemonde.fr/idees/article/2011/12/09/drones-le-mauvais-choix-du-gouvernement-francais_1615993_3232.html (accessed 25 March 2012).

⁴⁷ Graham T. Allison and Philip Zelikow, *Essence of Decision : Explaining the Cuban Missile Crisis*, 2nd ed. (New York: Longman, 1999), 143, 255.

⁴⁸ More specifically, a law in 2008 stipulates that only one state employee would be hired when two go into retirement.

indeed save considerable fuel expenses compared to a gas guzzler such as the Mirage 2000 doing the same mission. But the economic reality of the drones seems to be far from these hopes. In 2009 the National Assembly published a study on the recent use of drones in France. Part of the study was an assessment of the hourly cost of the Harfang compared to a fighter and an AWACS. These figures are official and come from the French Joint headquarters, and they include maintenance, personnel, fuel and operating cost:

Table 1: hourly cost of drones compared to conventional platforms. Source:

Platform type	Minimum	Maximum
Fighter airplane	€ 8,100	€ 20,000
AWACS	€ 37,000	€40,000
Drone (estimates for the Harfang)	€ 10,000	€ 15,000

Source: National Assembly Yves Vandewalle and Jean Claude Violette, "Rapport D'information Déposé en Application de L'article 145 du Règlement Par La Commission De La Défense Nationale Et Des Forces Armées sur les Drones," (2009), <http://www.assemblee-nationale.fr/13/pdf/rap-info/i2127.pdf> (accessed 23 March 2012).

Although the National Assembly admits that these figures may lack accuracy, the economic burden of the Harfang is also acknowledged by the Senate with an hourly cost reported to be above €10,000.⁴⁹ The drone is definitely not the big money saver that everybody was expecting. One of the reasons for the high cost of the drone is the small number of assets in the fleet. With only three Harfangs, economies of scale evaporate, and both the acquisition and operational costs are exorbitant for the French Air Force. As a comparative figure, the report of the National Assembly recalled that the estimated hourly cost for the Predator in the United States according to the US *Department of*

⁴⁹ Senat, "Projet de Loi de Finances pour 2011 : Défense - Equipement des Forces," <http://www.senat.fr/rap/a10-112-5/a10-112-512.html> (accessed 16 april 2012).

Homeland Security is around \$3,600.⁵⁰ While this may be a more affordable cost than the Harfang, when you consider the small fleet likely and the lack of economies of scale, the drone might not be much more economical than a manned aircraft for the French Air Force. With foreign drone acquisition as a stopgap measure until a national or European program becomes competitive, the French government will not be willing to invest in a large fleet of drones. Contribution to the national economy through the creation of jobs or the perspective of export sales is traditionally a requirement for large military spending. Therefore, the French Air Force will, at best, operate for the coming decades a small fleet of drones, which also means unreasonable cost.

On the social side, the drone development in the French Air Force first encountered much resistance. As Marc Grozel and Geneviève Moulard explain, pilots, whatever their origin (Army, Air Force or civilian) have been the strongest opponents to the development of drone systems. According to these authors, this phenomenon is not unique to France and exists all over the world, from China to the United States.⁵¹ But most of the pilots' rational arguments against the drones do not hold true with the latest technology. Statistically, pilots in aircraft are a major source of errors and accidents, while recent computing technology is in most cases able to fly safely in the most complex environments.⁵² But one less-official reason why pilots oppose the rise of the drone is the perception that a machine could replace humans in a cockpit and take the pilots' jobs. While this tendency is already happening, at least in the United States, there is a misperception of the speed at which a new technology takes over. As an example, Adam Tooze explains that, contrary to common belief, the horse remained the first mode of bulk transportation in Germany during World War II.⁵³ In a similar manner, it is probable that the drone will not take over all roles for the manned airplane in a short period of time.

⁵⁰ Yves Vandewalle and Jean Claude Viollet, "Rapport D'information Déposé en Application de L'article 145 du Règlement Par La Commission De La Défense Nationale Et Des Forces Armées sur les Drones," (2009), <http://www.assemblee-nationale.fr/13/pdf/rap-info/i2127.pdf> (accessed 23 March 2012).

⁵¹ Marc Grozel and Geneviève Moulard, *Drones, Mystérieux Robots Volants : les Yeux et le Feu du Xxie Siècle* (Panazol: Lavauzelle, 2008), 327.

⁵² *Ibid.*, 328.

⁵³ J. Adam Tooze, *The Wages of Destruction : The Making and Breaking of the Nazi Economy* (London ; New York: Allen Lane, 2006), 212.

