A Comparative Analysis of Technological Learning Systems in Emerging Rotorcraft Companies

By

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Submitted to the System Design and Management Program
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ABSTRACT

The aim of this research is to understand how emerging rotorcraft companies in various countries accomplished technological learning over the last sixty years. Owing to its unique products and growing market demand, rotorcraft industry is one of the most globalized and dynamic sectors of the aerospace industry. Understanding technological learning in the rotorcraft industry is important to industrial policy makers and corporate managers who are seeking more clarity in the relationship between rotorcraft companies and the global social-political environment. Although there has already been extensive research on technological learning in various industries, evidence of technological learning in the rotorcraft industry has been lacking. This research aims to fill this gap in the field of technological learning by unveiling the learning dynamic and technological evolution of emerging rotorcraft companies. This thesis will analyze these developments by research on emerging rotorcraft companies' National Innovation Systems (NIS) and their different modes of cooperation with foreign companies. The analysis on the companies' NIS is an important element of the research framework as it defines the national innovation environment for the industry. NIS represents the unique system of institutional, private and foreign stakeholders and their interaction in the country. The analysis on the different modes of cooperation with foreign companies is the second key element of the research framework as mode of cooperation is an important technological indicator for emerging rotorcraft companies. To substantiate the findings of technological learning in the rotorcraft industry, three case studies of emerging rotorcraft companies - Agusta (Italy), Avicopter (China) and Kawasaki Heavy Industries Aerospace (Japan) were made. Each case provides both holistic and detailed view of the unique technological learning system of the company by analyzing both national-level and company-level factors. This thesis synthesizes and compares the three companies' technological learning systems and draws conclusion in relationship to their respective NIS. This thesis has identified that concurrent internal learning, a history of cooperation, favorable national learning environment and production scale are essential for emerging rotorcraft companies to succeed. Moreover, it has also found that denial of technology access only slows down but does not prevent technological learning completely. This thesis will not only provide industrial policy makers and corporate managers with greater insight into the technological learning systems of emerging rotorcraft companies, but also a different perspective regarding technological transfer and cooperation. Finally, this thesis contributes to the research on technological learning through its original case studies from the rotorcraft industry.

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- Thiam Soon Gan

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CHAPTER 1: INTRODUCTION

1.1 Research Motivation

The aerospace industry is a highly visible and politically charged industry. Its use as a political and economical tool for promoting national pride and global technological leadership is indisputable. However, the global aerospace industry has become an overly complex social-technological system that is affected by a glowing market failure - the increasing need for costly transfer of technology and uneconomical global production work redistribution (either through cooperation and offset) among nations in the global market. This market failure is also exacerbated by market-distorting governmental subsidies and wrongly priced market outputs. My interest and concern in the ramifications of this market failure on sustainability and competitive issues have spurred me into taking a deeper look into this development.

I have chosen the rotorcraft sector of the aerospace industry due to a number of reasons. First, I have been working in the rotorcraft industry as an engineer and strategist. This research will provide me with greater understanding of the rotorcraft industry. Conversely, my working experience in rotorcraft industry has equipped me with necessary knowledge foundation to conduct independent research in this field. Second, the rotorcraft industry is often regarded as the less glamorous and visible sector of the aerospace industry. Past aerospace industrial research literatures have focused mainly on the more prestigious fixed-wing commercial companies such as Airbus and Boeing. However, the growing global misfortunes of the borderless natural disasters and human conflicts have led to the more visible social-political benefits derived from the rotorcraft industry. Hence, the dynamic and globalized rotorcraft industry deserves a closer look. Furthermore, while the large fixed-wing commercial aircraft industry has consolidated into the quasi-duopoly market, the market failure induced global environment has been rapidly incubating new rotorcraft companies. The following news headlines exemplify this recent trend. All these factors have collectively made new research on the rotorcraft industry timely and imperative.

Kawasaki decides on domestic solution to meet Japanese army requirement

Industry sources say Kawasaki Heavy Industries (KHI) has decided to offer an indigenous solution for Japan's UH-X program rather than propose license-producing a Western-developed helicopter. The company has already held talks with Western manufacturers interested in helping it develop a utility helicopter based on the OH-1.

- Flight International Magazine 2005

Hindustan Aeronautics to go it alone on [Indian Army] observation helicopter

[India's] Hindustan Aeronautics decided against seeking an international partner for its light observation helicopter program, and will undertake the development by itself. "We have gained a lot of experience and learned a lot over the years manufacturing the Cheetah and Chetak [helicopters], and then developing the Dhruv [advanced light helicopter]," said a senior official from the state-owned firm. - Flight International Magazine 2010

As the study of aerospace market failure is a very broad topic and in order to frame it into the scope of my masters' level thesis, I have selected the technological learning of rotorcraft companies to gain greater understanding of the interaction between the rotorcraft industry and the global environment. Technological learning in emerging rotorcraft companies is selected over other research areas as I believe it addresses the one of root causes (i.e. access to foreign technologies) of the market failure in the aerospace industry. This thesis does not attempt to explain the entire aerospace market failure, but only to highlight a relatively narrow aspect of the aerospace industry and perhaps provide impetus for future research.

1.2 Structure of the thesis

The first part (Chapter Two and Three) of this thesis provides the reader with a good overview of the rotorcraft industry, technologies and the technical challenges. This overview is essential for reader in understanding the case findings and analysis, which are presented in Chapters Six and Seven. Moreover, the taxonomy of the three different generations of rotorcraft companies will be shown. This generational classification of rotorcraft companies is important to highlight the different maturities of these companies in order to understand how technologies were transferred. The major market players in these three generations will be introduced. Next, the specific characteristics of the rotorcraft industry such as the dominant business model, the need and catalyst of cooperation will be discussed.

The second part (Chapters Four and Five) of this thesis presents the literature review of existing theories and frameworks that are relevant for this research. In this part, the review of the literatures on cooperation, organizational learning, technological learning and the concept of National Innovation System (NIS) will be discussed. The findings from this literature review were used for constructing the theoretical technological learning framework that will be used to explain technological learning of rotorcraft companies.

The third part (Chapters Six to Eight) of the thesis presents the case studies of three different rotorcraft companies. In each case study, the brief introduction of the company, its technological learning environment (represented by its National Innovation System) and its technological learning process will be presented and analyzed. The technological learning systems of the three cases will be compared to derive any implications and lesson learned for the industry. Finally, the potential future work and extension of this research will be discussed in the conclusion.

1.3 Research Questions

In this thesis, I will investigate the technological learning process of emerging rotorcraft companies, their technological learning environments and their relationships by answering the following four research questions:

1) How did emerging rotorcraft companies acquire their technologies?
2) What are the factors that influence the technological learning of emerging rotorcraft companies?
3) What are the outcomes of emerging companies' technological learning?
4) What are the implications of technological learning on key stakeholders in the rotorcraft industry?

By answering these questions, we will be able to understand the causes, mechanism and effects of technological learning in the rotorcraft industry.

1.4 Research Approach

In order to answer the aforementioned research questions, the research approach is tailored to provide the reader with sufficient technological background knowledge early in the thesis in order for him or her to understand the case studies and the analysis. The detailed steps of the research approach are listed as follows:

1) Review the industrial landscape of the rotorcraft industry
2) Identify and classify the major rotorcraft companies in the industry
3) Using theories and frameworks from existing literatures, construct a framework for decoding the technological learning process of rotorcraft companies.
4) Select three suitable emerging rotorcraft companies for case studies

5) Create the technological knowledge evolutionary map for each company using data from the case studies.
6) Compare and analyze the three technological knowledge evolutionary maps of the three companies in the case studies.
7) Draw lessons from the comparative analysis to derive implication of technological learning in the rotorcraft industry and other industries.

1.5 Definition of Key Terms

1.5.1 Original Equipment Manufacturer (OEM)

There is a wide range of definitions concerning Original Equipment Manufacturer (OEM). Moreover, the OEM term is used differently in different industries. For instance, OEMs in the electronic industry usually mean the main suppliers to brand manufacturers such as Motorola and Nokia. In the automotive industry, the term OEM is used for brand manufacturers themselves such as Toyota or GM. In the aerospace industry, OEMs are often referred as Prime Contractors or Systems Integrators, which are positioned at the highest level in the supply chain hierarchy. However, for simplicity and to be in line to the common understanding of OEM, this thesis will use OEM for all rotorcraft companies that carry their own brands (e.g. Bell, Boeing, Agusta, Avicopter, Kawasaki and Eurocopter).

1.5.2 Cooperation

Industrial cooperation has become a widespread practice in all kind of industries due to its advantages such as financing, risk pooling, economies-of-scale, politics and access to technologies. There are numerous interpretations of the term *cooperation* in the industry. This variation of the interpretation is caused mainly by differences in the *context* and *content* of the cooperation programs, but not in the *intent*. In simplest definition, cooperation used in this thesis has the same meaning of the word as defined in Merriam-Webster dictionary (cooperation is defined as action of cooperating, common effort or association of different person for common benefit). Furthermore, there is also the commonly used and similar term *collaboration*. In this thesis, collaboration refers to the more participative form of cooperation and hence, is a type of cooperation. However, these two terms will be used interchangeably without any difference in definition.

In the rotorcraft industry, cooperation between companies involves technological exchange and it can be classified in the following four main modes: licensed production, design- adaptation, co-production and co-development.

Licensed production refers to the production of an OEM product by another manufacturer under license agreement without any changes in production process and product design. Licensed production is usually a duplication of the production at the OEM and is usually carried out in parallel to the main production at the OEM. It is considered the simplest form of cooperation that has low level of cooperation complexity and interaction.

Design-Adaptation may be a cooperative or non-competitive in nature. Design adaptation involves the adaptation of the OEM's product design to new local requirement. This type of cooperation is usually carried out by the emerging company and has to be fully supervised and certified by the OEM, which holds the airworthiness certification of the products. The level of cooperation between the partners in terms of scope and complexity is generally low.

Co-production refers to joint production between partners. In comparison to licensed production, co-production is not a duplicated or a parallel production for the OEM. The partner companies usually are the sole suppliers of their production work share and are usually responsible for the both the design and operation of the production of their work share. Co-production requires considerably higher level of cooperation scope and complexity than licensed production and design-adaptation.

Co-development is the most comprehensive type of cooperation that involves joint design and development work between partners. It is the most complex form of cooperation due to the high level of interaction among partners. Usually, all partners shoulder the full cost and responsibilities of design and development of their work share, meaning the significant common interest in the success of the cooperation. This type of cooperation is usually formed by partnering companies that have complementary or comparable level of design and development competency. Co-development is the most complex and comprehensive mode of cooperation among all four modes of cooperation.

The definitions of these four modes of cooperation will be used throughout this thesis. Furthermore, these modes of cooperation are in line with the terms commonly used in the aerospace and defense community and literatures. As a reference, co-production and co-development are used by the International Armament Cooperation Handbook from the U.S. Undersecretary of Defense International and Commercial Programs. Licensed production and design-adaptation are terms commonly used in technological learning in various industries (Cynh, 2002; King & Nowack, 2003a).

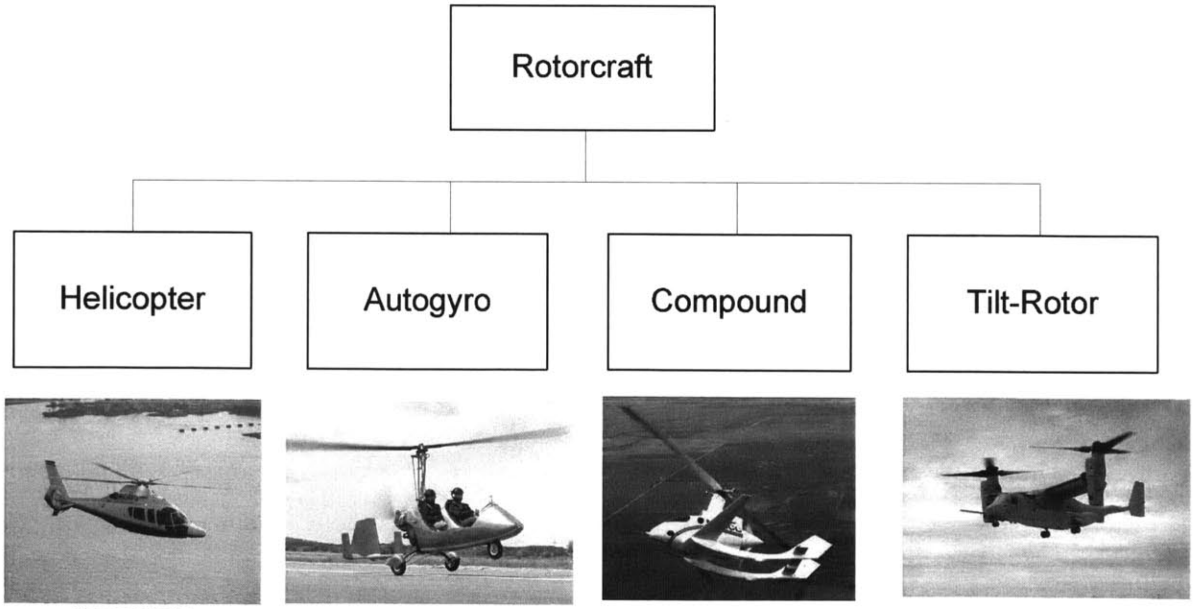
CHAPTER 2: THE ROTORCRAFT INDUSTRY

This chapter provides an overview of the industrial context used in this thesis. This chapter is important for reader to understand the challenges and intricacies of designing rotorcrafts and the structural complexity of rotorcraft industry. First, this chapter provides a concise technical overview of the rotorcraft system and the evolution of rotorcraft technologies to highlight the technological barriers of developing rotorcrafts. In addition, it highlights the uniqueness of rotorcraft technologies both in design and application. Second, this chapter introduces the major OEMs in the rotorcraft industry and defines the three different generations of rotorcraft OEMs. These generations are defined according to the technological maturity of rotorcraft OEMs.

2.1 Rotorcraft System

What is a Rotorcraft?

Rotorcraft is a family of heavier-than-air aircrafts that use rotating wings, which are technically known as rotor blades, to generate vertical and horizontal thrusts to fly. The most dominant forms of rotorcraft are known as *Helicopter. Autogyro, Compound* and *Tilt-Rotor* aircrafts constitute the remaining major members of the rotorcraft family. The family tree of rotorcrafts is shown below.



Source: Eurocopter Source: Autogyro GmbH Source: Aviastar Source: Boeing

Figure 1: Classification of Dominant Rotorcraft Designs

The most common helicopter design has a single main rotor and a smaller counter-yaw tail rotor. There are also derivatives of helicopter design such as the tandem rotor (e.g. Boeing CH-47 Chinook), intermeshing rotor (e.g. Kaman K-Max) and coaxial rotor helicopters (e.g. Kamov Ka-32). An emerging form of rotorcrafts found today in the market is *tilt-rotor* aircrafts such as the Bell-Boeing V-22 Osprey and Bell-Agusta BA609 that are equipped with transverse rotors. These transverse rotors can be tilted forward that transforms the rotorcrafts from helicopter mode to conventional fixed winged aircraft mode. This unique system provides the aircraft with both vertical take-off/landing and high speed capabilities.

Autogyro is a type of rotorcraft that does not have powered main rotor. It makes use of forward motion, which is usually propelled by another push propeller, to generate flow of air through its free-wheeling main rotor to create vertical lift. This method of generating vertical lift is also known as autorotation. Autogyro has not seen comparable market success similar to helicopters. Autogyros are commonly used for recreational and police surveillance purposes. *Compound aircraft* is a class of hybrid type of rotorcrafts that has technical features of helicopter and fixed-wing aircraft. In contrast to tilt-rotor rotorcraft, compound aircraft does not have a tilt-rotor system. Many compound aircraft have wings and push propellers designed for horizontal flight. So far, compound aircrafts have not seen any major market success since its conception in the early 1950s. However, the need for faster rotorcrafts has recently ignited new wave of development of compound aircrafts (e.g. Sikorsky X-2) and their derivatives in the industry (Figure 2).

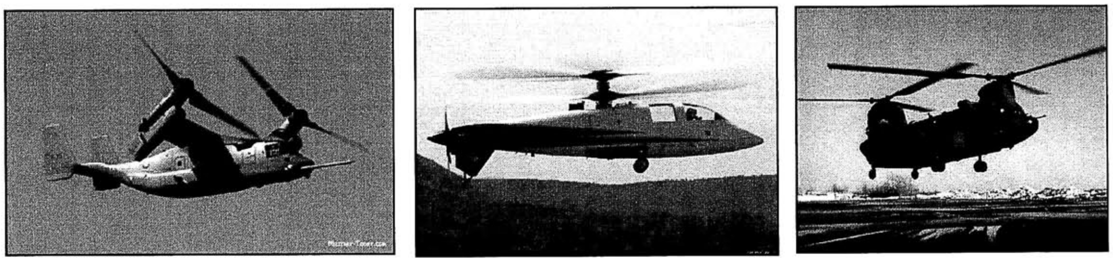


Figure 2: Rotor Systems - Tilt /Coaxial /Tandem (Military Today/Flight Global/Airliners)

Product Architecture of Rotorcraft System

One of the most generic ways to represent a rotorcraft system is using an Object-Process Diagram (OPD). The OPD diagram below shows the main processes, subsystems and elements (system architecture terminology) that are essential in the operation of a rotorcraft system (Figure 3 and 4). The main subsystems of a rotorcraft are as follows:

- Airframe
    - Structure (composite, metallic, mixed)
    - Undercarriage (wheels or skids)

- Dynamic system
    - Main rotor (e.g. Single, Tandem, Coaxial, Intermeshing, Tilt)
    - Tail rotor (opened, shrouded, ducted)
    - Drive train
    - Control system (hydraulic, electric or optical)

- Avionics system
    - Data system (flight and non-flight)
    - Power system (primary and auxiliary)
    - Mission system (inboard and outboard)

- Engine (gas turbine/turboshaft or piston engine)
    - Fuel system

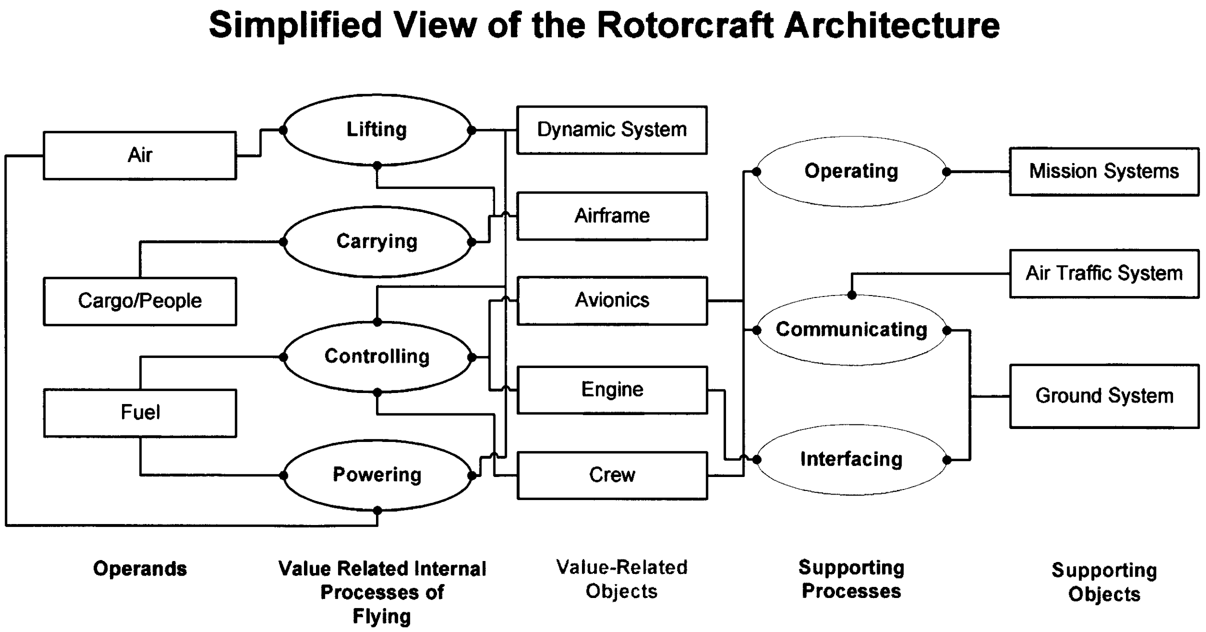


Figure 3: Object Process Diagram (OPD) of Rotorcraft Architecture

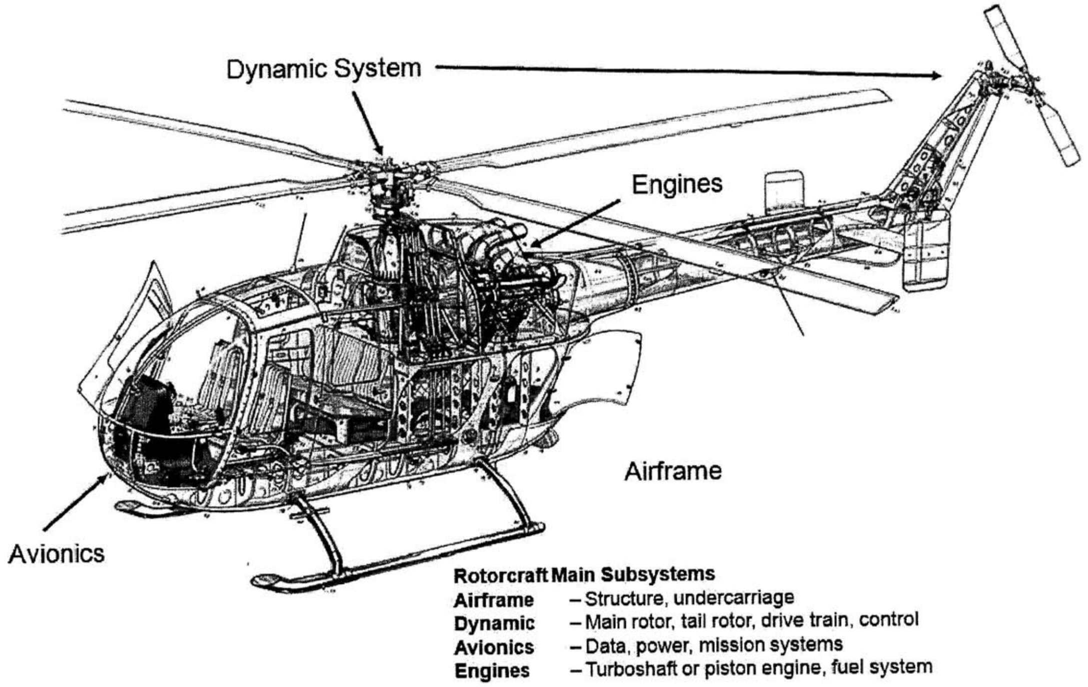


Figure 4: Simplified Representation of Rotorcraft Subsystems (Source: Flight International)

2.2 Rotorcraft Development

2.2.1 The Initial Challenges of Rotorcraft Development

The rotorcraft technology that we know today is a result of centuries of aviation creativities and engineering endeavors. Rotorcraft technology is based on the principle of rotating screw to generate aerodynamic lift. This principle has a very long history and its origin can be traced back to the Chinese toymakers (400 B.C.), Archimedes (287-212 B.C.) and Leonardo da Vinci (1452-1519 A.D.) (Polte, 2008). Nevertheless, similar to the development of fixed-wing aircrafts, the development of this principle into a practical technology was a very long and arduous endeavor. The first practical rotorcraft (Fw-61) was designed by the German aviation pioneer, Prof. Henrich Focke, and made its maiden flight in 1936. Three years later, the Russian-born American Igor Sikorsky flew the world's second practical helicopter, the VS-300. The main technical problems that delayed the development of rotorcrafts were the lack of *power density* and *flight control*.

Figure 5: A Rotating Screw by *Leonardo da Vinci* in 1483 (US Centennial of Flight Commission)

Early rotorcraft designers had experimented with various kinds of imaginable power sources available at those times. Power is required for driving the rotors that in turn generate aerodynamic lift. Early rotorcraft technology pioneers experimented with steam engine, winded spring, gun powder and electric motor. These sources of power proved to be unsuitable for sustained flight of more than a few seconds. Furthermore, all of these power sources did not have the required power density (power-to-weight ratio) to generate sufficient lift for the rotorcrafts. However, this changed with the advent of piston engines, which were first invented by a German engineer, Nikolaus August Otto, in 1876. Higher power-to-weight ratio piston engines were later developed and solved the power density problem since the early 1900s. Lighter and more powerful gas turbine engines eventually emerged as an even better source of power for rotorcrafts, however, only in a later half of the 20th century (Figure 6). In spite of the successful development of suitable power sources, flight control of rotorcraft remained a major technical hurdle until 1939.

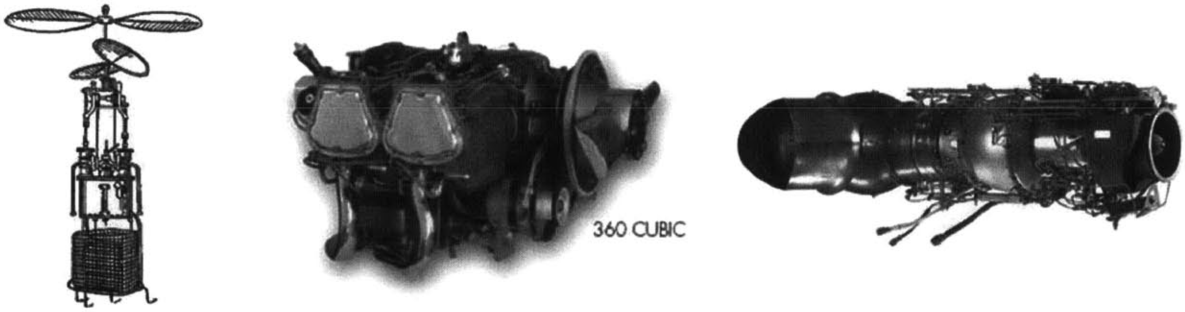


Figure 6: Steam, Piston engine, Gas Turbine (US Centennial of Flight Commission, Turbomeca)

Rotorcrafts designed before 1936 suffered from *flight instability* and lack of *flight control*. This is due to the lack of an effective rotor head technology, which actuates the rotor head tilt-direction (cyclic control – direction of rotorcraft horizontal motion) and pitch of the rotor blades (collective control – speed of rotorcraft vertical motion). The technology to actuate these two parts of the rotor system was not available until the early 1920s, when the Spanish aviation pioneers, Marquis Pablo Pateras Pescara and Juan de la Cierva, first demonstrated the effectiveness and practicality of this technology. Rotor head system still remains a key rotorcraft flight control technology up to today (Figure 7).

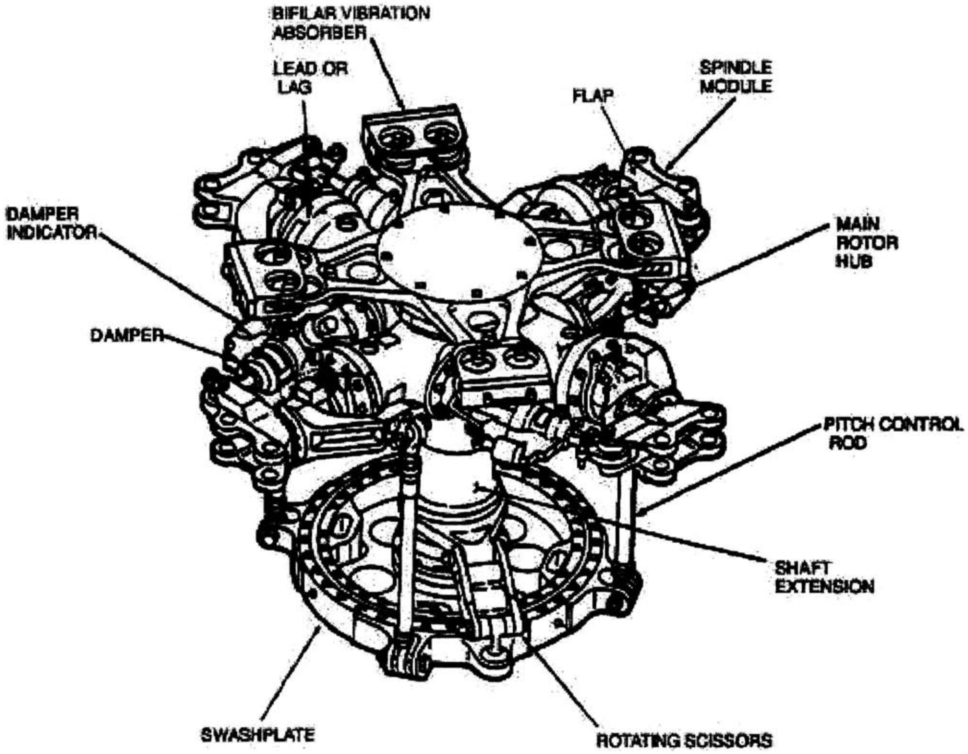


Figure 7: Picture of a Fully Articulated Rotor Head (Source: T-Pub)

With the ground-breaking high density power and flight control technologies, further development of rotorcraft technology in the post-1939 period focused on increasing the rotorcraft performance envelope such as range, speed and payload capacity. Nevertheless, the complexity of the two key rotorcraft technologies and the integration of rotorcraft system remain *high technological barriers* to any new market players in the rotorcraft industry. The evolution of the key rotorcraft technologies before 1939 is shown in the Table 1 below.

Evolution of Rotorcraft Technologies					
Pioneers	**Nationality**	**Year**	**Technology used**	**Technical Challenge**	**Innovation Result**
J.P. Paucton	French	1768	Muscle	Control	Concept
Sir George Cayley	English	1796	Muscle	Power	Concept
Jacob Degen	Swiss	1817	Spring	Power	Flight
Vittorio Sarti	Italian	1828	Pneumatic	Power	Concept
W.H. Philips	English	1842	Pneumatic	Power	Concept
Robert W. Taylor	American	1819	Collective	Control	Concept
Cossus	French	1845	Tilt-rotor	Control	Concept
Luther C. Crowell	American	1862	Tilt-rotor	Control	Patent
Henry Bright	English	1859	Coaxial	Control	Patent
Vicomte Ponton d'Amecourt	French	1861	Coaxial/Steam	Power	Flight
Alphonse Penaud	French	1870	Coaxial/Rubber-band	Power	Flight
Pomes et de la Pauze	French	1871	Gunpowder	Power	Concept
Enrico Forlanini	Italian	1878	Coaxial/Steam	Power	Flight
Fritz and Wilhelm Achenbach	German	1874	Steam	Control	Concept
Julius Griese	German	1879	Steam	Control	Patent
Thomas Edison	American	1879	Electric	Power	Concept
Wilhelm Kress	Austrian	N.A.	Electric	Power	Concept
Nikolaus A. Otto **Gottlieb Daimler**	German	1876	Piston	Power	Otto gas engine Enabling power source

Maurice Leger	Monaco	1905	Coaxial/Electric	Power	Flight
Louis & Jacques Bregeut	French	1907	Quad-coaxial/Piston	Control	1st manned Flight
F. Sternemann	German	1909	Coaxial/Piston	Control	Flight
Igor Sikorsky	Russian	1909	Coaxial/Piston	Control	Failed
Jacob C. Ellehammer	Dane	1911	Coaxial/Piston/ Collective/Cyclic	Control	1st use of full-rotor blade control
Marquis P. P. Pescara	Spanish	1922	Coaxial/Piston/Collective /Cyclic	Control	Flight (autorotation/ tiltable rotorhead)
Juan de la Cierva	Spanish	1923	Autogyro / Piston	Control	Flight / discoveries - autorotation/ asymmetrical lift distribution
Edouard Perrin	French	N.A.	Tandem rotor / Piston	Control	N.A.
Nicolas Florine	Belgian	1927	Tandem rotor / Piston	Control	1st Flight with tandem rotor
Raoul Hafner Bruno Nagler	Austrian	1930	Swash plate rotorhead / Piston	Control	Failed but laid foundation for further development
Louis Breguet Rene Dorand	French	1931	Coaxial/Piston	Control	Flight (controllable and sustained)
Henrich Focke	German	1936	Transverse rotors/Piston	Control	Flight (fully controllable and sustained)
Igor Sikorsky	Russian-American	1939	Conventional main plus tail rotor layout/Piston	Control	Flight (fully controllable and sustained)

Table 1: Evolution of Rotorcraft Technologies before 1939 (various sources)

Table 1 summarizes the long and arduous aviation journey to create the world's first fully controllable rotorcraft that was capable of sustained flight. This table shows incremental advancement of modern rotorcraft technologies that began about 160 years ago. It shows the integration of the enabling rotorcraft technologies, such as piston engine, collective-cyclic control and swash plate rotor head, which can still be found in modern rotorcrafts today. The major events that marked the vital step towards the realization of vertical flight are also shown in the table (highlighted rows). Nevertheless, these enabling technologies are just the explicit or visible aspects of technological evolution. The invisible aspect of rotorcraft technologies is the tacit knowledge of integrating these different technologies into a system that fulfill its design requirement – controllable and sustained flight. Tacit knowledge of system integration is found in the system interfaces such as cyclic-collective control model, optimum rotor speed, vibration damping, rotor blade elasticity, transmission ratio between engine and rotor, etc. While many of these mechanical systems can be acquired through reverse-engineering (another word of learning through disintegration, analysis and replication), however, many of these systems are getting more tacit as rotorcrafts become more wired-up. For instance, mechanical control system is now increasing replaced by fly-by-wire control systems, which are also lighter and easier to maintain (using digital diagnostic system to identify source of technical failure). The previously explicit characteristics of rotorcrafts are increasing embedded into complex black-box systems (avionic and autopilot) that are furthered encrypted in complex software codes. This recent development in turn increases the technological barrier of emerging rotorcraft companies in acquiring rotorcraft technologies.