Social resistance among the pilots to drones had some lasting consequences in the French program. In a public debate about the future of drones, General Jean Rannou, a former chief of staff of the French Air Force, recalled how the Air Force in the 1990s opposed the UAV and contributed to France's actual backwardness in the domain of MALE drones.⁵⁴ Even if this opposition from the Air Force is weakening, the drone still has a strong social impact within the organization. Since the French Air Force has long used the heroic image of the pilot as a sky warrior, drone pilots will probably seem less attractive and glamorous to potential recruits.⁵⁵ As an ultimate attempt to maintain esprit de corps, the drone operators in the French Air Force (as in most Air Forces, but unlike in the Army) still wear flight suits. The operators will also continue to receive flight pay, and the human resource division of the French Air Force is currently working on their profile in order to give them career opportunities similar to conventional pilots.⁵⁶

Environmentally, the first uses of drones in the French Air Force caused real constraints. The French drones fly at a slower airspeed than other military aircraft, and they do not have the eyes of the pilot to enforce the fundamental rule of aviation "see and avoid." But the Harfang is now integrated on the Recognized Air Picture (RAP), and the operators are in constant radio contact with the Air Traffic Controllers (ATC). Moreover, the French Air Force passed a new milestone during the operations in Libya, where the drones had to transit through Italian and the Maltese civilian airspace.⁵⁷ Despite problems, integrating the drone within its air environment seems to be technically manageable in the future.

Another environmental issue with the drone concerns the footprint in the electromagnetic spectrum. The drone requires a large bandwidth for data links with its ground station. But in France, the quantity of data links is limited essentially due to the small number space assets available. Thus, the electromagnetic spectrum is a fragile environment because it is precious, nearly saturated, and vulnerable to enemy attack and pollution. There are some technical solutions for preserving the electromagnetic

⁵⁴ Pierre Pascallon, *Satellites et Grands Drones dans le Cadre de la Politique Spatiale Militaire Française et Européenne* (Paris: Harmattan, 2005), 71.

⁵⁵ Marc Grozel and Geneviève Moulard, *Drones, Mystérieux Robots Volants : les Yeux et le Feu du XXI^e Siècle* (Panazol: Lavauzelle, 2008), 334.

⁵⁶ Interview with the deputy squadron commander of the 1/33 Belfort that operates the Harfang drone.

⁵⁷ Ibid.

environment, but these solutions may nevertheless be costly and also have some limits. While this issue is critical for drones, it should also raise some concerns about the new generation of manned aircraft which are also extremely dependent on the electromagnetic environment.⁵⁸

CLOSING REMARKS ON THE DRONE PROGRAM IN THE FRENCH AIR FORCE:

While the following remarks may appear as a plea for a pilot by a pilot, they should not be considered as such. C-130 crews actually do not feel much threatened by the rise of UAVs. On the other hand, the French government has clearly reached an impasse regarding the question of medium-altitude, long-endurance (MALE) drones. For cultural and historical reasons, the perspective of a political dependence on the United States with the Reaper—whether this dependence is a possible reality or an exaggerated fear—is no more acceptable than the option of buying the less-effective, more-expensive Dassault-IAI solution. While the following reflection minimizes neither the value of the drone nor its potential development in future operations, it nevertheless encourages original and alternative thinking. This reflection came from both the acknowledgement of the economic realities of the drone in France and comparison with the first case study of this research.

The issue of the drone in the French Air Force has indeed many similarities with the glider program in the US Army during World War II. As the Americans lagged behind Germany in their glider program, so too did the French Air Force trail behind other nations—the United States, but also many other European countries—in its drone capability. As a result, the likelihood of French industry building a competitive MALE drone seems small, and operating such a drone would remain extremely costly as long as the French Air Force decides to operate a small fleet. As long as the drone remains a marginal and complementary asset to the conventional manned aircraft, France cannot

⁵⁸ Marc Grozel and Geneviève Moulard, *Drones, Mystérieux Robots Volants : les Yeux et le Feu du Xxie Siècle* (Panazol: Lavauzelle, 2008), 330.

justify its own independent long-range drone industry. And with the recent introduction of the Rafale in the French forces —the new generation of fighter airplane—the prospect of a large fleet of drones replacing the manned airplane seems relegated to several decades in the future. Therefore a European project appears at present time to be the only affordable alternative to acquisition of U.S. drones and the consequent loss of independence. But until this European project becomes possible, or until a large fleet of drones replacing conventional airplanes changes the economic realities of UAVs, the decision makers may think about other stop-gap solutions. As airdrops were in most cases a more efficient and cheaper alternative to gliders during World War II, a modified manned platform may effectively replace the need for drones in most cases. A modification of a conventional manned aircraft, such as a twin turboprop, equipped with all the modern observation equipment could provide at least the same capability of the Harfang, and also be much simpler and therefore lower in operating costs.⁵⁹ This option would remove many uncertainties for the replacement of the Harfang, alleviate the social impact of the drone revolution, and give more time for the European industry to be ready for the next generation of drones. It may also provide some business opportunities for French industry in an almost non-existent market: a low-cost manned alternative to the drone. Even if the drone tends to attract all attention today, there is no reason to discard a legacy technological solution that could provide an effective response to the French operational need. The French Air Force's development of drones reveals some form of belief in technological determinism. As Michael Smith explained, a new technology is not necessarily synonymous with progress.⁶⁰ Compared to smart use of a manned aircraft, the only thing that the French Air Force drone program provides today is more operational limitations and more expenses.