2.2.2 Unbreakable Technological Barrier for Emerging Rotorcraft Companies

Due to the technological complexity and immense cost to design and develop modern rotorcrafts, it is interesting to note that no emerging rotorcraft companies from the newly industrialized and developing nations have succeeded in developing rotorcrafts without cooperation with incumbent OEMs from the leading nations with rotorcraft technologies. Furthermore, key rotorcraft technologies such as helicopter flight control system and rotor system are unique technologies that cannot be found in or derived from other industries. In comparison, airframe technologies such as metal sheeting forming and composite material manufacturing can be derived from the fixed-wing aircraft and automotive industry. Data gathered from the industry indicates that none of the emerged and emerging players have single-handedly developed their products without going through the *rite-of-passage* of cooperation with the incumbent players. Table 2 shows all the major emerged and emerging players and their respective cooperation partners.

Emerging Players (since 1950s)	**Country**	**Cooperation Partners**
Eurocopter	France & Germany	Bell/Sikorsky
Agusta	Italy	Boeing (MD) / Bell / Sikorsky
Westland (merged with Agusta in 2001)	UK	Boeing (MD) / Bell / Sikorsky
Kawasaki Heavy Industries Aerospace (KHI)	Japan	Boeing (MD) / Bell / Sikorsky
Korean Aerospace Industries (KAI)	South Korea	Bell / Boeing (MD) / Eurocopter
Hindustan Aeronautics Limited (HAL)	India	Eurocopter (formerly MBB)
Denel Aerospace	South Africa	Eurocopter (formerly Aerospatiale)
Avicopter	China	Eurocopter / Mil
PZL Swidnik	Poland	Oboronprom

Table 2: Cooperation Partners of Emerged/Emerging Rotorcraft Companies (various sources)

2.2.3 Modern Challenges of Rotorcraft Development

Besides understanding the complex system architecture of rotorcrafts, it is important to understand the complexity of design and development of rotorcrafts to appreciate the effort required to acquire and learn the art of rotorcraft design and manufacturing. The development of new rotorcrafts, especially military rotorcrafts, is a long and risky undertaking that often takes in excess of a decade. Rotorcrafts are becoming more complex mainly due to the increasing mission requirement and the associated mission system integration complexity, which requires significant design refinement iteration and validation time. As such, developing a new rotorcraft to *fly controllably* is often as difficult as designing it to *fulfill its designed mission* requirement, such as the ability to integrate and employ non-flight relevant mission equipment.

The business of designing and developing rotorcrafts is not always a guaranteed success. Recent examples of rotorcraft programs such as the U.S. Army Bell-designed Armed Reconnaissance Helicopter (ARH) and the Australian Navy Kaman-designed SH-2 Sea Sprite have experienced immense cost overrun and development delay, which eventually led to the termination of both programs (DefenseIndustryDaily, 2008a; US Army News, 2008). In both programs, the helicopters were already flying but were severely delayed by mission integration failure. In the case of the Bell ARH, Bell was unable to integrate the mission sensor package with the helicopter within the contractual timeframe and budget (GlobalSecurity, 2008a). Before the termination of the ARH program, the program budget overrun was estimated to be more 100% and delayed by four years. In the case of Australian Navy Kaman SH-2, Kaman, an American OEM, was unable to integrate its night-vision devices into the helicopter, rendering it incapable to fly at night or in low-visibility condition. The program was delayed by six years and overshot its budget by 50%. Furthermore, the development of rotorcraft flight control system is also a major challenge in rotorcraft program involving new generation rotor system. For instance, the development of the Boeing-Bell V-22 Osprey tilt-rotor rotorcraft has been delayed due to difficulty in achieving flight stability such as during the transition between hovering to forward flight mode and during high-speed descent maneuver. During the development of the V-22 rotorcraft, the difficulty in the development the flight control system resulted in three fatal and a non-fatal crashes before it achieved the technology maturity level that could be certified as airworthy for use by the U.S. military forces (GlobalSecurity, 2008b).

The following graph shows the long duration of development of major rotorcrafts and immense cost of development since 1980s. In additional to the long development time, development of new rotorcrafts requires immense financial resources. Development costs of rotorcrafts range from several tens of millions US dollars for light civilian rotorcrafts to several billion US dollars for military rotorcrafts. For example, the Kawasaki OH-1 helicopter cost US$ 1.1 billion to develop while the Bell-Boeing V-22 cost US$ 4.3 billion. Figure 8 shows the increasing trend of the rotorcraft actual development durations over the last four decades. This trend is an indicator of increasing complexity and challenges in the development of rotorcrafts in spite of increasing experience and advancement in technology and design processes.

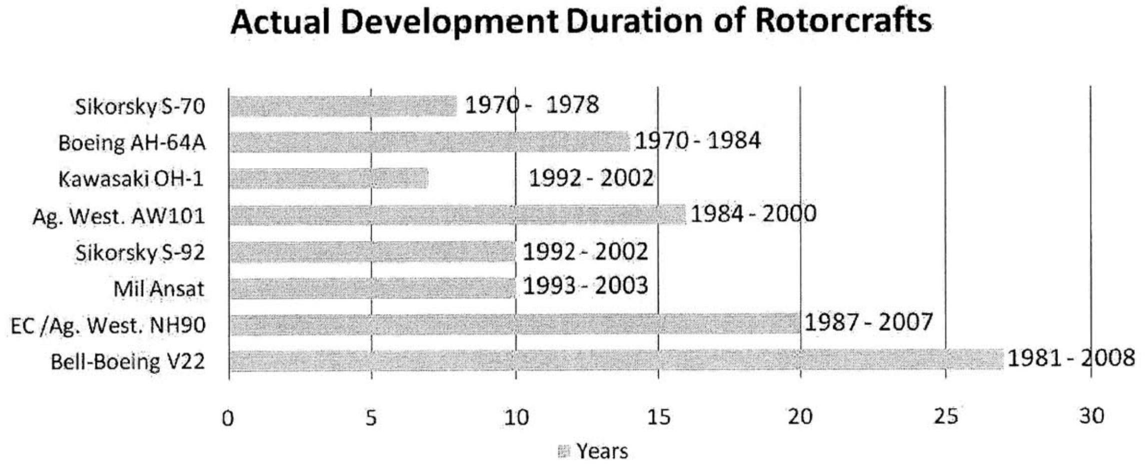


Figure 8: Actual development time of different rotorcrafts (Source: Jane's Defence)

In conclusion, the design and development of rotorcrafts is a highly risky undertaking in term of cost and time even for industrialized nations with significant aerospace capability. Failures of rotorcrafts programs are certainly not restricted to US companies. Other leading aerospace nations such as those in Europe have also experienced their share of program delay and cost overrun. Major European rotorcraft programs such as the NH-90 multi-role transport helicopter and TIGER attack helicopter programs are similar examples that have faced these common challenges.

2.3 The Market Players (OEM)

The Rotorcraft Market Overview

The rotorcraft industry has always been an important pillar of the aerospace and defense industry since 1950s. The first mass produced and operational rotorcrafts were developed during the Second World War for reconnaissance and transportation. After the Second World War, the use of rotorcrafts was proliferated by the US for medical evacuation, troop transportation and aerial fire support during the following two wars in Asia (Korea and Vietnam). Several thousand rotorcrafts, of which the majority was the venerable Bell UH-1s, were produced and put into service during these few decades. During the same period, the Russian manufacturers such as Kamov and Mil mass-produced great number of military rotorcrafts during the Cold War period. During the cold war era, in addition to the two superpowers, the other nations that were capable of designing and producing rotorcrafts in any substantial volume were the UK (Westland, Bristol, Fairy, Saunder Roe), Italy (Agusta), France (Sud Est Aviation/Aerospatiale) and Germany (Messerschmitt Bölkow Blohm, Dornier) (Polte, 2008). The use of rotorcrafts in Europe was also dominated by the militaries. Today, rotorcrafts are indispensible assets in any modern military forces. Their applications have also increased tremendously, especially in transport, precision strike, battlefield management and combat search & rescue (CSAR) operations.

The first commercial use of rotorcrafts dated back in the early 1950s. The use of rotorcraft commercially was limited due to their relatively high operating costs and limited use. Few private companies could afford the high acquisition costs of rotorcrafts. Furthermore, the limited range and lower comfort level restricted rotorcrafts' widespread commercial use other than in niche areas with special accessibility requirement, such as in the remote regions and energy exploration industries. Today, the use of rotorcrafts commercially has become widespread especially in VIP transport, medical evacuation, in tourism and homeland defense. Rotorcrafts are also indispensible transportation system for news agencies and home security agencies around the world. As a reference, the distribution of the world's fleet of helicopters is shown below in Figure 9.

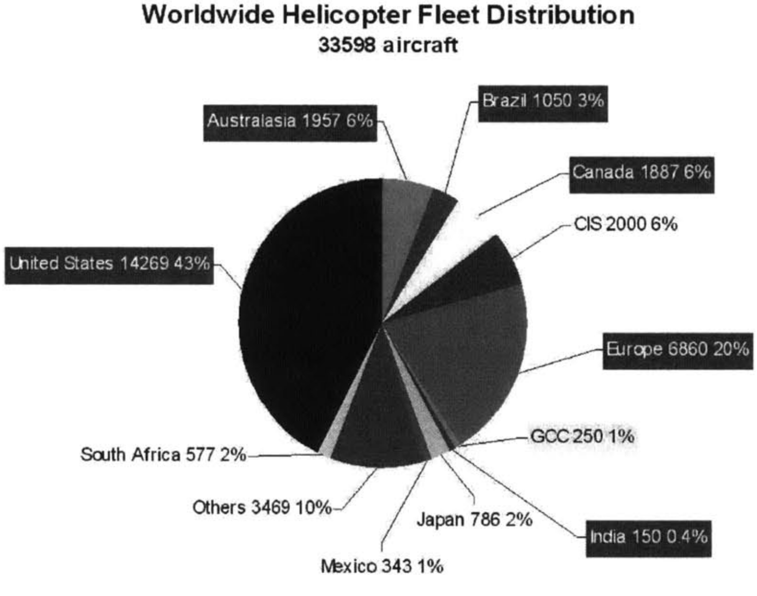
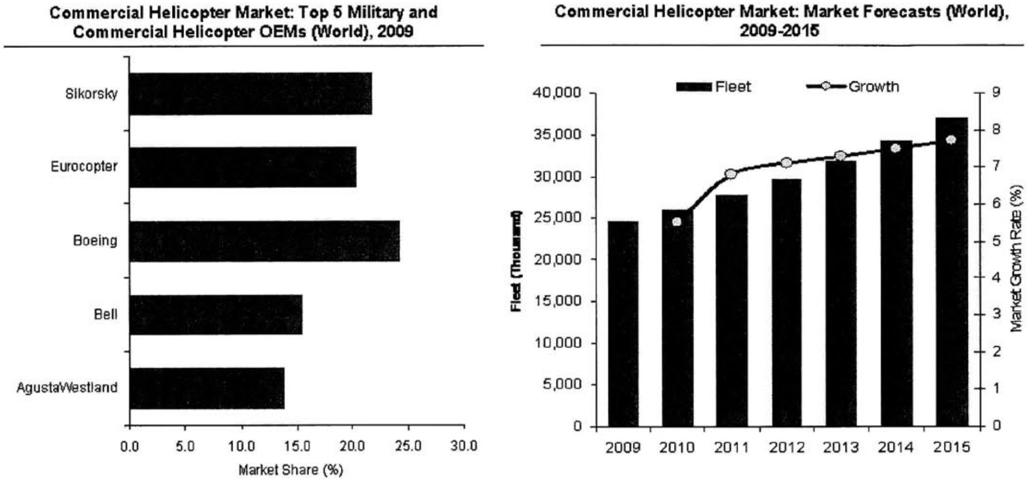


Figure 9: Estimated Worldwide Rotorcraft Fleet Distribution (Source: IHST, 2009)

The present rotorcraft market is an oligopoly that is dominated by six global OEMs (AgustaWestland, Bell, Boeing, Eurocopter, Oboronprom, and Sikorsky). These major OEMs possess more than 90% of the sales volume in the commercial and military markets (Figure 10). These six OEMs focus mainly on medium to high end turbine-powered products. On the lower end of the market, there are about 10 smaller OEMs (MD helicopter, Kawasaki Aerospace, Avicopter, Robinson, Enstrom, Denel Aerospace, Hindustan Aeronautics, etc.) that focus either on smaller, low cost piston-engine rotorcrafts or on the manufacture of licensed products from the six major OEMs.



Commercial Helicopter Market: Top 6 Military and Commercial Helicopter OEMs (World), 2009

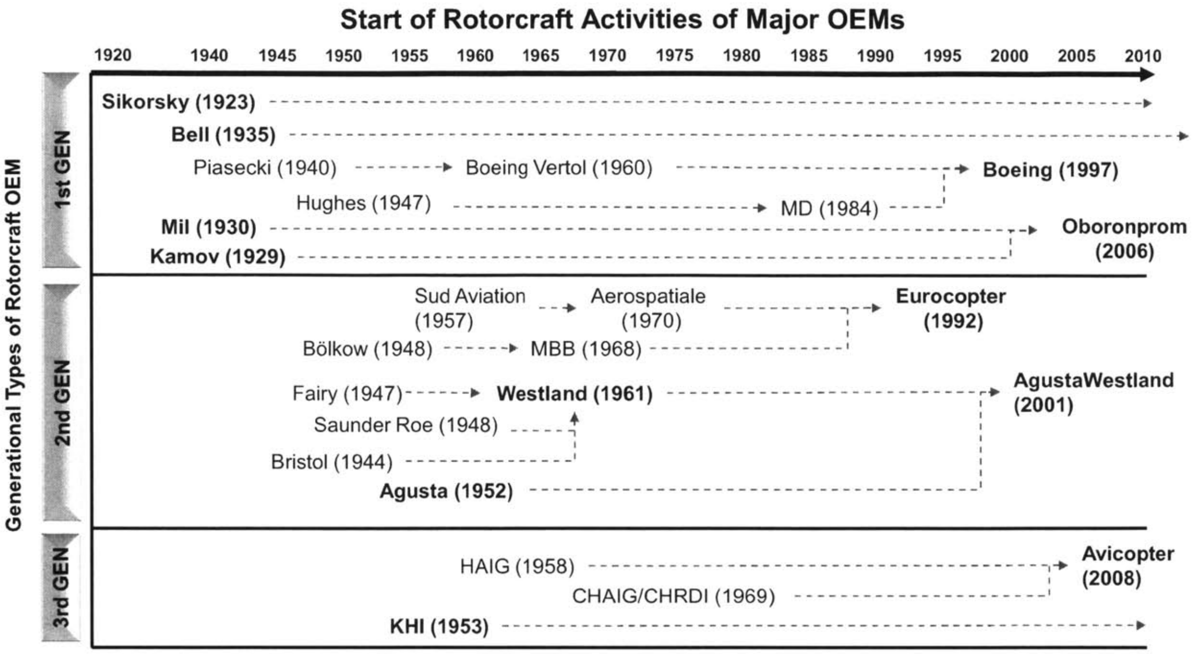
Commercial Helicopter Market: Market Forecasts (World), 2009-2015

Note: All figures are rounded; the base year is 2009.
Source: Frost & Sullivan

Note: All figures are rounded; the base year is 2009.
Source: Frost & Sullivan

Figure 10: Market Share and Growth Forecast 2009 (Frost & Sullivan, 2010)

The way all OEMs are categorized in this thesis is based on their technological capability and entry dates into the industry. First generation OEMs are the pioneering rotorcraft companies that were founded before 1945. These OEMs are from the US and Russia. The second generation OEM's are reconsolidated companies formed mainly from the remnants of the Second World War in Europe. After the war, a number of prominent rotorcraft manufacturers such as Focke-Wulf and Flettner discontinued operation due to the demilitarization of Germany. Second generation OEMs are located in Germany, France and the UK. Lastly, the remaining OEMs belong to the third generation OEMs such as Agusta, Avicopter and KHI. Third generation OEMs are characterized by the lack of indigenous rotorcraft technologies and were created from ground-up principally through cooperation with earlier generations of OEMs. Figure 11 shows the evolution of the three generations of OEM over the last century.



Notes:

1) The year in bracket indicates the commencement of OEM's rotorcraft activities or of its founding, whichever is known.

2) HAIG, CHAIG and CHRDI have been managed by China's aerospace industrial agency that was created in 1951.

Figure 11: Generational Types of Major Rotorcraft OEMs (various sources)

2.3.1 The Pioneering Players (First Generation)

The founding or first generation of the rotorcraft OEMs was dominated by the market players in the US, the UK and the then Soviet Union. During the decade after the Second World War, the destruction of industries in Continental Europe resulted in the outflow of rotorcraft technologies to these nations. The precise amount of rotorcraft technologies transfer to these nations remains unclear. However, the emigration and employment of many prominent rotorcraft engineers (Focke, Flettner, Hafner, Stephan, Doblhoff, Sikorsky, etc.) from Europe and Russia provided clear evidence of this trend. This post-war development invariably gave the US, the UK and Soviet Union a head start in the further development of rotorcrafts. Furthermore, post-war restriction that forbade Germany in developing its domestic aerospace industry until 1955 further exacerbated the loss of rotorcraft technologies as German engineers flocked to overseas OEMs to continue their development work. The major first generation OEMs (in terms of sales revenue) that still exist today is listed as follow:

- Bell (USA)
- Boeing (merged with Vertol, McDonnell Douglas & Hughes) (USA)

- Sikorsky (USA)
- MD Helicopter (USA)
- Oboronprom (including Mil, Kamov, Kazan, Ude-Ulan) (Russia)

The first generation rotorcraft companies are pioneering OEMs that developed their first products independently without cooperation with other OEMs. The brief introduction of some of the first generation OEMs that were analyzed in this thesis are shown in the following section.

Bell Helicopter (USA)

The company was founded by Larry Bell in 1935 as Bell Aircraft Corporation, which was the first OEM to obtain certification for a commercial helicopter. Today, it is a division of Textron Group. It is headquartered in Fort Worth, Texas and has plants in Amarillo, Texas and Mirabel, Canada. Bell started its aerospace business by designing and building fixed-wing fighter aircrafts. Later, Bell went into the rotorcraft business after it employed prominent American aviation pioneer, Arthur M. Young, who led Bell into the development of its first rotorcraft product – the Model 30.

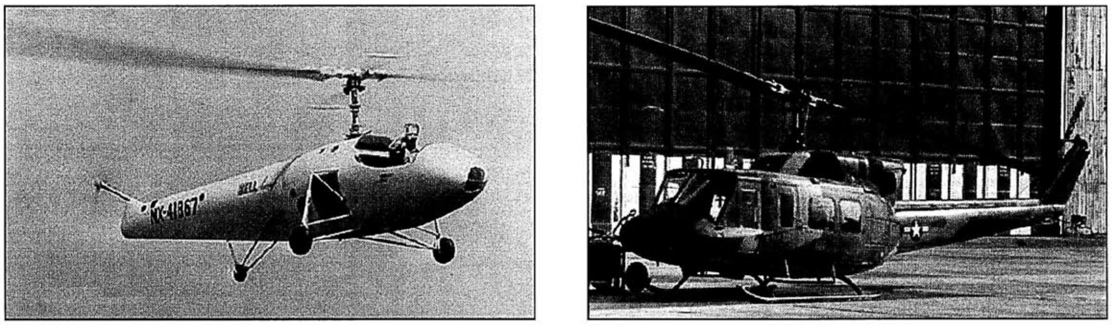


Figure 12: Model 30 and UH-1 Huey (Source: Aviastar)

Today, Bell is a global company that has delivered more than 35,000 aircrafts around the world. It is also the company that designed and manufactured one of the most familiar helicopters of all time – UH-1 Huey, which were the primary helicopters used by the U.S. military forces during the Vietnam War. Many of Bell products such as the B47, Bell 212, and Bell 412 have been licensed to many emerging OEMs such as Kawasaki Aerospace, Westland and Agusta for local production. Furthermore, Bell Helicopter invented tilt rotor aircraft (BA609) in cooperation with the Italian rotorcraft maker, Agusta. It also cooperates with Boeing in the design and production of V-22 Osprey tilt rotor aircrafts since mid-1980s.

Boeing Rotorcraft System (USA)

Boeing Rotorcraft Systems is a division of the Boeing Defense, Space and Security division and is based in Ridley Park, Pennsylvania. Boeing did not have its organic rotorcraft division until its acquisition of Vertol Aircraft Corporation in 1960 and later McDonnell Douglas Helicopter in 1997. Vertol Aircraft Corporation was formerly known as Piasecki Helicopter, which was founded by Frank Piasecki. Vertol is the second American rotorcraft company to successfully have flown a rotorcraft (PV-2, in 1943) after Sikorsky. Vertol is known for its tandem-rotor helicopters such as the CH-46 Sea Knight and CH-47 Chinook, which have been serving the U.S. military forces since the 1960s. Vertol was acquired by Boeing in 1960.

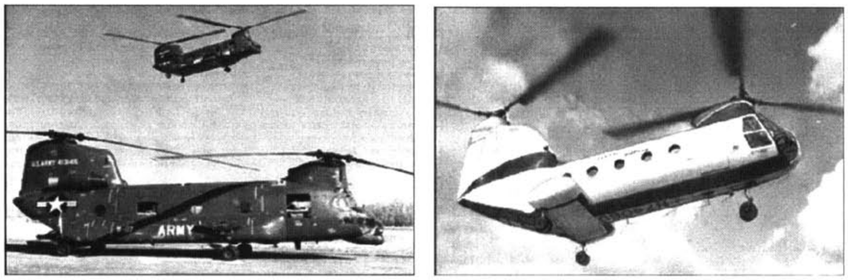


Figure 13: CH-47 Chinook and CH-46 Sea Knight (Source: Aviastar)

McDonnell Douglas Helicopters (MD Helicopters) was founded in 1947 as a division of the McDonnell Douglas Aircraft Corporation. MD Helicopters acquired Hughes Helicopters in 1984. MD Helicopters and Hughes Helicopters were both pioneering OEMs in the rotorcraft industry. MD flew its first rotorcraft, the XHJD-1 "Whirlaway" in 1946 while Hughes Helicopters flew its first rotorcraft, the Hughes Model 269, in 1956. Hughes Helicopters designed the famed AH-64 Apache attack helicopters, which were instrumental in defeat of Iraqi Army during the first Iraq War in 1991.

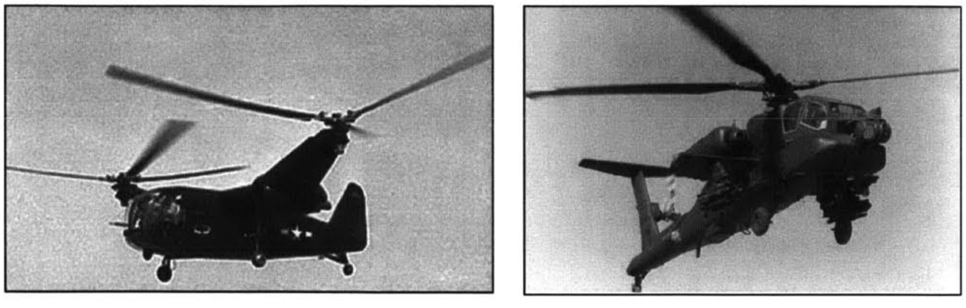


Figure 14: XHJD-1 "Whirlaway" and AH-64 Apache (Source: Aviastar)

Boeing Rotorcraft Systems only designed and manufactured military rotorcrafts and has a worldwide presence through the sales and licensed production of CH-47 and AH-64 by emerging OEMs such as Kawasaki Aerospace, Korea Aerospace Industries and AgustaWestland.

Sikorsky (USA)

Sikorsky Aircraft Corporation was founded in 1923 by the Russian-born American, Igor Sikorsky. Sikorsky is based in Stratford, Connecticut and is a division of the United Technologies Corporation today. Sikorsky flew the US first operational helicopter, the VS-300, in 1939. It has been a major OEM for modern military and commercial helicopters such as the S-76, UH-60 Blackhawk and CH-53 Super Stallion, which are used by countries worldwide. Sikorsky also owns Schweizer Aircraft that was acquired in 2004. Schweizer Aircraft is a small OEM that manufactures light piston-engine helicopters such as the S300 and sailplanes. Since its founding, Sikorsky has been a leader in the design and development rotorcrafts. Sikorsky is the earliest US rotorcraft OEM to export rotorcrafts and to cooperate with emerging OEMs. It has licensed the S-51, S-55, S-58 and S-61 to newly emerging OEMs such as Westland, Agusta, MBB and Kawasaki Heavy Industries.

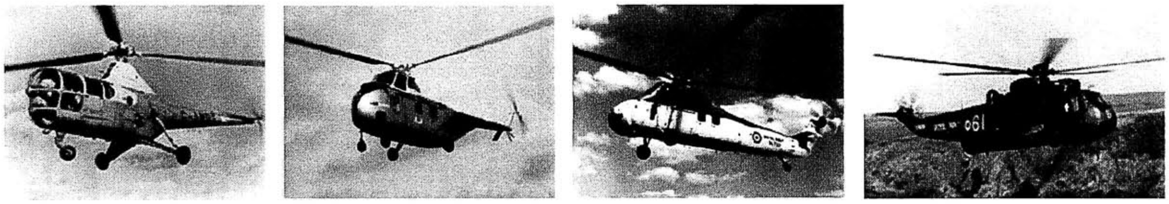


Figure 15: S-51, S-55, S-58 and S-61 (Source: Westland)

MIL (Russia)

Mil Helicopters was founded in 1947 by Mikhail Leontyevich Mil, a Russian aviation pioneer who started designing and building gyroplanes and helicopters in 1929. Mil flew its first product, the Mi-1, in 1948. Mil Helicopters is based in Moscow and has since become a major OEM in term of the number of rotorcraft built and the innovative rotorcraft technologies. Mil's wide range of products include the world's most proliferated helicopters, the Mi-8 "Hip", which are used by about fifty countries. In addition, Mil is also known for designing the world's largest operational helicopter, the Mi-26 "Halo". Mil has designed about 15 different types of rotorcrafts, which account for about a quarter of today's rotorcraft fleet in the world. Mil is also one of the earliest rotorcraft OEM to cooperate with emerging OEM. Counted as some of Mil's major foreign cooperation partners are Avicopter (China) and PZL Swidnik (Poland).

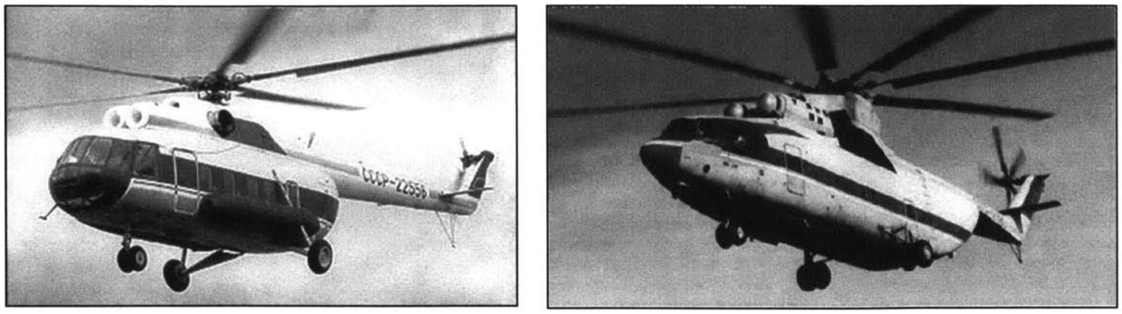


Figure 16: Mi-8 and Mi-26 (Source: Aviastar)

2.3.2 The Emerged Market Players (Second Generation)

The second generation rotorcraft companies are European OEMs that have been developing rotorcrafts after World War II using *indigenous rotorcraft technologies that survived the war* and *through cooperation* with American OEMs. As stated earlier in this chapter, much of the rotorcraft technologies were originated from Europe and Russia. These OEMs are a mix of private and state-owned companies, which were financially supported by their nations through the receipt of offset work packages such as licensed local production of military rotorcrafts or direct R&D funding for the development of indigenous rotorcraft products. These second generation OEMs also acquired rotorcraft technologies through cooperation with first generation OEMs such as Bell (e.g. Bell-Agusta AB139 and BA609). The major OEMs from the second generation are listed as follow:

- AgustaWestland (founded in 2001 by the merger of Agusta (Italy) and Westland (UK))
- Eurocopter (founded in 1992 by the merger of Aerospatiale (France) and MBB (Germany))

2.3.3 The Emerging Market Players (Third Generation)

The third generation rotorcrafts OEMs are rotorcraft companies that emerged after 1970. These OEMs have two things in common. They all lacked indigenous rotorcraft technologies initially and relied on cooperation with earlier generations of OEMs to acquire rotorcraft technologies. All these OEM underwent the common initial phase of incremental learning via numerous cooperation programs to acquire rotorcraft design and production capabilities from the first and second generation OEMs.

Furthermore, similar to the second generation OEMs, third generation OEMs are a mix of private and state-owned companies, which are indirectly and directly financially supported by their nations through the receipt of offset work packages such as licensed local production of purchased military rotorcrafts or direct investment funding for the development of indigenous rotorcraft products. The major third generation OEMs are listed as follows:

- Avicopter (China)
- Denel Aerospace (South Africa)
- Hindustan Aeronautics Limited (India)
- Kawasaki Heavy Industries (KHI) Aerospace (Japan)
- Korean Aerospace Industries (South Korea)

CHAPTER 3: COOPERATION IN THE ROTORCRAFT INDUSTRY

3.1 Architecture of the Rotorcraft Industry

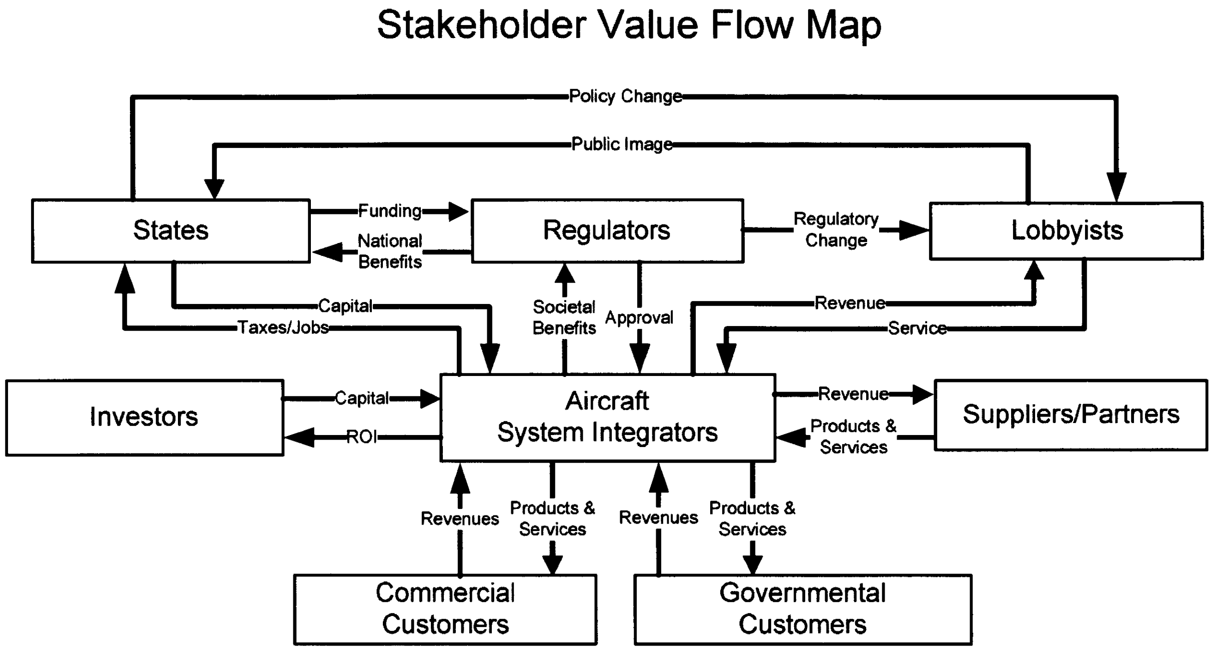


Figure 17: Stakeholder Value Flow Map of Rotorcraft Industry

In order to understand the motivations for cooperation among rotorcraft companies, it is important to understand the architecture of the rotorcraft industry. The rotorcraft industry is a part of the greater aerospace and defense industry, which has a complex stakeholder structure. The dual-use (commercial and military) nature of rotorcrafts makes them susceptible to pressure from both commercial market forces and national interests. Hence, rotorcraft industry is an ever-changing system of interacting interests and values. Competitive bidding of international contract is often more dependent on the political factors than product price and performance. Recent cases like the Indian Army Light Observation Helicopter program (Flight Global, 2010a) and the US Air Force KC-X tanker program clearly illustrated how market forces in the aerospace industries can be skewed by national and global political agendas (Flight Global, 2010b). Furthermore, many rotorcraft OEMs' dependence and obligation to their national governments make themselves extremely difficult to manage according to commercial business practices. On one hand, these OEMs are dependent on their sponsoring national governments for funding, investment and supportive regulative policies. On the other hand, these OEMs are also obliged to a great extent to support their national interests such as creation of domestic jobs, exports and national security. Often, commercial losses were offset by shady financial support and subsidies from governmental institutions (NYTimes, 2010). The overall industrial landscape of the rotorcraft industry is represented in a stakeholder value flow map shown in Figure 17.

Global Cooperation

Needs	Catalysts
1) Market Access	**1) Defense Policies**
2) Access to Technology	**2) Offset Requirement**
3) Cost & Risk Sharing	**3) Economics**

Figure 18: The Needs and Catalysts of Cooperation

A characteristic of the rotorcraft industry is the growing trend for more cooperation. The architecture of rotorcraft industry lays down the fundamental conditions for cooperation. In other words, cooperation is a result of this type of industrial architecture. Increasing cooperation among companies is not a unique to rotorcraft industry. Many other industries such as automotive, airline and computer industries are increasing engaged in more intense cooperation. Cooperation between companies can bring greater values to the industries. Contemporary researches on the cooperation between companies have justifies the value of cooperation. However, the need and catalyst of cooperation across the industries may be different. This section explains the needs and catalysts of cooperation in the rotorcraft industry. The overview of the needs and catalysts are shown in Figure 18.

3.2 The Need for Global Cooperation

3.2.1 Market

Most major rotorcraft companies rely heavily on commercial exports. The two leading European manufacturers, AgustaWestland and Eurocopter, have more than 50% of their sales from overseas (Frost & Sullivan, 2010). However, the demand in the European market is insufficient to sustain the survival of two large rotorcraft manufacturers. The sales of rotorcrafts overseas require globalization of most business operations such as design, marketing, production, MRO (maintenance repair and overhaul), customer service and support.

Market entry and penetration into the overseas markets in any countries, however, cannot be achieved without a holistic strategy. This strategy has to address political, protectionism regulation, industrial and security aspects of the market. In the US market, for instance, foreign defense and aerospace companies face immense competition and governmental regulations (e.g. Federal Acquisition Regulation) when bidding and supplying to the US government. US domestic players have significant political and operational advantages, such as having established acquisition processes and supply chain network. Furthermore, foreign players that want to be qualified as a US defense contractor have to go through a complex certification process that can be prohibitively uneconomical and operationally challenging. However, some companies, such as BAE Systems, has even come to the extent of creating independent business division in the US under a Special Security Agreement (SSA) to focus solely in the US market and be managed as a local US company (SIPRI, 2009). This can reduce business operational complexity of having to fulfill both US and UK regulations. An alternative bypass solution to the high market entry barrier is the acquisition of existing US companies by foreign players, which also has to satisfy the conditions of the SSA. The acquisition of DRA International by Italian defense giant company Finmeccanica is a good example of such market entry strategy. However, SSA is by itself a lower market entry barrier as it covers only selected NATO (North Atlantic Treaty Organization) and allied nations. Such security and protectionism barriers exist in other nations as well.

Cooperation with local industrial players is an alternative way to overcome these types of market and national protectionism obstacles. For instance, AgustaWestland has cooperated with Lockheed Martin and Boeing to supply the VH-71 presidential rotorcrafts. By working with two major local players, AgustaWestland has gained strong local partners (Airforce Technology, 2009), who understand the market and the political landscape in the US. As major contractors to the US government, Lockheed Martin and Boeing have extensive experience and competences working with the US military and acquisition agency. Often, the work share in the cooperation agreement is often divided into the militarized portion, such as mission systems, for the local players and non-militarized portion, such as airframe, for the foreign players. In this case, the foreign players may avoid or minimize the complex certification and the required enterprise transformational effort required by the US government by remaining as Commercial-Off-The-Shelf (COTS) subcontractors to their US cooperation partners.

3.2.2 Access to Technology

The rationalization of the rotorcraft industry in the last few decades has led to the polarization of competences among the industrial players. To list a few examples, Boeing is the only player that is still producing rotorcrafts with tandem rotor system, Kamov and Sikorsky with co-axial rotor system and Bell with its tilt-rotor system. Hence, it is common for players to cooperate in order to gain access to technologies that are only available through cooperation. For instance, the AgustaWestland collaborated with Bell, which possesses the unique tilt-rotor technology, to develop the BA609 tilt-rotor aircraft for the commercial market.

3.2.3 Cost and Risk Sharing

The technological complexity of modern rotorcrafts increases with increasing product requirement, especially due to more demanding and complex military and regulatory requirements. For instance, modern military rotorcrafts not only have to perform its basic missions such as transportation, attack and reconnaissance, but also have to survive in the hostile combat and harsh operational environment. The combination of these requirements generates immense amount of complexities such as configuration management, system design and development for the manufacturers. The cost of developing such multi-mission airborne systems is making independent venture a highly risky undertaking for a single company. Cooperation is a way to share cost and risk for the cooperating rotorcraft manufacturers (Darnis, et al., 2007). Nevertheless, the caveat of cooperation is the additional management complexity and risk to the rotorcraft program. If cooperation is not managed effectively and efficiently, the added complexity and risk may fully negate the advantages of cooperation.

3.3 The Catalyst of Global Cooperation

3.3.1 Global Defense Policies

The increasing pressure to get the most "bang for buck" out of the often tight national defense budgets has driven many countries into alternative solution. One of the most common solutions is through cooperation in defense equipment acquisition. Cooperation in the design and production of major defense equipment is very well established especially in countries with established security pact such NATO and European Defense Cooperation. The NATO agreement between the US and Europe constitutes an important enabling security framework that contributes to the transfer to rotorcraft technologies to the second generation rotorcraft companies in Europe and continuation of cross-Atlantic sharing of technologies. Furthermore, cooperation may increase redundancy and robustness of the defense supply chain to reduce the vulnerability of single sourcing in times of critical political or military events. Cooperation in defense aerospace systems acquisition programs also increases understanding and working experience among allied and friendly nations by setting up common industrial and cooperation standard. A common practice in the European defense industry is the setting up of institutionalized program management organizations such as the NAHEMA (NATO Helicopter Management Agency) and OCCAR (Organization for Joint Armament Cooperation) for the management of multi-national programs.

Cooperation in defense aerospace systems also enhances interoperability among allied and friendly nations. Interoperability among individual allied nations can be increased by using same equipment or same system interfaces. Interoperability not only improves command, control and communication of allied forces during operations, but also ensures commonality in spares and logistical aspect of operations (the use of NATO standard equipment and fuel type). However, cooperation may also lead to an unexpected negativity. Through transfer of technology in cooperation, partnering nations may acquire new capabilities from more developed partners and pursue nationally developed systems individually at a later stage (Moore, Lorell, & Lowell, 2002). Recent defense cooperation programs such as the F-35 JSF (Joint Strike Fighter) and MEAD exemplify this cooperative trend.

3.3.2 Offset Regulation

Most countries have national offset (compensation) regulation when making military or aerospace purchases from overseas companies. Offset regulation usually specify a certain percentage of the acquisition contract value that needs to be compensated, where 100% or more is common. Offset usually involves local production, local components sourcing or co-development of the purchased products. Furthermore, some countries allow the fulfillment of their offset regulations indirectly through barter trade, transfer of technologies, services, political favors or other unrelated economical activities, which can offset the outflow of national currency. Nevertheless, the most common form of offset is local production and co-development, which require close cooperation between the manufacturers and local industrial players of these countries. Currently, there is an increasing trend offset requirement that will accelerate pace of cooperation (Defense News, 2010).

3.3.3 Economics

As competition in the rotorcraft industry intensifies, the need to reduce operational cost drives manufacturers to source and produce in low cost countries. This leads to the globalization of their supply chain network by sourcing or producing in lower cost countries. Furthermore, the use of US dollar as the currency of transaction in the aerospace industry drives European manufacturers, which use Euro, to relocate their operation to countries located in the US dollar zone. The caveat of such change to the supply chain is the management and negativities of globalized supply chain such as lower product quality, decay of competences and creation of future competitors. The Sikorsky S-76 and S-92 programs exemplify this global trend in the rotorcraft industry.

3.4 The Implications of Global Cooperation

Since global cooperation among aerospace and defense companies is an unavoidable industrial requirement, rotorcraft OEMs should capitalize on their experience in global cooperation to negate the additional cost of cooperation. According to Nobel Prize laureate Douglass North (North, 2004) and a McKinsey & Company study, transaction costs, which include search, coordination and monitoring costs (Dyer, 2000b), account to more than 30% of all economics activities in the US. Cooperation projects, which usually have more complex cross-boundary and inter-company coordination and management costs, may incur even higher transaction costs. In other words, the drive for global cooperation is not without its costs, aerospace and defense companies have to account for the cost of cooperation into its business cost structure in order to ensure the economical and political viability of global cooperation. Hence, cooperation competence, the ability to effectively and efficiently cooperate, has to be considered as a critical core competence in this industry, which deserves the similar management attention like other core competences such as technologies and marketing.

Core competences are business activities, which differentiate the enterprise from its competitors (Porter, 1996). In contrast, Prahalad and Hamel (1990) suggest that core competence is the company's collective knowledge about how to coordinate diverse production skills and technologies. This definition is not restricted to a single technology or skill and is defined in the context of a company. The definition of core competence from Prahalad and Hamel (1990) also implies that the focus lies on the process, which is a form of codified knowledge, within the company to orchestrate the different resources required for accomplishing certain tasks that constitute core competencies. Hence, core competences can be classified by the type of business activities (e.g. design, production, retails) and the depth of business activities coordination (e.g. degree of outsourcing, control of supply chain, control of the retail network, etc.). However, core competences are, however, by no mean permanent state of enterprise. These core competences evolve according to the business cycle and to the enterprise's evolution in the value chain. For instance, the proliferation of simple aerospace composite manufacturing technologies to lower cost regions of the world makes 100% in-house manufacturing of simple composite components by the major airframe manufacturer such as Boeing and Airbus cost ineffective. In fact, major airframe sections of the Boeing 787 Dreamliner are manufactured by the Italian Alenia Aeronautica and the Japanese Mitsubishi Heavy Industries (Stern Magazin, 2007)

Similar to other core competences within the enterprise, enterprise's cooperation competence ensures aerospace and defense companies' competitiveness. Since the core competences are allocated a major portion of the enterprise operating budget, the lesser the cost of cooperation, the higher is the profit margin. Besides the cost competitiveness, the intangible but very important aspect in the aerospace and defense industry is reputation (Stuart & Robinson, 2006) and trust (Gulati R. , 1995). Potential partners (both state-owned and private) conduct due-diligence study before closing a cooperation contract with foreign companies. Companies that have more previous success in cooperation programs may have better chance of clinching aerospace and defense contracts, *ceteris paribus*. As rotorcraft OEMs transform themselves from vertically integrated manufacturers into horizontally integrated system integrators, cooperative competence will take the center stage in their competence portfolio.

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CHAPTER 4: LITERATURE REVIEW

This thesis analyzes how emerging rotorcraft companies use cooperation to conduct technological learning and how their technological learning process were affected by their national learning environments. Hence, this review focuses on existing literatures about cooperation, organizational learning, transfer of technology and the national learning environment.

The literature review indicates that there has been extensive research on cooperation (Axelrod, 1997; Dyer, 2000; Faulkner, 1995; Gulati, 1995, Gulati et al., 2009; Hamel & Doz, 1998) and organizational learning (Adler, 1991; Argyris & Schön, 1996; Roth, 2008; Schein, 1996; Senge, 1990). Transfer of technology, in the thesis context, is considered as an abstraction of cooperation and organizational learning. Organizational learning provides an insight into the mechanism of learning within the technology transfer process. Moreover, for technology transfer to occur it has to be carried out under certain cooperation framework, which includes certain learning mechanism between the knowledge transferor and receiver. The review also indicates the extensive literatures on transfer of technology (Chinworth, 1992; Cyhn, 2002; Dixon, 2000; Enos, 1991; Fransman, 1984; Gao, 2004; Johnson & Hall, 1968; King & Nowack, 2003; Lall, 1996; Lee et al., 1988; Lee, 2003; Luo, 2006) that cover wide range of industries such as aerospace, automotive, defense and electronic industries. The review on the national learning environment has revealed a number of frameworks such as the National Innovation System (Nelson et Al., 1993) and the Systems of Innovation (Freeman, 1988). The application of National Innovation Systems in decoding the development of industrial sectors and national technological capabilities was also found in several literatures (Cheung, 2009; Odagiri & Goto, 1993, 1996; Malerba, 1992, 1993; OECD, 2008). In summary, existing collection of literatures provides a good theoretical and data foundation for this thesis. Nevertheless, no specific research on cooperation and the transfer of technology in the rotorcraft industry has been found in this review. The following three sections of this chapter elaborate on these three literature review focal points.

4.1 Literature on Cooperation

The field of *cooperation* is a very broad research area that covers a wide range of academic disciplines. This is not surprising given the complexity and multi-disciplinary nature of cooperation, which no single academic discipline can adequately address. A review of the existing literature indicated that the field of cooperation has been researched in academic disciplines such as sociology

(Axelrod, 1984), evolutionary sciences (Dawkins, 1976; Axelrod & Hamilton, 1981; Piepenbrock, 2009), economics (Levine & Pesendorfer, 2005), political science (Axelrod & Bennett, 1997), business management (Doz & Hamel, 1998; Dyer, 2000; Ghoshal & Bartlett, 2002; Gulati et al., 2009; Robinson & Stuart, 2006) and systems engineering (Piepenbrock, 2009). The multi-disciplinary nature of the research on cooperation is represented in the Figure 19, which shows the three dimensions of cooperation research – the relevant academic disciplines, the different aspects of cooperation and the types of research methodology commonly used.

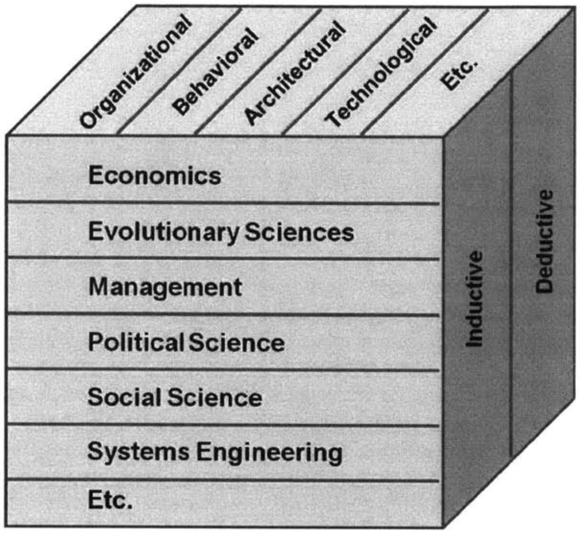


Figure 19: The Multi-dimensional Perspectives of Research in Cooperation

This figure is by no mean a complete representation of the field of research on cooperation. However, the most important elements of cooperation that are relevant or periphery to this thesis are shown in this figure. For example, cooperation can be researched at organizational levels such as inter-personal, inter-company, inter-network of companies and international. The book, *Common Knowledge*, by Dixon (2000) provides a good framework in which cooperation can take place at individual and group level under different knowledge transfer conditions. Hamel & Doz (1998) provide the different value-based motivations of cooperation at enterprise level. Dyer's research on US and Japanese automotive companies in the 1990s (Dyer, 2000) offers deep insight into the advantage of cooperation at extended enterprise level (adoption of the Japanese *Keiretsu* concept) using empirical analysis and in-depth investigation in the automotive industry. Furthermore, the work by Ghoshal & Bartlett (2002) in management of global corporations addresses the impact of globalization on the evolution of enterprise model from local to borderless transnational enterprise and the importance of effective cooperation and coordination between headquarter and overseas subsidiaries. Moreover, some research in cooperation focuses on the behavioral aspect of cooperation such as maximization of benefits from cooperation. Such research often involves the application of decision science and game theories (work based on the original works of Tucker, von Neumann, Morgenstern), which are often supported by empirical and mathematical analyses. These types of cooperation research focus primarily on the creation of behavioral models that can reproduce and predict cooperative behavior (such as *Trust* between cooperating members) of cooperating organizations or individuals (Axelrod, 1997; Gulati et al., 2009; Robinson & Stuart, 2006). In addition, there are also studies that investigate the optimal architectural design and management of cooperation (Hamel & Doz, 1998; Dyer, 2000).

Among the reviewed literatures on cooperation, the value-based cooperation framework by Hamel & Doz (1998) was found to be very useful to the thesis mainly due to the generic and simple taxonomy of cooperation used. For instance, the three types of market players (leader, follower and latecomer) and three types of cooperation motivation (co-option, co-specialization and learning & internalization) provide a simple but yet strong framework for the generational classification of the rotorcraft companies and their motivation to cooperate.

4.2 Literature on Organizational Learning & Technology Transfer

As mentioned earlier in this chapter, transfer of technology can be considered as an abstraction of cooperation and organizational learning. In order for technology transfer to occur, there must be some form of cooperation framework for transmission of knowledge and some form of knowledge transfer mechanism. In this section, the existing literature of the knowledge transfer mechanism will be discussed.

Knowledge transfer mechanism is a generic term that is part of a broader field known as organizational learning. Learning can take place at individual level and at organizational level (Shrivastava, 1983). In fact, individual learning and organizational learning come hand in hand. Without the capacity for individual learning, organizational learning can never occur. Shrivastava (1983) defines that organizational learning entails conversion of individual knowledge and insights into a systematic organizational knowledge base which informs decision-making. This may seem obvious however, the role and positioning of individual learning in the field of organizational learning is still an ongoing debate among scholars of organizational learning (Roth, 2008).

Furthermore, the range of literature on organizational learning is vast and diverse. Roth (2008) points out that current literature of organizational learning has not yet converged into a consistent and universally accepted set of theories. Nevertheless, among all the diverse perspectives on organizational learning, the works of Shirvastava (1983) and Roth (2008) offer a good and concise overview of the some broad perspectives of organizational learning. Roth (2008) expanded Shrivastava's four perspectives of organizational learning with the addition of the key enablers and barriers to learning (Table 3), which are useful in the diagnostic and application of learning system in an organization.

Organizational Learning Perspective	*Core Ideas*	*Enablers of Learning*	*Barriers to Learning*
As accumulated experience	Learning curve extended to management, decisions, efficiency, and productivity improvement.	Time and experience, better measurement and analysis, learning in socio-technical systems	Linkage between measurement and behavior, limitations in applying physical world insights to social science
As adaptation to environmental changes	Organizations adapt to changes in the environment by readjusting goals, attention rules, and search algorithms.	Analysis of environment, planning, engaging more of the organization in planning, more and better experiments	Inappropriate understanding of environment, social and satisficing behaviors.
As assumption sharing	Theories in use that result from shared assumptions, changing these assumptions and learning about learning.	Reflection and tools or techniques that make individual and collective thinking explicit.	People's defensive routines, needs to unlearn worldviews, enactment.
As developing knowledge base	Knowledge about action-outcome relationships is developed and used in various settings.	More and better experiments, acquiring and processing information and knowledge	Incomplete learning cycles, superstition, not unlearning, holding onto past success.

Table 3: Perspectives on Organization Learning (Roth, 2008)

Nevertheless, the focus of this thesis is on a relatively narrow area of organizational learning, which is learning through cooperation. Learning through cooperation is a cross-boundary form of organizational learning, which focuses on the transfer of technology between companies. Cyhn (2002) coined the term technological learning, which is an essentially a more specific form of organizational learning that involves the transfer of technological knowledge (both explicit and tacit) from a transferor to a receiver. Table 4 illustrates the different types of technological learning defined by Cyhn (2002). Similar to organizational learning, literatures that are related to technology learning is vast and diverse. As this thesis takes an enterprise-level approach in the analysis of transfer of rotorcraft technologies between companies, the different phases of technological learning, which are more visible and measurable, are more useful. The review also indicates that existing literature offers many perspectives of the technological learning process, which describes how latecomer companies acquire technologies to compete with the incumbent companies. The overview of these various work is shown in Table 5. Essentially, most of these frameworks of technological transfer are variations of the common framework of adoption, adaptation and generation of technologies (Lee et. al., 1988). However, there is another dimension of technological learning that should be considered – evolution of technologies. The book *Mastering the Dynamics of Innovation* by Jim Utterback (1994) reviews that technologies go through the fluid (emerging) to transitional (consolidation) and to specific (maturing) phase over their lifecycle. This implies that different phase in which the technological learning takes place could have different learning dynamic as well (Kim, 1998). This is particularly important as the follower (second generation) and latecomer (third generation) rotorcraft companies will face different technological learning challenges as the maturity of rotorcraft technology differs at the companies' point of market entry. Furthermore, the level of technological capability of the receiver company's national industry also needs to be considered (Hobdays, 1995).

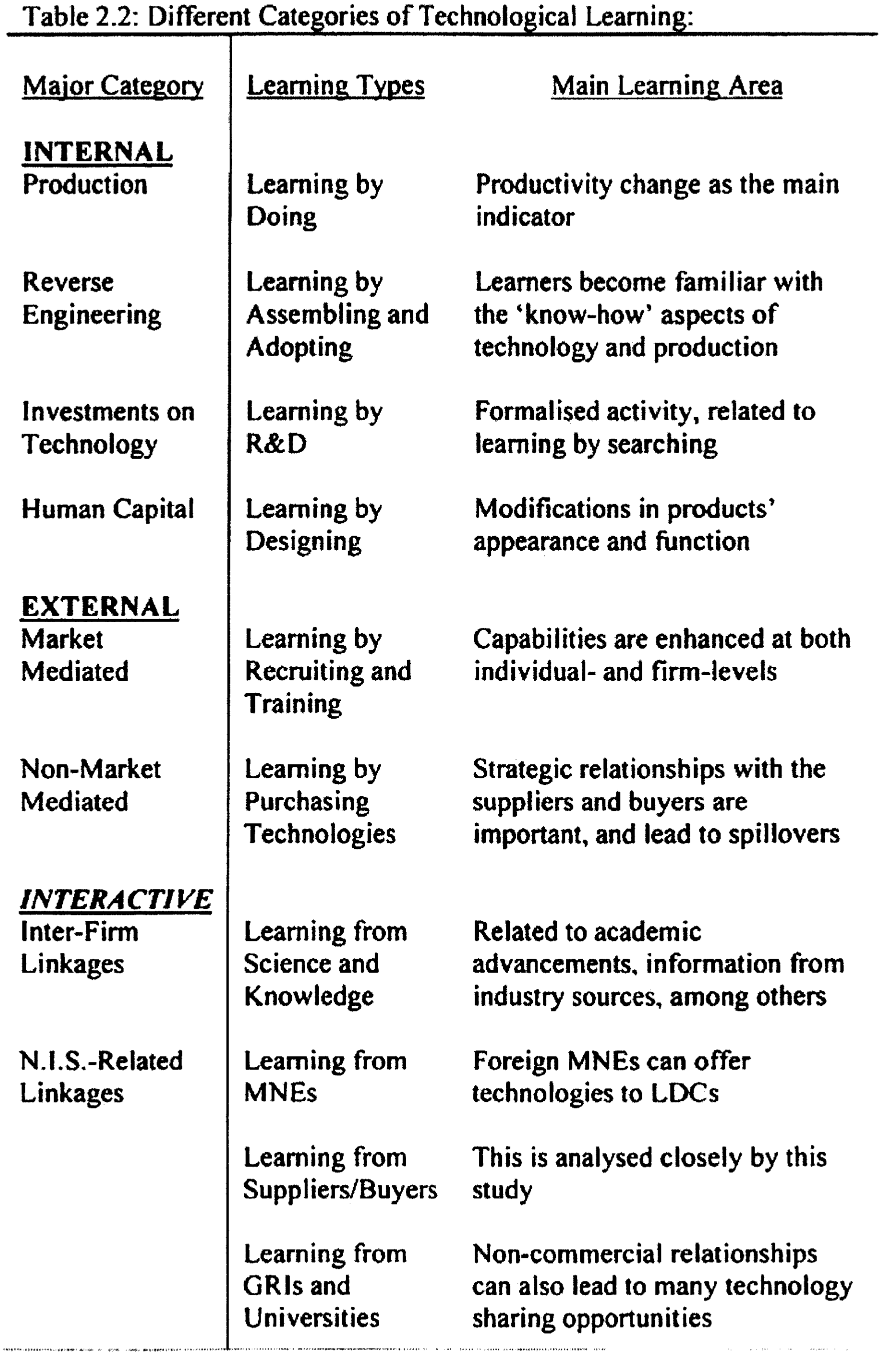


Table 2.2: Different Categories of Technological Learning:

Major Category	Learning Types	Main Learning Area
INTERNAL		
Production	Learning by Doing	Productivity change as the main indicator
Reverse Engineering	Learning by Assembling and Adopting	Learners become familiar with the 'know-how' aspects of technology and production
Investments on Technology	Learning by R&D	Formalised activity, related to learning by searching
Human Capital	Learning by Designing	Modifications in products' appearance and function
EXTERNAL		
Market Mediated	Learning by Recruiting and Training	Capabilities are enhanced at both individual- and firm-levels
Non-Market Mediated	Learning by Purchasing Technologies	Strategic relationships with the suppliers and buyers are important, and lead to spillovers
INTERACTIVE		
Inter-Firm Linkages	Learning from Science and Knowledge	Related to academic advancements, information from industry sources, among others
N.I.S.-Related Linkages	Learning from MNEs	Foreign MNEs can offer technologies to LDCs
	Learning from Suppliers/Buyers	This is analysed closely by this study
	Learning from GRIs and Universities	Non-commercial relationships can also lead to many technology sharing opportunities

Table 4: Different Categories of Learning (Cyhn, 2002)

In addition to the literature on technological learning, which is more focused on the phases of learning, Dixon (2000) offers another perspective of knowledge transfer based on the type of circumstance in which knowledge transfer occurs. Her work emphasizes the differentiation between explicit and tacit knowledge. In additional to literatures about technological learning, there are also works from Hamel & Doz (1998) and Dyer (2000) on the importance of learning in cooperation, which takes a broader view of organizational than technological learning. Hamel & Doz (1998) suggest that learning and internalization is one of the three main reasons of cooperation between companies by using examples like Toyota-GM automotive cooperation NUMMI and Philips-Siemens semiconductor cooperation. These examples of inter-company cooperation illustrate how learning and internalization can create value for cooperating companies. Using the case of Chrysler in the 1990s, Dyer (2000) shows that internal learning mechanism between OEM and suppliers and between suppliers themselves generated significant value to members of the cooperation network.

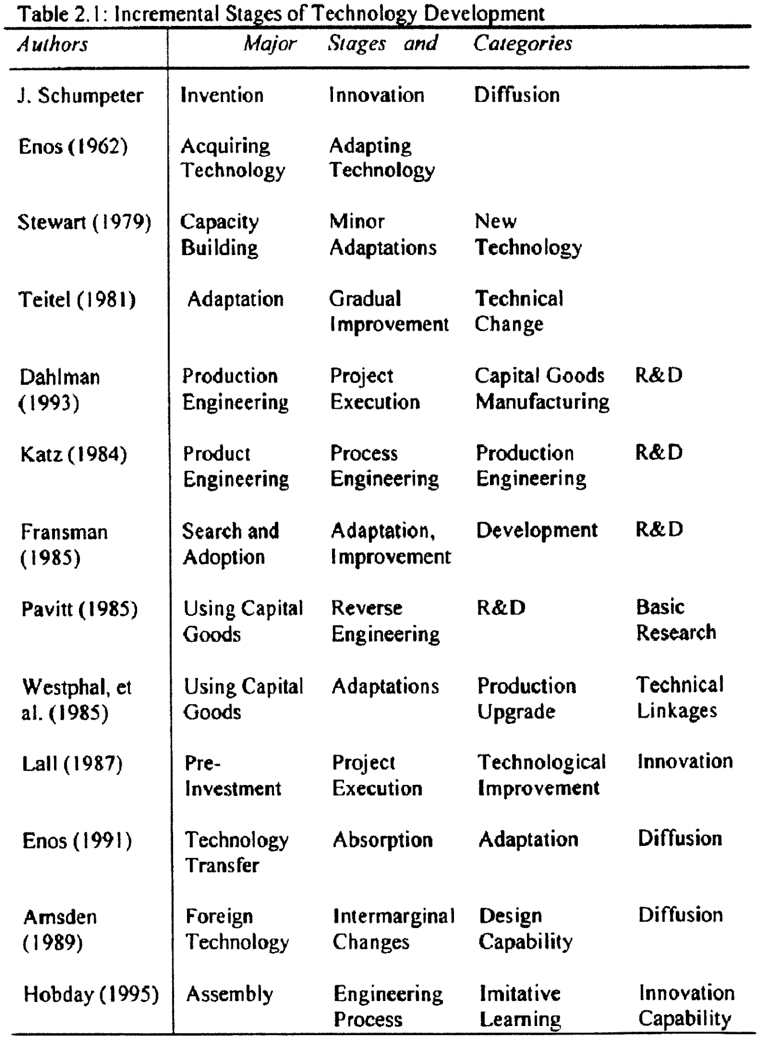


Table 2.1: Incremental Stages of Technology Development

Authors	*Major Stages and Categories*			
J. Schumpeter	Invention	Innovation	Diffusion	
Enos (1962)	Acquiring Technology	Adapting Technology		
Stewart (1979)	Capacity Building	Minor Adaptations	New Technology	
Teitel (1981)	Adaptation	Gradual Improvement	Technical Change	
Dahlman (1993)	Production Engineering	Project Execution	Capital Goods Manufacturing	R&D
Katz (1984)	Product Engineering	Process Engineering	Production Engineering	R&D
Fransman (1985)	Search and Adoption	Adaptation, Improvement	Development	R&D
Pavitt (1985)	Using Capital Goods	Reverse Engineering	R&D	Basic Research
Westphal, et al. (1985)	Using Capital Goods	Adaptations	Production Upgrade	Technical Linkages
Lall (1987)	Pre-Investment	Project Execution	Technological Improvement	Innovation
Enos (1991)	Technology Transfer	Absorption	Adaptation	Diffusion
Amsden (1989)	Foreign Technology	Intermarginal Changes	Design Capability	Diffusion
Hobday (1995)	Assembly	Engineering Process	Imitative Learning	Innovation Capability

Table 5: Different technological learning frameworks of latecomer companies (Cyhn, 2002)

Learning and technology transfer mechanism may vary across regions and countries. There is extensive collection of literatures that focus on country specific learning and technology transfer

(Figure 6). In line with the scope of this thesis, the review focuses primarily on China, Italy, Japan and a number of other emerging nations for reference. For China, Gao (2004), Luo (2006), Lee (2003), Cao (2004, 2009) and Cheung (2009) offer general insight into technology transfer and technological learning in the Chinese industries. Among them, Gao (2004) believes that the indigenous technological development (reinventing the technology) as one of the key competitiveness advantages of leading market players in the Chinese electronics industry. Cheung (2009) also supports this notion that successful technological learning has to be supported by indigenous research and development effort in additional to absorption of foreign technologies. As a reference for China's technological learning, a review has been done on other emerging countries in Asia. Cyhn (2002) focuses on the South Korean electronics industry. Hobday (1995) and Nelson & Kim (2000) highlight the dominant technological learning mechanisms in the industries of the four major Asian newly industrialized economies (South Korea, Taiwan, Hong Kong and Singapore).

For Italy, Malerba (1993) provide a detailed perspective of the Italy's national innovation system and its industrial development during the postwar years. He highlighted the existence of two distinct innovation sub-systems within Italy's national innovation system and their relative strengths and weaknesses. Modena (2001) and Belussi (2001) complement Malerba's earlier research by providing an updated view of Malerba's view in the early 2000s. For instance, they attribute the weak endogenous generation of technologies to the weak interaction between public R&D institutions and industries. On technological learning process in Italy, Malerba (1993) believes that most Italian firms learn by absorbing, adapting, improving and tailoring. He also claims that in the large Italian firms from 1950 to 1970 favored licensing of foreign technologies instead of indigenous R&D. Pittiglio and his colleagues (2009) complement Malerba's notion by stating that in order for Italian firms to innovate, internal R&D should be supported by international engagement, networking and the use of external knowledge.

	Nations	Generic Technological Learning Steps From National Innovation System Perspective →				Research Domain
Nelson & Kim (2000)	China	Duplicative Imitation	Design Copying	Creative Adaptation	Technological Leapfrogging	Research on Chinese industry
Kim (1997)	Japan	Knowledge Acquisition	Assimilation	Improvement		Research on Japanese industry
Malerba (1993)	Italy	Absorbing	Adapting	Improving	Tailoring	Research on Italian industry

Table 6: Learning variation across nations (complied & adapted by the author)

For Japan, the review indicates that technological learning in the Japanese aircraft industry has a long history even before the Second World War. However, Odagiri and Goto (1993) point out that most of Japanese aircraft industries were destroyed during the Second World War and Japanese aircraft manufacturers had to rebuild its aircraft industry from the beginning. Technological learning of aircraft technologies after the war was predominantly through licensed assembly and co-production of US products (Hall and Johnson, 1968). Odagiri and Goto (1993) believe that Japan's strong industrial capabilities from other industries such as ship building accelerated the learning speed of the aircraft industry. Hall and Johnson (1968) point out that Japanese aircraft industry was not only able to absorb significant aircraft technologies from US companies but also apply them successfully to develop indigenous aircrafts. King and Nowack (2003) analyze the technological evolution of Japanese aircraft industry's capability by mapping out the transition across different mode of cooperation between US and Japanese aircraft companies (Table 7).

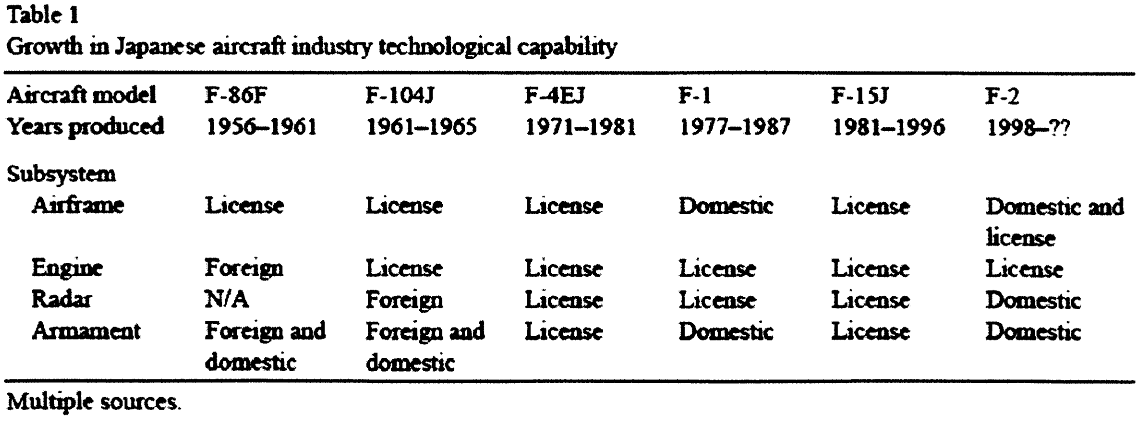


Table 1
Growth in Japanese aircraft industry technological capability

Aircraft model **Years produced**	**F-86F** **1956–1961**	**F-104J** **1961–1965**	**F-4EJ** **1971–1981**	**F-1** **1977–1987**	**F-15J** **1981–1996**	**F-2** **1998–??**
Subsystem						
Airframe	**License**	**License**	**License**	**Domestic**	**License**	**Domestic and license**
Engine	**Foreign**	**License**	**License**	**License**	**License**	**License**
Radar	**N/A**	**Foreign**	**License**	**License**	**License**	**Domestic**
Armament	**Foreign and domestic**	**Foreign and domestic**	**License**	**Domestic**	**License**	**Domestic**

Multiple sources.