⁵⁹ In order to match the Reaper capability, armament pods could be easily set under the wings.

⁶⁰ Merritt Roe Smith and Leo Marx, *Does Technology Drive History? : The Dilemma of Technological Determinism* (Cambridge, Mass.: MIT Press, 1994), 38.

CONCLUSION

The three case studies of this research are broad: they take place in different times, different countries, and within heterogeneous contexts. But despite this diversity, the study reveals that air organizations—whether civilian or military—display similar behavioral patterns when they seek to integrate an existing technology. Obviously, there are no systematic methods to comprehend an existing instance of technological adaptation, or to plan one with a guarantee of success. However, knowledge of history provides insights for critical analysis of technological adaptation. As in any other domain of interest for the strategist, there are no manuals or checklists for technological adaptation. Here again, the best hope to grasp the sheer complexity of the endeavor lies in a strong education and eagerness to contemplate history. Tocqueville, two centuries ago, mentioned that history “is a picture-gallery containing a host of copies and very few originals.”¹ While they all have their own characteristics, the recurring behavioral patterns among the three case studies tend to vindicate Tocqueville.

To ease the understanding of the case studies, this research suggested a theory of technological adaptation based on two different approaches. First the dissection of the process into its basic cognitive steps is a first avenue to comprehend the problem. The OODA-loop-type approach gives the opportunity to linearly analyze each critical stage of technological adaptation. Then an evaluation through the length of the concept of sustainable development provides an assessment of the strengths and weaknesses of an instance of technological adaptation. As the three case studies tend to indicate, the proposed theory seems adequate. It provides a valuable narrative of the cases and helps capture what went right or wrong during the process. But this proposed theory should not be considered an infallible methodology. For example, the second case study suggests that the social acceptance of the jet airliner was a surprise, at least to those attempting to predict market behavior. In a similar manner, the theory does not provide clear answers

¹ Alexis de Tocqueville and John Bonner, *The Old Regime and the Revolution* (New York: Harper & Brothers, 1856), 88.

to the current social and environmental concerns of the drone revolution. It only recommends that these issues be given critical thought. As most human behavior, technological adaptation is time—and environment—dependent. It is also a complex phenomenon which does not obey any systematic scientific rule. The theory guiding this research offers a way to simplify the process in order to make it intelligible. But in removing some of the complexity, and with only a limited number of case studies, it may also create a potential for excessive generalization. The following conclusions should therefore not be considered normative.

Because of its nature, technological adaptation is often accompanied with a form of belief in technological determinism. In all three case studies, each organization had great difficulties in considering alternative forms of development: for the US Army Air Forces, the glider appeared “inevitable,” as the jet engine for De Havilland or the drone for the French Air Force. This observation probably emanates from the feeling of frustration or paranoia that often triggers technological adaptation: unlike an invention, the process of technological adaptation begins with the recognition of some backwardness in a particular domain. The US glider program was launched because of a perception of inferiority compared to the Germans in air assault capability; the tremendous technological gap between post World War II military and commercial aviation gave birth to the jet liner; and the French Air Force felt no other choice than to invest into drones when it realized the large advance of the US during Desert Storm. Frustration about this feeling of backwardness creates a cognitive dissonance within the organization. Reducing the technological gap seems then to be the only rational option to balance the cognitive discomfort. Emotions then restrain alternative thoughts. This phenomenon is probably more prominent in aviation because of the peculiar reliance on technology. More than in any other domain, technological disadvantage in aviation is extremely difficult to accept and manage.

The initial theoretical approach of technological adaptation identified four essential steps in the process: observation, analysis, experimentation, and decision. All three case studies revealed that in the observation phase perceptions are often wrong. In the first and third case, the misperception was directly a consequence of emotions and an inclination toward technological determinism. Because they were new technological

developments, the glider and drone appeared immediately synonymous with progress. The case of the jet age is, however, slightly different. Contradicting any form of technological determinism, the initial feeling was that jet engines were not adaptable to civilian airplanes. But this first perception revealed itself to be incorrect, and another propensity to believe in technological determinism appeared when the jet race started. Airline industries, such as De Havilland, Douglas, and even Boeing, placed all their resources in the jet bet, because they had the feeling that this was a race for survival. In that regard history proved their assessment to be right. Awareness of the danger of deterministic behavior does not mean, however, that any new technology should be disregarded. In time, the race for a new technology may produce a winning strategy. The difficulty for the strategist is to identify which technology will likely be critical in the future, and which one may require a more reserved approach.