Table 7: The Evolution of Japanese Industry (King and Nowack, 2003)

4.3 Literature on National and Aerospace Innovation Systems

Firms are part of a greater system (e.g. national and global system) and they do not generally innovate in isolation (Edquist, 1997). As such, rotorcraft companies' technological learning processes are influenced by other actors and factors in the entire system. Hence, a framework to map this system is important to differentiate and compare the learning environments in which each rotorcraft company operates. In the literature review, I have found that the concepts of the National Innovation System (Nelson, 1993) and Systems of Innovation (Freeman, 1987; Edquist, 1997) especially relevant and useful for the mapping of the national learning environment of rotorcraft companies. The concept of NIS has gained importance over mainstream macro-economic theories, which have failed to deliver an understanding and control of the factors behind international competitiveness (e.g. technological knowledge) and economical development (OECD, 1997). NIS rectifies these shortcomings of existing macro-economic theories by offering a qualitative framework to map and analyze the interactions among the actors and factors in the system in addition to classical economical indicators (e.g. R&D investment and number of patents). The NIS concept has been adopted by the Organization for Economic Cooperation and Development (OECD) for analyzing nations' development of their industries and technological capabilities. While there is no single definition of the NIS, most of them converge in terms of underlying meaning and scope. Some of the definitions of the National Innovation Systems (NIS) are as follows:

" .. the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies." (Freeman, 1987)

"... a set of institutions whose interactions determine the innovative performance ... of national firms." (Nelson, 1993)

" .. the national institutions, their incentive structures and their competencies, that determine the rate and direction of technological learning (or the volume and composition of change generating activities) in a country." (Patel and Pavitt, 1994)

".. I define a system of innovation as "all important economic, social, political, organizational, and other factors that influence the development, diffusion, and use of innovations." (Edquist, 1997)

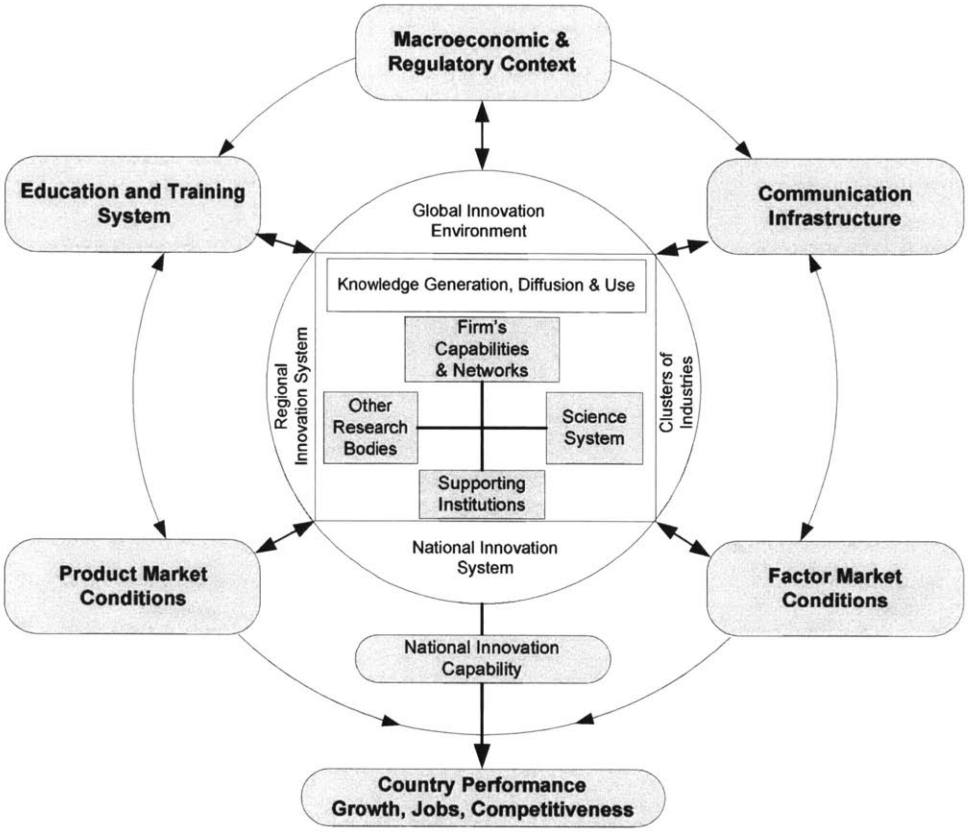


Figure 20: The Generic National Innovation System Map (OECD, 1999)

In essence, all these definitions are simply representations and interpretations of the complex national technological environment from different perspectives. All these definitions converge by suggesting that there is a national system that consists of a complex network of public and private stakeholders (Figure 20). The behaviour of this system is influenced by national policies and key multi-disciplinary factors affecting national technological development such as learning, adsorption and innovation. In the context of this thesis, all these definitions of the NIS are considered as equally valid and generic for all industries. The NIS is a very useful framework that explains the generic technological learning environment for rotorcraft companies.

Nevertheless, the generic definition of the NIS may not necessarily address all technological learning developments in the rotorcraft industry. Due to differences in product, market and regulation, every industry is somewhat unique. The rotorcraft industry is a very distinct industry, just like most high-technology industries. Many NIS actors and policies in that are unique to the rotorcraft industry may not be obvious or universal at NIS level. Hence, I will introduce a more specific view of the NIS termed as the Aerospace Innovation System (AIS) to complement the NIS.

The AIS can be considered as an abstracted view of the NIS that shows more specific influences of the NIS on the aerospace industry and vice versa. The AIS will provide a less-cluttered view than the NIS for analyzing the rotorcraft industry. In this thesis, both NIS and AIS will be presented in all the three case studies to provide high-level and industry-specific views of the national technological learning environment.

CHAPTER 5: RESEARCH METHODOLOGY AND FRAMEWORK

5.1 Scope of Research

This aim of this thesis is to confirm the importance of cooperation for market latecomers to acquire technologies from the market leaders and followers in order to move up the market hierarchy and value chain in the rotorcraft industry. Hence, the scope of the research work will be focused in the following dimensions. First the research will be confined to the rotorcraft industry, while drawing available theories and frameworks from other industries, especially those in the same countries. Second, the research will confine itself to the time frame from 1945 onwards (the advent of the rotorcraft industry). Third, the research will use multiple-case method to derive the technological learning framework for rotorcraft companies. The selected cases are Agusta (Italy), Avicopter (China) and Kawasaki Heavy Industries Aerospace (Japan), which will be used for in-depth analysis based on the evolution of their technological competencies over the last sixty years.

5.2 Research Methodology

Research in aerospace and defense-related industries is always difficult due to national security and protection of sensitive industrial trade secrets. A research that covers three different rotorcraft companies in three different non-English speaking countries based on primary sources such as interviews and direct access to companies' internal data will require significant resources and time that could be overwhelming. Hence, this thesis aims to capitalize on existing secondary sources to provide a third person's perspective of the rotorcraft industry and the technological learning process. The research employs a qualitative analysis for breadth and depth, based on data from a comprehensive range of current and historical literatures. The first part of this research will involve collection, comparison and analysis of technological performance indicators such as the speed of transition between phases of technological maturity (years), product development duration (years), production volume, innovations of the companies. The second part of this research will involve the analysis of the National and Aerospace Innovation System, in which the selected companies operate. This National and Aerospace Innovation System will include the respective national innovation and industrial policies, the likely technological learning processes, incentives for cooperation and other macro-economical factors that influenced the technological development of the rotorcraft companies.

5.3 Selection of Cases

The thesis will use multiple-case study method for the research. There are a total of six possible companies, which are Agusta, Avicopter, Denel Aerospace, Hindustan Aeronautics Limited (HAL), Kawasaki Heavy Industries (KHI) Aerospace, Korean Aerospace Industries (KAI). Agusta, Kawasaki Heavy Industries Aerospace (KHI) and Avicopter are selected as case studies due the following reasons (as summarized in Table 8):

1) They were not market pioneers (e.g. Sikorsky) at the advent of the rotorcraft industry.
2) They have undergone the complete technological learning cycle.
3) They developed under a single National Innovation System over a substantial evolutionary period.
4) They have potential to complete globally or have already become a global player.

Emerging Players (since 1950s)	Country	Cooperation Partners	Completed entire learning cycle	Non-Pioneering Players	Potential to be Global Player	Suitable Case
Agusta	Italy	Boeing (MD) / Bell / Sikorsky	Yes	No	Achieved	√
Avicopter	China	Eurocopter / Mil	Yes	Yes	Yes	√
Denel Aerospace	South Africa	Eurocopter (formerly Aerospatiale)	No	Yes	No	
Hindustan Aeronautics Limited (HAL)	India	Eurocopter (formerly MBB)	Yes	Yes	Yes	√
Kawasaki Heavy Industries Aerospace (KHI)	Japan	Boeing (MD) / Bell / Sikorsky	Yes	Yes	Yes	√
Korean Aerospace Industries (KAI)	South Korea	Bell / Boeing (MD) / Eurocopter	No	Yes	No	

Table 8: Selection Criteria for Case Studies

These selection criteria are important to ensure that the companies have already developed themselves through ground-up and have sufficient meaningful data for analysis. Agusta, Avicopter and KHI were selected as a result of these criteria. It is important to note that even though Agusta merged with Westland relatively recently in 2001, it remains a suitable research case as the merger occurred after Agusta was already a leading OEM. Furthermore, the potential of these three companies to become global players allows for future validation and review of research findings. Even though India's Hindustan Aeronautics Limited (HAL) has been identified as a suitable case study, it was not selected due to lack of data.

5.4 Research Framework

The multi-disciplinary nature of the technological learning of the rotorcraft companies makes it challenging to formulate a framework that can cover all aspects of the research scope. It is important that the framework captures and shows all important factors that could affect technological learning process in emerging rotorcraft companies. One way is to use or adapt relevant frameworks that have been identified in the literature review and earlier chapters for analyzing the technological learning system of emerging rotorcraft companies. Fortunately, this method turns out to be practicable. In this thesis, the existing frameworks of the National Innovations System, mode of cooperation and technological learning were selected and integrated into my thesis framework. The thesis framework is represented by the Technological Learning System (TLS) casual-loop diagram (Figure 21). The reasons of using these frameworks and how they are interconnected to form the TLS will be explained in this chapter.

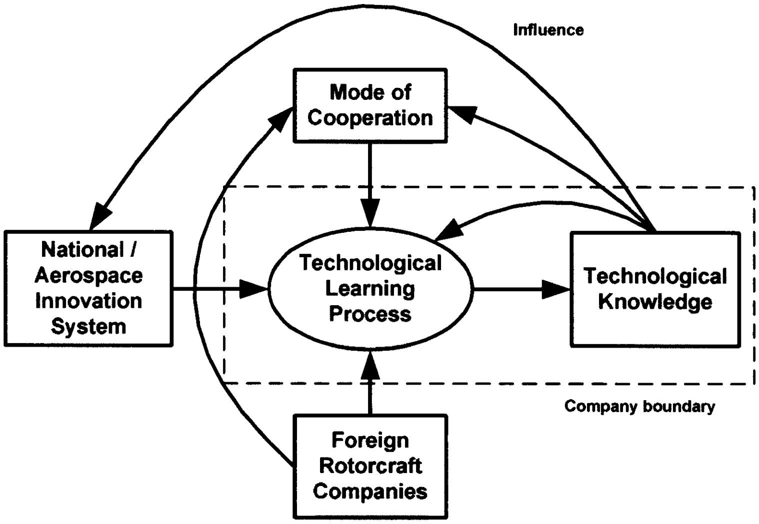


Figure 21: The Technological Learning System (Gan and Roth)

First, the NIS framework is used as one of the main elements in the TLS as it provides a broad but detailed insight of the national innovation and technological learning environments of the emerging rotorcraft companies. These environments define the constraints for technological learning process. Examples of these constraints are social-political, economical, cultural and historical aspects of the technological learning environment. Often, the most dominant factors within the NIS that affect the technological learning process are governmental policies, the dynamic of private companies and the level of collaboration between universities and industries. In this thesis, the NIS will be analyzed at national and industrial levels.

Second, cooperation and technological learning frameworks are used to explain how emerging rotorcraft companies obtain access to rotorcraft technologies. The cooperation framework is defined by the different modes of cooperation, which indicates the level of interaction and the technological learning opportunity between cooperating companies. My research has identified four main modes of cooperation that are commonly used in the rotorcraft industry - *licensed production, design adaptation, co-production and co-development.* I use these four modes of cooperation to define the level of interaction between the emerging rotorcraft companies and the foreign companies. Here, the link between the mode of cooperation and technological learning is established. Figure 22 shows the relationship between mode of cooperation and the type of technological learning (cooperative and non-cooperative). Furthermore, it is important to note that I do not distinguish between the three types (internal, external and interactive) of technological learning as defined by Cyhn (2002) in the literature review (Chapter Four). This is due to the fact that even the simplest mode of cooperation (i.e. licensed production) involves complex social-technical interaction between cooperating companies. In this regard, it will be reasonable to assume that all three types of technological learning take place in all four modes of cooperation. Since the underlying motivation of cooperation by emerging companies is to acquire technologies, regardless whether one-way or two-way flow technology between cooperating companies, it is reasonable to assume that technological learning takes place in all modes of cooperation. Figure 22 also shows the relative complexity of cooperation and the expected sequence of cooperation of rotorcraft companies over time.

Non-competitive learning activity like reverse-engineering is also shown as it usually takes in parallel to other technological learning activities within the cooperation. Reverse-engineering is an important technological learning activity for emerging rotorcraft companies. Cyhn (2002) defines reverse-engineering as internal type of technological learning. In most cases, selective reverse-engineering of components is secretly conducted by the emerging companies in the shadow of cooperation. However, in this thesis I define reverse-engineering as a major event that involves imitative production of the entire product of foreign companies.

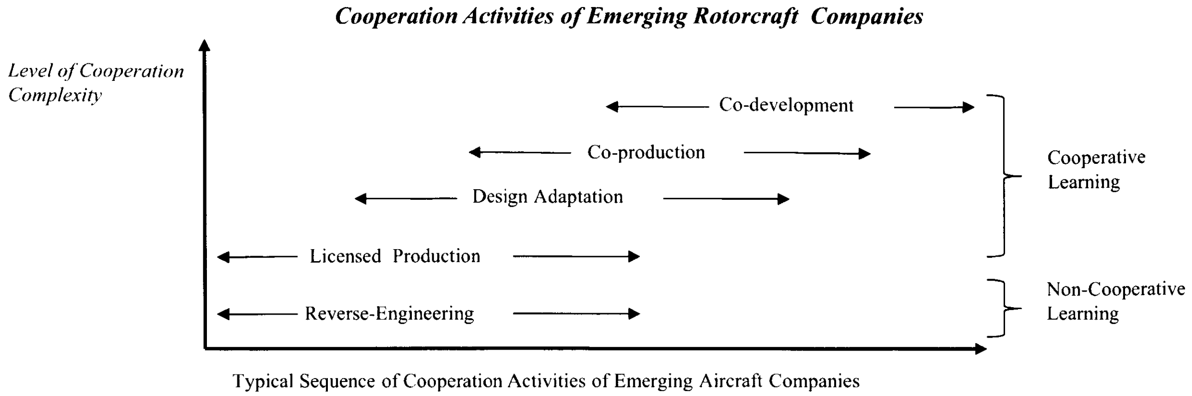


Figure 22: The Four Modes of Cooperation and Reverse Engineering

The TLS shows the conceptual relationship between the four main elements (NIS, mode of cooperation, technological knowledge) and the technological learning process. The company boundary shown in the TLS diagram demarcates where learning takes place. Here, the elements outside the company boundary are viewed as influences to the learning environment within the company. Furthermore, the TLS is a closed-loop system with an exogenous element (foreign rotorcraft companies). The flow of the influences between the system elements is shown by the arrows. The feedbacks (curve arrows) from the accumulated technological knowledge to the three system elements - NIS, mode of cooperation and technological learning process close up the influence-loop within the TLS. The technological knowledge in the TLS is considered as a "stock" of accumulated knowledge as defined in the organizational learning framework by Roth (2008). It is important to note that technological knowledge can either increase or decrease. For instance, technological knowledge can increase due to knowledge learned through cooperation with a more technologically advanced partner company. On the other hand, technological knowledge can decrease when competences are lost, for example, through outsourcing or loss of employees. Technological knowledge can influence these three TLS elements in the following ways.

First, the level technological knowledge in the emerging rotorcraft companies affects the mode of cooperation that the companies can be involved. As an example, advanced technological knowledge allows company to cooperate in more complex co-development program (share knowledge with partner) whereas low technological knowledge will certain restrict company to less complex licensed production program (obtain knowledge from partner).

Second, increase in technological knowledge can directly influence the technological learning process or indirectly influence through changes in the mode of cooperation. Within the technological learning process, continuous adjustment between internal, external and interactive types of technological learning will occur due to changes in technological knowledge. Through hard to quantify and however small it may be, technological knowledge spill-over from rotorcraft companies to the other industries in the NIS takes place.

Third, in the TLS the foreign companies are considered as an exogenous element in the system as it is usually independent of the rest of the elements and process of the system. Since cooperation dynamic such as the selection of cooperation partner and the definition of cooperation framework (i.e. mode of cooperation and work share) is complex and highly unpredictable, it will be reasonable to assume that foreign companies as an exogenous element that can influence the mode of cooperation with the emerging companies.

The variables in this TLS are the NIS, the technological learning process and the level of the technological knowledge. In this thesis, the variation of the first two variables NIS and technological learning process will be accomplished by the use of case studies of three emerging rotorcraft companies to investigate how these variables affect the TLS outcome, which is measured by the level of technological knowledge. The case studies consist of *Avicopter (China), Kawasaki Heavy Industries Aerospace (Japan) and Agusta (Italy),* which are selected based on criterion shown in the previous section.

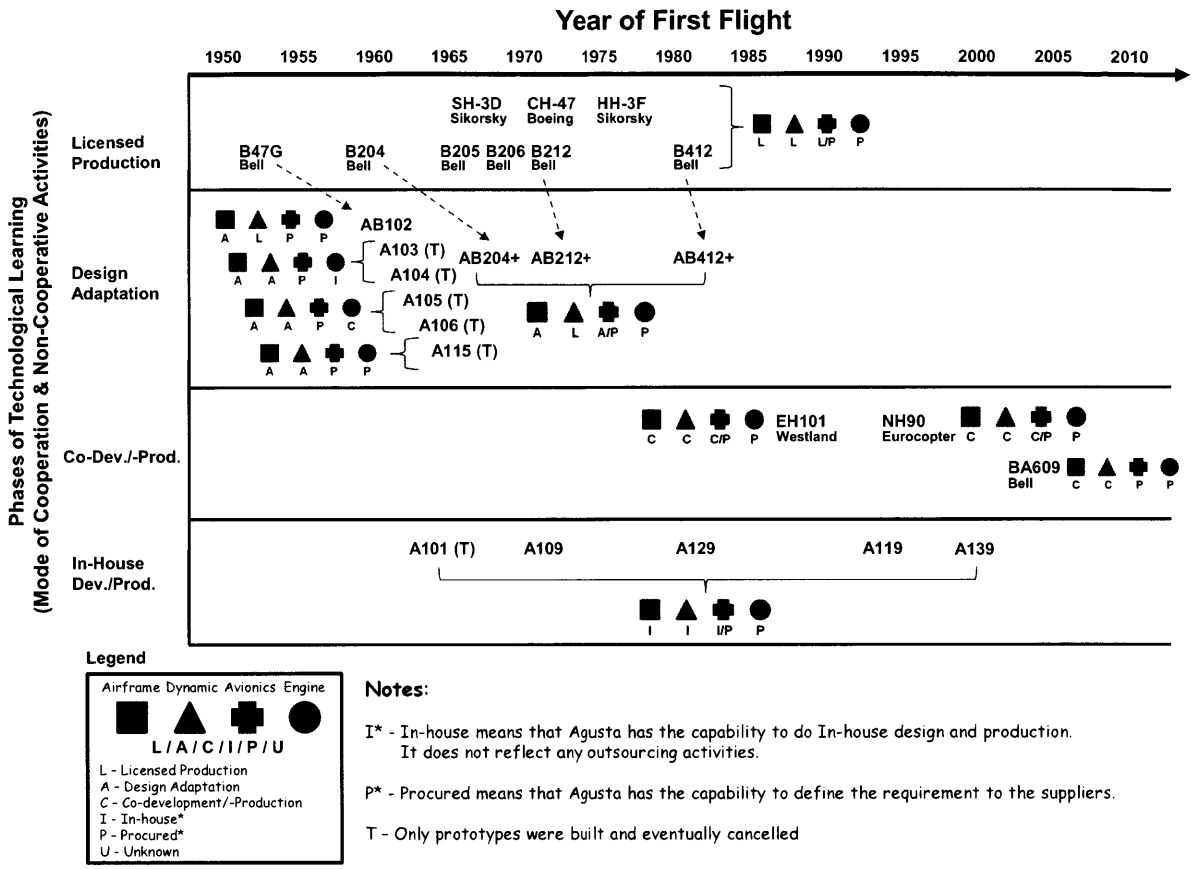
It is important to highlight the fact that there is an indirectly coupled relationship between the NIS and mode of cooperation. The NIS and the mode of cooperation are both influenced by the country's access to foreign technologies. The accessibility to foreign technologies shapes the NIS and determines the permissible mode of cooperation with foreign companies. Hence, there is no way to fully vary both variables independently. Fortunately, this coupling of the variables does not affect the objective of this thesis. This is because when comparing between emerging companies with different NIS, the coupled relationship between the NIS and mode of cooperation becomes less important than the relationship between the different the NIS or the mode of cooperation and the resulting technological knowledge change.

The third variable is technological knowledge in the rotorcraft companies. Technological knowledge is broken down to product subsystems level – airframe, dynamic system, avionic system and engine. The measurement of technological knowledge is through observation of the change in product subsystem technologies that occur after every cooperation program. In this thesis, I define program as an independent event that develops and produces a rotorcraft product independently or cooperatively by the OEM. The level of technological knowledge is measured by the mode of cooperative or non-cooperative activities involved in the development and production of the companies' programs. The non-cooperative activities include all activities that lead to the access of the subsystem technologies via reverse-engineering or in-house development and production. Depending on the OEM's learning objective, activities such as design-adaptation and procuring subsystems off-the-shelf can be either cooperative or non-cooperative in nature. The relative level of technological knowledge required for these cooperative and non-cooperative activities is indicated in Figure 23. The changes of the technological knowledge using technological level at subsystem level will be shown by plotting the evolution map shown in Figure 24 as an example.

Level of Technological Knowledge ↑

Types of Activities	Nature
In-house development/production	Non-Cooperative
Co-development	Cooperative
Co-production	Cooperative
Design Adaptation	Cooperative/Non-Cooperative
Reverse-Engineering	Non-Cooperative
Licensed Production	Cooperative
Procured	Cooperative/Non-Cooperative

Figure 23: Technological Knowledge Level and Cooperative/Non-Cooperative Activities



Notes:

I* - In-house means that Agusta has the capability to do In-house design and production. It does not reflect any outsourcing activities.

P* - Procured means that Agusta has the capability to define the requirement to the suppliers.

T - Only prototypes were built and eventually cancelled

Figure 24: Technological Knowledge Evolution Map (Example of Agusta)

Finally, in order to compare the three cases, the Technological Knowledge Evolution Maps for the three case studies will be plotted. This allows comparative analysis of the speed of technological learning in the course of these companies' development with respect to the type of NIS and mode of cooperation involved. The speed of technological learning has many implications for the TLS. For instance, at national level, the speed of technological learning could be due to the national policies within the NIS or the mode of cooperation accessible to the rotorcraft companies. Moreover, at company level, one can also draw conclusion on the way individual rotorcraft companies learn from analyzing the evolutionary pattern of cooperation mode and speed of change across different cooperation modes. These are just some examples of the important implications that will help policy makers from governmental organizations and private companies in the formulation of effective industrial and corporate policies for cooperation. More insight into the technological learning process of rotorcraft companies will be discussed in each case study (Chapter Six) and in the comparative analysis (Chapter Seven).

CHAPTER 6: CASE STUDIES

6.1 Case Study 1 - Avicopter

6.1.1 Company Introduction

Avicopter is a Chinese rotorcraft manufacturer and a division of the China's state-owned aerospace and defense conglomerate - Aviation Industry Corporation of China (AVIC). The company's main product portfolio includes small, medium and heavy weight helicopters. It also has business units that are involved in the design and manufacturing of wind-turbines and space systems. Avicopter was recently formed in 2008 after the consolidation of several state-owned rotorcraft companies - Harbin Aircraft Industries Group (HAIG), Changhe Aircraft Industries Group (CHAIG), Baoding Huiyang Aviation Propeller Manufacturing Factory (BPF) and the Chinese Helicopter R&D Institute (CHRDI). Even after Avicopter's headquarter was set up in Tianjin, a city situated 120 km southeast of Beijing, it still maintains the original sites of its consolidated subsidiaries. However, general administration, customer services, certain production and design activities of these subsidiaries were relocated to Tianjin in 2008. The key facts about the company structure and subsidiaries are shown below in Figure 25.

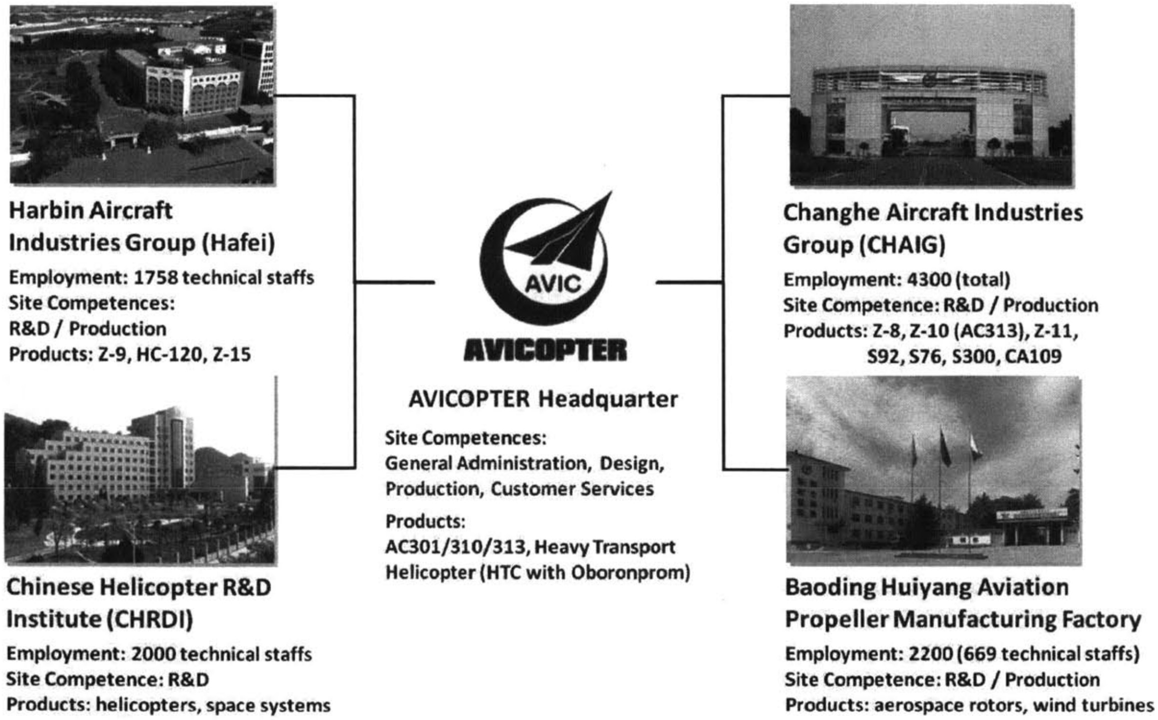


Figure 25: Avicopter Company Structure in 2009 (Sources: HAIG, CHAIG, CHRDI, Baoding)

The first subsidiary, HAIG, is based in Harbin, a city situated in the northeastern part of China. It was founded in 1952 to manufacture large military aircrafts and helicopters. In line with the Chinese defense industrial strategy before the recent Avicopter's consolidation, HAIG was responsible for the production of aircrafts that were designed by dedicated design organizations such as the CHRDI and the 602nd research institute. Before becoming part of Avicopter, HAIG had cooperated with the Russian helicopter OEM Mil in the licensed production of Mi-4 (locally known as Z-5). With the Franco-German OEM Eurocopter, HAIG cooperated in the licensed production of AS365 (Z-9) and currently co-produces EC120 (HC-120) and EC175 (Z-15) helicopters. Furthermore, HAIG is involved in an existing cooperation with the Brazilian fixed-wing aircraft OEM Embraer in the co-production of ERJ-145 commercial regional jets.

Figure 26: Cooperation with Eurocopter: Z-9, HC-120, Z-15 (Sino-Defence)

The second subsidiary, CHAIG, the largest subsidiary of Avicopter in terms of the number of employees, is located in Jingdezhen city of Jiangxi province. Besides HAIG, it was the only other rotorcraft manufacturing company in China until early 2000s, when China allowed foreign OEMs to enter the market by forming joint ventures with local companies. CHAIG was founded in 1969 by the Chinese state to manufacture helicopters for the Chinese People's Liberation Army (PLA). Unlike HAIG, CHAIG is solely dedicated to the manufacture of helicopters. Before its consolidation with Avicopter, CHAIG had established cooperation with Sikorsky (helicopter co-production for S-300, S-76 and S-92) and AgustaWestland (assembly of CA109 helicopter). It has also managed to reverse-engineer Eurocopter's legacy AS350 Ecureuil (locally named Z-11) and SA321 Super Frelon (locally named Z-8) helicopters. Currently, it is developing China's first indigenous dedicated attack helicopter, WZ-10, with technical assistance from anonymous foreign OEMs.

Figure 27: CHAIG products: Z-8, Z-11, WZ-10 (Sino-Defence)

The third subsidiary is the Chinese Helicopter Research and Development Institute (CHRDI), China's only dedicated research and development organization for helicopter technologies before the creation of Avicopter. It was founded in 1969 in the city of Jingdezhen, Jiangxi Province, and has been officially named as the "cradle" of Chinese rotorcraft technologies in China. CHRDI has always been an integral part of all international cooperation programs between Chinese rotorcraft companies (HAIG and CHAIG) and foreign rotorcraft OEMs. Having the necessary R&D facilities (Figure 28), CHRDI played a key role by supporting HAIG and CHAIG in the design and development of rotorcraft components and systems.

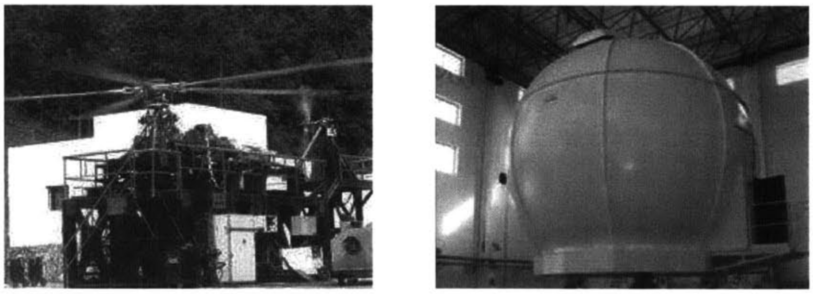


Figure 28: CHRDI R&D facilities – dynamic test bench and flight simulator (CHRDI)

Baoding Huiyang Aviation Propeller Factory (BPF) is the fourth subsidiary of Avicopter and was founded in 1960. Based in Baoding, Hebei Province, BPF is China's premier manufacturer of propellers and rotor systems that are used on fixed-wing aircrafts and helicopters. In addition, it has two joint ventures that design and manufacture commercial wind turbines. Unlike CHAIG and HAIG, BPF has both R&D and manufacturing capabilities.

Avicopter became the leading rotorcraft company in China in 2008. The consolidation of the four subsidiaries is clearly a move to bring their resources and technological knowledge that was learned from various cooperation projects with foreign OEMs closer together. It is important to note that CHAIG and HAIG do not have overlapping relationship with the foreign rotorcraft OEMs.

CHAIG has no cooperation with Eurocopter and Mil. HAIG has never cooperated with AgustaWestland and Sikorsky. This exclusive cooperation relationship network is likely a result of China's centrally-planned industrial policy. However, the consolidation in 2008 dissolved these exclusive cooperation networks. The way how Avicopter will handle this new combined cooperation network with competing foreign rotorcraft OEMs in the future remains unclear.

6.1.2 The Need for a Domestic Rotorcraft Industry

My research has identified both pull and push factors, which resulted from the unique economical, political and technological constraints in three distinct industrial periods of China – *pre-Deng era (before 1978), Deng era (from 1978 to 1997) and post-Deng era (beyond 1997).* Deng Xiaoping was the Chinese president who reformed China's economy and reopened it to foreign trade in 1982.

During the pre-Deng period, there were two needs to create a rotorcraft industry after the founding of the People's Republic of China (PRC) in 1949 from a pragmatic standpoint. First, there was an urgent need to create a fleet of rotorcrafts for national and civil defense. As discussed in Chapter Two, rotorcraft's unique vertical take-off and landing capabilities are critical to conduct diverse military and humanitarian operations by the Chinese People's Liberation Army (PLA). Second, Cheung (2009) found that aerospace technologies were identified by the Chinese government as key technologies that were needed and developed during the pre-Deng era. China's acquisition of a licensed production agreement of the Mil Mi-4 helicopters from the Soviet Union in 1958 confirmed this finding. However, the deterioration of relationship between China and the Soviet Union after 1960 disrupted China's access to Russian rotorcraft technologies. This event created a clear impetus for China to develop its own domestic rotorcraft industrial capability and to seek alternative foreign sources of technologies.

During the Deng period, unlike other commercial industries, market demand was not a rationale for China to create a domestic rotorcraft industry. Since the PLA is the controller of the Chinese airspace and the main user of rotorcrafts, the demand from a civil rotorcraft market is limited (with only a few exceptions such as governmental search and rescue and offshore energy exploration). Furthermore, before the economical reform in 1982, China was not yet a global exporter. There was no urgency of creating a domestic rotorcraft industry for export. Nevertheless, other economical rationales such as employment in the defense industry should not be overlooked. HAIG, CHAIG, CHRDI and BFP have a combined employment of 15,000 today. It is also reasonable to believe that the development of a rotorcraft industry has certainly provided economical relief for the regions where these companies are located.

However, the expansion of China's economy through foreign trade during the post-Deng period provided a new rationale for advancing the development of China's rotorcraft industry. Since 2008, the Chinese rotorcraft industry has already started implementing its strategy towards global export through the formation of Avicopter.

6.1.3 National Innovation System

The Chinese National Innovation System

China is currently still a developing nation that lags behind major developed nations in most technological fields (OECD, 2008). Several political events such as China's closed door policy and domestic political instability during Mao-era from 1949 to 1976 had negative impact on its economical development. The international arms embargo against China after 1989 further exacerbated the situation. China's development was slow in comparison to other Asian Newly Industrialized Nations (NIE) such as Taiwan, Singapore and South Korea. In fact, China is the last major East Asian nation to catch up with the industrialized western nations, the NIEs and Japan.

Research on the Chinese National Innovation System (NIS) indicates that China's technological learning process is generally similar to the developing Asian NIEs. Similar to the NIEs, China's technological learning process relies on the absorption of imported western technologies, incremental improvement and innovation through indigenous R&D. Figure 29 shows the main actors and factors that shape the Chinese NIS. These actors are private sector, public sector, market and foreign companies. The Chinese political regime and centrally-planned economy have been the strongest influences to China's NIS. However, Chinese private companies have recently started to play a greater role in technological innovation (OECD, 2008a). Some researchers argue that Chinese private companies are more interested in quick and short-term return and not interested in investing in long-term and costly R&D (Cao, Simon, & Suttmeier, 2009). This could result in the reliance on foreign technologies and lead to viscous cycle of lagging behind foreign companies. Nevertheless, there have been exceptions to this argument.

Gao (2004) found that the Chinese electronics industry is particularly innovative and competitive as it follows an alternative approach in technological learning. He believes that Chinese electronics companies are successful because they learn by "reinventing the wheel" instead of only adapting foreign technologies. However, other industries in China still compete in cost and not in innovation. From foreign investors' perspective, low-cost advantage is also one of the main motivations of continued foreign investment and foreign technology flow into China. Furthermore, it is reasonable to believe that no foreign companies will be willing to transfer technologies to China without tangible benefits. Long period of political isolation and foreign companies' reluctance to transfer the advanced technologies to China, partly also due to its poor intellectual property protection, hampered China's technological learning process. Moreover, Cao, Simon & Suttmeier (2009) believe that China's NIS is affected by a weak research culture in the Chinese universities and industries. They believe that this could be attributed to the effect of ideological suppression on the China's innovation culture. In addition, poor administration of national R&D policies and funding further exacerbated this situation. Another feature of China's NIS is the weak interaction between China's universities and industries.

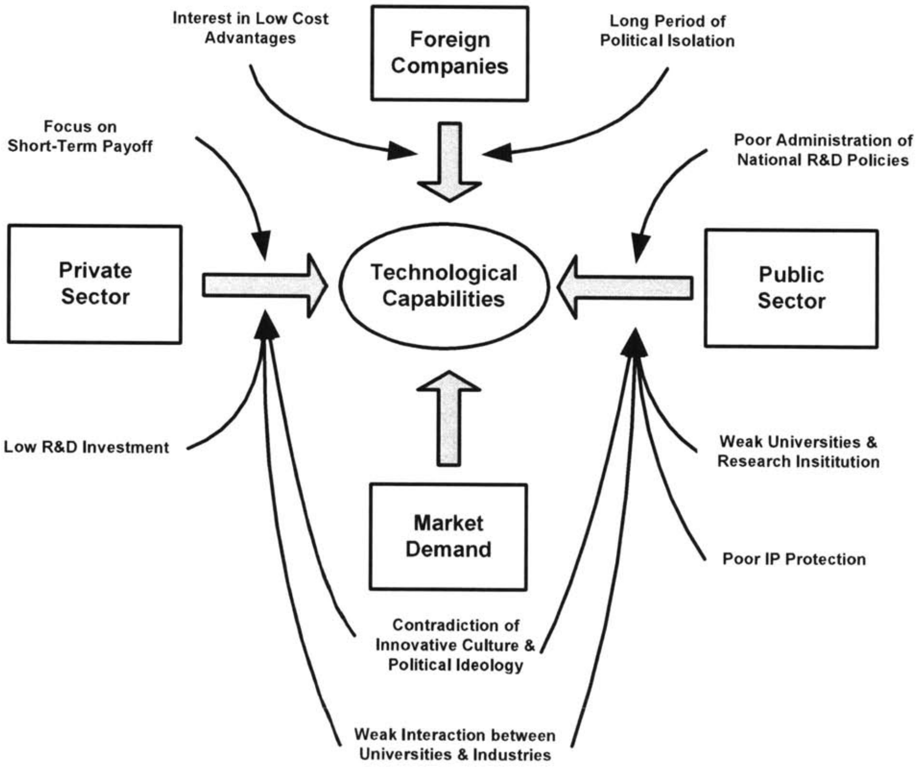


Figure 29: The Chinese NIS (adapted from various sources)

The Chinese Aerospace Innovation System

According to Cheung (2009), China's aerospace and defense industry is divided into two sectors – *strategic systems* and *conventional systems*. China's strategic systems industry designs and manufactures systems of strategic importance to the China's overall defense framework. For example, space vehicles, intercontinental ballistic missiles and nuclear weapons are part of the strategic systems industry. Conventional systems industry designs and manufactures all other systems that do not fall under the strategic systems category. Rotorcrafts and other aircraft systems are considered as conventional systems.

Cheung believes that the innovation systems in the strategic and conventional systems industries were not only different, but also received different level of resources and attention from the Chinese government. According to Cheung, strategic systems programs have always received higher level of political patronage and resources. This is a key reason why China's strategic systems industry have delivered continuous success and achieved technological capabilities that are comparable with those of the western nations. Examples of China's remarkable technological advancements are found in the missile, nuclear and space programs. Even though unspecified amount of the strategic systems technologies were obtained through informal means (Cheung, 2009b) (e.g. espionage and secret technical advisors), the ability of China's strategic systems industry in absorbing and industrializing these advanced technologies within such short period of time indicates its remarkable technological absorption capability in the strategic systems industry.

In contrast, the innovation system in the conventional systems industry had a very different development. The conventional systems industry was plagued by overly bureaucratic and complex management structure, low funding, ineffective knowledge diffusion process and lack of access to foreign information. Unlike China's strategic systems industry, conventional systems industry did not have the same level of political patronage, which could have been the critical factor for ironing out these problems it faced. In addition, China adopted the Soviet-style aerospace industrial model of separating R&D and production organizations. This industrial model was conceptualized primarily due to the need to have multiple production sites, especially in the remote regions, to enhance defense strategic depth and arms production redundancy in the event of war. However, this industrial model had a major flaw that greatly weakened knowledge diffusion between R&D and production organizations. Not only were the R&D and production carried out in different organizations, they were done in sequential mode, which greatly slowed down systems development. For instance, the design and development of rotorcraft systems was done by CHRDI, while CHAIG and HAIG were only responsible for the production. This inefficient industrial architecture of the Chinese aerospace industry certainly slowed down the technological learning process. For example, the lack of ownership of design documents by the design engineers after the transfer of documents from the design institutes to the production organizations effectively eliminates the accountability of the design engineers in the manufacturability of the rotorcrafts – absolute contrary to western modern systems engineering fundamental.

Cheung has also highlighted structural problems in the aerospace industry that hindered technological learning (Cheung, 2009b). First, there was little incentive in the aerospace industry to codify R&D knowledge. This made it very hard to maintain knowledge within the organizations and in the industry. Without codified knowledge, the dissemination of knowledge was difficult. Second, Chinese industrial standards and norms, which are important elements of codifying R&D knowledge, were underdeveloped. Third, the lack of intellectual property protection in China further weakens the creation of a favorable innovation environment and prevents the development of innovation culture. Third, there was little spillover of technologies from the commercial industries and universities to the aerospace industry. The Chinese commercial industries and universities were lagging behind the aerospace industries until recently. All these factors constituted major obstacles to the learning capability of Chinese rotorcraft companies.

As a result of these obstacles in the aerospace innovation system, the aerospace industry has experienced slow and difficult times during the pre-Deng and Deng period. However, the post-Deng era after mid-1990s was characterized by more aligned and effective innovation system that has already shown significantly improvement in products and technologies (Cheung, 2009a).

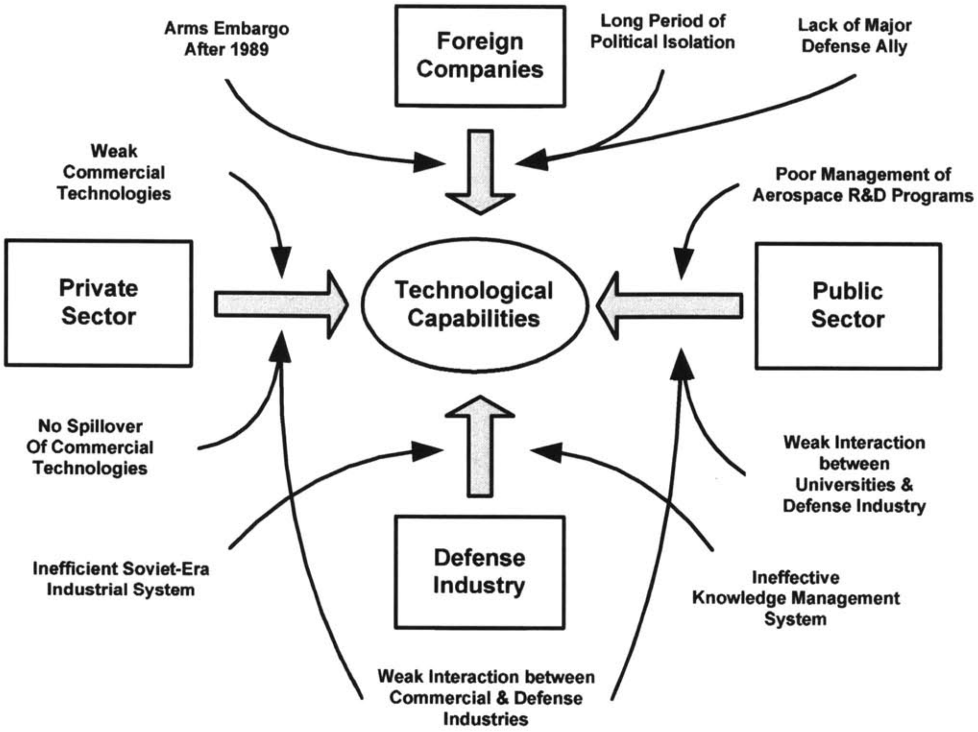


Figure 30: The Chinese Aerospace Innovation System (various sources)

6.1.4 Technological Learning Process

The previous sections of this chapter have shown that China's NIS poses a difficult technological learning environment for Avicopter. Despite this difficult environment, Avicopter has successfully adapted and worked within the constraints of China's NIS to learn and acquire rotorcraft technologies. Avicopter's technological learning effort is by no mean a pure governmental effort. Based on open sources from publications and documentaries in both Chinese and English languages, I have found out that a mixture of both private entrepreneurship and governmental support has made Avicopter technological learning process possible. Avicopter has a unique five-phase technological learning process, which is characterized by the zigzagging path it took between licensed production, design adaptation and reverse-engineering. Today, Avicopter is already capable of co-developing and co-producing rotorcrafts and their components with leading foreign OEMs (Figure 31). However, as a late-comer among the emerging rotorcraft companies, Avicopter has yet to develop its first indigenous product. The evolution of the mode of cooperation and the technological learning process (indicated by the subsystem capabilities) over the history of Avicopter are shown in Figure 32. The detailed technological learning process of Avicopter is discussed in detailed in the following sections.

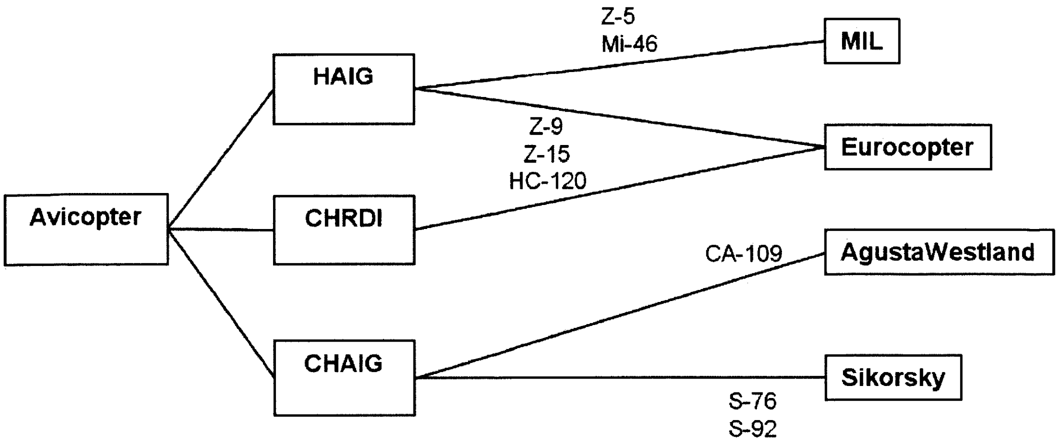
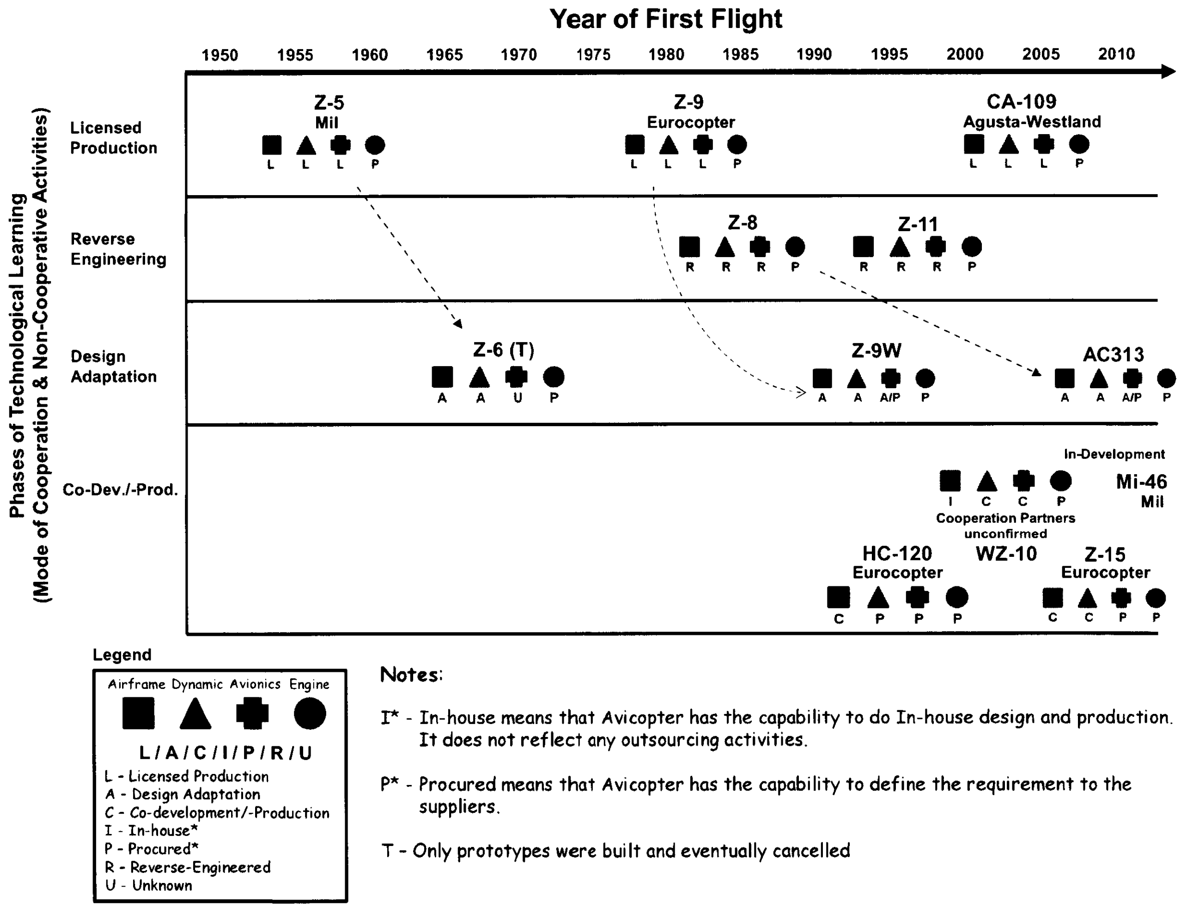


Figure 31: Cooperation Network between Avicopter and Foreign OEMs (various sources)



Notes:

I* - In-house means that Avicopter has the capability to do In-house design and production. It does not reflect any outsourcing activities.

P* - Procured means that Avicopter has the capability to define the requirement to the suppliers.

T - Only prototypes were built and eventually cancelled

Figure 32: The Technological Capability Evolution Map of Avicopter (various sources)

Licensed Production and Design Adaptation Phase I (1958 – 1980)

In 1958, Avicopter obtained a license from the Russian rotorcraft OEM Mil to locally produce the Mi-4 helicopters. The Mi-4 (locally known as Z-5) was China's first locally produced helicopter, of which a total of 545 were manufactured by 1980 (Helis, 2010). This large production volume provided Avicopter with considerable learning opportunity. Without much delay, Avicopter started to adapt the design of the Mi-4. The result was the Z-6, basically a modified version of the Z-5 with a redesigned airframe and a new turbo-shaft engine (Figure 33). The Z-6 marked the first case of design adaptation by Avicopter. The first Z-6 prototype was built in 1967. However, only 15 Z-6s were ever built as the Z-6 failed to survive through its prototyping phase due to severe product reliability issues (Helis, 2010). After that event, China's endeavor to adapt the design of foreign products did not resume until much later in the 1990s.

Figure 33: HAIG Z-5 and Z-6 (Helis/SinoDefence)

Reverse-Engineering Phase I (CHAIG) (1976 – present)

After acquiring a number of Aerospatiale (now Eurocopter) SA321 Super Frelon helicopters from France in the 1970s, China rekindled its technological learning effort in 1976 to reverse-engineer these French helicopters. This reverse-engineered product is locally known as the Z-8 that looks exteriorly like the SA321 (Figure 34) and the entire work was done at CHAIG. Even though Avicopter did not have access to the design and manufacturing data of SA321s from Aerospatiale as these helicopters were acquired from direct sales, Avicopter managed to recreate the components and assemble them into complete aircrafts through reverse-engineering. However, this learning phase took Avicopter about nine years before it achieved the first flight of the first Z-8 prototype. According to testimonies of lead engineers from Avicopter, the major issue that caused the long reverse-engineering duration was the lack of precision machineries to manufacture close-tolerance components (CCTV Z-9 Development History, 2009). For instance, water tightness issues and rotor head manufacturing problems were reported due to the lack of precision machineries. Much of the reverse-engineering work was done painstakingly using manual process. Z-8 has been developed into at least four different versions (Z-8A, Z-8F, Z-8J and Z-8K). The later versions of the Z-8 are powered by Pratt & Whitney PT6A-67B turboshaft engines instead of the older licensed-produced

Turbomeca WZ-6 engines (Jane's Defence, 2010). Other new design features include a new third generation rotor head system, bigger rear ramp, a new radome with radar, modified landing gears, a new glass-cockpit and electrical system. All these design modifications indicated the transition from reverse-engineering to design adaptation by creatively adapting foreign design to meet Chinese specific design requirement.

Figure 34: Aerospatiale SA321 and CHAIG Z-8 (SinoDefence)

Licensed Production and Design Adaptation Phase II (1978 – present)

After imitating rotorcrafts that were designed in the 1950s for 20 years, Avicopter's management realized that Avicopter was not able to close the thirty years of rotorcraft technological gap by merely learning through reverse-engineering. Hence, as part of its strategy to shorten the learning time needed to develop new generation of rotorcrafts, Avicopter acquired a license in 1980 from the French company Aerospatiale (now Eurocopter) to locally assemble 50 AS365 Dauphin helicopter (Figure 35). This was Avicopter's strategy to cooperate with Aerospatiale in order to absorb more advanced foreign rotorcraft technologies such as composite materials. From technological learning standpoint, Dauphin was an excellent candidate as it was one of the most advanced helicopters in the market in 1980 (CCTV Z-9 Development History, 2009). However, the learning curve was steep and difficult for Avicopter, which faced a number of major learning obstacles. First, Avicopter had an outdated and inefficient Soviet-era design and production system, whereas Aerospatiale was a western OEM with modern western design and production system. The transition from the Soviet system of design and producing rotorcraft to the French system was a major hurdle. The defining aspects of design and production system include knowledge such as engineering standards, quality assurance, manufacturing and supply chain processes. Moreover, process cultural difference between the two systems was significant.

Second, after the completion of assembling of 50 AS365s with technical assistance from Aerospatiale, Avicopter began to localize the design and manufacture of AS365 without further technical assistance (and without additional license approval) from Aerospatiale (CCTV Z-9

Development History, 2009). The assembly of aircraft kits delivered by Aerospatiale was relatively simple in comparison to Avicopter's subsequent localization effort, which included new and more complex aspects of aircraft development such as fabrication of components, system integration and testing. These aspects of localizing Aerospatiale AS365 into Avicopter Z-9 were not part of the cooperation arrangement with Aerospatiale. The manufacture of Z-9 composite and metallic components was one of the greatest obstacles for Avicopter as it did not have the advanced manufacturing technologies and equipment needed to make the component to the right tolerances. Avicopter mitigated these challenges through the import of US-made production equipment. However, it solved Avicopter's equipment gap but not its entire knowledge gap. This was partly due to the reluctance of US equipment manufacturers to provide complete technical assistance to Avicopter (CCTV Z-8 Development History, 2009). These events eventually forced Avicopter to find solutions through internal research and development efforts.

The Z-9 program is perhaps the most significant event in the Avicopter's technological learning process to become a full-fledged OEM. This program reduced the technological gap of 20 years mainly due to the absorption of advanced material manufacturing technologies and modern western production system (e.g. engineering standard, quality assurance, production and supply chain processes). The current CEO of AVIC, the holding company of Avicopter, labeled the Z-9 program as Avicopter's first program that has successfully gone through the complete learning cycle of "import, digest, absorb and reinvent".

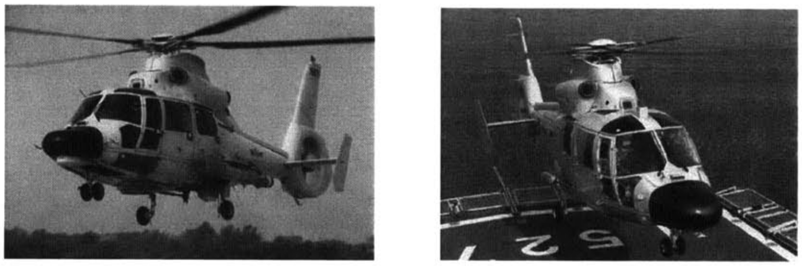


Figure 35: Aerospatiale AS365 and Avicopter Z-9 (SinoDefence)

Reverse-Engineering Phase II (1989 – present)

The valuable learning experience gathered by Avicopter from reverse-engineering of the Z-8 laid down the necessary foundation for a subsequent reverse-engineering program. The Z-11 program was started in 1989 to reverse-engineer Aerospatiale AS350 light-weight helicopter (Figure 36). Unlike the Z8, the Z-11 reverse-engineering work was done on a resale AS350 that was acquired from a US-based company instead from the Aerospatiale directly. According to Avicopter, the AS350 was chosen among all other products in the market due to its technical simplicity (CCTV Z-11 Development History, 2009). The reverse-engineering effort went smoothly without major technical problem. Within a reverse-engineering duration of only seven years, Avicopter was able to achieve the first flight of Z-11 in 1996. All major rotorcraft systems such rotor system, avionic and airframe were locally copied and manufactured. However, Avicopter still had to depend on the French engine supplier Turbomeca for the locally manufactured engines. The Z-11 helicopter was continuously developed into various versions for military and civilian purposes. There was no major obstacle reported during the reverse-engineering.

Figure 36: Avicopter Z-11 and Aerospatiale AS350 (SinoDefense/Eurocopter)

The Co-development and Co-Production Phase (1992 – present)

In 1992, Avicopter's growing technological capability clinched the cooperation arrangement with the Franco-German OEM Eurocopter in the co-development and co-production of a new generation of light-weight helicopter EC120. This program marked China's first international cooperation with a leading OEM as a full-fledged partner. The EC120 achieved its first flight in 1995, just three years after the commencement of the cooperation program. Previously, Avicopter had only cooperated as a licensed manufacturer, which did not have any design responsibility. It is important to note that Avicopter was given only the work of designing and producing the airframe in this cooperation. The key subsystems like the dynamic system, avionics and engines are being supplied by Eurocopter and its European suppliers. Despite this minor cooperation work-share, this program was a major milestone for Avicopter as it was recognized for the first time by a major foreign OEM as a worthy co-development and co-production partner.

In 2005, the existing cooperation between Avicopter and Eurocopter was further expanded to co-development and co-production of a new generation medium-weight helicopter, the EC175/Z-15 (Figure 37). This is an equal partnership program with equal design and production work-share. Unlike the previous EC120 cooperation, Avicopter has greatly increased its responsibilities for the design and production of EC175 subsystems that include airframe, main rotor, tail transmission, flight controls and fuel system (Aviation International News, 2010). A remarkable aspect of this program was the speed in which Avicopter was able to design and develop its work share. Avicopter was able to complete its design work share within a very short time frame of four years. This confirms significant progress in the technological learning process of Avicopter.

Figure 37: The first EC175/Z-15 airframe delivered by Avicopter (Flight Global)

In addition, Avicopter has been involved since early 2000s in several smaller cooperation programs with other major OEMs like Sikorsky and AgustaWestland as sub-contractors (Figure 38). For instance, Avicopter manufactures and supplies composite airframe components to Sikorsky S-76 and S-92 helicopter final assembly lines that are located in the US. Since 2005, AgustaWestland cooperates with Avicopter in the component manufacturing and assembly of AgustaWestland CA109 helicopters in China (Ainonline, 2010). In addition, Avicopter was involved since 1991 in a secretive cooperation program with a number of western OEMs to develop its first dedicated attack helicopter (WZ-10), which first flew in 2003. The dynamic and avionics systems were reported to have been co-developed with anonymous western OEMs (Jane's Defence, 2010). These cooperation programs have provided Avicopter additional technological learning opportunities for advanced manufacturing technologies.

Figure 38: Sikorsky S-76, S-92 and AgustaWestland CA109 (Airliners.net)

Avicopter technological learning process continues with newer programs in the pipeline. In 2009, Avicopter announced its cooperation with the Russian Mil in the co-development of new heavy-lift Mi-46 helicopter (Flight Global, 2009). The Mi-46 helicopter (Figure 39) will be the largest helicopter in the world and is designed to lift a payload of more than 20 tons. This will be a significant test of Avicopter technological capability as it has never built and designed helicopter of this weight category. Avicopter's heaviest rotorcraft (Z-8) has only a weight of 13 ton. It is likely that substantial amount of technologies will be transferred from the Mil to Avicopter in this cooperation as Mil has already extensive experience in the design and production of heavy-lift helicopters.

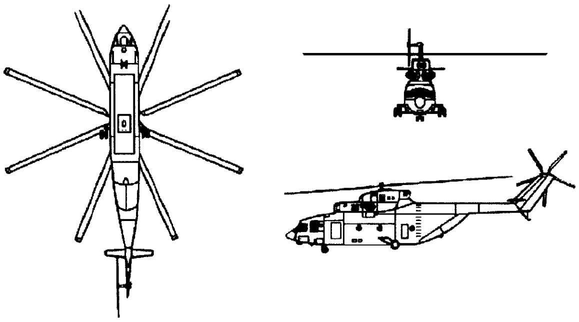


Figure 39: Mi-46 Concept Drawing (Russian Helicopters)

6.1.5 Technological Knowledge Learned

Avicopter has undergone through an adapted version of China's dominant technological learning process of absorption, adaptation and reinventing of foreign technologies. Instead of going through the normal sequential and progressive technological learning phases, Avicopter has learned by alternating (zigzagging) between cooperative (licensed production) and non-cooperative (design-adaptation and reverse-engineering) rotorcraft programs. This adapted learning process has enabled Avicopter to continuously learn and apply its technological knowledge. Perhaps even more importantly, this learning process exposed Avicopter to different western OEMs' technologies and processes.

The cooperation programs not only served as an avenue for Avicopter to absorb foreign technologies, but also as test-beds for the verification of its technological knowledge. For instance, technical problems caused by Avicopter's technological knowledge gap were likely to be rectified by its cooperation partners in order to avoid schedule delay and additional cost for the entire cooperation program. This often resulted in unavoidable transfer of knowledge, which was beyond the original cooperation scope. Furthermore, cooperation program always requires certain level of alignment of development (e.g. requirements management) and production processes (e.g. quality and material resource management) between cooperating companies. It is reasonable to believe that

Avicopter has benefited immensely directly and indirectly through these interactions with its cooperation partners.

The lack of access to technologies has led to intense reverse-engineering and internal R&D effort at Avicopter. Reverse-engineering is part of "reinventing the wheel" process, which was carried out in the Avicopter's Z-8 and Z-11 programs. Since Avicopter did not have any access to the propriety technical data from the OEMS to build these products, tedious and painstaking efforts to recreate these products were carried out (CCTV Z-8 Development History, 2009). Internal R&D played a strong part in the development of Avicopter's technological capability, which conforms to the results from Gao (2004) research findings on the use of "reinventing the wheel" in more successful Chinese electronic product companies. Furthermore, the lack of fundamental technologies and knowhow such as manufacturing equipment, industrial standards, production processes hindered the technological progress of Avicopter.

In line with Cheung's research, my findings in this case have indicated that the Chinese government did not always support Avicopter. The Z-8 program has shown that the financial and technical supports for the program for several years rested solely on Avicopter (CCTV Z-8 Development History, 2009). A period of financial difficulty in the Z-8 program from late 1970s to early 1980s resulted in the loss of skilled labor and suppliers, which invariably led to knowledge decay (CCTV-4). The total consequence of this incident remains unknown.

Avicopter has learned a broad range of rotorcraft technologies over the last several decades. It has gained experience in the design-adaptation and production of light-weight, medium-weight and heavy-weight rotorcrafts. It has shown significant advancement in development of indigenous airframe and avionic subsystems. However, the precise level of technological knowledge about Avicopter's design and production capabilities of dynamic system remains unknown. Avicopter does not possess any in-house capability in engine design and production. To conclude, all these evidences suggest that Avicopter certainly still has technological knowledge gap to fill before it could match other global OEMs.

6.1.6 Conclusion

Avicopter has grown from a licensed manufacturer to a domestic OEM with broad range of design-adaptation and production experience. It has accumulated technological capabilities in all weight segments of rotorcrafts (light, medium and heavy) through selective cooperative and non-cooperative efforts. However, Avicopter has not yet achieved the level of technological capability of leading rotorcraft OEMs. Its technological learning process can be considered as an impeded but continuous success. I believe the main constraining factors of Avicopter's market and technological position is China's limited access to foreign technologies and ineffective NIS.

China's political isolation (Soviet-Sino tension, UN arms embargo after 1989) for several decades has severely limited Avicopter's access to foreign design and manufacturing technologies. On the other hand, findings have indicated that this actually motivated Avicopter to conduct more internal R&D and "reinventing the wheel" efforts, which strengthened its technological knowledge. The technological learning result of Avicopter is quite remarkable given the limited access of foreign technologies. More importantly, Avicopter was facing an ineffective innovation system in its aerospace sector of its industry. The lack of spillover from the commercial industries and ineffective management also severely hampered the technological learning process in Avicopter.

Nevertheless, there are signs of improvement within China's NIS that could accelerate Avicopter technological advancement. The Chinese government has identified the need for restructuring of its aerospace industry. The consolidation of HAIG, CHAIG, CHRDI and BDP in 2008 under the Avicopter exemplifies this point. Even though these companies have been centrally managed by the AVIC conglomerate and closely linked through their R&D dependency on the CHRDI since their founding, there is a need for reorganization to enhance operational leanness and efficiency. In my opinion, this consolidation will have more impact on Avicopter's organizational efficiency than its existing technological capability. This consolidation will certainly alter the way Avicopter's technological learning process in the future. In addition, China also sees the need for greater synergy between the aerospace and commercial industries (Cheung, 2009). Potential technological spill-over areas from the commercial industries are avionics and composite materials, where these commercial industries have shown remarkable technological advancement. However, dynamic systems and engines will still remain the Achilles' heel of Avicopter at least for this decade.

Today, Avicopter is the leading rotorcraft company in China. Its current products may still lack international quality and safety standard, but China's turbocharged domestic market potential, which will create immense opportunity to learn and verify new technologies and processes, will certainly support the continued technological learning process of Avicopter.