While perception starts the process, analysis is the core element of technological adaptation. Looking back at history, it is easy and natural to criticize the involved organizations for their lack of analysis. But a present observer has obviously a privileged outlook on history compared to leaders who had to make decisions with limited information and a hazy view of the future. Nevertheless, deep thinking appears to make a difference compared to impulsive decisions. The glider, for example, was not well thought out by the US military: It was essentially used as an alternative to cargo airplanes, and the true advantages of gliders for stealthy point attacks on high-value objectives were not often exploited. Gliders consequently vanished from the US military with the advent of the helicopter. In the jet-age case, the winning company was also the one that invested the most brain power in the project. Boeing engineers worked hard on the design of the 707 and ended-up with a lasting concept. The 707 was a thoughtfully designed airplane that indeed answered most engineering questions about four-engine commercial jets. While the Comet was very innovative, the program appeared to be emotionally driven by the attempt to preserve national pride in the context of a collapsing empire. Deeper analysis and experimentation came only after the fatal accidents, but it was then too late to catch-up with the US industry. Regarding the drone case study, the French demonstrate significant, but also sporadic, analysis. They answer questions regarding the use of drones in general but they are unable to address their own need.

When the decision for the new generation of drone eventuates, political and industrial interests tend to supersede rational analysis. This will likely condemn the French Air Force to remain with a drone capability that will not meet its requirements in the future.

As analysis, experimentation is also a critical step during technological adaptation. But experimentation with no objective feedback is of limited value. The danger again lies in a potential deterministic vision of technology. The latent belief in technological determinism distorts the perception, shapes the analysis, and tends to censor any negative feedback. The US military never admitted the limitations of the glider. The Sicily disaster did not raise any question about large airborne operations, whereas the Germans decided to focus on small-scale, special-operations type missions for their gliders. The emotional surprise of the attack of Eben Emael, and the frustration in realizing the advance of the Germans in glider operations probably contributed to blinking the US leadership. The US glider program had to be successful, but its operational effectiveness was secondary. In a similar manner, the level of hope and emotions that the British placed on the Comet minimized the negative feedback they regularly received. At no point did the British consider the possibility that the Comet design had caused the recurring incidents during take-off and the first mid-air explosion. The Comet was the product of British intelligence; it was modern, innovative, and ahead of its time. For all these reasons it could not be defective regardless of some obvious negative feedback. In a same manner, the French government acknowledges its inability to acquire and integrate the drone technology in the French Air Force at a reasonable price, but also fails to put into question the relevance of UAVs for its specific needs. Because the drone fits into a US vision of modern warfare it becomes “inevitable” for the French even when their leadership faces impasse and has to decide between two unacceptable options.

Understanding and analyzing technological adaptation through its essential steps provides an entrée to discern potential glitches that can lead to costly decisions. The concept of sustainable development provides another cognitive approach to assess the value of adapting a new technology. In aviation, the economic factor appears decisive. Aviation programs require high-end technology, extensive experimentation, and therefore

large investment. The Waco, Comet, and Harfang were not economically sustainable for their organizations. Economic miscalculation is the first cause of failure.

Adapting new technology raises also social and environmental concerns. Contrary to the economic factor, the social and environmental questions seem more manageable and less decisive in most cases. The jet age contradicts this statement since the modern jet liner was itself emblematic of societal change. Had it failed to seduce the society, the jet liner would have been a failure. In the military, the social acceptance of technology can be forced to a certain degree. Nevertheless, the overall effectiveness of adapting a new technology will be directly dependent on the societal acceptance of this technology. Waterboarding may have been successful in extracting information from terrorists, but the practice was unacceptable to the societies whose agents maintained the practice. Similarly, killing with machines that present no danger to the operators may also be socially unacceptable. Social resistance needs to be alleviated to successfully integrate a new technology. Additionally, environmental issues need to be addressed but generally pose manageable constraints. But as pollution increases with activity, the environmental concerns of new technology may increase with the level of complexity. The environment of the drone, for example, is more complex than that of a WWII glider. Not only does the drone use the air and the land domain, but also space and cyber. It is possible that the development of modern technology may raise new critical environmental questions that we are not even aware of today.

Technological adaptation in military aviation happens frequently. The study of the three different cases sheds light on the logical development of the process. Not every idea is good to copy: however, there may be times when plagiarizing is necessary. But just because the technology has already been invented does not mean its adaptation will follow naturally. Different characteristics of the adapting organization can change the effectiveness of the technology. The factors to consider are economic, social, environmental, and also cultural. Finally, adapting technology in aviation requires caution, deep reflection, extensive experimentation, and above all, a large amount of humility.

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