6.2 Case Study 2 - Kawasaki Heavy Industries Aerospace

6.2.1 Company Introduction

Kawasaki Heavy Industries Aerospace (KHI Aerospace), the aerospace division of publicly-owned Kawasaki conglomerate, is headquartered in Gifu Prefecture and has two smaller other plants in Nagoya prefecture (Figure 40). KHI Aerospace is known as one of the three Japanese first-tier aerospace companies, which also include Mitsubishi Heavy Industries (MHI) and Fuji Heavy Industries (FHI). KHI Aerospace was founded in 1922 and started designing and manufacturing of military fixed-winged aircrafts until the end of World War II. After the war, Japan's aircraft industry was completely destroyed and it was barred under the post-war sanction from designing and producing aircrafts until 9th April 1952 (Hall & Johnson, 1968a). KHI Aerospace resumed its aerospace activities immediately after the lifting of the sanction through licensed production of predominantly US fixed-winged military aircrafts and rotorcrafts.

Figure 40: Gifu headquarters and Nagoya sites (Source: KHI)

The main site of KHI aerospace in Gifu has a comprehensive R&D and manufacturing facilities for both fixed-winged and rotorcrafts. All rotorcraft activities are located in Gifu. KHI Aerospace has been producing rotorcrafts under license since 1953. These include Bell B47G, Boeing V-107, CH-47J, Hughes OH-6 and most recently AgustaWestland MCH-101. KHI co-developed and co-produced the BK117/EC145 with Eurocopter and indigenously developed the OH-1 light observation helicopter (Figure 41).

Figure 41: Examples of Rotorcraft Products - BK117, CH-47J and OH-1 (Source: KHI)

Gifu is also the production site for a wide range of Japanese indigenous fixed-winged aircraft programs such as the F-2 fighter jet, C-1 transport aircraft and T-4 training jet (Figure 42). The two smaller sites in Nagoya prefecture are involved only in co-development and co-production projects with Boeing for commercial aircrafts such as the Boeing 767, 777 and 787. For instance, KHI Aerospace is responsible for the forward fuselage, main landing gear and main wing fixed and trailing edge for the Boeing 787 program.

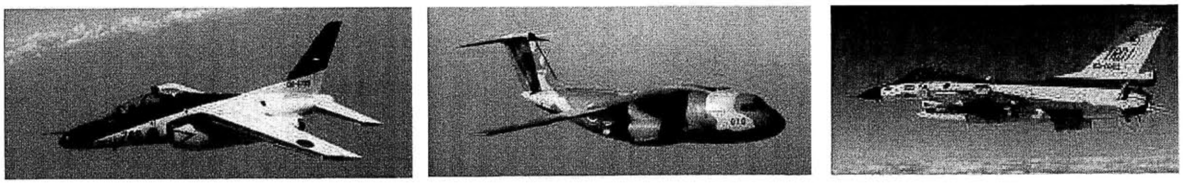


Figure 42: KHI Aerospace Fixed-Winged Programs – T-4, C-1 and F-2 (Source: KHI)

In additional to rotorcrafts and fixed-winged aircrafts, KHI Aerospace is a systems supplier for space and aircraft programs. KHI Aerospace designs and manufactures fairing for space vehicle and deliveries complete reusable space systems to the Japan Aerospace Exploration Agency (JAXA). For the aircraft systems programs, KHI manufactures under license critical rotorcraft systems such as turbo-shaft jet engines for leading engine OEMs such as Honeywell (US), Rolls-Royce (UK) and Turbomeca (France).

KHI Aerospace has come a long way after the lifting of the sanction that forbade the recreation of the Japanese aircraft industry in 1952. Today, KHI Aerospace is a competent aerospace company with the necessary technologies to become a mid-size aircraft OEM like Embraer or Bombardier. The speed of KHI technological learning since 1952 can be attributed to the generous access to US advanced aircraft technologies (King & Nowark, 2003b). At the same time, KHI's effective technological learning capability is the other enabling factor that has helped KHI Aerospace to regain its lost aerospace capability after the end of World War II.

6.2.2 The Need for a Domestic Rotorcraft Industry

There are two main factors that motivated Japanese government to recreate its rotorcraft industry. The first reason was national defense and security. After the Second World War, the threat of further international conflict did not subside. The rapid expansion of communism from the Soviet Union to Asia and the Cold War between the western nations and the Soviet Union generated significant security risk to the Asia-Pacific region. There was a need to create a credible self-defense force for Japan immediately after the war. Hence, the modernization of Japanese defense systems was a top priority for the post-war Japanese government (Pelvin, 2000). Rotorcraft has been a vital asset to military forces since the Korean War. Judging from the enormously large fleet of several hundred rotorcrafts in Japan's Self-Defense Forces today, the role of rotorcrafts in Japan's defense structure cannot be overstated. In fact, Japan has the largest rotorcraft fleet in the Asia-Pacific region, more than any other European nations (Jane's Defence, 2010). A domestic rotorcraft industry to support its domestic demand for rotorcraft was a vital strategic need.

The second reason for Japan to create a domestic rotorcraft industry was for economical benefits, as backed by many Japan industrial scholars. The Japanese government has been using defense spending to improve its national economy. In fact, economic factors are fundamental considerations of Japanese defense acquisition policies (Chinworth, 1992b). Defense systems such as rotorcrafts are very costly and create significant impact on Japan's balance to trade if sourced directly from foreign OEMs. The difficult post-war recovery period in Japan justified the use of local industries and resources in the acquisition of defense systems. For instance, local industries could produce defense equipment instead from buying off-the-shelf from overseas. Furthermore, the Japanese government saw the great spillover effect of aerospace technologies on other industries and identified aerospace technology as "key technology" (Alexander, 1993).

These two factors constituted rationales for the creation of a domestic rotorcraft industry. Due to the Japanese governmental policies (such as limiting ownership of capital assets by foreign companies in Japan), licensing of technologies to Japanese companies such as KHI Aerospace is the only avenue for foreign OEM to conduct defense business in Japan (Odagiri & Goto, 1993a, 1996a). In addition, it is important to note that KHI Aerospace is part of KHI conglomerate's diversified industries. Despite the fact that the manufacturing of aerospace products has not always yielded high financial returns (Odagiri & Goto, 1996b), prestige and potential technological spillover effect to other products (especially advanced materials) within the company should not be excluded as another possible motivation for KHI Aerospace's and other Japanese OEMs' diversification into the rotorcraft business.

6.2.3 National Innovation System

The Japanese National Innovation System

Despite the fact that Japan is a late-comer in the global economy in comparison to the western developed nations, it started acquiring western technologies as early as the Tokugawa era (1603-1868). Based on the detailed research conducted by Odagiri and Goto (1993, 1996), Japan had started importing technologies from the Netherlands, Germany, the US and the UK even before the Second War World. These technologies ranged from automotive, aerospace, metal processing to electrical devices. However, Japan lagged behind the western developed nations in technology until the later part of the 20th century. The catching up of Japan with the developed nations occurred only after the Second World War. So, how did Japan manage to learn and catch up with its rivals over the last fifty years? Odagiri and Goto offer a concise representation of the Japanese National Innovation System (NIS) during the post war era (Figure 43).

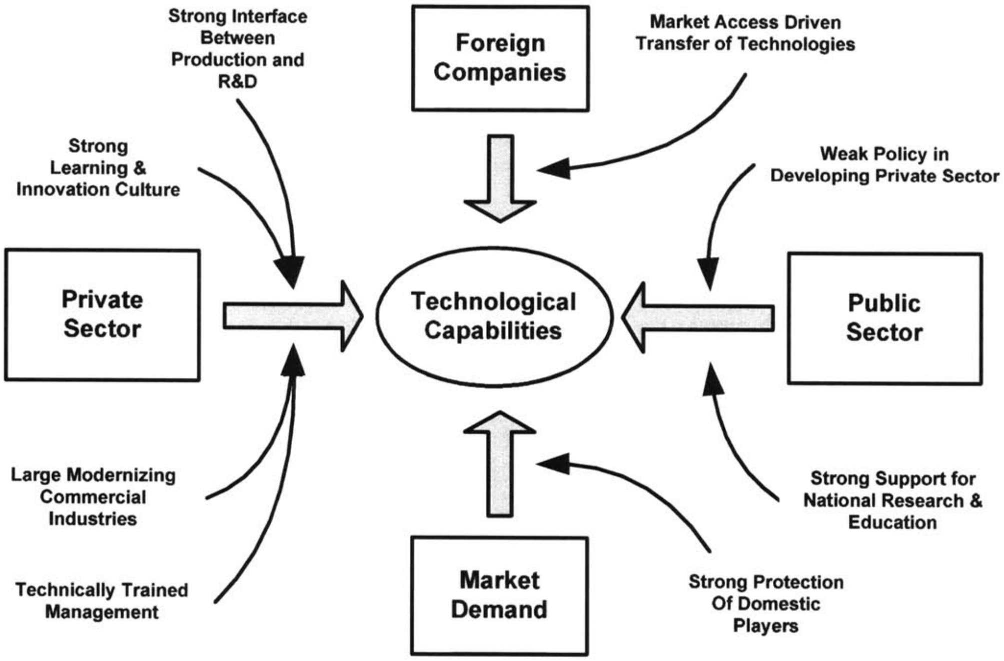


Figure 43: The Japanese National Innovation System (Adapted from Odagiri & Goto, 1996)

In Figure 43, Odagiri and Goto show the different factors that have influenced innovation (represented by technological capabilities) in Japan. The three main stakeholders in Japanese NIS are the Japanese private sector, the Japanese public sector (i.e. the Japanese government) and overseas stakeholders such as foreign companies and governments. These three stakeholders provide the innovation system essentials and catalysts such as access to foreign technologies, education, financial incentives, pro-domestic trade policies, firms' strong learning culture and indigenous R&D that facilitate innovation. Furthermore, the interaction between market demand, entrepreneurship and technological capabilities also determines the dynamic and outcome of the Japanese innovation system.

Odagiria and Goto also suggest that Japan has always pursued technological learning using a dual approach involving technology importation and domestic R&D (Odagiri & Goto, 1993a). This seems to converge with the dominant technological learning process for most late-comer developing nations such as China and South Korea, which conduct further improvement and adaptation after the absorption of technologies. Domestic R&D is also essential to enable firms to evaluate, adapt and improve imported technology (Odagiri & Goto, 1993a). In addition, their research findings indicate that this technological learning process is valid for all major Japanese industries like iron and steel, automotive and electronic (Odagiri & Goto, 1993b). However, Japanese government policies, owing to the modest level of incentives, were less effective than the private sector's own effort in driving innovation (Odagiri & Goto, 1993a).

Another important finding from their research shows the extensive use of technology licensing, cooperation, reverse-engineering and use of foreign advisors in technological learning (Odagiri & Goto, 1993b). Nevertheless, the most interesting reason of Japan's success in technological learning and catching up with the western nations is the innovation system within the private enterprises. More precisely, Odagiri and Goto believe that the most important reason of Japan's post-war industrial success is the human aspect of the innovation system. First, they attribute these aspects to the relatively high proportion of engineering and scientific trained managers in the Japanese company management echelon. Second, the long-term employment in Japanese working culture creates long term and close relationship between managers and workers. Such relationship is crucial for long term and sustainable management practices. Third, Japanese firms practise strong interfacing between R&D and production (Sakakibara & Westney, 1985), in contrast to the Chinese and Russian segregated innovation systems (i.e. deliberated geographical and organizational separation of production and design). High level of cooperation between OEM and their suppliers encourages innovation and cross-enterprise learning (Dyer, 2000). Finally, the generally long-term view taken by Japanese firms enables the periodical rotation of Japanese workers to acquire system-view of the company and greater job flexibility (Odagiri & Goto, 1993c).

The Japanese Aerospace Innovation System

The Japanese aircraft industry is highly-controlled industrial sector in Japan. Powerful stakeholders of the Japanese government and industry collectively shape the aircraft industrial innovation system. Figure 44 shows the innovation system of the Japanese aircraft industrial industry.

Defense policies such as arms export ban (including military aircrafts) and *Kokusanka* (self-reliance of arms production policy) have profound impact on the innovation system.

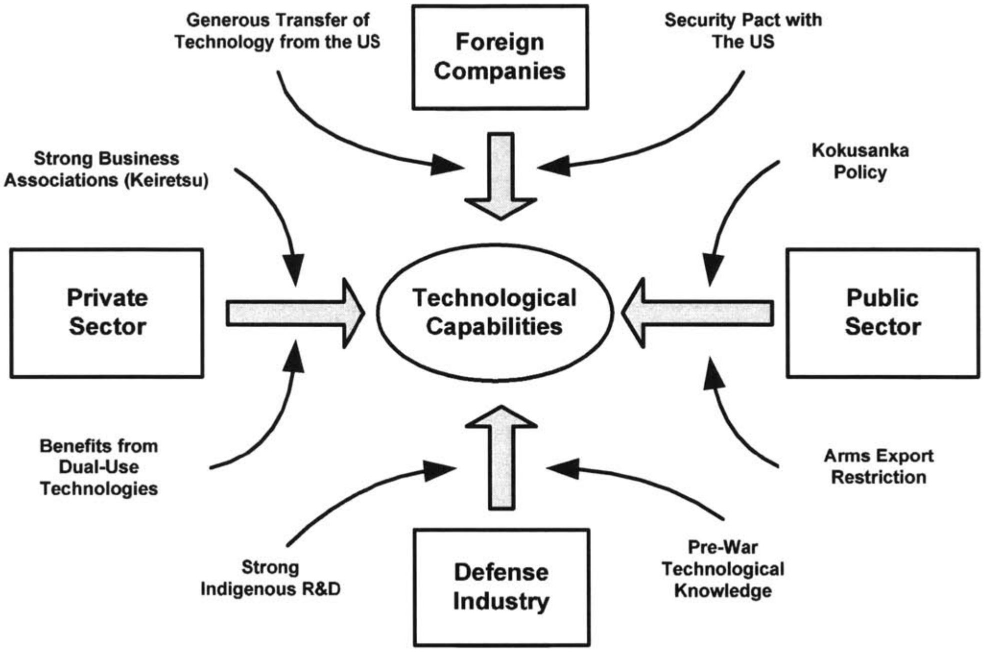


Figure 44: The Japanese Aerospace Innovation System (adapted from Chinworth, 1992)

Next, the industry influences the innovation systems through their accumulated aerospace technologies since their establishment and their current R&D activities. Chinworth (1992) points out that residual aircraft knowhow were used in the development of postwar fixed-winged aircrafts. For instance, some leading Japanese engineers involved in postwar aircraft programs had previously worked for pre-war aircrafts (Odagiri & Goto, 1993d). Nevertheless, even though aeronautical technologies have advanced, the fundamental principles of flight remain unchanged. Not having to relearn the basic aeronautical technologies has certainly helped to shorten the learning curve. Japanese government's policy of "no winner takes all" redistributes aerospace work contract by assigning the winning company as system integrator and losing companies as suppliers (Chinworth, 1992a). This ensures the survival of all major aerospace companies and hence protecting their technologies. Unlike the common aerospace industrial practices in the US, Japan's "no winner takes all" policy may be a solution for ensuring technologies and jobs sustainment, but it is also an expensive solution. As a consequence, Chinworth believes that Japanese indigenous aerospace products are not as cost-competitive as western products (Chinworth, 1992a).

Furthermore, the private sector consisting of business associations and commercial technological firms are important stakeholders in the Japanese aerospace innovation system. Business associations and interlocking companies' stakeholder relationship (*Keiretsu*) promote cooperation among aerospace firms and suppliers. This cooperation includes sharing of knowledge in both technologies as well as processes (Chinworth, 1992b). Additionally, private sector provides the supply of dual-use technologies to the aerospace industry. Dual-use technologies such as manufacturing technologies, material technologies and electronics can be applied in both commercial and aerospace products.

Finally, the last element of the Japanese aerospace innovation system is the access to foreign technologies. The rapid modernization of the Japanese aerospace industry can be attributed solely to the almost unimpeded access to US technologies. This access to US aerospace technologies continued unimpeded until the late 1970s when the US started to worry about the "boomerang effect" of creating a world class competitor that will ultimately compete with US players (Odagiri & Goto, 1996b). After the 1970s, the US implemented stricter control of technologies to Japan and ensured the flow back of technologies resulting from cooperation between the two countries. Similarly, the postwar technological learning in Japanese aerospace industry was possible through the extensive licensed production of US aerospace products. However, I believe that key elements of Japan's national innovation system such as the human and management aspects of enabling innovation and technological learning contributed significantly to the development of aerospace industry.

On the other hand, Japanese aerospace industry is heavily dependent on military contracts from the government as there is limited domestic demand due to geographical constraints and its restriction on export hinders the greater rate of advancement in its aerospace technologies and productivity (Odagiri & Goto, 1996b).

6.2.4 Technological Learning Process

Japan's relatively easy access to the US aerospace technologies after 1952 generated a unique technological learning dynamic for Japanese rotorcraft companies. Besides KHI Aerospace, Fuji Heavy Industries (FHI) and Mitsubishi Heavy Industries (MHI) are also involved in rotorcraft cooperation with foreign OEMs. These foreign OEMs are mostly from the US. KHI is unique among the three Japanese companies due to the fact that it is the only one that has cooperated with

European OEMs. This includes the co-development and co-production of the BK-117 helicopter with Eurocopter since 1977 and the licensed production of AgustaWestland MCH-101 helicopter since 2006. FHI and MHI have only been involved in licensed production with US OEMs Sikorsky and Boeing. Most importantly, KHI Aerospace has demonstrated its superior technological capability over MHI and FHI due to the fact that it is the only one that has successfully led the development and production of an entirely new rotorcraft as system integrator. In comparison, FHI and MHI have only been licensed production contractors and systems suppliers to KHI up to now. MHI has once tried to introduce its own independently designed helicopter MH2000, which failed due to a crash and the lack of market interest. Figure 45 shows the cooperation network and the products involved between KHI and the foreign OEMs.

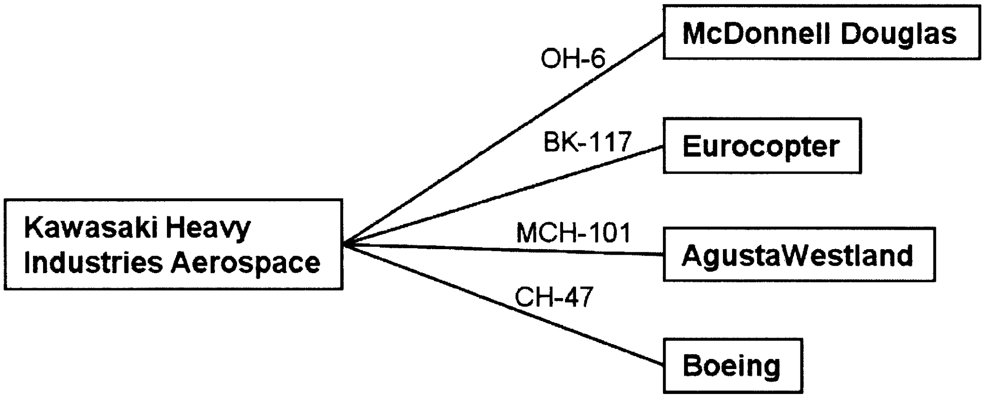
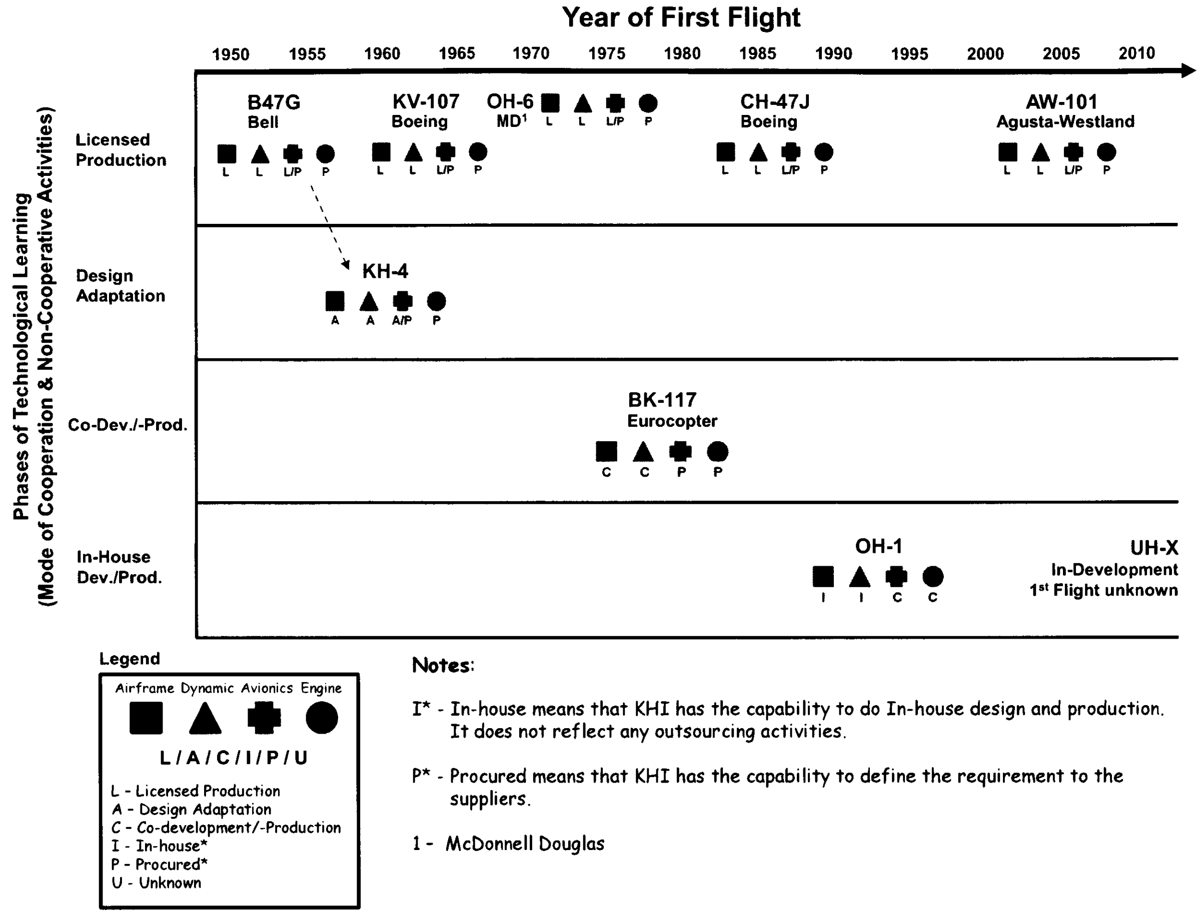


Figure 45: Cooperation network between KHI and Foreign OEMs (various sources)

The technological learning process of KHI can be divided into four phases. First, KHI carried out licensed production of US products from 1950 to 2009. This involved the manufacture of 236 units of Bell B47G helicopter since 1953 to the 1960s (SJAC, 2009). This was then followed by the licensed production of 106 units of Boeing V-107 helicopters, 387 units of McDonnell Douglas OH-6 helicopters, 82 units of Boeing CH-47J/JA and 12 units of AgustaWestland MCH-101. The second phase involved the design adaptation of Bell B47G into KH-4 helicopter, which was basically a heavily modified clone of the Bell B47G. The third phase involved the co-development and co-production of the BK-117 helicopter with Eurocopter from 1977 onwards. The fourth phase is the indigenous development of the OH-1 helicopters with MHI and FHI as systems suppliers. As of today, KHI is developing a transport derivative of the OH-1 observation helicopter, the UH-X. The evolution of the mode of cooperation and the technological learning (indicated by the subsystem capabilities) over the history of KHI are shown in Figure 46. These two figures collectively provide the unique "DNA" of the technological learning process of KHI. The following sections of this chapter provide detailed description of the four technological learning stages of KHI.



L - Licensed Production
A - Design Adaptation
C - Co-development/-Production
I - In-house*
P - Procured*
U - Unknown

Notes:

I* - In-house means that KHI has the capability to do In-house design and production. It does not reflect any outsourcing activities.

P* - Procured means that KHI has the capability to define the requirement to the suppliers.

1 - McDonnell Douglas

Figure 46: Technological Knowledge Evolution Map of KHI (various sources)

Licensed Production Phase (1953 – present)

The first phase of technological learning was a significant learning opportunity for KHI solely from the production volume standpoint. These licensed production programs of B47G, OH-6, KV-107 and CH-47J (Figure 47) amounted to about 800 units of helicopters in total. Such a large production volume allowed KHI to refine production processes and improve its technological learning curve. For the case of licensed manufacturing of Boeing CH-47J, KHI learned the art of building CH-47J from Boeing using a three-phase process (Flight International, 1986). This three-phase process (Figure 48) clearly showed the characteristic of "learning by doing" introduced by Malerba (Malerba, 1992). In the first phase, KHI carried out the installation the interior equipment such as trims and avionics into two flyable "green aircrafts" delivered by Boeing. Installation of interior equipment is considered as low-complexity work that can be readily learned and applied. Often, installation work consists of straightforward and simple screwing and bonding of equipment in the aircraft that do not require complex tools or machines.

In the second phase, KHI assembled four CH-47 complete knocked-down kits, which consisted of subassemblies and systems delivered from Boeing. Assembly of subassemblies and systems will usually require special rigs and tools and special technical knowhow to ensure correct alignment of these aircraft subsystems. This kind of work is more complex than installation work. In the third phase, KHI was responsible for the manufacture of the semi-finished mechanical dynamic components, part of the airframe fuselage, cockpit, wiring system and integration of Boeing-supplied systems.

Figure 47: KV-107, OH-6 and B47G (KHI & Aviastar)

The third phase is the most complex among the three phases and it takes the longest time to master as manufacturing demands more tacit knowledge and processes than assembly. Even though few details concerning the exact localization level of these licensed produced rotorcrafts are known, the localization level for all these licensed products can be assumed to be similar to those of fixed-winged aircrafts licensed produced in the same period. As a reference, the localization rate of fixed-winged aircrafts such as F-104J Star Fighter jet licensed produced by KHI reached around 45% of the aircraft value, where the rest were procured from lower tier suppliers (Hall & Johnson, 1968b). This localization level was comparable to the average value for US OEMs during the same period (1960s). There were no reasons why KHI did not pursue this high localization level as it was also involved in the parallel licensed production of other fixed winged aircrafts from the US OEM Lockheed.

The research by Hall and Johnson on KHI – Lockheed cooperation in the licensed production of fixed-winged aircrafts such as the T-33A, P2V-7 and F-104J indicates similar systematic and comprehensive transfer of technologies within these licensed production cooperation. This transfer included the co-location of Lockheed technical assistance teams at KHI, the training of KHI staffs in the US and the provision of all tooling and design documentations. Furthermore, the production plan was targeted at achieving rapid localization of the US products with high Japanese local content. On the other hand, KHI demonstrated immediate learning capability by adapting and finding innovative technical solutions, which were better than the original US solutions, to its localized products (Hall & Johnson, 1968c). This exemplifies the technological learning through learning by improving in Japanese companies.

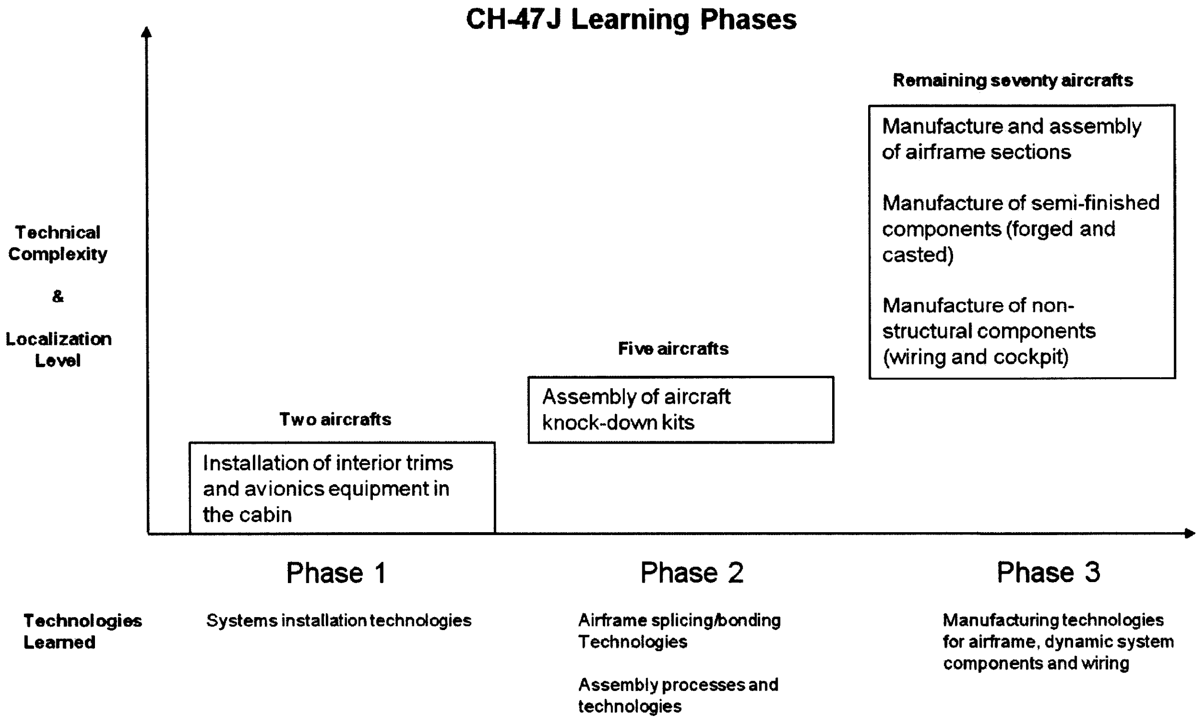


Figure 48: The 3-phase Tech. Transfer Process of Boeing CH-47J (Gan/Flight International)

The Design Adaptation Phase (1953 - 1972)

The development of KH-4 helicopter (Figure 49) marked the beginning of KHI's second phase of technological learning. I believe that the unimpeded transfer of US aerospace technologies to KHI and its meticulous technological learning system explains why KHI Aerospace was able to deliver the KH-4 only seven years after it delivered its first licensed produced Bell B47G helicopter (SJAC, 2009). KH-4 is basically a heavily modified version of the Bell B47G. KH-4 had a modified cabin, cockpit, three-blade rigid rotor head (KHR-1 prototype), new engine and fuel system. Here again, the huge production volume of 236 units of Bell B47G provided ample opportunity for component level reverse-engineering and design adaptation for KHI. Furthermore, the fact that a further 203 units of KH-4 helicopters were produced by KHI indicates that the KH-4 was a successful design-adaptation program.

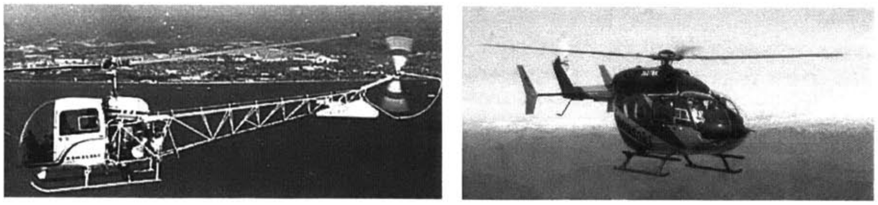


Figure 49: B47G and BK-117 (KHI)

The Co-development and Co-Production Phase (1977 – present)

The third phase of the KHI technological learning process was the co-development and co-production of BK-117 (Figure 49) with Eurocopter (previously named MBB before its merger with Aerospatiale) since 1977. The first flight of BK-117 took place in 1979. In this cooperation, KHI was given a large part of the work share that included airframe, main gear box, mechanical control system, fuel system and cockpit (Polte, 2008). This was a significant increase of technological capability for KHI. Furthermore, the partnership was a huge testament of KHI's technological capability by Eurocopter, a leading rotorcraft OEM today. The cooperation was a success without parallel in Eurocopter and KHI (Eurocopter, 2009). The following quotes from an exclusive interview of program manager of KHI testify the extraordinary long and successful cooperation with a foreign OEM it had carried out so far.

Masahiko Yokota (KHI - Program Manager BK-117): *"I have a great deal of respect for the German and Japanese employees who have contributed to this (BK-117) program. Our 30-year-long history is proof that our decision to cooperate with Eurocopter (MBB at that time) for the manufacture of civil helicopters was the right choice. KHI is very proud and pleased that together with Eurocopter we have been developing the BK-117 product family for 30 years........ The co-development project has gone smoothly as a result of our common motivation." (Eurocopter, 2009)*

Figure 50: Signing of BK-117 Cooperation Contract in 1977 (Source: EADS)

Indigenous Development (1992 to present)

The fourth phase of KHI technological learning was marked by the OH-1 helicopter program, which was brought to life in 1992. KHI was designated the prime contractor (60% work share) of this program with MHI and FHI as system suppliers each having 20% of the work share. The first flight of the OH-1 took place in 1996. The OH-1 is in many ways a helicopter that is far more advanced than KHI's previous products like BK-117 and KH-4. The OH-1 possesses state-of-the-art rotorcraft innovations such as shrouded Fenestron tail rotor, elastonomer rotor head, 40% composite airframe (Flight International, 1996). OH-1's asymmetrically spaced eight-bladed shrouded "Fenestron" tail rotor was not only an innovation for KHI but also an innovation for the world's rotorcraft industry. The asymmetrical spacing of the eight tail rotor blades reduces the OH-1's noise level, which is an advantage for military rotorcraft. Furthermore, the major systems such as engines (MHI/KHI), engine control (KHI) and avionics (Fujitsu, Yokogawa Electric, NEC, and Shimadzu) are entirely supplied by Japanese suppliers or produced in-house (Flight International, 1996). This high level of localization and the use of advanced rotorcraft technologies in the OH-1 indicate significant increase in technological capability of KHI, especially as a system integrator. KHI has delivered a total of twenty-seven OH-1 of the 200 ordered to the Japanese Self-Defense Forces by 2008 (SJAC, 2009). Not only has KHI succeeded in the development of its first product, it also succeeded in serialization of its production as measured by the constant production flow rate of about three aircraft per year between 2000 and 2008. Constant production rate is an important indication of manufacturing and process capabilities of a rotorcraft OEM. Report of usual material and system integration problems that typically affect all OEMs was not known.

In 2005, KHI announced the development of a transport derivative of the OH-1 to bid for Japan's new helicopter requirement (UH-X) to replace its aging fleet of Bell UH-1 helicopters. KHI's UH-X concept was to use existing technologies derived from OH-1. This marked KHI's ambition to further its status as Japan's leading rotorcraft OEM. The development status of the UH-X transport helicopter is unknown up to now. However, reports have indicated some technical issues that might force KHI into another co-development and co-production program (Flight Global, 2005).

6.2.5 Technological Knowledge Learned

KHI has learned through sequential cycle of licensed production, design adaptation, co-development of older generation of helicopters (B47G, OH-6 and V-107). KHI's technological learning process conforms to the technological learning process in Japanese NIS and aerospace innovation system. From the case of CH-47J licensed productions, it was found that the learning process in licensed production program was progressive and effective. However, it is interesting to note that there was a return to licensed production of more advanced and complex new generation of heavy-weight helicopters (CH-47/MCH-101). This step backwards to license production of heavy-weight products is likely to be due to KHI's inability to adsorb technological knowledge to develop this category of products (heavy-weight). Nevertheless, KHI has made more rapid advances in airframe and dynamic system than the other subsystems like avionic system and engines from 1953 to 1977.

In 1992, KHI has proven that it has succeeded in leading the design and production the entire helicopter system (OH-1) independently as a system integrator. The OH-1's 100% localization level (airframe, engine, avionic and dynamic system) has not only demonstrated the full-spectrum technological knowledge of the Japanese aerospace industry in the design and production of rotorcraft subsystems, but also proven the advanced system integration capability of KHI. Nevertheless, KHI has so far only demonstrated this technological capability in light-weight helicopters (KH-4, BK-117 and OH-1) and the majority of the KHI programs (five out of nine) are licensed production. Most of the cooperation involved all subsystems except engine, which became an item of cooperation programs only very recently (MCH-101 with AgustaWestland) and indigenous programs (OH-1 and UH-X). Also, KHI did not carry out complete reverse-engineering of foreign products.

KHI has gained rotorcraft technologies through cooperation with foreign OEMs. KHI has also demonstrated its ability to adapt and apply learned technologies to indigenous products like the KH-4 and OH-1. More importantly, KHI has mastered the complete set of technological knowledge needed to development and produce light-weight helicopter after 40 years of technological learning. However, evidences from recent programs such as the failed medium-weight UH-X and return to licensed produced of heavy-weight product (MCH-101) suggest that KHI still have some distance to go before becoming a full-pledge OEM in the rotorcraft industry.

6.2.6 Conclusion

KHI has grown from a licensed manufacturer to a domestic OEM with comprehensive rotorcraft technologies, which are confined to the lightweight product segment. Nevertheless, KHI has not achieved the technological capabilities that could match those of leading global OEMs such as Eurocopter or Bell. I believe that the main contributing and constraining factors of KHI's market and technological position from the NIS analysis are the easy access to foreign technologies and Japan's self-imposed policy of arms export ban. Easy access to foreign technologies (especially US) could have caused Japanese government's unwillingness to fund the more indigenous R & D in rotorcraft product systems level. Having the technological knowledge but without the funding to apply this technological knowledge could explain the current KHI's domestic OEM position. Furthermore, Japan's small domestic market and lack of access to the global market offer little economical reason for KHI to pursue privately funded product development.

The analysis of KHI's technological learning process has unraveled interesting insight into how KHI acquired its technologies over its history. KHI's technological learning process can be considered as unimpeded but surprising slow after the completion of KH-4. KHI acquired rotorcraft technologies through a number of different modes of cooperation programs with foreign OEMs. The dominant mode of cooperation of KHI is licensed production. Even though KHI had access to foreign technologies through cooperation, it has not made significant progress in the indigenous design and development of newer rotorcraft products. Its technological learning process was found to be successful as there was no indication of technological absorption issues with KHI based on the normal production and delivery schedules of its programs. In addition, increasing localization of subsystems has indicated successful technological learning within KHI and further supports this conclusion.

Interestingly, similar trend has been found in the Japanese fixed-winged sector. KHI and the other major Japanese aerospace OEMs have been supplying major airframe structures to Boeing and Airbus. However, these Japanese OEMs are just systems suppliers and not OEMs (systems integrator). MHI and KHI have designed and produced military fixed-winged aircrafts but they are not for export. In the commercial sector, MHI and FHI are developing small-size fixed winged aircrafts. It is probable that Japanese OEMs are not ready for large commercial passenger jets mainly due to the lack of technological capability (especially systems integration) and the high financial risks. The current incumbent market players like Boeing and Airbus are alleged to be heavily subsidized by their respective governments (LA Times, 2010). This unfair market practices pose significant obstacles for Japan's entry into this high risk market. Here again, Japanese governmental policies within the NIS determine the level of support for global aerospace industry in the global market.

Hence, I conclude that the technological evolution of KHI was strongly due to economical and political constraints in the NIS, which favors licensed production over indigenous R&D of rotorcrafts. This situation affected KHI technological learning process by limiting KHI's chance to carry out more in-house R & D of rotorcraft technologies and practice system integration. KHI's position in the global rotorcraft industry as a subsystem supplier and domestic OEM will certainly remain unchanged if the Japan's current national policies continue.

6.3 Case Study 3 – Agusta

6.3.1 Company Introduction

Founded in 1923, Agusta (full name - *Construzioni Aeronautiche Giovanni Agusta SpA*) is an Italian company based in Cascina Costa, Italy. Agusta started its business in manufacturing of fixed-wing aircrafts. In 1952, Agusta entered the rotorcraft business through licensed production agreement with the American rotorcraft OEM Bell. This agreement was possible after the Allied Forces lifted the Second World War sanction that banned aircraft production in Italy in 1950. Bell, the maker of the successful B47 helicopter, was looking for a company that could produce the same helicopter for the European market. The cooperation agreement between Agusta and Bell included both production and marketing of the B47G (Museo Agusta). In the 1969, Agusta expanded its fixed-winged aircraft business through the acquisition of an Italian fixed-winged OEM SIAI-Marchetti.

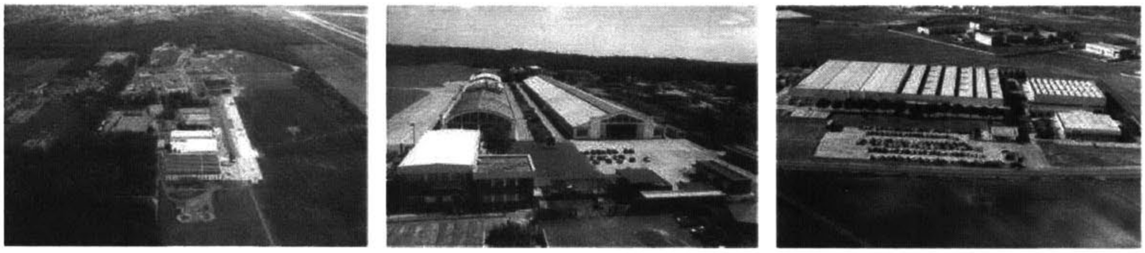


Figure 51: Main Sites – Cascina Costa, Vergiate & Anagni (Source: AgustaWestland)

Agusta is located in six geographically dispersed locations in Italy. These locations include Cascina Costa (headquarter, R&D and transmission), Vergiate (finally assembly), Sesto Calende (training), Anagni & Frosinone (rotor head and composite component), Benevento (metallic casting) and Brindisi (airframe). Since 1952, Agusta has evolved rapidly through a long period of licensed production, design-adaptation, co-design and co-production to become a global OEM. Its notable products include the A109, the world's first second generation helicopter, the A129, Europe's first tandem-seat dedicated attack helicopter and the BA609, the world's first commercial tilt-rotor aircraft (Figure 52). In 2001, Agusta merged with the British rotorcraft OEM GKN-Westland to form AgustaWestland, which also became a subsidiary of the Italian defense conglomerate Finmeccanica.

Figure 52: Agusta Products – A109, A129 and BA609 (Source: AgustaWestland)

6.3.2 The Need for a Domestic Rotorcraft Industry

After the Second World War, Italy needed a domestic rotorcraft industry due to the growing market demand for air transportation and defense (Chiesa, 1982). It is important to note that Italy did not have rotorcraft technologies until Agusta created its rotorcraft division. However, Italy had a fixed-winged aircraft industry that was founded in 1907. By the end of Second World War, the Italian aircraft industry had a peak workforce of 150,000 workers and manufactured a total of 11,500 fixed-winged aircrafts during the four-year war. Hence, the design and manufacturing of fixed-winged aircrafts was a major industry in Italy until the end of Second World War. In 1978, the Italian government's Interdepartmental Committee for the Industrial Policy (CIPI - Comitato Interministeriale per la Politica Industriale) supported the development of Italian rotorcraft industry by designating aerospace industry as a priority industry (Chiesa, 1982). Moreover, private entrepreneurship was the other driving factor for the creation of Italian rotorcraft industry. Before 1973, Agusta was a private industrial company, which also designed and manufactured commercial products such as the famous MV Agusta motorcycles and fixed-winged aircrafts. Agusta's most significant progress in rotorcraft technologies occurred before 1971, the year Agusta introduced its first globally competitive product, the A109 helicopter. Hence, a combination of both national and entrepreneur needs have contributed to the creation of the Italian rotorcraft industry.

6.3.3 National Innovation System

The Italian National Innovation System

Italy is considered a late industrial latecomer among industrialized nations (Malerba, 1993; Belussi, 2001). Compared to the more industrialized western-European nations, Italy had a relatively weak history of innovation until the latter half of the 20th century. Its national innovation system is considered dualistic in nature due to the co-existence of two distinct types of innovation systems. The first type of innovation system is known as the Small Firm Network, which is formed by small and medium sized firms (SME). Firms are classified as SME if they have between 10 and 249 employees (Lindner, 2003). In the Italian manufacturing industry, small and medium firms constitute more than 90% of all firms (Coletti, 2007). The second type of innovation system is known as the Core R&D system, which is formed by large firms and public research institutions such as universities and research centers. The key actors in Italy's NIS are the public sector, private sector, foreign firms and the market (Figure 53).

The Small Firm Network is viewed as the more dynamic and innovative part of Italy's NIS due to its highly dynamic "atomistic learning activities" found in the network (Malerba, 1993). Malerba believes that the Small Firm Network uses informal learning instead of formal R&D to innovate. This informal learning is carried out by doing, using and interacting with the customers and other firms. It is important to note that individual firm does not innovate alone but rather in collaboration with other firms in the network (Belussi, 2001). The firms that operate in this type of innovation system are usually from the traditional industries (e.g. textiles and leather products) and equipment manufacturing industries (e.g. machine tools and robotics).

In comparison, the Core R&D system is viewed as the weaker part of Italy's NIS. The effectiveness of the Core R&D system has been hampered largely by poor formulation and implementation of national R&D policies, cultural and structural issues (Belussi, 2001; Malerba, Italy, 1993; Modena, Gottini, Balconi, & Vita-Finzi, 2001). In the private sector, large firms favored import of foreign off-the-shelf technologies through licensed production instead of creating their internal technological capabilities. Moreover, large firms were contented with the strategy of being technological followers instead of technological leaders (Coletti, 2007; Malerba, 1993). This trend in Italy's NIS could have severely stifled internal innovation capability in these large firms. In the public sector, fragmented public R&D activities, the lack of coordinated R&D collaboration among sectors, the lack of adequate national R&D funding and infrastructure have collectively weakened Italy's global standing in innovation of advanced technologies (Chiesa, 1982; Malerba, Italy, 1993). In addition, Italy's weak national education system has failed to produce the skilled labors that are needed in the increasingly knowledge-based economy.

Italy's reentry into the world economy after the Second World War resumed its access to foreign investment and technologies. From 1950s to 1970s, a large part of the technological changes in Italian firms were obtained through licenses from foreign companies (Malerba, 1993). The influx of foreign technologies was due to foreign companies' interest in using Italy as a market entry point for the greater European market due to Italy's relatively low cost and geographical advantages.

On the whole, Italy's NIS has been considered a failure by many research scholars. Italy's Small Firm Network has been considered as more successful than the Core R&D system. Since 2005, the Italian government has started to implement new measures such as the National Reform Program (NRP) to rectify Italy's competitive lag behind other industrialized nations. However, the success of such additional national program, as opposed to a more regional or local program, is still under continuous debate.

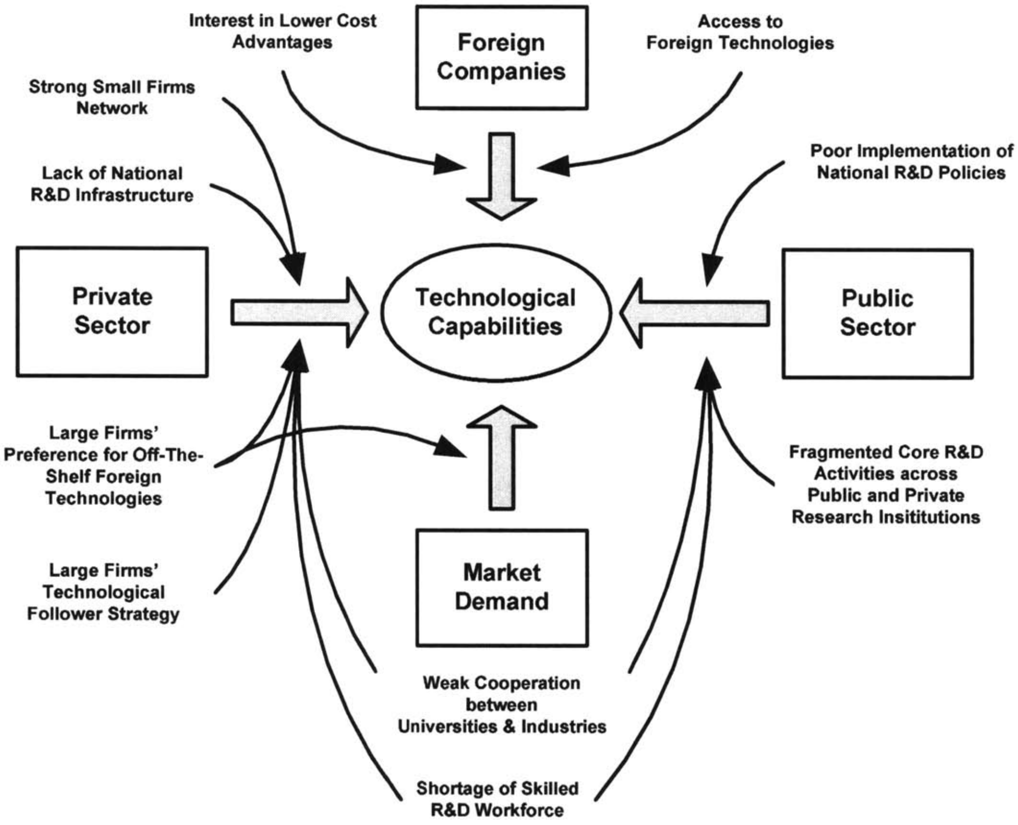


Figure 53: View of the Italian National Innovation System (various sources)

The Italian Aerospace Innovation System

The Italian Aerospace industry has been a state-owned industry since 1973. The Italian aerospace industry's direct employment has grown from about 5,000 workers in 1950 to about 50,000 today (Chiesa, 1982; BMI, 2010). The Italian aerospace industry is currently monopolized by the aerospace and defense conglomerate Finmeccinica Group, which owns several major global aerospace players such as Agusta-Westland, Alenia Aeronautica and Alenia Aermacchi. Since early 1980s, the Italian aerospace industry has been singled out as a prioritized industry and supported by government funding such as the Technological Innovation Fund for Aeronautics (Malerba, 1993; Chiesa, 1982). Moreover, bureaucracy that used to hinder inter-firm R&D cooperation was reduced by the introduction of the Law 240, which led to vertical and horizontal cooperative arrangement among aerospace firms, other firms and research institutions during the 1980s (Malerba, 1993). As a result of these governmental measures, the Italian aerospace industry could have experienced a different innovation environment that created a flourishing innovation oasis within Italy's weak Core R&D system.

Italy's membership in the NATO (North Atlantic Treaty Organization) security pact was a key factor to gain access to American aerospace technologies. For instance, all major American rotorcraft OEMS such as Bell, Sikorsky and Boeing have transferred licenses to Agusta since the 1950s to manufacture helicopters locally (AgustaWestland). Similarly, American fixed-winged OEM Lockheed provided the Italian industrial giant Fiat Group with licenses to manufacture 199 F-104 Star Fighters in Italy (Stoelinga, 2005). More importantly, the access to foreign technologies was not only tied to the Italian governmental defense procurement contracts, which were often considered as indirect financial supports to the Italian aerospace industry. Many production licenses obtained by Agusta were also meant for export to foreign customers (Flight International, 1971).

Italian aerospace industry is an exceptional sector within the Italian NIS on how government policies could mitigate the aforementioned shortcomings in the Italian NIS. In comparison, the Italian government policies have been considered as unsuccessful in the development of other high technological products (Coletti, 2007). The Italian aerospace industry is not immune to the same macro-economical issues like the shortage of skilled technical workforce and the lack of coordinated technological effort among the key actors in the NIS. However, Italian globally competitive and innovative aerospace products such as the Aermacchi fixed-winged jets and Agusta rotorcrafts have proven otherwise. A detailed study of Agusta in the next few sections might reveal some insight on these aspects of the Aerospace Innovation System (Figure 54).

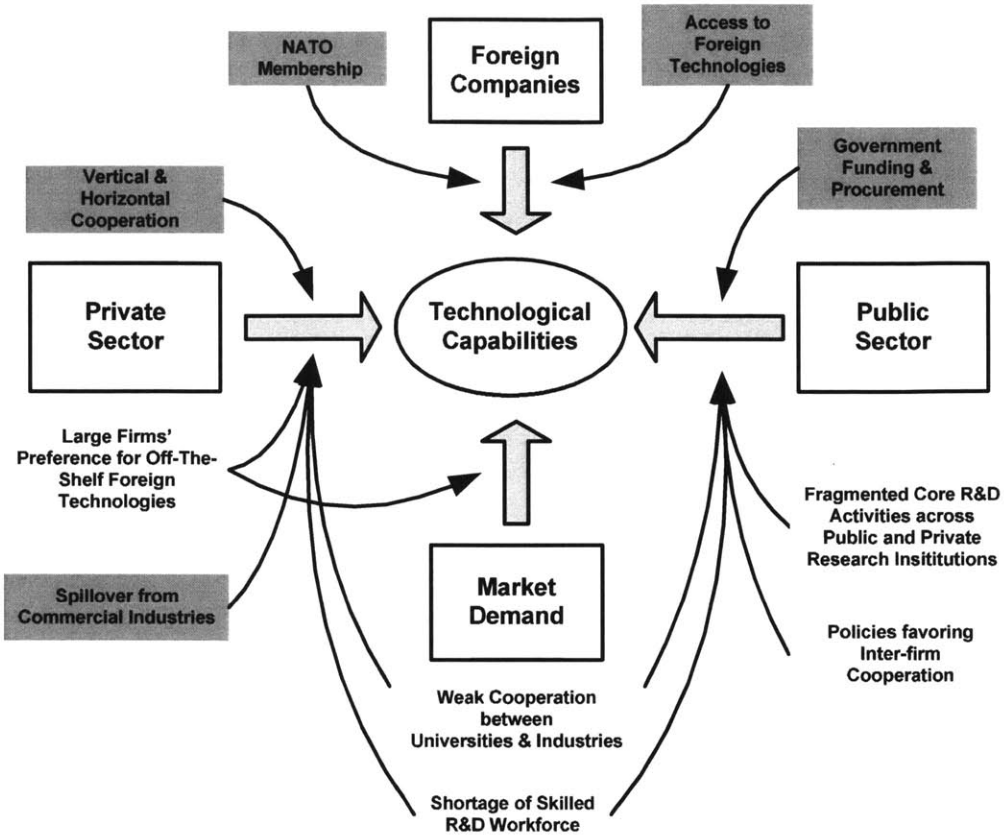


Figure 54: Innovation System in the Italian Aerospace Industry (various sources)

6.3.4 Technological Learning Process

Agusta's technological learning process began with its first cooperation with Bell in the licensed production of Bell 47G helicopters. Agusta's technological learning process consists of licensed production, design-adaptation, internal R&D and co-development/production of rotorcrafts with leading OEMs. Agusta's rapid technological growth can be attributed mainly to the technological learning from the licensed production of foreign OEMs' products (Figure 55) and its concurrent in-house R&D effort. Furthermore, Agusta's learning success has certainly benefited from Italy's innovative and competitive machines and tooling industries, which provide Agusta with precision manufacturing technologies for producing its rotorcraft subsystems such as gear airframe and dynamic systems. In addition, it is reasonable to believe that Agusta's pre-war fixed-winged airframe industry and association with its parent aerospace and defense company Finmeccinica Group have also accelerated the learning curve in rotorcraft airframe design and production.

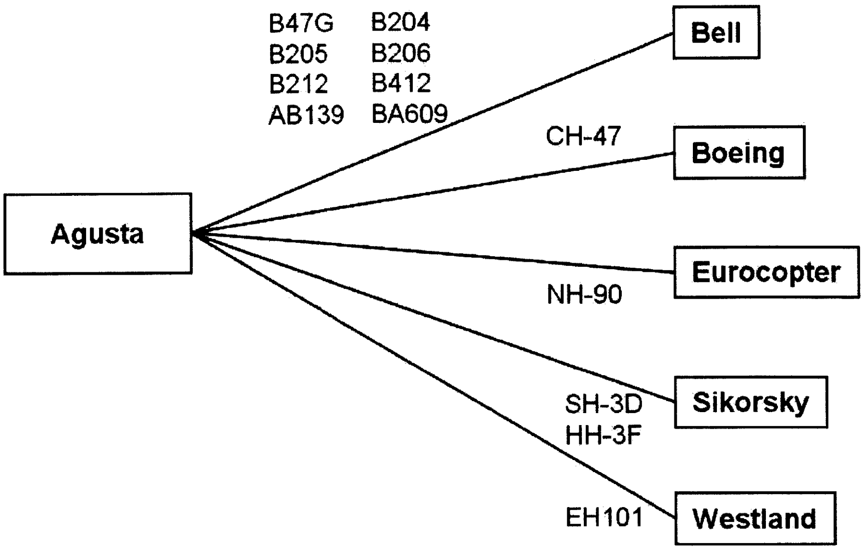
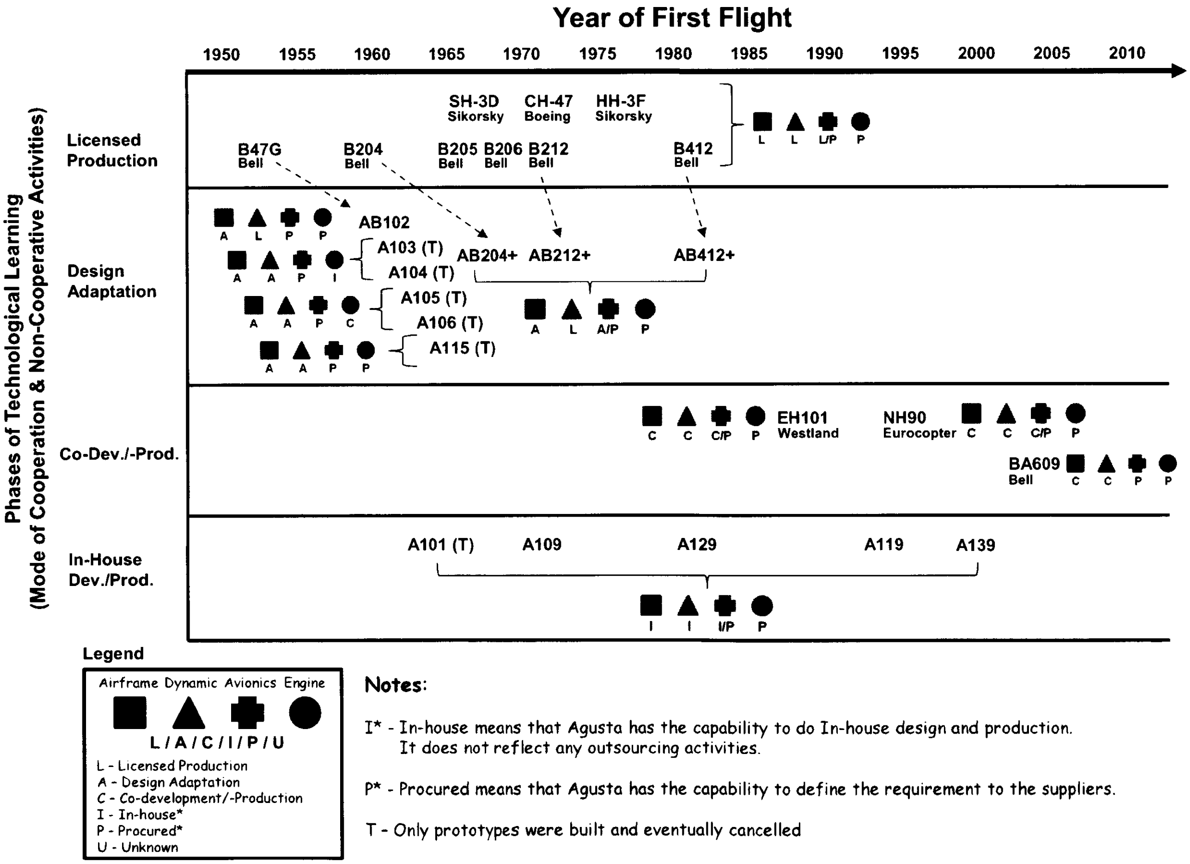


Figure 55: Cooperation network between Agusta and Foreign OEMs (various sources)



Notes:

I* - In-house means that Agusta has the capability to do In-house design and production. It does not reflect any outsourcing activities.

P* - Procured means that Agusta has the capability to define the requirement to the suppliers.

T - Only prototypes were built and eventually cancelled

Figure 56: Technological Knowledge Evolution Map of Agusta (various sources)

The technological learning process of Agusta is shown in Figure 56. This figure shows the different phases of technological learning, which consists of the four different cooperative and non-cooperative learning phases shown on the vertical axis. The horizontal axis shows the time dimension of Agusta's technological evolution. The year of first flight was chosen as the rotorcraft programs' reference point as it is always considered a major development milestone in the aerospace industry. Most importantly, all Agusta's rotorcraft programs are shown with their respective cooperation OEMs and the level of Agusta's technological knowledge of the four main subsystems in the figure. The detailed technological learning phases of Agusta, with reference to Figure 56, will be discussed in detail in the following sections.

Licensed Production Phase (1952 – est. 2000)

Licensed production has been the core business activity of Agusta for almost 50 years. In fact, without any prior rotorcraft technologies before 1952, Agusta was only able to jump-start its rotorcraft business through the licensed production of American OEMs' products. Licensed production has been the key source of technologies for Agusta's technological evolution. Agusta has manufactured not only products from all major American OEMs (Bell, Boeing and Sikorsky), but also all weight categories of rotorcrafts in high production volume (e.g. light-weight Bell B47G, medium-weight Sikorsky SH-3D and heavy-weight Boeing CH-47). In essence, licensed production has provided Agusta with immense qualitative (design) and quantitative (process) opportunities for technological learning.

Design learning opportunities could have come from the diverse product designs and production processes that Agusta adopted from cooperating OEMs. Some of the technological learning activities that might have occurred in Agusta was comparing and benchmarking of best technical and process designs. For example, benchmarking of component materials (composite versus metallic airframes), dynamic system concept (tandem versus conventional rotor systems) and scale of component (tooling for assembly and machining) could have provided valuable technological learning points for Agusta.

Process learning opportunities could have come from the high production volume. Agusta has manufactured not only for the Italian domestic market but also for the export markets. These export agreements with American OEMs have increased Agusta licensed production volume significantly (Flight International, 1974). The following table (Table 7) shows the estimated production volume of Agusta's licensed products. From 1952 to late 1990s, Agusta manufactured through licenses more than 2121 rotorcrafts, which are considered as enormous in the low-volume rotorcraft industry. High production volume would provide immeasurable process learning opportunity for Agusta as process learning usually increases with routine.

Model	Licensor OEM	License Start	Cooperation Type	Production Volume of Agusta
B47G	Bell	1952	Licensed Production	>1000
B204	Bell	1960	Licensed Production	237
SH-3D	Sikorsky	1967	Licensed Production	94
B206	Bell	1968	Licensed Production	>100
B212	Bell	1971	Licensed Production	240
CH-47	Boeing	1972	Licensed Production	>190
B412	Bell	1981	Licensed Production	260
			Total	**>2121**

Table 7: Licensed Production Volume of Main Products (various sources)

Figure 57: Bell B47G, B204 and B412 (Agusta / Vector Site)

Agusta began its long series of licensed production with the Bell B47G light-weight utility helicopter in 1952 (Figure 57). More than 1000 units of Bell B47G were manufactured by Agusta. Eight years later, Agusta acquired new licenses to produce the more advanced Bell B204 light-weight utility helicopters, of which more than 237 units were manufactured by Agusta. Similarly, further cooperation with Bell in licensed production was extended for the B205, B206, B212 and B412 helicopters. In these licensed production cooperation, due to Agusta's large production volume, significant transfer of technology from Bell to Agusta for component manufacturing and final aircraft assembly was likely to have taken place. Hence, this broad and deep Agusta-Bell cooperation arrangement undeniably made Bell the most important contributor to Agusta's technological evolution.

In addition, Agusta obtained licenses from Sikorsky and Boeing to locally manufacture 94 units of SH-3D (from 1967) helicopters and more than 190 units of CH-47 (from 1972) helicopters respectively. Both helicopters were also exported to foreign markets. A follow-up license for a few dozens of HH-3F naval helicopters was obtained from Sikorsky in 1976. These medium and heavy-weight helicopters represented significant leap in technology as compared to Bell products. The licensed production of the SH-3D, HH-3F and CH-47 (Figure 58) greatly expanded Agusta technological learning scope by introducing newer technologies such as complex rotor heads (three- and five-blades), heavier dynamic systems (10-23 ton class) and production challenges (multi-product complexity).

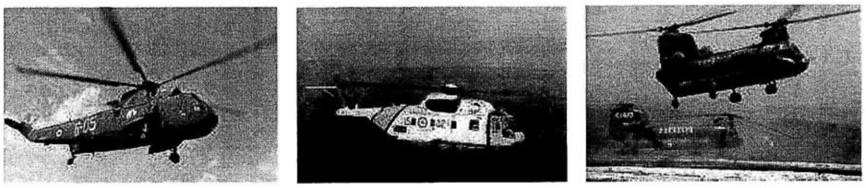


Figure 58: Sikorsky SH-3D, Sikorsky HH-3F and Boeing CH-47 (Agusta)

The Design Adaptation Phase (1953 – late 1990s)

In the shadow of licensed production of foreign products, Agusta started its design and development activities in the mid-1950s. Agusta adapted the designs of Bell products to create its own range design-adapted products such as the A102, A103, A104, A105, A106 and A115.

The A102 (Figure 59) was first flown in 1959 and it was based on the B47G. The piston-engine powered A102 was equipped with a larger airframe to accommodate up to eight instead of two passengers (Flight International, 1962). Moreover, it was the most commercially successful design-adapted product among the earliest Agusta products in the 1960s. Two A102s were sold to a commercial customer in Italy. However, the advent of gas-turbine powered helicopters in the mid 1960s eventually disrupted the further market success of the AB102 (Marchetti, 1984; Aviastar).

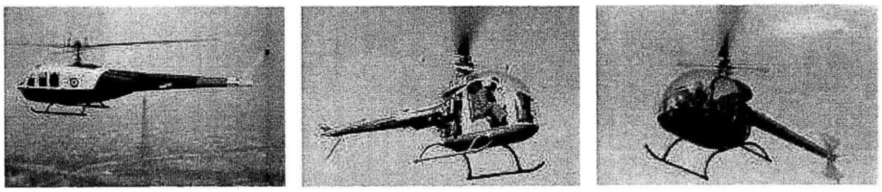


Figure 59: A102, A103 and A104 (Agusta)

The A103 and A104 (Figure 60) were single-seat and twin-seat versions of the same type of piston-engine powered light-weight experimental helicopters that were first flown in 1960 (Flight International, 1962). Based on the same dynamic system used in the Bell B47G, these helicopters were retrofitted with Agusta-designed piston engines (MV A70 and A140V) and turboshaft engine (TAA-230). However, both products were eventually cancelled. Nevertheless, these experimental products highlighted Agusta's internal effort to internalize engine integration technologies by adapting its existing in-house engine technologies from its fixed-winged and motorcycle divisions onto its design-adapted rotorcrafts.

Figure 60: A105, A106 and A115 (Agusta)

The A105 and A106 (Figure 60) were double-seat and single-seat versions of the next series of design-adapted rotorcraft products that first flew in the mid 1960s. The innovations in the A105 were the use of Agusta in-house designed TAA-230 turboshaft engine (cooperation with Turbomeca) and transmission gear box (Aviastar). In addition, both versions had modified airframes. The A105 had a passenger cabin that could accommodate up to two crews. The A106 was a dedicated naval helicopter that had only a single crew cabin and was equipped with an anti-submarine warfare system. However, both designs did not achieve any commercial success and were cancelled by early 1970s (Flight International, 1971). In 1971, Agusta completed its design-adaptation phase with the A115, which the final B47G-clone built by Agusta primarily to test turboshaft engine (Turbomeca Astazou II) (Flight International, 1962).

At the same time, design customizations were also carried out directly on licensed-produced Bell B204, B212 and B412 helicopters. Agusta enhanced the Bell basic models with highly tailored systems for the customers (Flight International, 1974). These design modifications were done mainly on structural and avionic interfaces for installing additional customized equipment for the customers from the Italian and foreign navies. No major design changes were made on the basic aircraft designs. Interestingly, Agusta-made Bell products were considered by many customers as more competitive than Bell-made products because Agusta was more meticulous in tailoring its products to customers' requirements at competitive prices (Flight International, 1974). This was a positive indicator of Agusta's progress in its technological learning process. In this technological learning phase, these design-adaptation programs have provided Agusta with valuable learning opportunities for integration of subsystems (airframe, dynamic system and engines) and design tailoring (integration of equipment).

The Co-development and Co-Production Phase (1977 – present)

Agusta embarked on its first co-development and co-production program in 1977 with the British rotorcraft OEM Westland to develop the EH101 Merlin naval helicopter (Figure 61). The EH101 was conceived as a replacement for the aging Sikorsky Sea King series of naval helicopters, which were used by the British and Italian navies. In this cooperation program, Agusta and Westland divided the subsystems (airframe, dynamic system and avionics) for co-development and co-production. Agusta was responsible for main gear box, rotor head, rotor head control, tail rotor hub, tail rotor control, drive shaft, coupling, hydraulics, cabin (66%), rear fuselage, tail, electrical wiring (50%) and avionics (50%). Westland was responsible the main blades, cabin (34%), forward fuselage, automatic flight control system, undercarriage, fuel system, electrical wiring (50%), avionics (50%) and floatation (Barker, 1998). The EH101's triple turbo-shaft engines were supplied by General Electric and Rolls Royce-Turbomeca.

The EH101 helicopter program was a particularly challenging one with very steep learning curve for Agusta. On the technical side, Agusta was faced with immense technical problems that led to the crashes of three pre-production prototypes. On the management side, Agusta was initially overwhelmed by complex international development and production organization (Flight International, 1999). The initial lack of a single program management organization between Agusta and Westland greatly hampered the system integration work between the helicopter and the complex mission systems (especially the anti-submarine/surface ship warfare system). This was later rectified by the creation of a single prime contractor management organization (EH Industries), which oversaw Agusta, Westland and other systems suppliers as sub-contractors. On the other hand, Agusta was able to capitalize on its past experience from its first in-house developed A101 helicopter in shortening the duration of EH101 systems development. In spite of this, the EH101 program was delayed by six years. Another core technological knowledge that Agusta learned was about the design and production of airframe using advanced light-weight aluminium lithium alloy, a material that is 10% lighter and 60% more fatigue resistance than conventional aerospace aluminium alloys (Barker, 1998).

Figure 61: EH101 and NH90 (AgustaWestland)

The next co-development and co-production program was the NH90 (Figure 61) multi-role medium-weight military helicopter. This program was formed in 1992 as a consortium (NH Industries) consisting of Agusta (32% stake), Eurocopter (63% stake) and Fokker (5% stake). In this program, Agusta was responsible for part of the airframe (rear fuselage), dynamic system (main gear box, automatic flight control and hydraulics) and avionics (anti-submarine/surface warfare (ASW) systems integration). It is interesting to note that Agusta's work share in the NH90 program is very similar to that of the EH101 program. Moreover, Agusta had previous experience in integrating ASW systems in Bell helicopters. The development of the NH90 started as early as mid 1980s and the first flight took place in 1995. The NH90, the world first serial rotorcraft that has a full-composite airframe and fly-by-wire system, is in many aspects a technologically advanced helicopter. As a key stakeholder in this cooperation program, Agusta had the opportunities to learn about the technical (e.g. advanced composite material) and process (international program management) aspects of cooperation with Eurocopter and Fokker.

In 1998, Agusta deepened its already strong relation with Bell by creating the joint venture Bell Agusta Aerospace Corporation (BAAC). In this joint venture, Agusta co-developed and co-produced the BA609 tilt-rotor aircraft, which successfully made its first flight in 2003. Agusta has a minority stake of 25% in the BA609 program and is responsible for the design of gear boxes, wiring, tail and ailerons (Flight International, 1998). Furthermore, Agusta will also assemble BA609 in its main final assembly plant in Italy, in additional to the Bell's plant in Texas. Technological learning opportunity for Agusta in this program was relatively small, since Agusta's work share included only matured technologies. The design and manufacture of key tilt-rotor technology (i.e. dynamic system) remained solely with Bell. Nonetheless, Agusta could have benefited from its 50% work share in BA609 flight test program (Flight International, 2000).

In-House Development (1960s - present)

Agusta began its in-house development activities early in its technological learning process. Its first flyable product was the A101 triple-engine heavy-lift helicopter. The first flight took place in 1964 and a total of three prototypes were ever built before it was cancelled in 1971. One reason of developing the A101 was reported to be Agusta's competitive strategy against Sikorsky's bid for the Italian Navy helicopter contract in the mid 1960s. Using this strategy, Agusta managed to gain cooperation agreement with Sikorsky in the licensed production of Sikorsky SH-3 Sea King helicopters. The A101 was withdrawn as a result and it never reached serial design maturity. Nevertheless, the A101 was a remarkable achievement by Agusta, which took only twelve years after its market entry to develop a flying prototype of this scale (11-ton weight). The A101 had a number of notable design features such as triple-engine power pack, a rear ramp and a five-blade rotor head. The A101 five-blade rotor head was especially remarkable as all previous Agusta's products, including licensed products from Bell, had the technologically simpler double-blade rotor heads. The details about the development of this innovative rotor head were unknown.

In 1971, Agusta took the incumbent market leaders by surprise with the first flight of the A109 light-weight helicopter (Figure 62). The development of the A109 began in 1967 and serial production began in 1976 (Aviastar). The A109 was the world's first second-generation helicopter, which had innovative features such as retractable landing gears, a four-bladed rotor head and an aerodynamic partial composite airframe (Chiesa, 1982; Flight International, 1973). It was designed for multi-purpose operations such as transport, rescue and military missions.

After the success with the A109, Agusta continued to design a new generation combat helicopter, the A129 (Figure 62), to satisfy the requirement of the Italian Army. The A129 was derived from the A109 and the first dedicated combat helicopter that was completely designed in Europe. This innovative twin-engine, tandem-seat helicopter made its first flight in 1983. Other innovations such as advanced nose-mounted day/night sensors, damage tolerant rotor blades and crash-survivable airframe set Agusta further apart from the other leading OEMs. The introduction of the innovative A109 and the A129 established Agusta's position as one of the leading rotorcraft companies in the world. Further development of the successful A109 continues with newer derivatives such as the A119 (first flight in 1994, lighter single-engine version) and the A139 (first flight in 2001, higher seating capacity and payload) helicopters.

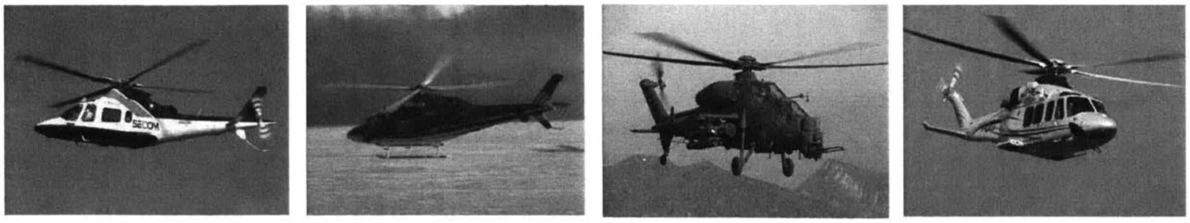


Figure 62: A109, A119, A129 and A139 (AgustaWestland)

6.3.5 Technological Knowledge Learned

The case findings have shown that Agusta has successfully acquired the necessary rotorcraft technological knowledge to design and produce its own products after roughly 30 years of licensed production, design-adaptation, co-development/-production and in-house development. Case findings have revealed that licensed production played the most important role in jump-starting Agusta's technological learning process. The mass-production of American OEMs' products (Bell, Boeing and Sikorsky) has provided Agusta with invaluable qualitative and quantitative learning opportunities. The qualitative learning opportunities were derived from the diverse licensed products, which allowed benchmarking of best designs and innovation. The quantitative learning opportunities were derived from the high volume of licensed products, which allowed routine learning and internalization of tacit knowledge.

The second technological learning phase was design-adaptation. Here, technological knowledge from licensed production of Bell products was capitalized. For example, Agusta progressively adapted Bell products into a number of different prototypes (from A102 to A115) to test different technologies such as engines, airframe, dynamic system and systems integration. This effort allowed Agusta to "learn by adapting and tailoring". One of the lessons learned was the discontinuation of in-house development of Agusta engines in order focus on the other three main subsystems. This was in line with most other leading OEMs, which regarded engine not as a core technology. Furthermore, Agusta's tenacity in tailoring its licensed products (B204+, B212+ and B412+) to customers' requirement was found, highlighting Agusta's improving and differentiating design capabilities.

The third technological learning phase was co-design and co-production with foreign OEMs. As with the case of design-adaptation, knowledge gained from previous learning phases was capitalized. For instance, early experience (dynamic system - five-blade rotor head and heavy transmission system) gained from Agusta's prototype A101 was used in the co-development of

EH101. Based on the design and production work shares in the EH101 and NH90 programs, it was evident that technological knowledge gained from the EH101 and Bell program (ASW system integration) was also transferred to the co-development and co-production of the NH90.

In the final phase of Agusta's technological learning process, case findings have revealed Agusta's technological progress by the technological innovations introduced by the in-house developed products (A109, A129, A119 and A139) since the 1970s. After only about 30 years, Agusta has successfully transited from technological learning phase into technological innovation phase. Its cooperation since the late 1990s in radically new rotorcraft products such as tilt-rotor aircraft further exemplifies this transition.

In conclusion, this case has shown that Agusta successfully learned through different modes of cooperation with foreign OEMs. There are indicators that confirm the transfer of technological knowledge between programs. Most importantly, the case leads to the conclusion that Agusta's technological learning has not been only one-sided. Its technological learning has made use of cooperation with foreign OEMs and concurrent in-house development.

6.3.6 Conclusion

This case has shown that Agusta's technological learning process was shaped by the constraints in Italy's NIS. Even though the Core R&D system of the Italy's NIS generally did not provide a favorable environment for innovation and technological learning in large firms, the case findings have shown that Agusta was an exceptional case among Italian large firms, which were typically technological followers. Agusta's technological advancement and innovations showed that there are ways to mitigate the effect of the ineffective Core R&D within Italy's NIS. On the other hand, the technological learning success of Agusta could also be attributed partially to the positive aspects of the Italy's NIS.

First, Italy's NIS provides unrestricted access to American rotorcraft technologies through Italy's membership in the NATO. From market standpoint, Italy's defense and low-cost advantages could have led to Bell's strategic move to use Italy-based Agusta as a low-cost production base for export to Europe and other regions of the world. Second, there were strong machineries and tooling industries in Italy's successful and innovative Small Firm Network. These industries were important to the production of Agusta's products dynamic and airframe components. Third, the prioritized financial and political supports from the Italian governmental program have contributed to Agusta's technological learning activities such as costly prototyping and testing activities. Fourth, the technological spillover from the engine and fixed-winged divisions within the Agusta Group and sister defense companies within the Finmeccinica Group should not be overlooked, especially after the enactment of the Law 240, which encouraged cooperation among Italian firms in R&D.

The initial technological learning phases (licensed production and design-adaptation) of Agusta have also confirmed the general preference of Italian large firms for importing foreign licensed technologies instead of in-house R&D. However, Agusta eventually transited from a licensed manufacturer to an innovator. Furthermore, case findings have also confirmed the more vertically-integrated production structure of Italian large firm (Barker, 1998). In fact, more than 60% of Agusta's work share in the EH101 program was manufactured in-house. In comparison, Westland only manufactured the rotor blades in-house while out-sourcing the rest of its work share.

Agusta is the only major western rotorcraft company that was created from ground-up after the Second World War. In spite of the weaknesses in Italy's National Innovation System and the lack of rotorcraft technologies, Agusta has successfully acquired the technologies to become a world class rotorcraft OEM. From this perspective, Agusta's technological learning success can be considered as truly exceptional.

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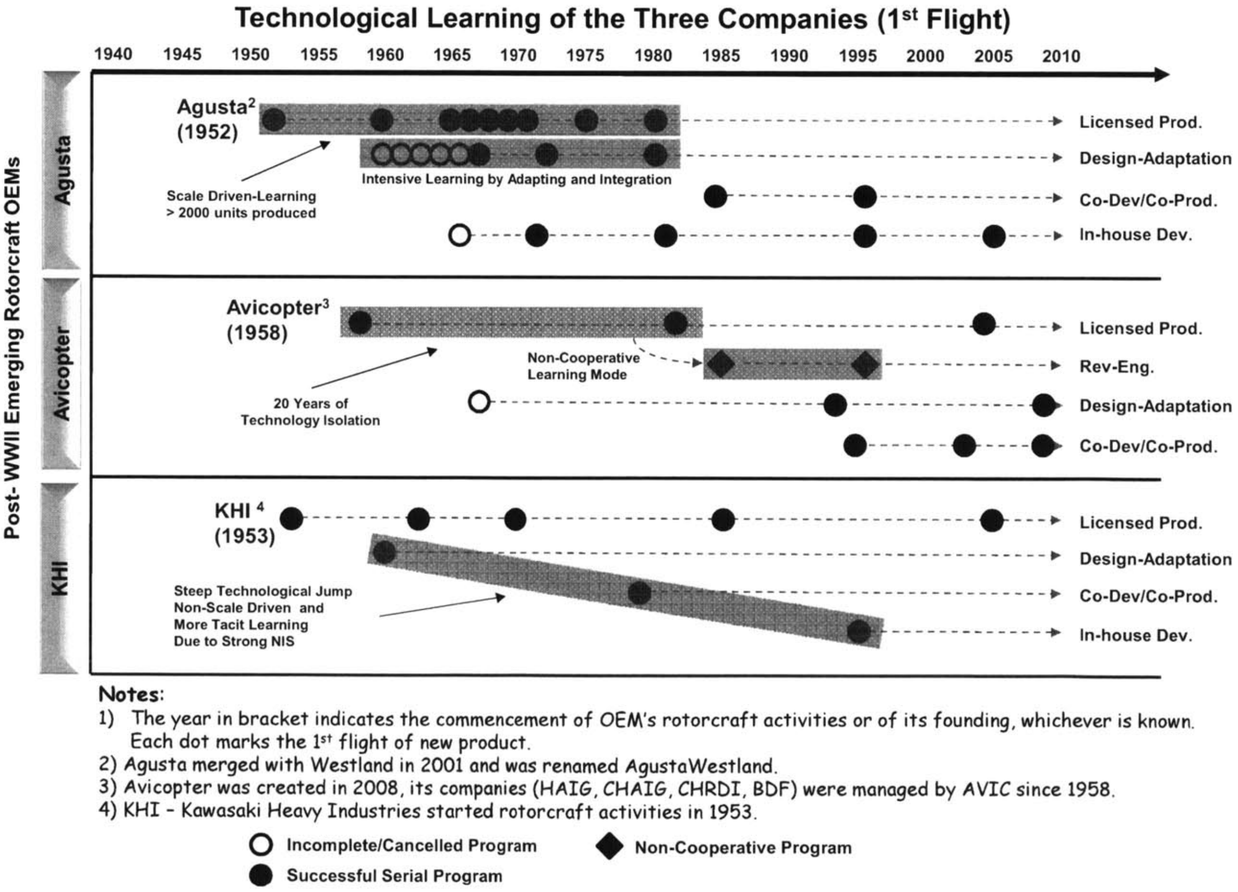
CHAPTER 7: COMPARATIVE ANALYSIS & FRAMEWORK REVISIT

7.1 Comparative Analysis

The three cases have shown the different ways emerging rotorcraft companies evolved technologically at systems and subsystems level. In this chapter, I will draw key lessons by comparing the technological learning processes of the three companies. Figure 63 provides an abstracted view of their technological learning processes for comparative analysis. This comparison has revealed a number of important lessons that can change the way we view the rotorcraft business model today. The quintessential lessons are as follows: concurrent internal learning is important for emerging companies to gain technological knowledge, a history of cooperation with incumbent OEMs are important for learning, denial of technology transfer to competitors only slows down but do not stop their technological learning process, the catalytic effect of scale and the importance of favorable learning environment.



Notes:

1) The year in bracket indicates the commencement of OEM's rotorcraft activities or of its founding, whichever is known. Each dot marks the 1st flight of new product.
2) Agusta merged with Westland in 2001 and was renamed AgustaWestland.
3) Avicopter was created in 2008, its companies (HAIG, CHAIG, CHRDI, BDF) were managed by AVIC since 1958.
4) KHI - Kawasaki Heavy Industries started rotorcraft activities in 1953.

○ Incomplete/Cancelled Program
◆ Non-Cooperative Program
● Successful Serial Program

Figure 63: Comparative Diagram between the Cases (Compiled by Author)

Importance of Concurrent Internal Learning

All three cases have shown that emerging rotorcraft companies, which did not possess any previous rotorcraft specific technologies, have succeeded in learning rotorcraft technologies from ground-up. It is important to note that under licensed production agreement, foreign OEMs (licensor) usually transfer just enough production technologies to enable the licensee companies to duplicate OEMs' products. In other words, technologies transferred in these licensed production agreements alone are insufficient for licensee companies to be capable of designing their own products. Thus, all three cases demonstrated that concurrent internal learning through in-house R&D (design-adaptation, reverse engineering) was needed in addition to technological knowledge gained from licensed production. Licensed production cooperation was the starting point for further technological learning in all three companies.

A History of Cooperation Needed

The common feature of all three companies is that they all began rotorcraft development through cooperation with foreign first generation OEMs. It is important to note that there were variations of technological learning process using licensed production with first generation OEMs. For example, Agusta exploited licensed production strategically to accelerate its technological learning process. Not only did Agusta manage to license-produce significantly more rotorcrafts than Avicopter and KHI combined, but it has also learned quickly by tailoring and adapting Bell products better than Bell itself. In addition, Agusta adapted Bell designed products to build its series of prototype products (A102 to A115). These prototypes allowed Agusta to learn by integrating various in-house developed subsystems such as gas-turbine engines, airframe and equipment. That made Agusta the earliest among the three companies to learn by systems integration. Another common feature of the three cases is the successful transition of all three companies to participate in more complex co-design and co-production cooperation with earlier generations of OEMs, after decades of licensed production, design-adapting and reverse-engineering.

Denial of Technology Access Does Not Prohibit Learning & Imitation

Avicopter represents a unique case in the analysis. Avicopter's first licensed production was disrupted due to the Sino-Soviet political split in 1961. However, its technological learning process did not stop there. It is conceivable that this incident motivated Avicopter to use reverse-engineering as an alternative learning mode to licensed production. With no access to rotorcraft technologies from other OEMS for about 20 years, Avicopter had no technological foundation to start its own R&D but had to resort to the pain-staking reverse-engineering of foreign products. The contrasting results of the two different technological learning paths are evident. Avicopter's reverse-engineering program of the Z-8 (copy of French Aerospatiale SA321 helicopter) took ten years, which is 27 years after Avicopter started licensed producing its first rotorcraft. In comparison, Agusta only took five years to develop its first in-house product (A109), about 19 years after Agusta licensed produced its first rotorcraft (Bell B47G).

The Importance of Favorable Learning Environment

The sequence and duration of the different modes of cooperation in their technological learning processes were dependent on the NIS and AIS. The interactions among all the four principle actors (public sector, private sector, foreign companies and market demand) in the NIS and AIS have generated unique constraints and catalysts for technological learning in these companies. The weak NIS and AIS of China resulted in the relatively slow technological learning process as compared to the more effective AIS of Italy and NIS of Japan. The stronger NIS in Japan may have enabled KHI to learn more tacitly. It succeeded in developing its first in-house OH-1 helicopter even though it had only completed two programs (KH-4 and BK117) previously. Among the three companies, KHI appears to have experienced the most significant technological leap from licensed production to in-house development. This leap is evident from KHI's rapid transition between licensed production, design-adaptation and co-development/production.

The Catalytic Effect of Scale on Learning

Agusta case provides an important lesson, which suggests that high production scale could compensate the effect of the weak Italian NIS. Agusta's large production scale enabled greater opportunity for learning. Conversely, the increase of production scale due to export market demand may also create a positive reinforcing causal-loop effect that can accelerate technological learning, which in turn result in better products that increase export market demand. Based on Malerba's (1993) original definition of learning, I call this effect the virtuous cycle of scale-driven technological learning. This effect is essentially learning curve effect with additional reinforcing effect of export. Interestingly, similar observation can be made in fixed-winged aircraft sector. For example, the success of the Brazilian fixed-winged aircraft manufacturer Embraer (world's 3rd largest fixed wing

OEM) is attributed to this virtuous cycle of scale-driven technological learning (Hira & Guilherme de Oliveira, 2007). On the other hand, KHI represents a contra-case. The lack of an export market due to Japan's self-imposed export ban of military-related products (includes rotorcrafts) may have prevented KHI from benefiting from the virtuous cycle of scale-driven technological learning. Agusta case highlights the negative consequence of subcontracting the production of entire rotorcraft systems to emerging companies for short term advantages such as low cost and market access.

7.2 Framework Revisit

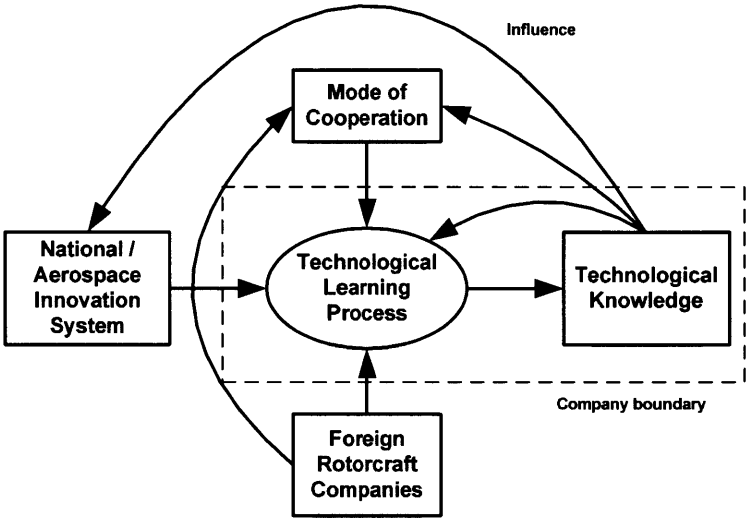


Figure 64: The Technological Learning System (Gan & Roth)

Revisiting the TLS Framework

Based on the findings and analysis from the three cases, we will now revisit the TLS framework (Figure 64) and highlight its value to policy makers and corporate managers. In the first part of this chapter, I will review the main elements of the TLS framework and the interaction among them using examples from the cases. In the second part of this chapter, the value of the TLS on globalization and national policies will be discussed.

The TLS is made up of the National and Aerospace Innovation Systems (NIS & AIS), mode of cooperation, foreign companies, the technological knowledge level and learning process in the company. The ways these elements are interconnected are discussed in the following sections.

National and Aerospace Innovation Systems (NIS and AIS)

First, the technological learning process of a company is influenced by the NIS and AIS. The NIS and AIS define the environment for technological learning in the country. In this environment, the company is influenced by actors such as other private companies (e.g. suppliers), public organizations (e.g. government) and individuals (e.g. work force). The NIS is the broad national environment that affects the technological capability of all industries in the country. The AIS is the more aerospace industry specific view of the NIS. The influence of the NIS and AIS on the technological learning process of emerging rotorcraft companies has been shown extensively in the three cases. The NIS and AIS are able to influence the technological learning process through the unique constraints (e.g. weak industry-university cooperation) and catalysts (e.g. strong learning culture) found in these systems.

Foreign Companies and Mode of Cooperation

Second, foreign companies can influence technological learning process directly and indirectly via the mode of cooperation with emerging companies. Foreign companies can influence technological learning process indirectly by determining the mode of cooperation with emerging companies. As already explained in Chapter Five, the mode of cooperation is both a mode of learning and an indicator of the technological knowledge level of emerging companies. The choice of the mode of cooperation between the foreign and emerging companies depends on their collective needs (e.g. co-specialization to reap economies of scale) and constraints (e.g. offset requirement to gain sales). For example, Bell has cooperated with Agusta using different modes of cooperation at different stages of their evolutions (from low cost subcontractor to co-specialized partnership).

Foreign companies can also influence the technological learning process directly through their technology transfer process, not just in the selection of cooperation mode. For instance, the progressive three-stage technology transfer process between Boeing and KHI in the licensed production of CH-47J exemplifies how Boeing can influence the technology transfer process for KHI. Similarly, the level of technological knowledge in the company influences the technological learning process directly. Higher level of technological knowledge enables learning of more complex technologies in a more interactive organizational environment (e.g. more complex mode of cooperation).

Another important factor affecting the foreign companies' influence on emerging companies is their national policies on technology export. For example, the ITAR (International Traffic in Arms Regulations) restricts the export of certain US technologies by US companies and their re-export by overseas companies. This kind of technology control will certainly influence the way foreign companies (OEMs) cooperate with emerging companies.

Technological Learning Process and Knowledge Level

The outcome of technological learning process is the level of technological knowledge in the company. Both technological learning process and technological knowledge are co-located within the boundary of the company. Knowledge is cumulative in nature and can be gained or lost. Increasing knowledge can change the learning process. For example, all three companies went from a passive learning (e.g. duplication) to more participative learning (e.g. design adaptation) during their evolution. Similarly, technological knowledge influences the mode of cooperation. All three cases have showed that increased technological knowledge enabled them to participate in more complex mode of cooperation (e.g. from licensed production to co-development). Moreover, greater technological knowledge level not only offers emerging companies a wider choice of cooperative learning mode but also strategic flexibility in the selection of cooperation partner. Lastly, technological knowledge in these companies can affect their NIS, whether to a small or large degree, through technological spillage and organizational isomorphism. This technological spillage in the NIS also accounts for any technological knowledge loss in the company (e.g. outsourcing to local suppliers and losing the competence over time).

The Value of the TLS Framework on Globalization Policy

From a company standpoint, the TLS provides global industrial policy makers with a systemic view on how emerging players can learn to become more competitive. This is extremely useful for the formulation of cooperation, technology transfer and industrial policies in companies that are constrained by the offset and cooperation requirement in the aerospace market. The TLS does this by providing a framework that enables paradigm shift in the way potential partnering companies can be evaluated both in the short-term and long-term. Contemporary due-diligence study on potential partner company in the industry focuses mainly on financial and technological analysis. It may work for innovative companies in developed countries, where technological companies develop themselves through innovation. However, in emerging countries, it is more about learning first than innovating. Hence, such due-diligence study offers an incomplete assessment of the potential partner by missing the learning dimension. In essence, the TLS enhances contemporary due-diligence study by offering a more complete assessment of emerging partner by unveiling other major factors like "hidden costs of cooperation" that could severely undermine the viability of cooperation. With the TLS, potential cooperation companies can be evaluated according to their competencies and learning environments. In an ideal cooperation, emerging companies should benefit from the cooperation (e.g. complementary work and financial sharing) but not gain technologies that will close the gap between them and the incumbent partners.

The Value of the TLS Framework on National Policy

From a national standpoint, the TLS does exactly the opposite by providing national policy makers the framework to design a favorable learning environment for their national companies that were selected to gain technologies in order to develop. Government can implement policies appropriately to maximize technology transfer from foreign companies and encourage internal R&D within their national companies. It is important to note that the TLS can also help to avoid national policies that could be excessive and counterproductive. For instance, counterproductive policies are those that drive product contract cost up (e.g. exorbitant offset requirement – 200% of contract value!) and learning efficiency down (e.g. importing technologies without the resources and capabilities to absorb).

In the next chapter, the application of the TLS on the current and future development in the rotorcraft industry will be discussed. The potential application of the TLS will be illustrated through the discussion of some new rotorcraft cooperation projects that are on the horizon.

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CHAPTER 8: CONCLUSION AND RECOMMENDATION

The use of Technological Learning System (TLS) to map and decipher technological learning process of emerging companies has helped me to understand the wider implication of technological learning on the global rotorcraft industry. The increasing mandatory need for transfer of technology in international rotorcraft sales transaction has generated enormous market inefficiency and unnecessary high transaction costs for manufacturers in the market. As these long term economical costs of technology transfer are difficult to quantify using classical economics theories, the thesis has managed to correct this shortcoming partly by revealing the implications of technology transfer between rotorcraft companies. Rotorcraft market competition mechanism that requires deliberate transfer of technology induces leading rotorcraft companies to win short term sales but to lose their overall competitiveness in the long run. Leading rotorcraft companies lose their competitiveness in the following three ways.

First, emerging rotorcraft companies' learning progress is faster than leading companies' innovation process. The rotorcraft industry is a low clockspeed and low volume industry with product lifecycle of up to 50 years. Rotorcraft's global annual production volume of several thousand is miniature as compared to about 60 millions in the automotive industry in 2009 (Frost & Sullivan, 2009). Rotorcraft's long product life cycle allows emerging companies plenty of time to catch up. Agusta clearly illustrates this point. Second, offsets that provide emerging companies access to foreign technologies also bring significant cost advantages as these companies do not have to start from scratch in R&D. Third, technology transfer process in leading companies is very complex and costly due to the need to reorganize their global supply chain architecture, rebalance internal work capacity (similar to outsourcing), train foreign companies, account for product quality loss (e.g. learning curve of foreign companies) and pacify strong trade union, etc. The transaction cost of such endeavour is further exacerbated by the loss of work force morale and productivity.

In essence, one may clinch an international contract today but lose its competitiveness in the long run. Referring to one of the principles of war from Sun Tzu, it's analogous to winning a battle but only to lose a war. This thesis has clearly shown that technology transfer that aids technological learning can indeed create future competitors. Industrial policy makers and corporate strategists should carefully consider the implication of technological learning on their organizations. The key question is: How could the TLS help companies in their global strategies when compelled to transfer technologies to emerging companies in the future?

First, the TLS provides industrial policy makers and corporate strategists a systemic framework on how emerging technology recipient companies could use cooperation (recalling the four modes of cooperation) to further their long term competitive objectives. By carefully analyzing the variables in the TLS, incumbent companies can strategically formulate their cooperation policies and package their sales offset content that offers less critical technologies in the long run. To illustrate the application of the TLS, I will use the recent case of cooperation arrangement between Russian Mil and Chinese Avicopter to design and produce the Mil-46 heavy weight helicopter. The Russian OEM Mil can use the TLS to analyze and design its cooperation scope with Avicopter. The TLS will lead Mil to analyze the Chinese NIS. Such analysis will reveal that China has recently shifted its focus from fixed-winged technologies to rotorcraft technologies against the backdrop of rapidly modernizing commercial industries. Moreover, the TLS will reveal the technological readiness of Avicopter by uncovering its latest cooperation programs and their respective subsystems capabilities. Such knowledge will compel Mil from cooperating in dynamic system with Avicopter, which not yet possesses heavy dynamic system knowledge. Furthermore, Mil should not only avoid co-develop dynamic system with Avicopter, but also in co-production to minimize technological knowledge leakage through transfer of manufacturing processes. One way to realize this preventative measure is to deliver Avicopter the entire dynamic system as a "black box" for integration into the airframe, which could be manufactured and designed by Avicopter. However, the outcome might be different if the cooperation partner of Mil was American Sikorsky, which already possesses heavy dynamic system technologies, or Indian Hindustan Aeronautics Limited, which does not have absorption capability due to weak Indian AIS. Similarly, vital knowledge from the analysis on the remaining elements of the TLS market demand and its own capabilities can be done. This example illustrates the usefulness of the TLS by providing Mil a framework to conduct analysis of potential partner company systematically and systemically.

To sum up, rotorcraft companies need more than good products to compete in the competitive global rotorcraft market. The key to success is not only about best product features and price, but also about the technological package for offset. Companies have to start to understand the implication of technological learning and incorporate it into their business cases to avoid the mid-term and long-term repercussions. At the time of completion of this thesis, a number of recent market developments in the rotorcraft industry have incited further work on the TLS. Recent developments in the rotorcraft industry like AgustaWestland (emerged player) licensing its product (AW101) to Boeing (first generation incumbent player) for the new US-presidential helicopter program have shown a new trend emerging (Flight Global, 2010c). This particular event represents the pinnacle of success that any emerging companies could ever achieve. So, where do we go from here?

This event has shown that the chance that KHI and Avicopter will emerge as serious competitors to the existing incumbent players should not be underestimated. Recent and likely changes in the conditions within Chinese and Japanese NIS will accelerate the technological learning processes in Avicopter and KHI. For the case of Avicopter, China's rapidly modernizing commercial industry and national education system, backed by its strong economy, will ensure greater absorption capability of and technological spillage into Avicopter. For the case of KHI, likely constitutional change to allow export of defense related products will enable virtual cycle of scale-driven learning that will increase KHI's technological competitiveness. The quintessential message from these current and future likely events for incumbent companies is that there is an urgent need for a better technological transfer policy and an alternative strategy. This alternative strategy will manifest itself by addressing the key question: Is there any potential for a collective effort among incumbent players to mitigate the effect of offset in order not to lose their technological edge against the emerging players? As of now, there is no clear indication of this strategy but I am certain that more can be done among incumbent players in this area.

The TLS has been developed with a focus on the rotorcraft industry. It is by no mean a universal framework for all industries. However, I believe that it will be useful to other industries that use technology transfer as a core element of making sales transaction. I believe that there are some specific conditions that would make the TLS useful. For example, the TLS is useful in an oligopoly market condition as the TLS requires a number of unequal market players that are engaged in the cycle of learning, transferring and innovating. Hence, the TLS will not be applicable in monopoly or duopoly markets. A *laissez-faire* market that lacks state control (e.g. mandatory offset, restricted technology diffusion) and has infinite homogenous market players would also render the TLS useless. For example, the TLS will not be applicable to an open knowledge Cloud computing industry. The TLS will be more applicable to industries with long product lifecycle (in excess of 10 years) such as those of train, ship and automotive products.

I hope the TLS framework and the thesis results have provided a new perspective on technological learning. In view of the rapidly industrializing emerging countries in Asia and the Latin America, I am certain that more works can be done to expand the validity of the TLS framework. The use of system dynamic analysis to expand the utility and application of the TLS framework would be a viable extension of this research. Furthermore, I believe that the research should be extended to the supplier base as the rotorcraft companies are becoming more dependent on suppliers. The next decade will be a revolutionary period for the rotorcraft industry with regards to its market, supply chain and technology. Amongst these changes, technological learning will certainly remain one of the key enablers of this revolutionary period!

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